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ANALYSIS OF GENOTYPE x ENVIRONMENT INTERACTION OF GROUNDNUT (*Arachis hypogaea* L.)

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ABSTRACT

Twenty two groundnut genotypes collected from International Crops Research Institute for Semi Arid Tropics (ICRISAT) and local sources were cultivated in two different locations during 2003, 2004 and 2005 planting seasons. Data on yield was subjected to the additive main effect and multiplicative interaction (AMMI) and joint regression analysis. Differences between the genotypes and environments accounted for 58% and 28% of the total variance respectively while genotype x environment interaction accounted for 14% of the total variance. The first, second and third interaction axes captured 56%, 16% and 6% respectively of the total variation due to GxE interaction. The AMMI plot accounted for 96% of the total sum of squares. The environment differed in main and interaction effects. The first (E1) and fourth (E4) environments had positive interaction effects while the second (E2), third (E3) and fifth (E5) had negative interaction effects. First environment and second environment had the highest (3.52) and least (-0.15) interaction effects respectively. Groundnut genotypes used in this study exhibited similar response to different environment except for ICG-6402. ICG-4998 was the most favoured genotype in all the environments. However, most genotypes recorded highest yield during the 2003 planting in first environment (E1).

Key words: Additive Main Effect and Multiplicative Interaction model, biplot, joint regression analysis, Principal Component Analysis

INTRODUCTION

The effect of Genotype x Environment (GxE) interaction poses a problem to plant breeders when comparing the performance of genotypes across environments. GxE is said to occur when the performance of genotypes is not consistent from one environment to another. Under this condition, the relative performance cannot be predicted with absolute confidence (Perkins and Jinks, 1968). Studies on GxE interaction may help determine whether or not a genotype is stable in performance over a range of environments. A number of methods have been used for measuring these interactions which have practical implications for stability of performance of many crop varieties. These methods include the combined analysis of variance (ANOVA), linear regression analysis, additive main effects and multiplicative interaction (AMMI) analysis and joint regression analysis. However, the linear regression analysis on the environmental mean has been criticized (Baker, 1969; Freeman and Perkins, 1971; Easton and Clement, 1973 and Ariyo 1990) due to the dependency between the response variable and the explanatory variable.

A more flexible model has been developed as an alternative to traditional stability analysis (Zobel, *et al*., 1988; Crossa *et al*., 1991). In particular, more precise stability estimates will increase the probability of making successful selections. The Additive Main Effect and Multiplicative Interaction (AMMI) model (Kempton, 1984; Crossa *et al*., 1990) has proved superior to previous techniques by being more effective in explaining the GxE interaction. Gauch and Zobel (1988) reported that AMMI analysis significantly improved probability of successful selection. AMMI model is fitted by carrying out a mean polish (Marsh, 1990) on the raw GxE matrix and then fitting Interaction Principal Component Axes (IPCA) to the matrix residual using singular value decomposition (Dongara *et al.*, 1979). AMMI plot of genotype and environment scores

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(Bradu and Gabriel, 1978) form the interpretative tools. The AMMI model has been used to analyse GxE interaction in many crosses (Bradu, 1984; Gauch, 1990; Crossa *et al*., 1991; Ariyo, 1998).

This study aimed at determining the performance of twenty-two groundnut genotypes as well as their adaptation under different environments and compares the relative effectiveness of AMMI model and joint regression analysis technique in measuring GxE interaction.

MATERIALS AND METHODS

The twenty two genotypes of groundnut used in this study comprised of 15 accessions collected from International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. The remaining 7 genotypes were collected from different research centers within Nigeria, Table 1 shows the genotype coding with their collection centre. The plantings were carried out in two major locations: Location I; Department of Botany Nursery, Lagos State University-Ojo Campus, Lagos (6º 36'N, 3º 34'E) Lagos State, Nigeria. Location II; University of Agriculture, Abeokuta Research and Experimental farm, UNAAB permanent site, Alabata, Abeokuta (7º 10'N, 3º 20'E) Ogun State, Nigeria. Three plantings were undertaken at Lagos (Lagos 2003, 2004 and 2005), while, in Abeokuta only two plantings were undertaken in 2004 and 2005. Each planting was taken to represent an environment in this study. Detailed information on the plantings, planting dates is presented in Table 2.

After field preparation, the genotypes were laid out in double-row plots, replicated thrice in a Randomized Complete Block Design (RCBD). Each row contained ten stands spaced 40cm apart. An inter-row spacing of 1m was maintained (1m x 4m plot size). Each stand was thinned to one plant at two weeks after planting. Manual weeding was done at regular intervals to ensure minimal crop -weeds competition. There was no application of inorganic fertilizers and chemicals (herbicides and pesticides) throughout the plantings. The rainfall, relative humidity and temperature data of the study sites are presented in Table 3. Data on yield was collected by harvesting pods on per plant basis, labeled separately and weight of pods collected from individual plants was determined using Mettler top loading digital balance.

Yield data from the five environments (Lagos 2003, E1; Lagos 2004, E2; Lagos 2005, E3;

Table 1. Code names and source/ origin of groundnut genotypes

Number	Genotype	Source/origin
1	ICG – 4998	ICRISAT India
2	ICG – 862	ICRISAT India
3	ICG – 6402	ICRISAT India
4	ICG – 8490	ICRISAT India
5	ICG – 4412	ICRISAT India
6	ICG – 156	ICRISAT India
7	ICG – 14466	ICRISAT India
8	ICG – 12370	ICRISAT India
9	ICG – 2106	ICRISAT India
10	ICG – 4343	ICRISAT India
11	ICG – 12189	ICRISAT India
12	ICG – 442	ICRISAT India
13	ICG – 4598	ICRISAT India
14	ICG – 7000	ICRISAT India
15	ICG – 1399	ICRISAT India
16	ICGY-6M – 5236	Zaria, Nigeria
17	ICG-IS – 11687	Zaria, Nigeria
18	ICGY-5M – 4746	Zaria, Nigeria
19	ICG-IS – 6646	UNILORIN, Nigeria
20	ICG-IS – 3584	UNILORIN, Nigeria
21	ICG49 – 85A	UNAAB, Nigeria
22	UGA-7 – M	UNAAB, Nigeria

Table 2. Plantings, experimental site, date of planting and designation for each planting

Plantings	Site	Date of planting	Designation
1	Lagos I	12th April, 2003	E1
2	Lagos II	19th October, 2004	E2
3	Lagos III	26th August, 2005	E3
4	Abeokuta I	24th July, 2004	E4
5	Abeokuta II	2nd June, 2005	E5

E = Environment

Table 3. Mean rainfall, temperature, and relative humidity for the planting period, the planting date and soil type for the two locations and five environments

Location	Year	Planting date	Mean rainfall (mm)	Mean temperature (°C)	Mean relative humidity (%)	Soil type
Lagos	2003	April	137.26	27.34	80.40	Silty
	2004	October	64.90	28.60	66.40	Silty
	2005	August	103.32	27.72	75.80	Silty
Abeokuta	2004	July	58.14	26.10	63.20	Sandy-loam
	2005	June	130.40	26.50	76.20	Sandy-loam

Abeokuta 2004, E4 and Abeokuta 2005, E5) were subjected to joint regression analysis according to the procedure of Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Zobel *et al*. (1988). The yield data was also subjected to Additive Main Effect and Multiplicative Interaction (AMMI) analysis using the MATMODEL version 2.0 (Gauch, 1986). The model presented the Principal Component Analysis (PCA) and Finlay and Wilkinson's (1963) Linear Regression (LR) analysis as sub-model. The main effect is the additive part of the model and was analyzed by ordinary analysis of variance (ANOVA) leaving the non-additive residual, than is the GxE interaction which is the multiplicative part of the model to be analyzed by PCA. For any particular genotype-environment, the main effect equals the cultivar mean plus the environment mean minus the grand mean. The interaction is the cultivar PCA score multiplied by the environment score. When a cultivar and an environment have the same sign on their respective first PCA axes, their interaction is positive; if different, their interaction is negative.

The AMMI 1 biplot was obtained from the graphical ordination of mean pod yield and the first interaction principal component axis (IPCA1). Similarly, the AMMI-2 biplot was constructed from the first two IPCA. The biplot presents a graphical view of the transformed GxE interaction for easy interpretation (Kempton, 1984). Cultivars that appeared almost on a perpendicular line had similar means and those that fall almost on a horizontal line had similar interaction pattern. Similarly, environment that occurred almost on a perpendicular line had similar means and those on horizontal lines had similar interaction.

The joint regression analysis was done as described by Perkins and Jinks (1968). The means of various characters were regressed on the environmental means to determine the pattern of response. The GxE was partitioned to obtain the heterogeneity and the deviation components of the total variance.

RESULTS

The mean yield of the twenty two genotypes grown in five environments, the environment means as well as the first PCA scores from AMMI analysis are presented in Table 4. Mean yield ranged from 10.387g per plant for G15 (ICG- 1399) to 34.400g per plant for G1 (ICG 4998). Ten of the genotypes (less than 50%) yielded above average, out of which G1 (ICG-4998), G8 (ICG-12370), G9 (ICG-2106), G13 (ICG-4598), G20 (ICG-IS-3584) and G22 (UGA-7-M) yielded consistently above the environment average. G10 (ICG-4343) and G21 (ICG-49-85A) recorded below average yields in E4 (Abeokuta 2004) while G19 (ICG- IS-6646) recorded below

Table 4. Yield (g plant^{-1}) for 22 groundnut genotypes (G) in 5 environments (E), means value and First PCA scores for the AMMI model for analysis of interaction

S/N	Genotype	Environment					Mean yield (g plant^{-1})	First PCA score
		Lagos I E1	Lagos II E2	Lagos III E3	Abeokuta I E4	Abeokuta II E5		
G1	ICG-4998	50.03	38.13	32.47	19.43	31.93	34.40	0.66
G2	ICG-862	21.87	22.27	21.60	14.20	22.83	20.55	-1.51
G3	ICG-6402	12.67	23.93	12.00	14.40	14.40	15.48	0.97
G4	ICG-8490	23.47	23.80	23.47	14.73	20.63	21.22	0.73
G5	ICG-4412	22.83	24.27	22.47	11.53	18.83	19.99	0.49
G6	ICG-156	19.87	22.00	22.27	11.80	19.17	19.02	-0.24
G7	ICG-14466	17.57	21.13	18.93	11.00	20.53	17.83	-0.53
G8	ICG-12370	37.53	29.87	31.40	15.60	26.97	28.27	0.07
G9	ICG-2106	28.83	30.13	26.67	15. 26	24.10	27.43	0.03
G10	ICG-4343	27.63	25.27	27.27	12.60	22.00	22.95	-0.98
G11	ICG-12189	19.63	20.27	17.40	12.27	16.87	17.29	-2.63
G12	ICG-442	22.67	22.47	21.33	11. 27	20.23	21.68	2.11
G13	ICG-4598	34.27	33.53	31 87	15.87	28.70	28.09	0.79
G14	ICG-7000	16.70	16.33	16.73	10.53	14.60	14.98	0.42
G15	ICG-1399	11.80	11.80	12.33	6.87	9.13	10.39	0.56
G16	ICG-6M-5236	14.67	15.53	15.53	7. 93	12.53	14.57	0.87
G17	ICG-IS-11687	13.07	13.73	13.60	7.40	11.50	11.86	0.47
G18	ICGY-5M- 4746	19.77	19.80	19.67	11. 07	19.57	19.70	-1.02
G19	ICG-IS-6646	32.33	31.33	33.00	14.20	30.87	28.35	-1.16
G20	ICG-IS-3584	25.17	24.47	24.40	16.73	22.07	22.57	0.41
G21	ICG-49-85A	32.03	27.60	27.93	12.73	30.53	29.53	0.71
G22	UGA-7-M	34.70	29.60	29.20	14.93	30.93	27.87	-1.20
	Mean	24.51	23.97	22.36	13.18	21.32	**21.55**	
	First PCA score	3.52	-0.15	-3.31	0.31	-0.37		

average yield in E2 (Lagos 2004). Eight genotypes; G7 (ICG-14466), G11 (ICG-12189), G12 (ICG-442), G14 (ICG-7000), G15 (ICG- 1399), G16 (ICGY-6M-5236), G17 (ICG-IS-11687) and G18 (ICGY-5M-4746) yielded consistently below average in the entire environments. E1 (Lagos 2003) recorded the highest mean yield (24.505g) per plant while, E4 (Abeokuta 2004) had the least mean yield (13.32 g) per plant.

The joint regression analysis is presented in Table 5. The environment, location x year, genotypes and GxE interaction effects were highly significant. Significant location effect was also observed. Heterogeneity between regression was highly significant, indicating the non-linear behavior of the genotype while the residual effect was not significant. The amended Finlay-Wilkinson (1963) linear regression analysis (Zobel *et al*., 1988) which partitions GXE interaction into joint regression, genotype regressions and environmental regressions as well as the residual is presented in Table 6. The LR accounted for 94.94% of the treatment sum of squares leaving 5.06% in the residual. The genotype, joint and environmental regressions were significant and accounted for 28.83%, 19.24% and 8.54% respectively of the GXE sum of squares while, the residual accounted for 43.48%. The residual contained more than twice the amount accounted for by genotype regressions in the GXE sum of squares and it accounted for more than the joint and genotype regressions combined. Thus, it is possible that some amount of variation was still confounded within the residual.

The AMMI analysis is presented in Table 7. The model revealed that differences between the genotypes accounted for more than half (58.01%) of the treatment sum of squares. The environments and GxE interaction also accounted significantly for 28.78% and 11.45% respectively of the treatment SS. Partitioning of the interaction sum of squares by AMMI was very effective as the mean square for the first PCA axis was several times the mean square for the residual. The first interaction PCA was highly significant, capturing 36.80% and 25% of the interaction sum of square and degree of freedom respectively. The second interaction PCA was also significant (P< 0.05). The first three PCA axes jointly accounted for 94% of the interaction SS, leaving 6% of the variation due to GxE interaction in the residual. The residual accounted for 1% of the total SS.

The biplot of the AMMI – 1 result is presented in Figure 1. The biplot accounts for 96.52% of the treatment sum of squares (TSS) leaving a non-significant 1.47% in the residual. G17 (ICG-IS-11687), G14 (ICG-7000), G5 (ICG-4412), G20 (ICG-IS-3584) and G1 (ICG-4998) appear to have similar interaction with the environment but differ in yield. G12 (ICG-442) had the largest positive interaction (2.11) with the environment while G11 (ICG-2106) had the largest negative interaction (-2.63) with below average mean yield of 17.29g per plant. G6 (ICG-156) is considered an average and stable genotype being the only genotype closest to zero. G1 (ICG- 4998) had the highest mean yield (34.40g/ plant) and low positive interaction with

Table 5. Joint regression analysis of yield in groundnut over five location-year environments

Source of variation	Df	MS
Environment	4	4630.38**
Location (L)	1	2625.21**
Year (Y)	2	468.65^{NS}
Location x Year (LxY)	2	1536.52**
Genotype (G)	21	556.86**
Genotype x Environment (GxE)	84	28.46**
Heterogeneity	21	3.05**
Residual	63	0.031
Error (pooled)	220	1.72

*, **, ^{NS} Significant, highly significant at 5 and 1% and not significant respectively.

Table 6. Regression analysis for yield plant^{-1} in groundnut following Finlay-Wilkinson (1963) model as amended by Zobel *et al.* (1988)

Source	df	Sum of Square	Mean square
Environment (E)	4	6009.04	4630.38***
Rep (Env.)	10	24.10	2.41^{NS}
Genotype (G)	21	11694.06	556.86***
Genotype × Environment (GxE)	84	2390.48	28.46***
Joint Regression	1	689.32	689.32***
Genotype Regressions	20	858.24	42.91***
Environmental Regression	3	403.47	134.49***
Residual	60	439.45	7.32*
Error	220	361.07	1.72
Total	319	20894.49	

*, **, *** = Significant at P< 0.05, 0.01 and 0.001 respectively.
NS = Not Significant.

Table 7. AMMI analysis of variance of yield plant^{-1} in groundnut

Source	df	SS	MS
Treatment	119	509.33	188.16***
Environment (E)	4	18521.52	4630.38***
Rep (Env.)	10	24.10	2.41^{NS}
Genotype (G)	21	11694.06	556.86***
Genotype × Environment	84	2390.48	28.46***
IPCA 1	24	1676.08	69.84***
IPCA 2	22	376.40	17.11***
IPCA 3	20	201.31	10.07***
Residual	18	136.69	7.59***
Error	220	385.17	1.72
Total	319		

*, **, *** = Significant at P< 0.05, 0.01 and 0.001 respectively.
NS = Not Significant.

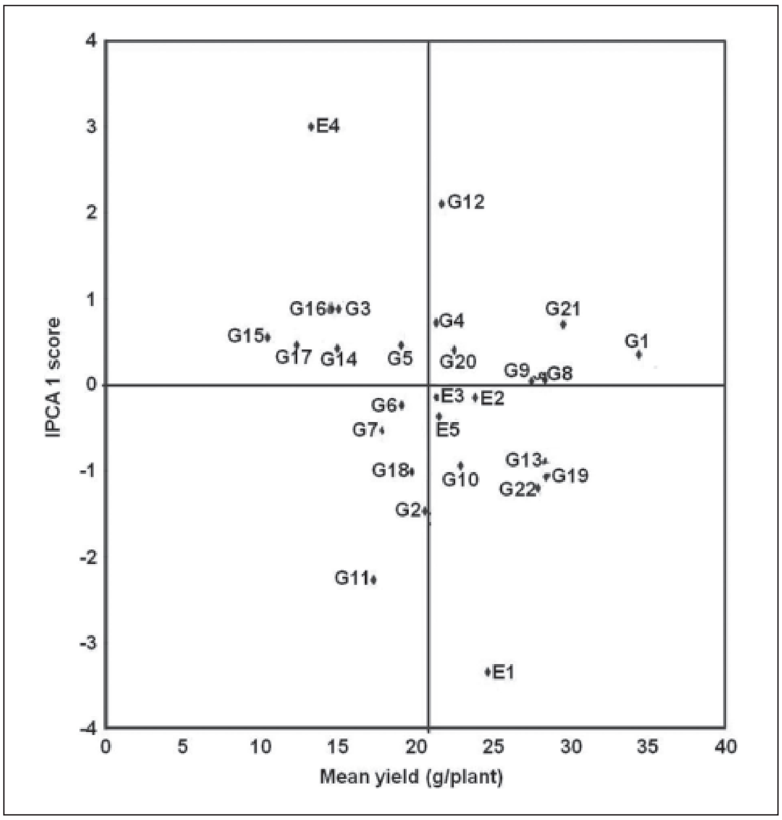

Fig. 1. AMMI-1 model for yield plant^{-1} showing the means of genotypes (G) and environments (E) against their respective IPCA-1 scores.

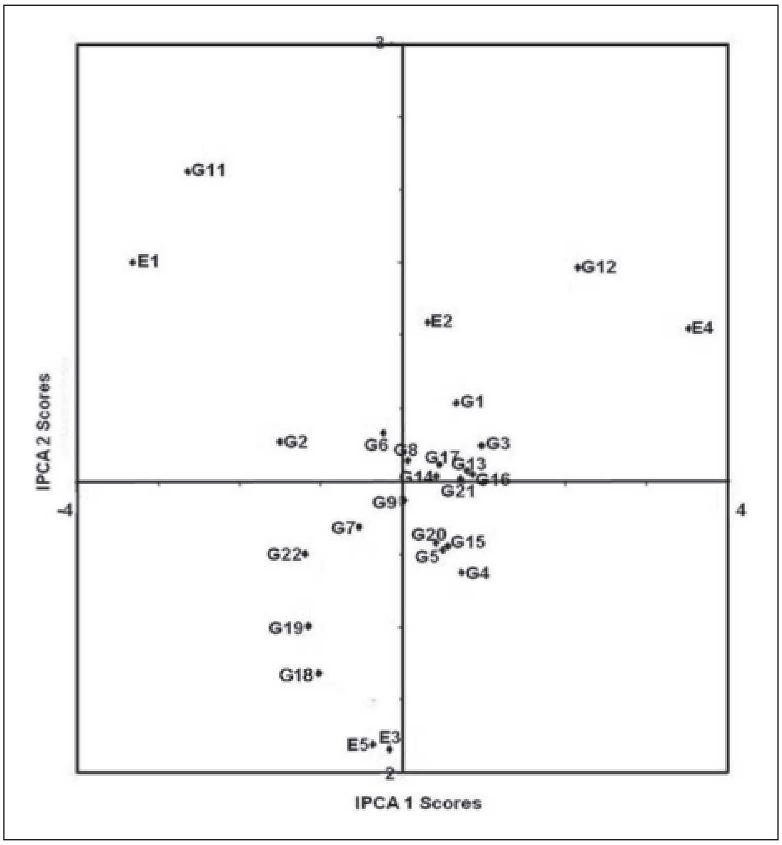

Fig. 2. AMMI-2 model for pod yield plant^{-1} showing the IPCA scores of groundnut genotype (G) planted across environments (E).

environment. G8 (ICG-12370), G13 (ICG-4598) and G19 (ICG-IS-6646) were similar in main effect but vary appreciably in interaction. While, G1 (ICG-4998), G5 (ICG-4412), G14 (ICG-7000), G17 (ICG-IS-11687) and G20 (ICG-IS-3584) showed similar interaction but varied considerably in yield. G15 (ICG-1399) had the least mean yield (10.39g plant^{-1}) and relatively large interaction with environment. The environments were also variable in both main effects and interaction. However, E2 (Lagos 2004) and E3 (Lagos 2005) showed similarity in their interaction with genotypes while, E2 (Lagos 2004) and E5 (Abeokuta 2005) had similar mean yield. Figure 2 presents the AMMI-2 biplot, with the IPCA 1 and IPCA 2 for yield per plant. AMMI-2 accounted for 85.86% of the GxE interaction sum of squares for yield in groundnut. G4 (ICG-8490), G11 (ICG-12189), G12 (ICG-442) and G18 (ICGY-5M-4746) were the most divergent genotypes in interaction while, E1 (Lagos 2003), E3 (Lagos 2005) and E4 (Abeokuta 2004) were the most divergent environments in interaction. G13 (ICG-4598), G14 (ICG-7000), G16 (ICGY-6M-5236) and G17 (ICG-IS-11687) had consistently low interaction with varying direction across the environments.

DISCUSSION

Selection of specific crop genotypes in plant breeding is often preceded by multi-locational testing in which the relative performance of the test genotypes almost invariably varies from one environment to another. The presence of genotype x environment (GXE) interactions 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 (Funnah and Mak, 1980; Ariyo and Ayo-Vaughan 2000). The different performance of genotypes across environments could also be indicative of wide variation in climatic conditions and soil types in the different growing environments. When genotype x environment interaction is highly significant for a particular trait such as, pod yield, days to 50% flowering, final plant height and others in this study, no valid comparison could be made regarding the relative performance of genotypes over all environments. Consequently, comparisons can only be made in each environment separately (Breese, 1969). Crossa *et al*. (1991) had noted that the use of AMMI in GxE interaction analysis would lead to the selection of superior genotypes even in an on farm experiment.

The high and significant proportion of total variation due to GxE interaction implied that selection for yield in groundnut, based on the additive model alone, would be misleading. The inability of the simple ANOVA to elaborate on the specific components accounting for the GxE interaction further makes it unsuitable for predicting genotypic response to varying environments. The partitioning of GxE interaction into joint, genotype and environmental regressions and the residual, is an improvement on both the ANOVA and PCA. The significant genotype regression indicates that some amount of GxE can be explained by the linear response of genotypes to cultivation environments. However, significant residual effect implies that certain structural variation within the data still remained unexplained. This often is one of the shortcomings associated with use of linear regression for GxE interaction analysis (Mclaren and Chaudhary, 1994; Gauch and Zobel, 1988).

The combined analysis of variance was able to shed some light on the variations that existed within each environment by revealing highly significant interaction between genotype x location x year effects indicating that genotypes performed differently within sites and years and that location differed between years. Highly significant location x year interaction showed that the micro – environments under which each planting was conducted in a particular location over the three years actually had considerable variations in weather conditions. The within year similarity and between year differences in crop performance indicated that meteorological information might be useful in the classification of genotypes by trial interaction (Van Euwijk and Elgersma, 1993; Makinde and Ariyo 2010).

The amended LR model provided a clear explanation by capturing 94.7% of the trial SS and reducing the residual mean square, but was not able to effectively explain the amount of interaction due to heterogeneity of regression. It only explained that 28.8% of the interaction SS was due to joint regression in this study. Thus, its power of significant testing was relatively low (Zobel *et al*., 1988; Ariyo, 1990). The relatively large percentage (35.9%) of interaction SS attributed to genotype regressions and tended to indicate that genotypes were probably very diverse and they responded differently to different environments, whereas environments alone did not dictate genotype performance. The fact that the biplot accounted for a large portion (96.5%) of the treatment SS showed that AMMI model was more appropriate in explaining the GxE interaction. In a biplot display, any genotype or environment that appears almost on a perpendicular line of the graph has similar mean yields and those that fall almost on a horizontal line have similar interactions (Crossa *et al*., 1991). As a result of their low interactions, genotype G8 (ICG-12370), G9 (ICG-2106) and G6 (ICG-156) could be considered stable in any environment. Genotypes G13 (ICG- 4598), G19 (ICG-IS-6646), G21 (ICG49-85A) and G22 (UCG-7-M) on the other hand can be justifiably and safely recommended for any environment provided that improved management set up and optimum climatic factors are in place.

In general, both the genetic and environmental factors have been assumed to affect the performance of all cultivars used in this study. Unexpected drought (stoppage of rainfall) coupled with extremely harsh and hot afternoon weather in Abeokuta, during 2004 planting (E4) probably resulted in early senescence, pod failure and consequent low yields in all genotypes investigated. It follows that groundnut requires humid conditions especially during pod formation for good yield. This corroborates the earlier conclusion of Makinde and Ariyo (2010) that groundnut requires humid and warm conditions for optimal performance. A highly significant first interaction PCA observed in this study is in support of effect of variations in weather conditions on cultivar performance. This is in line with an earlier report by Gauch and Furnas (1991) and Nassir and Ariyo (2007) that, the first PCA of AMMI model usually relates to the length of growing environment or warmth for environments and to maturity group for genotypes. AMMI analysis identified G8 (ICG-12370) as having a combination of low GxE interaction and above average yield, making it the most suitable for cultivation across environments in the study locations.

By incorporating the additive and multiplicative components into an integrated, powerful least- square analysis (Gollob, 1968; Gabriel, 1978; Freeman, 1985; Gauch, 1986), AMMI analysis has been used to examine whether or not a particular sub-case of the complete AMMI model could provide a more appropriate analysis over others. AMMI analysis is a first statistical analysis of yield data that has GxE interaction. Results of the current study showed that both LR and AMMI model could be used to interpret the GxE interaction of yield data in groundnut. However, AMMI remains the most effective model because it has provided an insight for causal factors that have potentials for making better varietal selection and management recommendations (Aremu, *et al.*, 2006; Gauch and Furnas, 1991). Genotypes with highest true mean yields could be selected with greater success thereby increasing the speed and effectiveness of a breeding programme (Gauch and Zobel, 1988). AMMI analysis is much better than the joint regression analysis in SS recovery (Gauch, 1990; Yau, 1995) because it reveals high significant interaction component that has clear agronomic meaning. Analysis of variances demonstrated that there were significant genetic variations among groundnut genotypes. Furthermore, all statistical models used confirmed significant genotypes x environmental interactions. This is in good agreement with those reported by Abdul, *et al.*, 2002; Hasan (1978) and Sardana *et al*. (1984). In conclusion, the analysis of GxE interaction provided an opportunity to understand the performance of groundnut genotypes over different growing environments with respect to yield and other characters. The Additive Main Effect and Multiplicative Interaction (AMMI) analysis remains the most current and most integrated and powerful statistical tool for GxE interaction analysis of yield data. It has also proved to be the most effective in the recovery of total sum of squares and it provides agronomically meaningful insight into data structure. For the purpose of yield improvement and genotype adaptedness in groundnut, it would be more suitable to use AMMI analysis to interpret the GxE interaction.

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