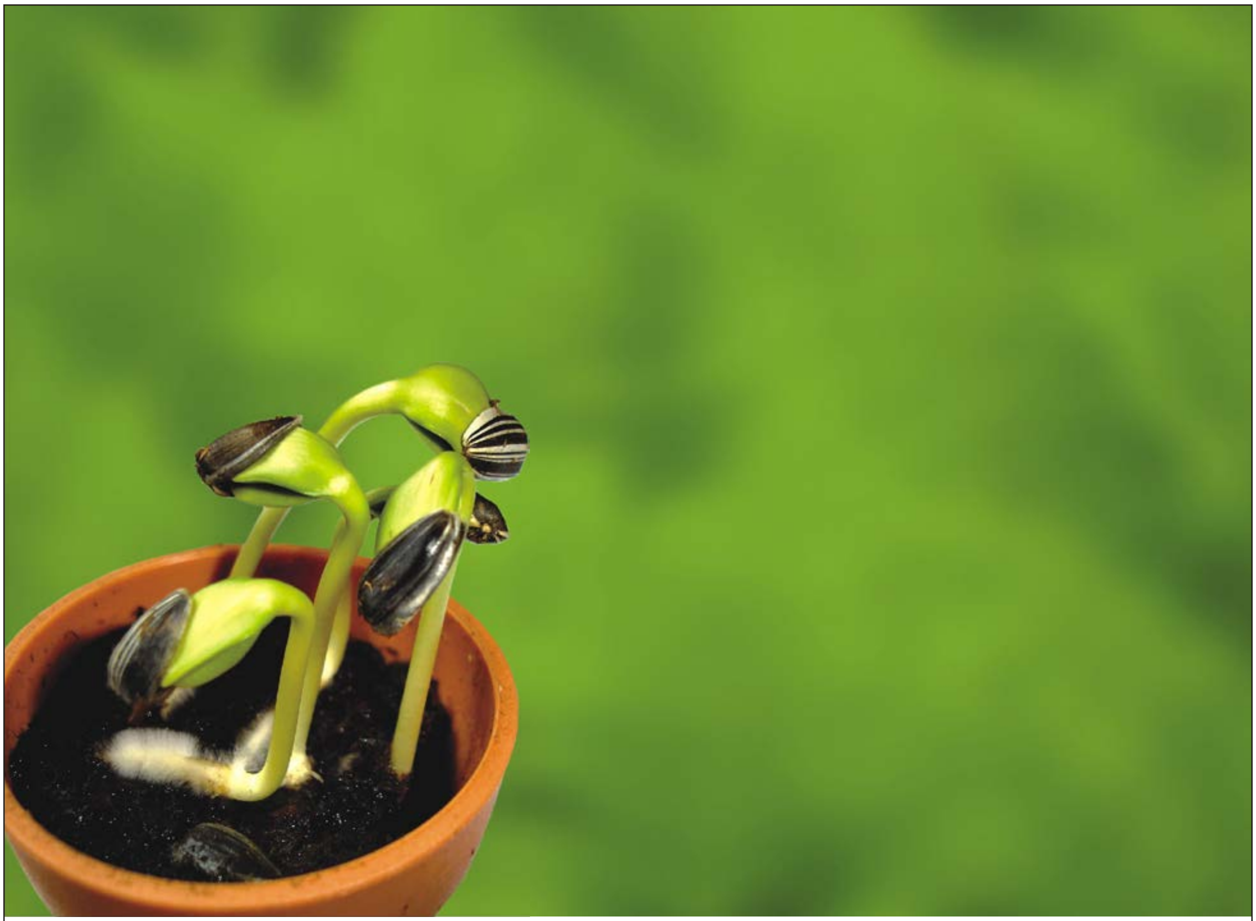

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Genotype×Environment Analysis of Some Yield Components of Upland Rice (*Oryza sativa* L.) Under Two Ecologies in Nigeria

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ABSTRACT

Seasonal variation in the grain yield of rice in upland tropical ecology stimulate the compelling need to develop a fairly stable cultivar for the low input farmers across fairly wide cultivation zones. Yield analysis has always been the main focus but the complex interaction of the panicle and grain attributes are equally important. Fifteen upland rice (*Oryza sativa* L.) varieties were cultivated in five environments in Ago-Iwoye (rain forest ecology) and Ayetoro (derived savannah ecology) of South Western Nigeria. Data were collected on panicle and grain yield characters and subjected to genotype by environment analysis using the additive main effect and multiplicative interaction, AMMI and the genotype and genotype and environment interaction (GGE). From the AMMI analysis, the genotype, environment and the interaction components jointly captured 71.8% of the total sum of squares (TSS). The environment accounted for 62.25% of treatment sum of squares while the interaction and genotype portion was 26.8 and 10.95%, respectively. The GGE biplot summarized 64.2% of the interaction component and separated the genotypes and cultivation environments into three groups. The GGE Interaction Principal Component Axis (IPCA) 1 was significantly correlated with grain length (-0.621) while the GGE IPCA 2 had significant correlation with primary branching (0.636) and spikelets fertility (-0.604). WAB (96-1-1) had the highest grain production and appeared to be adaptable to E3 and E5 which are low rainfall environments. Other matters important to genotype by environment interaction as a guide for development of high yielding and fairly stable varieties are discussed.

Key words: Upland rice, *Oryza sativa* L., additive main effect, multiplicative interaction, genotype and genotype and environment interaction, genotype stability, grain yield

INTRODUCTION

A major constraint to sustained increase in rice (*Oryza sativa* L.) production in the upland ecology is the unpredictability of rainfall and the concomitant drought which could occur at any period during the field life of crops, manifesting as vegetative, intermittent and terminal drought (Kamoshita *et al*., 2008). The consequent response of available varieties is often negative through, eventually, a decline in grain yield. Yield losses of up to 82% have been reported (Pantuwan *et al*., 2002). Variable grain yield due to differential adaptation to cultivation environment have been reported across hydrological regions through the use of G×E models (McLaren and Chaudhary, 1994; Ouk *et al*., 2007; Acuna *et al*., 2008; Nassir and Ariyo, 2011). Genotype by environment analysis for grain yield has been the main aim of the stability analysis in these crops. These have adopted models like the AMMI, GGE and principal components analysis (PCA) to interprete multi environment yield data and advise on compatibility or otherwise of genotypes with different environment (Yan *et al*., 2000, 2007;

Gauch, 2006). Recently, there have been some amount of controversy on the superiority or otherwise of the GGE analysis over AMMI in terms of genotype and environment evaluation and mega-environment analysis for selection of most suitable cultivars (Gauch, 2006; Yan *et al.*, 2007). It would appear, however, that the combination of the models in order to take advantage of the respective areas of strength of each analysis would serve the purpose of recommendations for what to plant in a location. This additional advantage of guiding the direction of breeding for genotype adaptation to environment becomes a more overriding interest. Indeed, most of the genotype-environment interactions are often accounted for by environmental effect (Yan *et al.*, 2000; Samonte *et al.*, 2005; Gauch, 2006; Acuna *et al.*, 2008; Nassir and Ariyo, 2011) and this underscores the need for continuous efforts to further understand character response for the purpose of evolving reasonably stable genotype. The eventual yield response of varieties would normally occur through the panicle and grain characters. The relationships of panicle and grain characters with grain yield have been well reported (Padmavathi *et al.*, 1996; Kato, 1997; Rao *et al.*, 1997; Nassir and Ariyo, 2007). Differences in the effects of these characters on grain yield were often obtained but deductions from Suarez *et al.* (1989), Selvarani and Rengadamy (1998), the differences is attributable to differences in genotype and possibly cultivation environment. Yan and Hunt (2001) introduced a link between yield and agronomic traits through a correlation between yield genotypic Principal Components (PC) scores and agronomic indicators and disease scores and implicated plant height as major contributor to G×E interaction. Similarly, Nassir and Ariyo (2011) reported differences in tillering and final height as agronomic factors underlying G×E interaction. Acuna and Wade (2012) also investigated the influence of genotype by environment influence on the eventual performance of genotype under variable soil environment in wheat and emphasized different root trait combination for different environments. Extending this procedure by conducting separate G×E analysis for each of the panicle and grain characters in rice may offer certain pattern information on their contribution to grain yield and the response of the latter response to different environment.

The objective of this study was therefore to evaluate some upland rice varieties over a number of environments with emphasis on G×E interaction effect on the production of grains along with the panicle and grain characters which determine grain yield.

MATERIALS AND METHODS

This study was conducted at the College of Agricultural Sciences Olabisi Onabanjo University, Nigeria. The first four plantings were done at Ago-Iwoye (3.92°N, 6.95°E) tropical rainforest ecology from 2001-2004. Two plantings were done at Ayetoro (6.5°N, 5°E); a location with derived savanna ecology in 2009 and 2010. However, the 2009 data could not be used due to severe drought.

Fifteen varieties of upland rice obtained from the West African Rice Development Association (WARDA) substation of the International Institute of Tropical Agriculture (IITA) Ibadan were used for this study as experimental materials. These are: IDSA 10, IGUAPE CATETO, WAB 35-2-FX, WAB 56-60, WAB 33-25, WAB 96-1-1, WAB 99-1-1 and WAB 375-B-5-H2-1 from Cote D'Ivore; ITA II7, ITA 150 ITA 257, ITA 315 and ITA 321 from Nigeria; LAC 23 from Liberia and OS 6 from Zaire.

Varieties were raised in a nursery and transplanted onto ploughed upland paddy as soon as rainfall became steady. There were fifteen plants per single row plots, arranged in a randomized complete block design with three replicates. Plants were separated by 30 cm between and within rows. Weeding was done at three and six weeks after NPK fertilizer was side dressed at 3 WAP at the rate of 8.3 g per plot (100 kg N ha^{-1}). Disease control was done with foliar sprays of Karate at 2 mL L^{-1} of distilled water were applied at four and nine weeks after planting against aphid infestation.

Data collection: Only the five inner plants from each plot were used for data collection, i.e., boarder rows were excluded. The data collected on each plants included both panicle and grain characters as described by the Standard Evaluation System for Rice (SESR) (Anonymous, 1988).

Data analysis: The analysis was based on the five seasons data referred to as the environments. All the data obtained were subjected to statistical analysis using the means recorded on the characters for each variety. Analysis of Variance (ANOVA) and AMMI analysis were done using the GenStat version 12. The five-season grain weight data per plant was further subjected to the genotype and genotype by environment interaction (GGE) as described by Yan *et al.* (2000). Correlation coefficients were calculated between panicle and grain characters and the principal component axes 1 and 2 of the GGE and also of the panicle and some grain characters with monthly rainfall, total rainfall, minimum and maximum temperature.

RESULTS

AMMI analysis: The major feature of the G×E interaction, as clearly expounded by the AMMI analysis is the reiteration of the importance of differential environmental influence on character expression. The consequent cumulative effect of this is shown to be capable of creating a complex plant trait-environment interaction which might not be totally repeatable. This would in effect dictate the need for environment-based development of genotype even within the larger interest of having a super genotype adapted to a wide range of environment. Improvement in grain production would therefore, continue to draw from this. The AMMI 1 analysis for grain weight is presented in Table 1. Grain production per plant was significantly ($p<0.001$) influenced by the treatment effect as contained in the genotype, environment and the interaction components and they jointly captured 71.8% of the total Sum of Squares (SS). The environment accounted for 62.25% of treatment SS while the interaction and genotype portion was 26.8 and 10.95%,

Table 1: AMMI analysis of grain weight per plant for upland rice genotypes cultivated in five environments

Source	df	Sum of Squares (SS)	Total SS (%)	Treatment SS (%)	Interaction SS (%)	Mean squares	Interaction MS (%)	F-ratio	F-prob.
Total	224	26086				116.5			
Treatments	74	18728				253.1		6.54	<0.001
Genotypes	14	2050	7.86	10.95		146.4	4.3	3.78	<0.001
Environments	4	11658	44.69	62.25		2914.6	86.2	15.05	<0.001
Block	10	1937	7.43			193.7	5.7	5.00	<0.001
Interaction	56	5020	19.24	26.80		89.6	2.7	2.32	<0.001
IPCA 1	17	2621	10.05	14.00	52.21	154.2		3.98	<0.001
IPCA 2	15	1588	6.08	8.50	31.63	105.8		2.73	<0.010
Residuals	24	812	3.11	4.30	16.18	33.8		0.87	0.637
Error	140	5421	20.78			38.7	1.1		

AMMI: Additive main effect and multiplicative interaction, MS: Mean squares, IPCA: Interaction principal component axis respectively. The first and second principal component axis are significant ($p<0.001$ and 0.01, respectively) and are responsible for 14 and 8.5% of the treatment sum of squares, respectively. The two axes jointly explained significant 83.84% of the interaction sum of squares leaving a non significant 16.3% in the residual. The Mean Squares (MS) from the analysis represent the variance of component and captured 98.9% of the variation with environment accounting for the largest portion of 86.2% of the total variation. The block and genotype main effects had 5.7 and 4.3% of the variation, respectively. The interaction component is responsible for 2.7% of the total variation. The biplot from the AMMI 1 analysis is shown in Fig. 1. The plot which encompasses the G, E and IPCA 1 captured illustrated 86.9% of the treatment sum of squares. Most of the genotypes clustered between -1 and +1 IPCA 1. The mean grain production for ITA 315, G10 (20.4 g), WAB 33-25, G12 (18.6 g) and 15 (18.3 g) was above average and they also interact positively with improved environment, E1 in this case. G13 (WAB 96-1-1) and G14 (WAB 99-1-1) also recorded above average grain production but negative IPCA 1 scores. Indeed G 13 recorded the highest above average grain weight of 24.6 g and also highest value of 29.4 g in E5. G14 also recorded mean grain production of 19.2 g. Overall, G4 (WAB 35-2-FX) is closest to the center of the plot thus having a combination of an average yield and low IPCA score.

GGE analysis: The biplot of the Genotype (G) and Genotype and Environment (GE) analysis is presented in Fig. 2. The plot summarized 64.2% of the interaction component and separated the genotypes (and cultivation environments) into three groups. Genotypes 10 (ITA 315) and 15 (WAB 375-A-B-H2-1) had high IPCA 1 values and is expected to have better grain production with improved environment as specified by E1 and E2. Correlation between PC1 and actual grain yield was high ($r = 0.89$, $p<0.05$), hence, the PC1 can fairly represent genotype grain production.

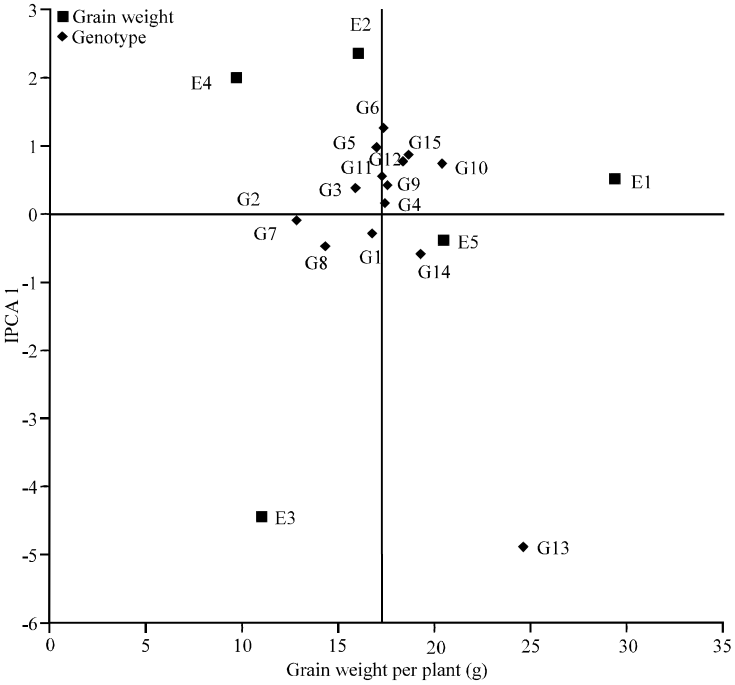

Fig. 1: AMMI 1 biplot of genotype and environment grain weight per plant, IPCA: Interaction principal component axis, AMMI: Additive main effect and multiplicative interaction

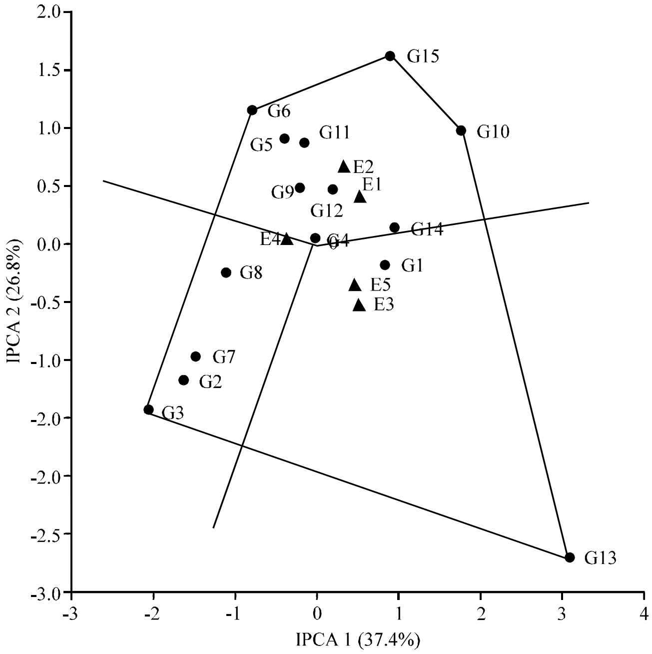

Fig. 2: Genotype×environment interaction plot for grain weight for 15 rice genotypes cultivated in five environments for environment centered data, IPCA: Interaction principal component axis

G10 however, had lower IPCA 2 scores relative to G15. The G13 (WAB 96-1-1) had the highest grain production and appeared to be adaptable to E3 and E5. The genotype also recorded the largest negative IPCA score. G1 also performs well in E3 and E5. G3 (ITA 257) performs best in E4 along with ITA 150 and two other genotypes. The four genotypes however recorded the least grain production over the environments. Overall, G14 (WAB 99-1-1) had the best combination of low IPCA 2 and high IPCA 1. E1 also had the largest IPCA 1 and low IPCA 2 and presented the best discriminating condition.

Yield components: The Mean Squares (MS) and the percentage of total mean squares of the main effects and the interaction for panicle characteristics are presented in Table 2. All the panicle characters showed significant main effects and interaction ($p<0.01$). For panicle number, primary branches and spikelets number per panicle, the environment recorded over 90% of the total MS. It also accounted for a relatively lower 86.6 and 80.1% of the total MS for panicle length and secondary branching, respectively. Genotype and interaction values for mean squares were relatively lower for all characters compared to the environment mean squares. The Interaction Principal Component Axes (IPCA) 1, 2 and 3 were significant for all the characters except primary branches in which case only the first and second IPCA were significant. Table 3 presents the MS and %MS for some grain characters of upland rice. The genotype, environment and the IPCA 1,2 and 3 were significant for all the grain characters. The IPCA 1 and 2 axes however captured 70% and above of the interaction sum of squares for all the characters. Notably, however, 28 and 12% of the total variation is confined in the interaction component for grain length and width, respectively. With the exception of grain length, environment accounted for the largest part of the

Table 2: Mean squares (MS) and percent mean squares (%MS) for some panicle characters of upland rice

		Panicle number		Panicle length (cm)		Primary branches		Secondary branching		Spikelets number per panicle	
Source	df	MS	%MS	MS	%MS	MS	%MS	MS	%MS	MS	%MS
Treatments	74	22.36**		57.50**		37.63**		1.148**		9961**	
Genotypes	14	4.59*	1.4	51.49**	7.7	28.32**	5.2	1.214**	10.5	5948**	4.4
Environments	4	305.81**	94.6	580.75**	86.6	501.90**	91.3	9.235**	80.1	121737**	90.6
Block	10	4.09	1.3	11.29*	1.7	8.69*	1.6	0.307	2.7	2724**	2.0
Interaction	56	6.55**	2.0	21.62**	3.2	6.79**	1.2	0.554**	4.8	2980**	2.2
IPCA 1	17	10.53**		30.87**		11.25**		0.864**		4184**	
IPCA 2	15	7.18**		23.23**		6.74*		0.472*		3163**	
IPCA 3	13	5.14**		21.36**		4.23		0.421*		2348**	
Residuals	24	1.24		5.44		3.00		0.347		21619	
Error	140	2.18	0.7	5.10	0.8	3.79	0.7	0.218	1.9	953	0.7

*,**Significant at $p<0.05$ and 0.01 probability levels, respectively, IPCA: Interaction principal component axis

Table 3: Mean squares (MS) and percent mean squares (%MS) for some grain characters of upland rice

		Grain weight per panicle (g)		100-grain weight (g)		Grain length (mm)		Grain width (mm)		Spikelets fertility	
Source	df	MS	%MS	MS	%MS	MS	%MS	MS	%MS	MS	%MS
Treatments	74	4.905**		0.932**		0.795**		0.526**		4.079**	
Genotypes	14	4.284**	8.5	2.403**	35.7	1.086**	36.3	0.747**	13.0	5.940**	24.3
Environments	4	39.382**	77.8	3.780**	56.2	0.881**	29.5	4.819**	83.5	14.266**	58.3
Block	10	3.528**	7.0	0.092	1.4	0.204*	6.8	0.026*	0.5	0.857	3.5
Interaction	56	2.598**	5.1	0.361**	5.4	0.716**	24.0	0.164**	2.8	2.886**	11.8
IPCA 1	17	3.623**		0.600**		1.035**		0.281**		5.025**	
IPCA 2	15	2.655**		0.324**		0.808**		0.157**		2.613**	
IPCA 3	13	2.711**		0.313**		0.492**		0.111**		2.156**	
Residuals	24	0.803		0.098		0.362**		0.057**		0.815	
Error	140	0.819	1.6	0.095	1.4	0.101	3.4	0.014	0.2	0.530	2.2

*,**Significant at $p<0.05$ and 0.01 probability levels, respectively, IPCA: Interaction principal component axis

variation and ranged from lowest value of 29.5% for grain length to 77.8% for grain weight per panicle. Genotype also accounted for sizable amount of variation for grain length, 100 grain weight, spikelets fertility and secondary branching. Actually, the GGE IPCA 1 was significantly correlated with grain length (-0.621, $p<0.05$) while the GGE IPCA 2 had significant correlation with primary branching (0.636, $p<0.05$) and spikelets fertility (-0.604, $p<0.05$). With respect to the environmental variables, monthly rainfall at panicle appearance/grain filling stage showed significant positive correlation ($p<0.01$) with grain weight per panicle (0.991) and grain weight per plant (0.979). The minimum temperature at the maximum tillering/panicle initiation stage was also negatively correlated ($p<0.01$) with grain length (-0.888) and grain width (-0.949).

DISCUSSION

Differential environmental influence is dictated by location and year differences extended by the interaction of the environmental indices to create a continuous array of environmental conditions separated by little or large differences. The significant contribution of environment to the differences in genotype expression across locations and cultivation seasons would therefore, remain a serious challenge in both crop management and breeding for varieties with little variation (stable) or improved performance due to environmental changes. The observations here are consistent with those expressed by Yan *et al.* (2000), Samonte *et al.* (2005), Gauch (2006), Cairns *et al.* (2009) and Hoffmann *et al.* (2009) using different crops data. Large contribution of the environment component to grain production in rice has been similarly reported by many works (Wade *et al.*, 1999; Samonte *et al.*, 2005; Acuna *et al.*, 2008; Nassir and Ariyo, 2011). Although, there are differences in the amount of variation accounted for by the environment, the values obtained are large enough to emphasize the necessity of delineation of environments for the ultimate interest of powering the direction of plant breeding for stable or positive response, as the case may be, to changes in cultivation environments. The variable proportions of the total variance due to environment for different characters are consistent with the various reports on the magnitude of environment contribution to eventual crop performance. For most of the reported studies on G×E interaction, environmental component of the Genotype (G), Environment (E) and G×E interaction range from 96% for grain yield of wheat across locations and years; 84% for rice grain yield in diverse hydrological environments (Acuna *et al.*, 2008); 55.4% for rice grain yield across cultivation environments (Samonte *et al.*, 2005), 48% for root traits in wheat across soil environment (Acuna and Wade, 2012). The underlying causes of the large environmental effects on genotype performance also do vary with studies, crop genotypes and perhaps study location. In *Brassica*, Gunasekera *et al.* (2006) inferred from the correlation of environmental factors with principal component axes and concluded different effect of rainfall and temperature on the seed oil and protein content. Samonte *et al.* (2005) identified heat index, derived from a combination of temperature and relative humidity, as important discriminatory component of the environment and the two top yielding cultivars of rice in the study separate along relatively higher and lower minimum heat index. The hydrological conditions was expectedly the underlying factor in genotype-environment influence on rice grain yield reported by Ouk *et al.* (2007) and Acuna *et al.* (2008). Shrestha *et al.* (2012) however, reported diverse response of yield components in upland rice to environmental variables for low medium and high altitude locations and concluded that the contribution of yield components to genotypic performance vary change with environments. In this study, relatively lower temperature and moisture availability, especially at the grain filling stage are the indices of good grain production. The study locations experienced low night temperature which may continue for most part of the day during occasional periods of continuous rainfall. Since this may not always be the prevailing condition, however, the development of cultivars for the typical tropical conditions with complex drought conditions and concomitant high temperature must take cognizance of these factors.

The interaction component of the Total Sum of Squares (TSS) in this study was small relative to the environment but larger than the genotype component for most of the characters. This was similarly observed by Wade *et al.* (1999), Yan *et al.* (2000), Samonte *et al.* (2005), Ouk *et al.* (2007), Acuna *et al.* (2008) and Acuna and Wade (2012). This is however contrary to the findings of Ouk *et al.* (2007) for days to flowering in rice, Egesi *et al.* (2007) for root yield in cassava and Hoffmann *et al.* (2009) for root yield and quality indices in sugar beet. The finding of the later reports is however, similar to the results obtained in this study for most of the characters at the level of actual variance of individual components. This is perhaps indicative that characters contributing to eventual yield data may not always be similar in their interaction with the environment, thereby creating an array of expression which would contribute to inconsistencies in genotype performance. This becomes very important for genotypes and traits with pronounced reaction to extreme environments and consequently deserves consideration in development of rice genotypes for tropical rainfed ecosystem, with its characteristic within- and between-season moisture and temperature variation. As observed, grain length had larger genotypic contribution to total variance relative to both the environment and the interaction suggesting that the character can still be improved for better expression and stable performance. This would necessarily impact positively on spikelets fertility, grain weight and consequently grain yield. This position is further strengthened by the high genotype and genotype-environment interaction obtained for grain width and spikelets fertility.

In terms of high grain production genotypes 10, 12 and 15 are expected to increase grain production with improvement in environment 1 or similar environments. This was obtained for both the GGE and AMMI biplots indicating synergy in the use of the models. Rainfall in season represented by E1 was quite high and well distributed over the vegetative and ripening period. G13 though produce more grains than the average in E1 E3 and E5, it is quite unstable as its ranking was not consistent across environments. The genotype however appeared to be adapted to low rainfall and high temperature environments typical of E3 and E5. It also had moderate panicle and tiller number and days to flowering (Nassir and Ariyo, 2006) and this possibly makes its adjustment to poor moisture condition striking. It also shared these traits with G14 to an appreciable extent.

The GGE analysis classified genotypes and the environments at the level of adaptability or at least compatibility. The E3 and E5 from observation for instance had low and fairly irregular rainfall pattern. The E3 was located in the rain forest zone but the rainfall of the year was quite poor and most varieties performed poorly. The E5 is in the derived savannah zone with the characteristic low and erratic rainfall pattern. The genotypes are worth upgrading for cultivation in the poor rainfall regions. Genotypes like with positive PC 1 scores and near zero PC scores are taken to be capable of better grain yield with Environments like E1 and E2 which also had positive PC1 scores (Zobel *et al.*, 1988; Gauch, 2006; Yan *et al.*, 2007). G4 exhibit fairly stable (and average) grain production and would be expected to perform averagely in the environments. The genotype had the one of the least panicle number and the largest grains. The significant correlation of PC1 of GGE with illustrates that the axis can appreciably represent the genotype main effect at least for grain production as the correlation of the same axis was not significant for other panicle and grain characters except grain length. As observed by Yan *et al.* (2001), this is an indication of complex form of interaction between the characters and the environment. Since, the cumulative effect of these interaction manifests in grain production, emphasis on breeding for certain characters which have pronounced effect on varietal response to environmental differences becomes almost as important as the final grain yield. In this study, the significant correlation of primary branching and spikelets fertility with IPCA 2 of GGE denotes the need to breed for consistency in the performance of genotypes for the characters so as to confer some level of stability on grain yield.

CONCLUSION

In general consideration, the observed disparity in cultivation conditions and the inconsistencies in individual genotype expression, even within an environment and for single year cultivation, are generally indicated by the significant mean squares for the treatment components. This would continue to whip up challenges that would keep breeders active for the sole purpose of developing new genotypes or upgrading existing ones for adaptation to reasonable fluctuations in environmental indices. The devolution of the analytical tools, AMMI, GGE and other stability measurement models, for expounding specific intricate interactions that would guide this would indeed be beneficial. In this study, adaptation to typically high tropical temperature at panicle initiation and adequacy of moisture at grain filling are important environmental indices that should guide in genotype development for high grain yield for the ecology. The divergence in adaptation of genotypes to specific environment and the underlying response of grain length and width, primary branching and spikelets fertility would require further insight to obtain a balance in the concentration of these characters for the ultimate aim of increased and fairly stable grain production.

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