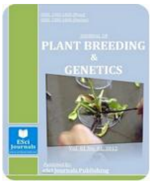

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EVALUATION OF MARKETABLE LEAF YIELD OF FLUTED PUMPKIN IN DIFFERENT ENVIRONMENTS USING ADDITIVE MAIN EFFECTS AND MULTIPLICATIVE INTERACTION (AMMI) MODEL

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ABSTRACT

This study was conducted to determine the yield stability and to analyse the Genotype by Environment Interaction (GEI) of twenty five genotypes of fluted pumpkin genotypes. The experiment was laid out in a randomized complete block design (RCBD) with three replications under four environments using Additive Main effects and Multiplicative Interaction (AMMI) analysis. The mean squares of the analysis of variance revealed significant genotype, environment and GEI on marketable leaf yield per plant. AMMI analysis revealed that the major contributions to treatment sum of squares were environments (3.24%), GEI (46.90%) and genotypes (49.70%), respectively, suggesting that the marketable leaf yield of the genotypes were under the major genotypic effects of GEI. The first two principal component axes (PCA 1 and 2) cumulatively contributed 93.50% of the total GEI and were significant ($p \leq 0.01$). The biplot accounted for 85.82% of the total variation. The AMMI model identified genotypes Ftn44, Ftk20, and Fts34 as most stable, while Fta39 with highest yield (398.80g/plant) had the largest negative interaction. The best genotype with respect to Abeokuta location was Ftw21 while Fta39 was the best for Akure area. Therefore, these genotypes can be recommended according to their specific adaptation areas. Abeokuta in the 2012 and 2013 had positive interaction values of 14.38 and 9.46 respectively whereas Akure in 2012 and 2013 recorded negative interaction values of -5.03 and -18.81 respectively. Akure 2013 was the most discriminating environment and had the highest mean yield thus it is considered as a very good environment for cultivation of fluted pumpkin for marketable leaf yield.

Keywords: Fluted pumpkin, AMMI model, GEI, Marketable leaf yield.

INTRODUCTION

Fluted pumpkin (*Telfairia occidentalis*) of the family *Cucurbitaceae* is one of the neglected and underutilized species (NUS). It is among the priority species for NUS research in West Africa (RUFORUM, 2010). It is a very important indigenous leaf and seed vegetable in West Africa. This valuable crop provides appreciable money to small farm families (Akoroda, 1990). In most cases, women and unemployed youth are involved in the production of this crop. Though no statistical data are available on the total production in Nigeria, the demand is on the increase and this is evidenced by the volume of its leaf and fruit traded on daily basis across the country and by this, the vegetable is gradually displacing other vegetables like *Amaranthus*, *Celosia* and others in Nigerian markets (Fayeun *et al*., 2012). Sustainable leaf production of this crop requires identification and cultivation of stable cultivars. GEI is ubiquitous irrespective of test materials and test environments. GEI causes differences in ranking of superior genotypes from one environment to another, thereby making evaluation genotypic adaptation a serious concern in plant breeding.

An understanding of environmental and genotypic causes of GEI is important at all stages of plant breeding, including ideotype design, parent selection based on traits, and selection based on yield (Jackson *et al.*, 1998; Yan and Hunt, 1998). This can be used to establish breeding objectives to identify ideal test conditions and to formulate recommendations for areas of optimal cultivar adaptation (Jackson *et al.,* 1998). GEI affects breeding progress because it complicates the

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demonstration of superiority of any genotype across environments and the selection of superior genotypes (Magari and Kang, 1993; Ebdon and Gauch, 2002).

The relative performance of genotypes across environments determines the significance of an interaction. There is no GEI when the relative performance among genotypes remains constant across environments (Xu, 2010). The GEI is considered as crossover or qualitative if it leads to change in relative ranking of genotypes in different environments. The non-crossover or quantitative GEI, on the other hand results in differential change of mean but not of ranking of different genotypes. Genotypes tends to have wide adaptation for many environments in non-crossover situation while in the case of crossover genotypes are adapted to specific environments. Hence, crossover interaction is important in agricultural production in contrast to non-crossover interactions (Baker, 1988; Crossa, 1990). Different statistical methods have been proposed for estimation and partitioning of GEI such as variance components, regression methods, multivariate analyses (cluster techniques, AMMI and GGE Biplot) (Eberhart and Russel, 1966; Crossa, 1990; Gauch, 1992; Yan, 2001). Kempton (1984), Crossa *et al*. (1989) and Gauch (1992) suggested AMMI model as a more flexible model for analysis of cultivar adaptation. The model extends the classical additive main effect models for genotypes and environments by including multiplicative term for the interaction. The AMMI model has proved superior and more effective in explaining the GEI than the traditional stability analysis (Crossa *et. al.*, 1991).

AMMI analysis has been reported to have significantly improved the probability of successful selection (Gauch and Zobel, 1989) and has been used to analyze GEI with greater precision in many crops (Bradu and Gabriel 1978; Crossa *et al*., 1991; Ariyo, 1998; Alake and Ariyo, 2012; Makinde *et al*., 2013). Information on the effect of genotype, environment and their interaction on marketable leaf yield of fluted pumpkin under diversified agro-ecologies in Nigeria is rare. Therefore, the objective of this study is to examine the reaction of fluted pumpkin genotypes to different environments for marketable leaf yield, using AMMI model.

MATERIALS AND METHODS

The twenty five genotypes of fluted pumpkin used for this experiment were collected from two agro-ecological zones in southern Nigeria: rain forest (16) and derived savannah (9). The experiment was carried out at two locations for two years (2012 and 2013), making four environments (Table 1). Location I: Teaching and Research Farm Directorate of Federal University of Agriculture, Abeokuta (FUNAAB) Ogun State, Nigeria (7º25'N, 03º25'E) with sandy loam soil and Location II: Teaching and Research Farm of Federal University of Technology, Akure (FUTA) Ondo State, Nigeria (7º16'N, 05º12'E) with sandy clay loam soil. Land preparation involved manual clearing within the sites. The experiment was conducted in a randomized complete block design (RCBD) with three replications. Each replication had 25 plots of 2 m x 2 m, with 1 m inter-plot spacing. Seeds were first raised in the nursery using saw dust as growth medium as suggested by Akoroda and Adejoro (1990). Seedlings were transplanted directly on flat ground two weeks after planting. One seedling was transplanted per hole at a spacing of 1 m by 1 m resulting in 9 plant stands per plot. Trellises of 2 m x 2 m x 1.5 m high were constructed on each plot to support the vines. Manual weeding was done at 3 weekly intervals to keep the field weed-free. There was no application of fertilizers and pesticides throughout the experimentation.

Data were collected at harvest (8 weeks after transplanting) on marketable leaf yield. Marketable leaf yield data was the weight of freshly harvested main vine including the branches and the leaves cut at 100cm above soil level. It was weighed in gram using electronic balance. The marketable leaf yield data of the twenty five fluted pumpkin genotypes were subjected to analysis of variance (ANOVA) and AMMI analysis using GenStat Discovery Edition 4 statistical software (GenStat, 2011). The additive main effect and multiplicative interaction (AMMI) method combines the analysis of variance and principal component analysis (PCA) into a unified approach (Gauch, 1988) and is especially useful in analysing multi-location trials (Gauch and Zobel, 1988). The AMMI analysis first fits the additive main effects of genotypes and environments by the usual analysis of variance and then describes the non-additive part and the GEI by PCA. The AMMI model does not make provision for a specific stability measure to be determined and such a measure is essential in this study in order to rank genotypes in terms of stability. Purchase (1997) proposed the formula to calculate AMMI's stability value (ASV) as follows:

$$ASV = \sqrt{\left[\frac{IPCA1SS}{IPCA2SS} IPCA1\ scores\right]^2 + [\text{IPCA 2scores}]^2}$$

ASV is the distance from zero in a two dimensional scattergram of IPCA 1 (Interaction Principal Component Analysis 1) scores against IPCA 2 scores, Where SS = sums of squares.

Table 1. Rainfall, relative humidity and temperature data for Abeokuta and Akure in 2012 and 2013.

Month	Abeokuta								Akure							
	2012 (Environment I)				2013 (Environment III)				2012 (Environment II)				2013 (Environment IV)			
	Rainfall (mm)	Temperature (ºC)		Relative Humidity (%)	Rainfall (mm)	Temperature (ºC)		Relative Humidity (%)	Rainfall (mm)	Temperature (ºC)		Relative Humidity (%)	Rainfall (mm)	Temperature (ºC)		Relative Humidity (%)
		Min	Max			Min	Max			Min	Max			Min	Max	
July	155.4	22.2	29.9	80.9	202.6	22.3	28.7	82.4	100.0	18.3	27.5	77.5	106.9	15.4	26.9	76.9
August	36.3	22.6	28.4	82.6	35.2	21.1	28.6	80.2	121.0	18.7	28.0	76.1	121.0	16.7	27.1	80.4
September	181.4	22.7	29.6	76.0	136.0	22.4	28.9	77.5	58.5	17.3	28.9	80.8	263.0	19.0	26.1	84.0
October	184.7	22.1	32.2	77.5	94.4	31.7	22.4	76.9	167.0	17.3	30.8	74.5	121.0	18.3	30.2	84.6
November	49.6	23.3	33.0	81.9	15.6	23.5	33.1	76.1	0.0	19.5	31.4	73.1	27.9	19.0	30.0	87.7
December	1.3	22.7	34.8	78.5	0.0	22.4	35.5	74.5	0.0	19.2	30.3	73.0	0.0	18.4	32.0	79.8

Source: Agro-meteorology and Water Management Department, FUNAAB and Agro-climatological and Ecological Project, Ondo State Ministry of Agriculture, Akure.

RESULTS

Result for AMMI analysis of variance for fluted pumpkin genotypes on marketable leaf yield according to the best AMMI model fit are shown on Table 2. AMMI model demonstrated the presence of GEI and this has been partitioned among the first three IPCA axes and this is about 874 times the MS of the error. The model revealed that differences between the genotypes accounted for almost half (49.70%) of the treatment sum of squares. The environments and GEI also accounted significantly for 3.24% and 46.90% respectively of the treatment sum of squares. Partitioning of the interaction sum of squares by AMMI was very effective as the mean square for the first PCA axis was almost 10 times the mean square for the residual. The first three interaction PCA axes were highly significant and cumulatively contributed 100% of the total GEI. IPCA 1, IPCA 2, IPCA 3 explained 70.10%, 23.40 and 6.40 of the total GEI sums of squares percentage at 46.90% of the interaction degrees of freedom respectively.

Table 2. AMMI analysis of variance for 25 genotypes of fluted pumpkin marketable leaf yield tested over four environments.

Source	DF	SS	MS	% Treatment	% Interaction
Genotypes	24	2067319.00	86138.00**	49.70	-
Environments	3	134875.00	44958.00**	3.24	-
Block	8	479.00	60.00ns		-
Interactions	72	1950854.00	27095.00**	46.90	-
PCA 1	26	1368674.00	52641.00**	-	70.10
PCA 2	24	455978.00	18999.00**	-	23.40
PCA 3	22	124492.00	5658.00**	-	6.40
Residuals	22	126203.00	5736.00	-	-
Error	192	5926.00	31.00	-	-

Ns: not significant, **significant at level $P \leq 0.01$

Table 3 presents the genotype and environment means as well as their respective first PCA axes from the AMMI analysis. Ftg22 had the largest positive interactions while Fty28 recorded the positive least interaction. Fta39, Ftm12 and Ftk16 had high negative effects of -14.86, -11.48 and -5.72 respectively. Akure in both years had higher marketable leaf yield mean value than Abeokuta in both years. Abeokuta in the 2012 and 2013 had positive interaction values of 14.38 and 9.46 respectively whereas Akure in 2012 and 2013 recorded negative interaction values of -5.03 and -18.81 respectively. Ftw21, Ftg22, Fte41, Ftm11 and Ftd1 were the best genotypes in Abeokuta 2012 while Fta39, Ftd21, Ftm12, Ftn47 and Ftm11 were the best genotypes in Akure 2012. In both years, Ftw21 and Ftg22, Ftd1 were the common high yielding genotypes in Abeokuta likewise Fta39, Ftd1 and Ftn12 were the common high yielding genotypes in Akure.

Table 5 shows the AMMI model IPCA1 and IPCA2 scores of marketable leaf yield for each genotype and the AMMI stability value (ASV) for 25 fluted pumpkin genotypes. According to ASV ranking, genotype Ftn44 had the lowest value, thus the most stable genotype, followed by Ftw20, Fts34, Fts33 and Fty28 while genotype Fta39, Ftm12, Ftg22, Fte41 and Ftk16 were unstable. Interestingly, Fta39 ranked best in yield and at the same time the most unstable genotype according to ASV ranking. In addition, Fts34 ranked as the poorest in terms of yield and third most stable genotype.

Table 3. Means and the first PCA scores from AMMI analysis of marketable leaf yield for 25 genotypes fluted pumpkin studied in four environments.

Genotypes	Abeokuta 2012	Akure 2012	Abeokuta 2013	Akure 2013	Mean	IPCAg[1]
Fts33	135.30	175.40	141.70	244.10	174.10	-1.76
Fty28	97.20	49.90	184.10	158.90	122.50	1.33
Fte42	185.60	165.30	319.20*	333.10*	250.80	-0.61
Ftr13	255.00	228.60	144.00	149.80	194.30	3.05
Ftw21	310.80*	256.90	332.70*	298.10	299.60	2.54
Ftk16	41.20	160.90	57.70	276.00	133.90	-5.72
Fte40	242.80	200.20	142.00	124.30	177.30	3.69
Ftg23	224.40	188.60	148.90	141.00	175.70	3.01
Ftg22	258.90*	64.30	274.10*	34.50	157.90	9.39
Ftw20	90.30	133.60	53.90	161.20	109.80	-1.33
Fte41	301.60*	205.50	222.70	126.90	214.20	5.96
Fty29	192.00	77.90	239.00	116.70	156.40	5.08
Ftn43	246.00	217.70	180.70	183.70	207.00	2.51
Fty30	190.00	157.70	87.80	85.10	130.10	3.21
Ftk17	212.50	263.00	54.70	172.80	175.80	0.00
Ftn44	102.10	127.50	34.10	115.30	94.80	-0.03
Ftn45	126.60	177.50	189.50	307.50*	200.30	-3.06
Ftn46	202.00	144.10	292.30*	251.70	222.50	1.79
Ftm11	302.10*	268.90*	220.90	216.90	252.20	2.96
Ftg24	168.20	71.00	215.50	117.80	143.10	4.27
Fta39	183.40	488.50*	217.30	705.70*	398.80	-14.86
Ftd1	302.10*	420.80*	267.10	484.10*	368.50	-4.96
Ftm12	151.90	349.20*	316.00*	646.90*	366.00	-11.48
Ftn47	158.40	268.50*	43.70	248.40	179.80	-3.45
Fts34	45.70	90.60	18.70	128.30	70.80	-1.53
Env. Mean	189.00	198.10	175.90	233.10	199.15	
Env. IPCA 1	14.38	-5.03	9.46	-18.81		

*The first five best genotypes per environment   Env: Environment

Figure 1 depicts AMMI1 biplot for fluted pumpkin marketable leaf yield grown in four environments. The biplot was used to study the pattern of response of genotype, environment, and GEI using main effect of means vs the first Interaction Principal Component Analysis Axis (IPCA1). It was also used to identify genotypes with broad or specific adaptation to target environments for marketable leaf yield. By plotting both genotypes and environments on the same graph, the association between the genotypes and the environments became more obvious.

Displacement along the abscissa reflected differences in main effect, in this case, the marketable leaf yield while displacement along the ordinate exhibited differences in the first PCA. The biplot accounted for 85.82% of the treatment sum of squares leaving 14.18% in the residual. The additive part of the AMMI equals the genotype mean plus the environment mean minus the grand mean and the multiplicative part i.e interaction effect, is the product of G and E for instance, the main effect of Ftn43 grown in Abeokuta 2013 was 180.70 + 175.90 – 199.15 = 157.45g/plant. The interaction effect was 9.39 x 2.51= 23.74. Therefore AMMI model gave a yield estimation of 181.19g/plant instead of 180.70g/plant.

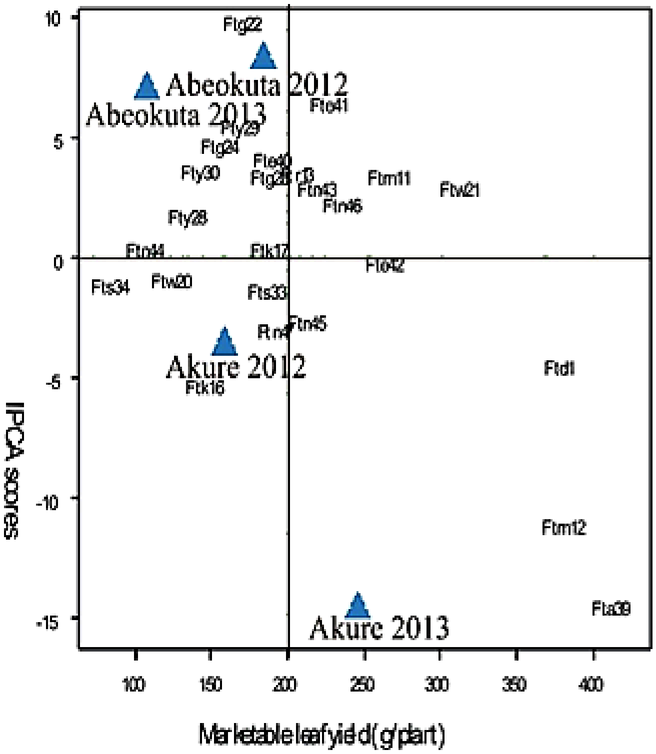

Figure 1 AMMI1 biplot for marketable leaf yield mean (g/plant) and IPCA 1 scores.

Similarly, Ftw21 in Abeokuta 2013 gave the yield of 333.48g/plant instead of 332.70g/plant while Fty28 in Abeokuta 2012 gave the yield of 106.18g/plant instead of 97.20g/plant. Ftg22 had the largest positive interaction (9.39) with the environment while Fta39 had the largest negative interaction (-14.86) with the highest mean yield of 398.80g per plant. Ftn44 considered the most stable genotype being the only genotype closest to zero. The genotypes Fta39, Ftd1, Ftw21, Fte42, Ftn45, Ftn46, Ftn43, Ftm11, Ftn43 and Ftm12 were generally high yielding since AMMI1 placed them on the right hand side of the midpoint of the axis. The environments were also variable in both main effects and interaction. However, Abeokuta 2012 and Abeokuta 2013 showed similarity in their interaction with genotypes while Akure 2013 was highly different from other environments. Abeokuta 2012 and Akure 2012 had relatively similar mean yield. IPCA2 scores were significant (23.40 %) in explaining the GEI, therefore it necessary to plot the first two IPCA axes against one another to investigate the GEI pattern of each genotype (Figure 2).

AMMI2 analysis positioned the genotypes in different locations, indicating the adaptation pattern of the genotypes. Similarity in performance of the genotypes was observed because most of them were close to one another. Genotype Ftn44, Ftw20, Fts34 and Fts33 seemed to be the most stable genotypes because they were located very close to the origin point and genotype Fta39, Ftm12 and Ftg22 as the most unstable as they were far from the origin. When looking at the environments it is clear that there is a good variation in the different environments. E4 was the most discriminating environments as indicated by the longest distance between its marker and the origin (Figure 2).

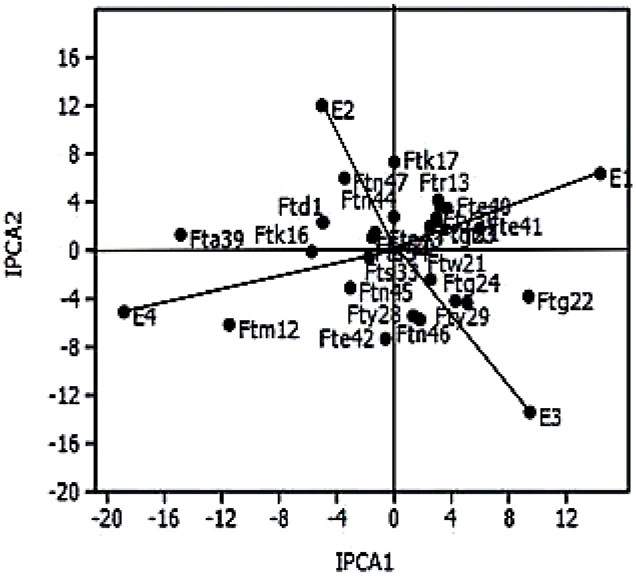

Figure 2. AMMI 2 biplot for marketable leaf yield of fluted pumpkin genotypes showing the plotting of IPCA1 and IPCA2 of genotypes across four environments E1= Abeokuta 2012, E2= Akure 2012, E3= Abeokuta 2013, E4= Akure 2013.

Table 4: IPCA scores for genotypes, AMMI stability value (ASV), Rank and mean performance for marketable leaf yield (g plant-1) of 25 fluted pumpkin genotypes grown at four environments

Genotype	IPCA 1	IPCA 2	Yield	Rank	ASV	Rank
Fts33	-1.76	-0.55	174.10	16	5.31	4
Fty28	1.33	-5.40	122.50	22	6.71	5
Fte42	-0.61	-7.28	250.80	6	7.50	7
Ftr13	3.05	4.20	194.30	11	10.08	14
Ftw21	2.54	-2.41	299.60	4	8.00	10
Ftk16	-5.72	-0.07	133.90	20	17.17	21
Fte40	3.69	3.52	177.30	13	11.61	16
Ftg23	3.01	2.41	175.70	15	9.35	12
Ftg22	9.39	-3.78	157.90	17	28.44	23

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Ftw20	-1.33	1.51	109.80	23	4.26	2
Fte41	5.96	1.85	214.20	8	17.97	22
Fty29	5.08	-4.32	156.40	18	15.86	20
Ftn43	2.51	2.01	207.00	9	7.80	8
Fty30	3.21	3.71	130.10	21	10.32	15
Ftk17	-0.00	7.33	175.80	14	7.33	6
Ftn44	-0.03	2.79	94.80	24	2.79	1
Ftn45	-3.06	-3.09	200.30	10	9.68	13
Ftn46	1.79	-5.69	222.50	7	7.83	9
Ftm11	2.96	2.71	252.20	5	9.30	11
Ftg24	4.27	-4.12	143.10	19	13.46	18
Fta39	-14.86	1.33	398.80	1	44.64	25
Ftd1	-4.96	2.35	368.50	2	15.08	19
Ftm12	-11.48	-6.11	366.00	3	34.99	24
Ftn47	-3.45	6.01	179.80	12	11.98	17
Fts34	-1.53	1.08	70.80	25	4.73	3

DISCUSSION

The presence of GEI makes it difficult for breeders to decide which genotypes should be selected (Makinde *et al*., 2013). 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). Environmental factors such as variation in climatic conditions and soil types in the different growing environments may cause differences in performance of genotypes across environments. This is made manifest in this present study. Akure had higher yield in both years than Abeokuta. Akure and Abeokuta are located in the rainforest and derived savannah ecologies respectively, likewise the soil type of Akure site is sandy clay loam while that of Abeokuta is sandy loam. Differences in rainfall pattern and soil type have been reported to cause significant GEI in groundnut by Makinde and Ariyo (2011). Whenever GEI is highly significant for yield trait, comparison could not be reliable regarding the relative performance of genotypes over all environments. As a result it is not only average performance that is important in genotype evaluation programmes, but also the magnitude of interactions (Gauch and Zobel, 1997). Therefore, there is need to use stability analysis procedures that can elucidate GEI puzzle and guide breeders to select genotypes based on performance and stability.

The fact that the AMMI biplot accounted for a large portion (85.82%) of the treatment sum of squares showed that AMMI model was more appropriate in explaining the GEI. 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 complete AMMI model contained 100% of the sum of square due to GEI and without residual. This observation is in line with that of Adomou *et al*. (1997), Ariyo (1998), El-Nasr *et al*. (2006), Makinde and Ariyo (2011) and Makinde *et al*., 2013. By incorporating the additive and multiplicative components into an integrated, powerful least square analysis (Gollob, 1968; Freeman, 1985), 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 (Makinde *et al*., 2013). In AMMI biplot display, any genotypes or environments that appear almost on a perpendicular line of the graph had similar mean yields and those that fall almost on a horizontal line had similar interactions (Crossa *et al*., 1991) and genotypes placed at the right hand are high yielding. Hence, Ftd1, Ftm12 and Fta39 are high yielding genotypes and had similar mean. However, these genotypes are not stable. The closer the ASV scores to zero, the more stable the genotypes across their tested environments. Thus, genotypes Ftn44 though a poor yielder, is the most stable.

In conclusion, results of the current study showed that AMMI model could be used to interpret the GEI of yield data in fluted pumpkin and it is an effective model because it has provided an insight for causal factors that have potentials for making better varietal selection and management recommendations (Gauch and Furnas, 1991, Putto *et al*., 2008). Genotypes with highest true mean yields could also be selected with greater success thereby increasing the speed and effectiveness of a breeding programme (Gauch and Zobel, 1989).

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