Evaluation of Some Promising Rice Genotypes for Grain Yield Stability Using AMMI Model

Ehirim, B.O.,[1,2*] Bashir, M.,[1]Gana, A.S.,[2]Salaudeen, M.T.,[2]Tolorunse, K.D.,[2]Uyokei, U.,[1]Onotugoma, E.,[1] and Uwuigbe, E.U.[3]

National Cereals Research Institute P.M.B 8 Badeggi, Nigeria[1]
Department of Crop Production, Federal University of Technology, Minna, Niger State, Nigeria[2]
Department of Agronomy, Forestry and Wildlife, Delta State University, Abraka, Delta State, Nigeria[3]

Abstract
Plant breeders are always faced with the difficulty of haven to develop genotypes that are not only high yielding but combined with stability across varied locations (environments). Stability and sensitivity estimate were investigated on grain yield of 13 lowland rice genotypes of which, 2 commercially released rice varieties (FARO 44 and FARO 52)were used as checks, for 4 years; 2013, 2014, 2015 and 2016. The experiments were laid out in a randomized complete block design in three replications. The Analysis of Variance for Additive Main Effect and Multiplicative Interaction (AMMI ANOVA)revealed that grain yield differed significantlyfor both genotypes and environment at P = <0.01 indicating that both the genotypes and the environment (years) of investigation responded differently. The partitioning of GGE through GGE biplot analysis showed that, principal component1 and principal component 2 accounted for 50.46% and 24.78% of GGE sum of squares, respectively, explaining75.24% of the total observable variations noticed. AMMI 2 biplot revealed that, genotype G11 (FAROX521-H137-1) was the most stable across the years investigated, indicating its consistency across the different environments. Hence, the genotype would be considered more adapted to wide ranges of environments than the rest genotypes.

Keywords: *AMMI, Genotype, Stability*

Introduction

In Nigeria, rice is a leading staple crop cultivated in virtually all the agro-ecological zones of country, from the mangrove and swampy environment of the coastal areas, to the dry zones of the Sahel in the North [1].It is a major food crop but its global supply is not keeping pace with demand. Rice is the world's leading food crop with over half of the world's population depending on it for nutrition and calories which is driven by changing food preferences in both rural and urban area. Rice consumption in the Saharan and Sub-Saharan Africa increased by 5.6% per annum between 2001 and 2006, which doubles the rate of population growth [2]. Global Rice Science Partnership [3](GRISP, 2013) reported that, Nigeria is blessed with three major rice production environments and their coverage is rainfed lowland (69.0%), irrigated lowland (2.7%) and rainfed upland (28.3%). More than 90% of Nigeria's rice is produced by resource poor small-holder farmers, while the remaining 10% is produced by cooperate/commercial farmers[3].

While the global populace and governments battle the short supply of rice to feed its teeming population, environmental fluctuations and seasonal influences impact the growth of rice and other field crops. Therefore, G X E interaction andgenotypic stability are important tools plant breeders use in distinguishing genotypes. Plant breeders often prefer varieties with good quality, high yields and are varieties with capacity to adapt for ranges of environment. The agreement on the importance of goodphenotypic stability is common to breeders, but there is much less agreement onthe most appropriate definition of stability and the statistical measure of stability in yield trials [4].

Stable genotypes are particularly of great importance in Nigeria, where particular crops are grown under varied environmental conditions. Allard and Bradshaw[5]have critically reviewed this phenomenon and brought out the implications of stable genotypes in applied plant breeding. Thus, the stability of a genotype is germane in the expression of quantitative characters, which are controlled by polygenic systems and largely influenced by environmental fluctuations.The process of identification of stable genotype is difficult because of the influence of G × E interaction. Although plant breeders have often observed genetic differences for crop adaptability, they have been unable to fully exploit these differences in breeding stable genotypes largely due to the problem of defining and measuring phenotypic stability.

Statistical approach of Finlay and Wilkinson [6] has considerably shown to be a useful means and toolto measuring the phenotypic stability in the performance of genotypes. They considered linear regression slope (bi) as a measure of stability. This regression analysis proposed by Finlay and Wilkinson was improved upon by Eberhart and Russell[7]. They introduced one more parameter; deviation from regression (S2di) which accounts for unpredictable irregularities in the response of genotypes to varying environments.

[8] proposed another methodology known as GGE-biplot for graphical display of GE interaction pattern of MET (Multi-Environment Trial) data with many advantages. GGE biplot analysis considers both genotype (G) and GE interaction effects and graphically displays GE interaction in a two-way table [8]. GGE biplot is an effective method based on principle component analysis (PCA) to fully explore MET data. It allows visual examination of the relationships among the test environments, genotypes and the GE interactions. It is an effective tool for: (i) mega-environment analysis (e.g. "which-won-where" pattern), where by specific genotypes can be recommended to specific mega-environments [9]-[10], (ii) genotype evaluation (the mean performance and stability), and (iii) environmental evaluation (the power to discriminate among genotypes in target environments) [11].

A population which can adjust its genotypic or phenotypic state in response to environmental fluctuations in such a way that it gives high and stable economic returns, can be termed as "well buffered" [12]. It is with respect to these facts that the yield data of 13 promising rice genotypes were subjected to grain yield stability evaluation for 4 years.

Materials and Methods

Eleven (11) lowland rice genotypes with 2 standard checks (FARO 44 and FARO 52)developed in the breeding program of the National Cereals Research Institute,Badeggi, Nigeriaand evaluated for 4years (2013, 2014, 2015 and 2016) were used for these experiments.The experimentswere conducted ina randomised complete block design with three replications. The plot size was 4mx 3m in a spacing of 20 cm inter and intra row. Fertilizerapplication was 40 kg N, 40 Kg P_2O_5 and 40 Kg K_2O at transplanting,while additional 40 kg N per ha was used as top dressing at vegetativeand panicle initiation in equal split. Weed control started with chemical at21 days after transplanting (DAT) using a formulation of Propanil and2-4-D (Orizo Plus(R)), and subsequently by hand weeding at 43 daysafter transplanting. Grain yield was recorded at 14% moisture content after harvest and was subjected to analysis of variance (ANOVA). Stability of rice grain yield was determined by subjecting the grain yield data to additive main effect and multiplicativeinteraction (AMMI), GGE-biplot and Boxplot analysis using BreedingView (BV) statistical package in the breeding management system, version 3.0.9.[13]

Results and Discussion

Table 1: Analysis of variance using F&W Regression Analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr
Genotypes	12	19034867	1586239	2.97	0.0057
Environments	3	8658387	2886129	5.40	0.0036
Interactions	36	19251789	534772		
IPCA 1	14	9550551	682182	1.63	0.2215
IPCA 2	12	5509052	459088	1.10	0.4491
Residuals	10	4192185	419219		

From the Finlay and Wilkinson regression analysis, there were significant differences among the tested genotypes across the four years investigated (Table 1). However, the environments showed wide range of differences too within the years as shown in Table 1. IPCA 1 and IPCA 2 were not significantly different meaning that IPCA 1 and IPCA 2 contributed little or nothing to the observable differences in the grain yield of the genotypes within the respective years. Identifying high yielding and stable genotypes is easier when such significant differences are observed [14].

Table 2: Grain yield (tonnes^{-h}) performance of 13 rice genotypes across four years

Genotypes ID	Designation	2013	2014	2015	2016	Mean
G1	FARO44 (Check)	806	2087	3578	1743	2053.50
G2	FARO52 (Check)	1214	1773	3753	2950	2422.50
G3	FAROX521-A542-1	1161	2805	1323	1637	1731.50
G4	FAROX521-A139-1	1271	1459	1484	2957	1792.75
G5	FAROX521-E250-1	2044	3101	1851	723	1929.75
G6	FAROX521-E470-1	2283	2563	2035	1590	2117.75
G7	FAROX521-A139-2	998	4028	3508	3939	3118.25
G8	FAROX521-A5-1	1177	2015	1697	3200	2022.25
G9	FAROX521-H19-1	1235	2142	2404	2850	2157.75
G10	FAROX521-H261-1	1563	1521	1790	2650	1881.00
G11	FAROX521-H137-1	4070	3947	4063	3773	3963.25
G12	FAROX521-H234-1	1203	3049	2412	2677	2335.25
G13	FAROX521-H469-1	2115	2996	2955	3073	2784.75
	5%LSD	451	534	379	493	464
	CV%	53.06	37.21	32.60	35.64	39.62

G1-G13= Identities for the Designations found in Table

Table 3:Genotypes stability parameters for grain yield based on the Finlay and Wilkinson (1963) stability model

Genotype ID	Designation	Sensitivity (b)	static stability	dynamic stability	Mean	Mean square deviation
G1	FARO44 (Check)	1.632	1325963	2434852	2053	1073727
G2	FARO52 (Check)	1.930	1310270	1789498	2422	685894
G3	FAROX521-A542-1	0.467	551225	2845602	1731	752023
G4	FAROX521-A139-1	1.031	611472	2756216	1793	551746
G5	FAROX521-E250-1	–0.712	949109	2524951	1930	1249265
G6	FAROX521-E470-1	–0.451	170308	1871272	2118	185706
G7	FAROX521-A139-2	2.805	2049547	1218151	3118	370305
G8	FAROX521-A5-1	1.386	735794	2320712	2022	443478
G9	FAROX521-H19-1	1.399	463855	1941553	2158	23254
G10	FAROX521-H261-1	0.683	276789	2424768	1881	254898
G11	FAROX521-H137-1	–0.179	19268	4265	3963	17953
G12	FAROX521-H234-1	1.417	638038	1687072	2335	267259
G13	FAROX521-H469-1	0.913	201755	858084	2785	16456

G1-G13= Identities for the Designations found in Table

The existence of Genotype x Environment interaction (GEI) raises the need to identify high yielding and stable genotypes because an ideal cultivar is one which would have both a high average performance over a wide range of environments plus stability[7]. Genotypic sensitivity is indicated by b value. This explains the changes experienced in the quality of environments; where values of b > 1 mean genotypes with a higher sensitivity than average sensitivity (b=1), and such genotypes are less stable;while b < 1 means genotypes that are less sensitive and more stable. It should therefore be noted that the best genotypes within the four (4) years of study are those that are within the b = <1 range of sensitivity and should be noted that the lesser that b value the more stable the variety. From Table 3, (G5)FAROX521-E250-1 with a b value of -0.712 was the most stable genotype followed by (G6) FAROX521-E470-1 with a b value of -0.451. However, (G11) FAROX521-H137-1 with a b value of -0.179 would be the most preferred genotype to be selected for further breeding because of its high mean yield value of 3963 $^{t\text{-}h}$ rice, outperforming G5 and G6 with 1930 $^{t\text{-}h}$ and 2118 $^{t\text{-}h}$ rice, respectively (Table 2). The idea behind stability as opined by [15] is reflected here and can be concluded that though G5 and G6 had better stability rating, G11 would be selected because of its consistency in yield performance over other stable genotypes, which implies that no matter how the environments (year) fluctuated, the yield was not compromised indicating a more static stability. This finding, agrees with [15] who opined that,an ideal genotype isthe genotype with high performance combined with good stability to different environments

The differences among genotypes in terms of direction and magnitude along the X-axis (yield) and Y axis (IPCA 1 scores) are provided by AMMI biplot using the main effect and the first principal component scores of interactions (IPCA1) of both genotypes and environment (Fig. 2).

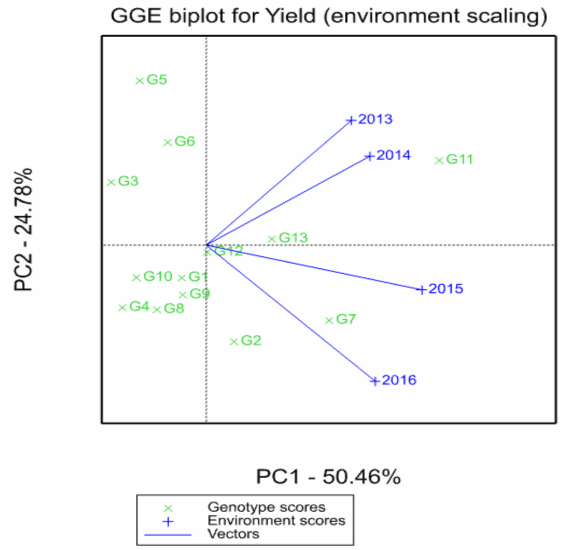

Fig 1: Biplot of AMMI for 13 rice genotypes across four years

In the bi-plot, genotypes or environments that appear almost on a perpendicular line of the graph have similar mean yields and those that fall almost on a horizontal line have similar interaction [16], which however, explains the variability due to environments being greater than that due to genotype differences. Genotypes or environments on the right side of the midpoint of the perpendicular line have higher yields than those on the left side. Genotypes G11 and G13 (FAROX521-H137-1, FAROX521-H469-1) exhibited the highest mean grain yield of 3,963.25$^{t\text{-}h}$ and 2,784.75 $^{t\text{-}h}$, respectively and were most stable in the year 2013 and 2014.

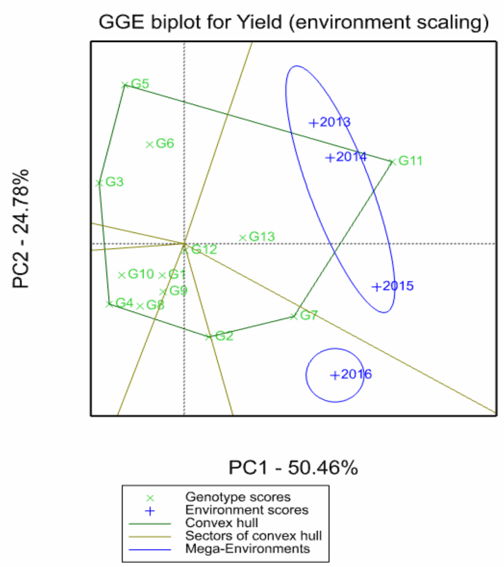

Fig 2: GGE biplot for best genotypes in different years for grain yield

The biplot of the best genotypes in each of the environments for grain yield is presented in Figure 3. The polygon view of the GGE-biplot explicitly displays 'which-won-where' i.e. (best genotype in each environment) and it is a summary of the GEI pattern of the different years yield data. The genotypes that were distanced from the origin center of the biplot and are closed to or at the vertex point of the polygon are said to be the most stable and shapes the polygon. To each side of the polygon, a perpendicular line, starting from the origin is drawn and extended beyond the polygon so that the biplot is divided into several sectors, and the different environment were separated into different sectors.[14].The genotype at the vertices of each sector was the best performer at environments included in that sector. In this study there were six sectors only and two mega environments identified. From the Fig 2, 2013 and 2014 and 2015 showed almost same environmental quality but 2016 was grouped differently as an environment. However, for 2013, 2014 and 2015, genotype G11 and G13 won or were the best genotypes for those yearswhile for 2016, genotype G7 won thoughdid not have yield the highest across the environments.

Conclusion

AMMI statistical model is a tool in selecting the most suitable and stable high yielding crop genotype for specific as well as for diverseenvironments. In the present study, it was shown that, the largest proportion of the total observable variations in the grain yield of the rice genotypes were attributed to years (environments). The mean grain yield value of genotypesaveraged over environments indicating that (G11) FAROX521-H137-1, and (G13) FAROX521-H469-1 had a small GE effect, indicative of the fact that theywere stable genotypes and being less influenced by the environments.

References

[1] Akande S.O (2002) An Overview of the Nigerian Rice Economy, NISER, Ibadan.

[2] F.A.O. (1990). Technical Hand Book for the paddy rice industry in Developing countries [www.fao.org/docrept/t1838e].

[3] GRISP (Global Rice Science Partnership) (2013). Rice almanac, 4th edition. Los Banos (Philippines) International Rice Research Institute: 283.

[4] Shrief, S.A., (2003). Parametric and non-parametric measures of stability in oil seed rape hybrids. Proc. 3rd plant Breed.Conf. April 26, Giza, Egypt. J. plant Breed. 7(1): 689-706

[5] Allard RW, Bradshaw AD (1964). Implications of genotype × environment interaction in applied plant breeding. Crop Sci. 4:503-508.

[6] Finlay, K.W., Wilkinson G.N. (1963). The analysis of adaptation in a plant breeding programmeAust. J. Agric. Res. 14:742-754.

[7] Eberhart SA, Russell WA (1966). Stability parameters for comparing varieties. Crop Sci. 6:36-40.

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

[9] Yan W, Kang MS (2003) GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists and Agronomists. 1st Edn., CRC Press LLC., Boca Roton, Florida, pp: 271

[10] Yan W, Tinker NA (2006). Biplot analysis of multi-environmental trial data: Principles and applications. Can. J. Plant Sci. 86:623-645.

[11] Ding M, Tier B, Yan W (2007) Application of GGE biplot analysis to evaluate genotype (G), environment (E) and GxE interaction on P. radiata: A case study. Paper presented to Australasian Forest Genetics Conference Breeding for Wood Quality, 11¬14 April 2007, Hobart, Tasmania, Australia.

[12] Singh S.V., Singh R.B. (1980). Stability of component charactersin relation with the stability of yield. Indian J. Genet.40:93-98

[13] Breeding Management System (BMS). (2015). Breeding management system. Version 3.0.8. Integrated Breeding Platform (IBP), Mexico.

[14] Ishaq M.N., H. Agrama and A. Adeleke (2015). Exploiting Genotype X Environment Interaction in Soybean breeding in Nigeria. Int. J. Adv. Res. Biol. Sci.2(1)2015: 24-32

[15] Maji, A. T., Bashir, M., Odoba, A., Gbanguba, A. U., Audu, S. D., (2015). Genotype × Environment Interaction and Stability Estimate for Grain Yield of Upland Rice Genotypes in Nigeria. J Rice Res3:136.

[16] Crossa, J., 1990. Statistical analyses of multilocation trials. Adv.Agron., 44: 55-85.

[17] Egesi, C.N. and R. Asiedu, (2002). Analysis of yam yields usingthe additive main effects andmultiplicative interaction(AMMI) model. Afr. Crop Sci. J., 10: 195-201.