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Original Article

MULTI-LOCATION YIELD EVALUATION OF LOWLAND HYBRID RICE VARIETIES IN NIGERIA

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ABSTRACT

This study evaluated the yield stability of three commonly grown hybrid rice genotypes across seven locations in the Northern Guinea Savannah (NGS) and Sudan Savannah (SS) of Nigeria. Three inbred commercial rice varieties were used as local checks. The rice cultivars were arranged in three replicates using Randomized Complete Block Design (RCBD). Grain yields were analysed using Additive Main Effects and Multiplicative Interaction (AMMI). Although the environment effect was significant ($p<0.05$), genotypes, the first and second interaction principal component axes were not significant. Environment effect accounted for 93.8 % of the total variation. The rice cultivar CP 801 produced the highest (5998 kg^{-ha}) grain yield while CHAOTA gave the lowest (4853 kg^{-ha}). The highest environment mean grain yield was observed in Kano (SS) (11899 kg^{-ha}), followed by Kaduna (NGS) (8898 kg^{-ha}). The hybrid CP 801 was identified as genotype adapted to wider environments, and hereby recommended for cultivation in NGS and SS of Nigeria

Keywords: Yield; lowland; rice; hybrid; yield stability; environments; G × E interaction

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INTRODUCTION

Hybrid rice is a reliable food source in developing countries owing to its high yield potential (Cheng *et al*., 2007). However, before releasing these hybrids for cultivation, estimation of their adaptability and suitability for those areas is a prime step as they show considerable amount of genotype × environment (G × E) interaction. One of the reasons for slow progress in developing rice varieties and hybrids is the prevalence of large genotype × environment interactions (GEI), which results from differences in the genotype adaptation and heterogonous environments (Fuka and Cooper, 1995). Since the advent of hybrid rice technology in Nigeria, the rate of adoption is low. However, the research on the effects of heterogeneity on performance and stability hybrid rice is limited. This warrants the attention of plant breeders to evolve superior hybrids that would sustain well in the stressful situation. Panwar *et al.* (2008) observed varying magnitude of heterosis over environments and stressed the need to evaluate hybrid across environments in order to identify those with desirable stability.

Evaluation of genotypes over a range of environments enables plant breeders to identify genotypes that are adapted to a particular environment and those that are stable over a wide range of environments. Because of the intensity of efforts required for developing new variety identification of cultivars with wide adaption is of utmost importance to plant breeders in most crop improvement programs (Muhammad *et al.*, 2003). The crop environment refers to all factors outside the genetic constituents of the genotype (Fikere *et al.*, 2014). These include water, nutrition, temperature and diseases that induce significant variation in plant growth and yield. However, studies have shown that the more stable genotypes adjust their phenotypic responses to provide some measure of uniformity in spite of environmental fluctuations (Patil *et al.*, 2014). The environmental factors which induce G × E interaction could be predictable or unpredictable. The predictable factors could be managed by allocating specific cultivars to specific locations. In practice, several genotypes are evaluated over a number of sites, seasons and years. Genotypes responses across locations could be visualized by means of graphical display of the data (Yan *et al.* 2001). Thus interrelationship among environments, genotypes, and interactions between genotypes and environments could be obtained using biplot analysis. The most widely used are the AMMI biplot (Gauch, 1988; Gauch and Zobel, 1997) and the genotype and genotype × environment (GGE) biplot (Yan *et al.*, 2000; Ma, 2004). In the AMMI 1 biplot, the displacements along the vector line indicate variability in main additive effects. Conversely, displacements along the ordinate reveal variation in interaction effects. Genotypes that clustered together responded similarly while environments which grouped together exerted similar effect on the genotypes (Kempton, 1984). However, it is possible for the best genotype to plot far from the environment. In a situation where genotypes have interaction principal component axis (IPCA) 1 score of nearly zero, they are less influenced by the environment, with little interaction effects and are said to be stable. If a genotype and an environment have the same sign on the PCA axis their interaction is positive and vice-versa.

Although rice is grown in different parts of Nigeria, there is dearth of information on yield stability of the hybrids under study. This information would be useful for accelerating rice breeding program in the country. This study was carried out to determine the stability of grain yield from hybrids rice varieties at seven different locations in northern Nigeria.

MATERIALS AND METHODS

Three lowland hybrid rice genotypes (CHAOTA, HHZ-1 and CP 801) were received from Green Agriculture Seed Company, Abuja, Nigeria in order to compare their yields with three improved rice varieties, which served as standard checks; these were FARO 44, FARO 52 and FARO 57. The rice genotypes were arranged in three replicates using Randomized Complete Block Design (RCBD) across seven locations in northern Nigeria (Kano, Kaduna, Badeggi-irrigated, Badeggi-rainfed, Wushishi, Badeggi013 and Gwagwalada). Each plot of 4×3 $m^2$was transplanted with 21-day old seedlings at 20 × 20 cm spacing. The land was ploughed, harrowed and later paddled and leveled before transplanting. In general, fertilizer application was 120 kg nitrogen per ha at three splits of 60, 30, and 30 at transplanting (basal), 21 and 42 days after transplanting (DAT), respectively. Thereafter, 60 kg P_2O_5 and 60 kg K_2O were applied at transplanting. Weeds were controlled by the use of OrizorPlus, a formulation of Propanil and 2-4-D, at the rate of 4 litres per ha at 21 DAT. This was followed by hand weeding at 45 DAT. Grain yields were determined at 14 % moisture level and data were subjected to AMMI analysis using Breeding Management System (BMS, 2015) package.

RESULTS

Grain yield differences among the evaluated genotypes

The variation in grain yield among the rice genotypes tested in seven environments revealed that the main effects of genotypes and environments accounted for 1.03 % and 93.8 % variation, respectively; only 2.5 % variation was caused by G × E interaction effects (Table 1). The analysis showed that variances due to genotypes, IPCA 1 and IPCA 2 were not significant (p>0.05). The presence of genotype × environment interaction was evident when the interaction was partitioned. The first two IPCAs indicated that IPCA 1 and IPCA 2 explained 1.1 % and 0.7 % of the GEI sum of squares, respectively (Table 1).

Table 1: Genotype, environment and interaction effects on the grain yield from six rice genotypes across seven locations in northern Nigeria

Source	DF	SS	MS	VR	F pr	SS (%)
Genotypes	5	5276395	1055279	2.43	0.0581	1.03
Environments	6	476027060	79337843	182.59	<0.001	93.8
Interactions	30	13035398	434513			2.5
IPCA 1	10	5791166	579117	2.03	0.1228	1.1
IPCA 2	8	3818575	477322	1.67	0.2035	0.7
Residuals	12	3425656	285471			0.67

Stability analysis by AMMI model

The rice genotypes performance over the seven environments showed that the genotype CP 801 and CHAOTA had the highest (5998 kgha^{-1}) and the lowest (4853 kgha^{-1}) yield, respectively. The environments mean grain yields ranged from11899 kgha^{-1} (in Kano) to 1927 kgha^{-1} (in Badeggi013). On the other hand, the mean grain yield, regardless of the environments and genotypes was 5355kgha^{-1}. Figure 1 showed the high yielding genotypes CP801, FARO 44, FARO 52 and FARO 57 aligning on the right hand side of the biplot while HHZ-1 is found below the origin at the left hand side of biplot. In contrast, low yielding genotypes CHAOTA and HHZ-1 are concentrated on the left hand side of the biplot. Figure 1, displayed the four mega environments as well as the best genotypes in each environment. The biplot showed that Kano, Gwagwalada, Wushishi, Badeggi-irrigated and Badeggi-rainfed formed one mega environment with genotype CP 801, FARO 44 and FARO 52 as the best genotype in these environments. Badeggi-rainfed formed another mega environment within the first mega environment with FARO 52 performing best in this environment while Kaduna formed the third mega environment with FARO 57 as the best genotype. Similarly, FARO 57 and HHZ-1 were the genotypes in the last mega environments Badeggi013.

In the biplot (Fig. 1), CP 801, FARO 57, FARO 52 and FARO 44 exhibited high grain yield. Moreover, these genotypes showed high additive effects with positive IPCA1 score but CP 801 was the best genotype for grain yield.

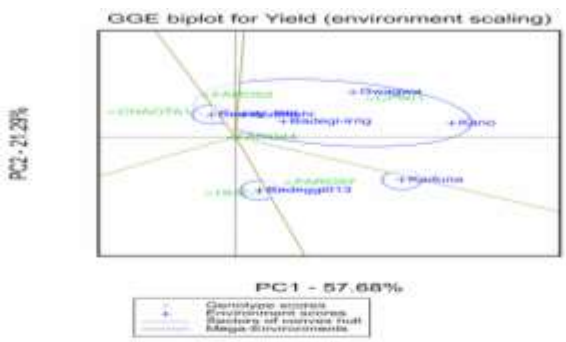

Fig. 1: Additive main effects and multiplicative biplot of the six rice genotypes evaluated for grain yield across seven environments

The result of AMMI 2 biplot is presented in Fig. 2. It revealed the presence of sites with short and long vector lines. In the biplot, all the environments are connected to the origin. The result revealed that Badeggi-rainfed, Badeggi-irrigated and Wushishi had short vector lines while Kano, Gwagwalada, Kaduna and Badeggi013 exerted long vector lines. FARO 44 and CHAOTA were close to the origin while CP 801, FARO 52, FARO 57 and HHZ-1 had more response to GEI

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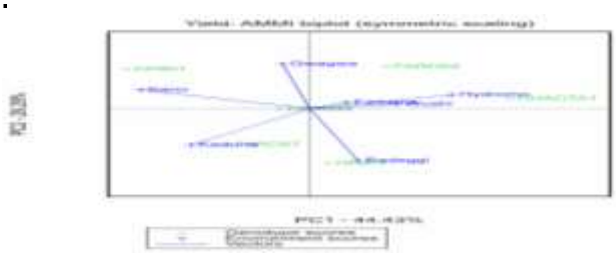

Fig. 2: AMMI 2 biplot for six rice genotypes grown in seven environments

Box plot display

The environmental means for grain yield across seven locations are shown in box plot graph (Fig. 3). Genotypes that contributed to high diversity for grain yield were found at Kaduna, Gwagwalada and Badeggi013, while narrow diversity was found at Kano, Badeggi-irrigated, Wushishi and Badeggi-rainfed. Mean grain yield of the genotypes varied in every environment which ranged from 1972 kg^{-ha} for Badeggi-irrigated to 11899kg^{-ha} for Kano, with a grand mean of 5355 kg^{-ha}.

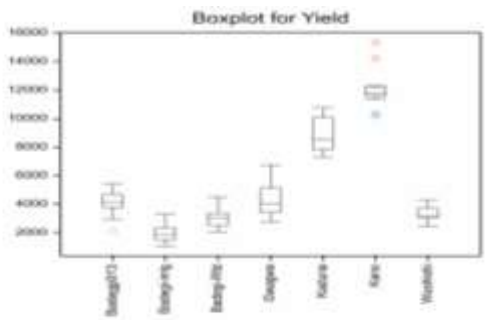

Fig. 3: Box plot of the grain yield from six rice genotypes in seven locations displaying total range, inter-quartile range and median

Table 2: Summary statistics of the seven environments for rice grain yield

	Mean	Median	Min	Max	Range	Lower quartile	Upper quartile	Standard error of mean	Variance	% cv
Kano	11899	11849	10288	13712	3424	11698	12000	445.9	1193064	9.18
Kaduna	8898	8792	7806	10222	2416	8000	9778	390.7	915993	10.76
Gwagwa	4301	4388	3215	5229	2013	3511	5075	337.4	683135	19.22
Badeggi013	4108	3987	3359	4922	1563	3692	4700	243.4	355532	14.51
Wushi	3342	3319	3107	3620	513	3144	3542	94.6	53681	6.93
Badeggi-rainfed	3013	2976	2412	3697	1284	2757	3258	178.8	191745	14.53
Badeggi-irrigated	1927	1867	1348	2840	1492	1556	2086	211.8	269209	26.92

Grain yield result as shown in Table 3 revealed that, there were significant (p<0.05) differences in genotypes, environments and genotypes sensitivities. In addition, results in Table 4 show that genotype CP 801 and CHAOTA statistically gave the highest and lowest mean grain yield of 5998 and 4853 kg^{-ha}, respectively, across the seven locations. There were no significant differences among the check varieties (FARO 44, FARO 52 and FARO 57), though they statistically ranked second best after the hybrid rice genotype CP 801. However, environments were significant with Kano and Badeggi-irrigated giving the highest and lowest mean grain yield of 11899 and 1927 kg^{-ha}, respectively . On the other hand, Badeggi013 and Gwagwalada locations statistically ranked the same with mean grain yield of 4108 and 4301 kg^{-ha}, respectively.

Table 3: ANOVA of the grain yield for six rice genotypes across seven locations

Source	DF	SS	MS	VR	F pr.
Genotypes	5	15980044.6242	3196008.9248	5.05	<0.001
Environments	6	1428057088.0396	238009514.6733	375.85	<0.001
Sensitivities	5	14291365.4505	2858273.0901	4.51	<0.001
Residual	109	69024638.5370	633253.5646		
Total	125	1527353136.6512	12218825.0932		

Table 4: Mean grain yield of six rice varieties across seven locations in Nigeria

	Location Mean yield (kg/ha)							
Genotypes	Badeggi-irrigated	Badeggi013	Gwagwalada	Badeggi-rainfed	Kaduna	Kano	Wushishi	
CHAOTA1	3359^{c}	2086^{b}	3511^{b}	3258^{ab}	7806^{b}	10288^{c}	3663^{ab}	4853^{b}
CP801	3692^{bc}	2840^{a}	5229^{a}	2945^{ab}	9778^{a}	13712^{a}	3788^{a}	5998^{a}
FARO44	4013^{abc}	1808^{bcd}	4125^{ab}	2412^{b}	8667^{ab}	12000^{b}	3572^{ab}	5228^{ab}
FARO52	3961^{abc}	1348^{d}	5075^{a}	3697^{a}	8000^{b}	11698^{b}	3025^{ab}	5258^{ab}
FARO57	4700^{ab}	1556^{cd}	4651^{ab}	3008^{ab}	10222^{a}	11964^{b}	2964^{b}	5581^{ab}
HHZ-1	4922^{a}	1925^{bc}	3215^{b}	2757^{ab}	8917^{ab}	11733^{b}	3037^{ab}	5215^{ab}
Location Means	1927^{f}	4108^{cd}	4301^{c}	3013	8898^{b}	11899^{a}	3342^{e}	
$LSD_{0.05}$	1044	504	1521	1025	1563	1344	704	533.2
CV%	14.51	26.92	19.22	14.53	10.76	9.18	6.93	9.1
Heritability	0.68	0.90	0.64	0.42	0.72	0.84	0.62	0.72

DISCUSSION

The large sum of square for environments revealed the diversity of the study locations which ultimately caused most of the variation in mean grain yield. Furthermore, the pattern of GEI indicated that the interaction of the rice genotypes with study locations was predicted by the first two components. A similar result was encountered by Gauch and Zobel (1996) who reported suitability of the first two IPCAs for predicting AMMI analysis. However, this contradicted the results of Sivapalan *et al*. (2000). In general, this investigation revealed that significant variation due to environments represents adequate heterogeneity among the environments for grain yield. The grain yields of the rice genotypes relative to their positions in the biplot agreed with the observations reported by Gauch and Zobel (1996), that genotypes and environments on the same side of the ordinate line produced similar yields.

The high grain yield obtained from CP 801 in Kano, Kaduna, Gwagwalada and Badeggi013 revealed that these environments could be considered as the wide range suitable for this genotype. In the AMMI 2 biplot, sites with short vector lines did not exert strong interactive forces while those with long vector lines exerted strong interaction. This is in agreement with the result of McDermott and Coe (2012) who reported that a longer vector line influenced a location in which there was a large range of genotype performance. The genotype occurring close to the environments had similar yield performance in those environments while genotypes far apart differed in mean yield or showed a different pattern of response over the environment. Therefore, rice genotypes near the origin were not sensitive to environmental interaction and genotypes distant from the origin were sensitive and had large GEI. Since FARO 44 and CHAOTA were close to the origin, it could argued that they were not sensitive to environment interactive forces, while CP 801, FARO 52, FARO 57 and HHZ-1 had more response to GEI.

Variation in grain yield might have been caused by several factors such as soil fertility, structure, texture and rainfall. Unpredictable environmental factors such as temperature and rainfall even at a single location may contribute to genotype by environment interaction over years. In the multi-location trials, the environments at which the field experiments were conducted were geographically and temporally different. This was probably responsible for a large environmental effect. This confirmed the opinion of Eberhart and Russel (1966) that testing genotypes over locations with large variability is a suitable approach for selecting stable candidates.

CONCLUSION

This investigation demonstrated the suitability of AMMI statistical model for identifying stable and high-yielding rice genotypes for specific as well as diverse locations. In the present study, the result of AMMI analysis of variance showed that genotypes IPCA1, IPCA2 and interaction were not significant, while the environments’ effect was significant with 93.8 % variation. Similarly, stability analysis revealed that genotype CP 801 gave the highest mean grain yield of 5998 kg^{-ha} across the locations. Though the evaluated genotypes exhibited inconsistent performance, Kaduna and Kano gave the highest environments mean grain yield of 8898 and 11899 kg^{-ha}, respectively. The mean grain yield over environments and genotypes was 5355 kg^{-ha}. Additionally, AMMI biplot revealed that CP 801, FARO 44, FARO 52 and FARO 57 genotypes gave the highest mean grain yield and generally exhibited high main additive effect. The hybrid CP 801 was identified as a genotype adapted to wider environments, and hereby recommended for cultivation in NGS and SS of Nigeria

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