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Original Research Article

GGE Biplot Analysis of Yield Stability in Multi-Season Trials of Early Matured Rice (*O. Sativa*) Genotypes in Rain Fed Lowland Ecosystem

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ABSTRACT

The study was conducted in western part of Ethiopia at Assosa with the objective to identify better performance and stable rice genotypes under rainfed lowland rice ecosystem. Eighteen early matured rice genotypes were tested for three consecutive years at Assosa agricultural research centre. The experiment was conducted in randomized complete block design with three replications. Combined mean analysis was computed after using Anderson-Darling normality test and Levene homogeneity test. Genotype and Genotype by environment interaction (GGE) biplot analysis were computed to evaluate stability and adaptability of the grain yield of rice genotypes. The result of ANOVA indicated that the combined mean grain yield ranged from 3319 kg ha^{-1} for G_{13} (STEJAREE 45) to 6711 kg ha^{-1} for G_2 (YUNJING 23). The rice genotypes that were evaluated in the second and third seasons had below the mean average grain yield. However, the highest grain yield recorded in season one with mean yield of 5501 kg ha^{-1}. GGE biplot analysis was also computed to identify performance and stability of genotypes and hence a total of 87.93 % variation was showed for the tested rice genotypes. The research finding indicated that the most responsive of corner genotypes were genotype one, genotype eleven, genotype two, genotype fourteen and genotype thirteen. Similarly, genotype fourteen and genotype one were highly unstable whereas genotype six and genotype thirteen including invisible genotypes were highly stable and had poor grain yield performance. In terms of stability and performance genotype two was the highest followed by genotype ten. GGE biplot analysis was the most powerful method to analyze, visualize and interpret the genotype and environment interaction. It was also a convenient procedure to genotypes stability studies and environments that has to be applied in plant breeding program.

Key words: *Ecosystem, GGE biplot, Grain yield, Performance and Stability*

INTRODUCTION

Rice (O. Sativa L.) is one of the second world wide crop and stable food for more than half of the world population. Even though rice in Ethiopia is recently introduced, due to a wider range of climate from humid tropics to alpine climates, a wide range of altitudes and huge potential of natural resources the crop is widely and rapidly adopted in different parts of the country. From the total potential of 30 million hectare of rainfed upland and lowland rice ecosystems about 5 million hectare is found in Benishangul -Gumuze region which is highly suitable for rice production (MoA, 2010).

Study conducted on early matured rice germplasms for consecutive three years under lowland rice ecosystem. Early matured rice genotypes are one of the basic characters and have an essential role for the increment of rice production and productivity. Therefore, to determine early matured genotypes, heading date is one of the basic factor which is controlled by the genetic makeup of the plant and environmental factors. Genetically, the heading date of rice genotype is determined by a combination of diverse natural variations alleles of a series of genes and qualitative trait loci involved in the rice photoperiodic flowering pathways (Matsubara *et al*., 2012).

It is important to carry out multi environment trials to evaluate new rice germplasms at different seasons or environments before a specific genotype is released for production (Rahmatollah K. *et al*, 2013). Environmental factors are essential for crop growth and the interaction effects will result on phenotypic variation of an individual genotype. The performance of a given genotype determined by the place where it growth, the genetic constituent of a genotype and the interaction of both environment and genotype. This revealed that genotypes are responsible for the genotype by environment interactions in any breeding program (Gauch and Zobel., 1996).

Evaluations of rice genotypes under different environments have a significant role to assess performance and stability. One season trial is not sufficient to measure the genetic potential of a genotype because of the interaction effects. Due to fluctuation of climate the same genotypes tested at different season may not have similar performance in terms of yield and other traits (Annicchiarico, 2002 and Kang, 1998).

Different methods can be applied for statistical analysis to evaluate performance and stability of genotypes and one of the most frequently used method is the genotype main effects and genotype by environment interaction effects (GGE) model (Gauch, 2006). This is the most powerful and recent model that can be used for a more complete and visual evaluation of the data by creating a biplot that simultaneously represents mean performance and stability (Ding *et al*., 2007; Yan, 2001; Yan and Kang, 2003). A GGE biplot is a tool that can be used to show graphically a GE interaction pattern. The grain yield performance of the genotypes, stability and evaluation of test environment from bigotry part can be described by using this method. The interaction between genotypes and environment will provide different ranking of genotypes at different growing environment and may harmonize the process of selection and also to recommend a genotype for that particular environment (Ebdon and Gauch, 2002; Gauch, 2006).

In order to apply GGE model early matured rice genotypes were evaluated in lowland rice ecosystem at Assosa agricultural research center. The experiment set an objective to evaluate the performance and stability of rice germplasms and to recommend the well performed genotype and to use the material for rice improvement breeding program. Therefore, the main objective of this study was to evaluate early matured rice genotypes and to apply a GGE biplot to identify better performance and stability on grain yield and hence to recommend the best genotype for rice producers in the region and also for similar agro-ecologies of the country.

MATERIALS AND METHODS

Eighteen rice genotypes including one standard check (EDIGET) were used as experimental materials (Table 2). The experiment was conducted in randomized complete block design (RCBD) with three replications for consecutive three years from 2013 to 2015 during rainy seasons under rain fed lowland condition. Seed sowing was done manually in drilling methods with row spacing of 20 cm apart. The plot size was 1.2 m width and 5 m length and the harvestable plot size was $4m^2$. The site was at Assosa agricultural research center on station in lowland rice research field. The annual metrological data for the growing seasons were indicated in Table 1.

Combined mean analysis was computed after using Anderson-Darling normality test and Levene homogeneity test.

The analysis of GGE for genotypes tested at different environments the yield performance in an environment was a mixed effect of genotype main effect (G), environment main effect E and genotype by environment interaction (G x E). Hence, G plus GE variability in grain yield of rice genotypes the following model was applied (Yan *et al.*, 2002)

$$Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

where Y_{ij} is the average yield of genotype i in environment j, μ is the grand mean, β_j is the main effect of environment j, $\mu + \beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively, ξ_{il} and ξ_{i2} are eigenvectors of genotype i for PC1 and PC2, respectively, η_{j1} and η_{j1} are eigenvectors of environment j for PCl and PC2, respectively, ε_{ij} is the residual associated with genotype i in environment j.

Table 1: Mean annual rainfall and temperature during the experimental period on station

Season 3 (2013)			Season 2 (2014)			Season 1 (2015)		
Temperature (°C)		Rainfall	Temperature (°C)		Rainfall	Temperature (°C)		Rainfall
Max.	Min.	(mm)	Max.	Min.	(mm)	Max.	Min	(mm)
28.93	14.38	1132.90	28.65	14.10	1031.70	29.66	15.75	1132.90

RESULTS AND DISCUSSION

Descriptive analysis

The yield performance of eighteen rice genotypes grown at different seasons described in Table 2. The mean grain yield ranged from 3319 kg ha^{-1} for G_{13} (STEJAREE 45) to 6711 kg ha^{-1} for G_2 (YUNJING 23). Seven of the rice genotypes showed above the mean average yields. Among the seasons, season two and season three had below the mean average yields. The highest yield was recorded in season one (in 2015) with mean yield of 5501.05 kg ha^{-1} followed by season two and season three with mean yield of 4311.41 and 3843.67 kg ha^{-1} respectively.

Combined Analysis

Early matured rice genotypes evaluated at different years are described in Table 3. Analysis of combined ANOVA for early matured rice genotypes the mean grain yield showed highly significant variations for years, genotypes and genotype by year interactions as indicated in Table 3.

GGE biplot analysis

The GGE biplot analysis showed that PCA 1 and PCA 2 described for 68.10 % and 19.83 of GGE sum of squares respectively for grain yield of early matured rice genotypes, elucidating a total of 87.93 % variation as indicated in Figure 1. The GGE biplot analysis for early matured rice genotypes grown in three seasons presented in Figure 1. According to the biplot graphical representation genotypes located at the corner were the most responsive and could easily be determined. The most responsive of the corner genotypes were G_1, G_{11}, G_2, G_{14} and G_{13}. As indicated in the figure for those genotypes tested at three seasons were divided in to two sectors. The first sector represent season one and season two for the trials that were conducted in 2015 and 2014 growing season. The second sector represents season three, with G_{14} as the most favorable genotype. In season one (S_1) genotype two (G_2) was the highest yielding genotype and also this genotype was appeared to be more favorable in season two (S_2) as well. The other corner genotypes of G_1 and G_{13} were the poorest yielding genotypes (Fig. 1). For those genotypes that were located far away from all tested seasons, revealing that the yield performance were poorest as compared to others. In addition, those genotypes which are located within the polygon for instance G_7 and G_{18} were less responsive as compared to corner genotypes. As indicated in scatter analysis in figure 1, genotypes for instance G_2 and G_{10} were favorable in sector two (season one and season two). Hence, G_2 and G_{10} are the most promising lines that can be produced under lowland rice ecosystem.

Table 2: Mean grain yield performance (kg ha^{-1}) of 18 rice genotypes under three different seasons

Genotypes	Code for genotype	Season 1 (2015)	Season 2 (2014)	Season 3 (2013)	Mean
IR74052-184-3-3	G_1	5165	4278	1646	3696
YUNJING 23	G_2	9128	5915	5090	6711
WAB502-8-5-1	G_3	6123	4096	4757	4992
PSBRC44	G_4	4590	5260	4229	4693
WAB376-B-10-H3	G_5	4880	4470	4123	4491
IR83222-F11-167	G_6	3968	3216	3326	3503
IR83222-F11-18	G_7	5965	4277	4428	4890
IR83222-F11-200	G_8	4094	3707	3803	3868
IR8322-F11-209	G_9	4331	3120	4459	3970
IR8322-F11-66	G_{10}	6550	7314	4000	5955
IR76999-52-1-3-2	G_{11}	7493	5719	3199	5470
IR83249-F9--29	G_{12}	5909	4797	3800	4835
STEJAREE 45	G_{13}	3509	3303	3145	3319
CHOMRONG	G_{14}	4558	3092	5447	4366
WAB880-1-38-20-17--P1-HB	G_{15}	5468	3866	3773	4369
WAB880-1-32-1-2--P1-HB	G_{16}	5584	3232	2566	3794
IRAT112	G_{17}	5944	3994	3592	4510
EDIGET (check)	G_{18}	5761	3950	3805	4505
Mean		5501	4311	3844	4552
CV		16.37	20.23	19	
P-value		**	**	**	

Table 3. Combined ANOVA analysis of early matured rice genotypes evaluated over years

Source of variation	DF	Sum of square	Mean square	F-value
Year	2	78856666.1	39428333	56.64**
Genotype	17	114212060.9	6718356.5	9.65**
Y x G	34	85732289.8	2521537.9	3.62**
**, * and ns = significant at 0.01 and 0.5 probability level and ns non-significant respectively. DF=Degrees of freedom, Y x G =. Year by Genotype interaction.				

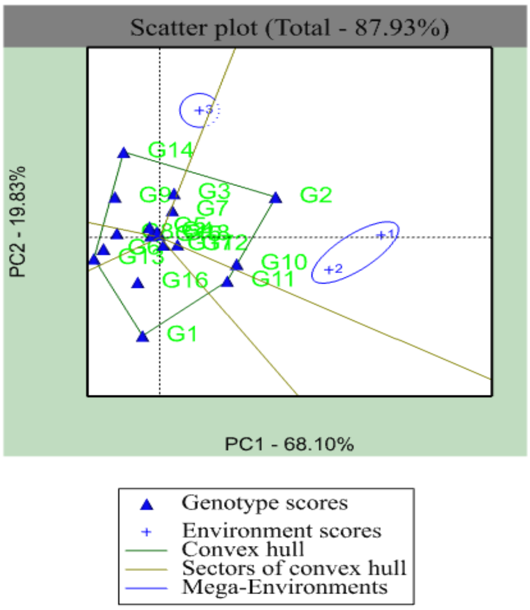

Figure1: GGE biplot analysis of 18 rice genotypes evaluated for three consecutive years

For early matured rice genotypes the average performance and stability were indicated in figure 2. Genotypes were arranged in ranking along the average environment coordinate or average environment axis (AEC x-axis) with an arrow indicating the highest value based on their mean performance over all seasons. Genotype two (G_2) which was closer to the AEC x-axis arrow had the highest mean grain yield followed by G_{10}; whereas genotypes of G_{13}, G_6, G_1, G_9, and other invisible genotypes which were located further away from the AEC x-axis arrow had the poorest yields. Genotypes of G_{14} and G_1 with the longest projection from the AEC x-axis were highly unstable. Similarly, G_6 and G_{13} and some other invisible genotypes were highly stable and had poor grain yield performance. In stability and performance G_2 was the highest followed by G_{10} (Fig 2).

There is also a double arrowed line that was separated the graph for genotype ranking to determine performance and stability. This line divided the above average mean grain yield of the rice genotypes (G_2, G_3, G_7, G_{10}, G_{11}, G_{12}, G_{15},

G_{17},) and from the below average mean grain yield rice genotypes (G_1, G_4, G_5, G_6, G_8. G_9, G_{13}, G_{14}, G_{16}, G_{18}) as indicated in Figure 2.

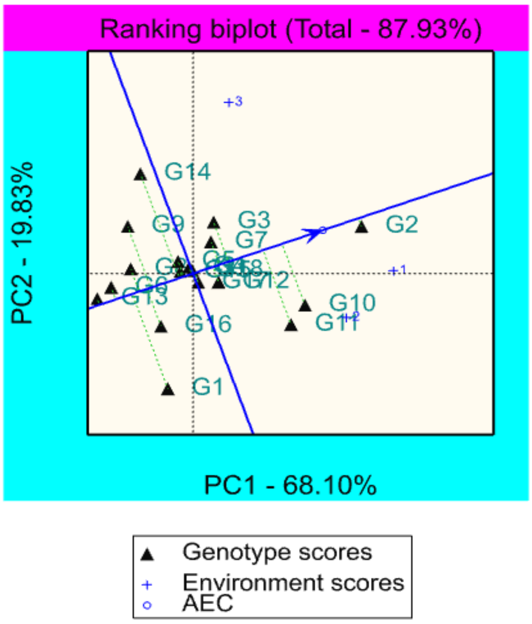

Figure 2: Mean performance and stability of early matured rice genotypes

An ideal genotype where the high mean grain yield and most stable genotypes showed based on the center of the concentric circles (Fig 3). This means projection of the ideal genotype on an average tester coordinate (ATC) horizontal axis is equal to the longest vector of all genotypes and its projection on ATC vertical axis is zero that means it is absolutely stable. Hence, G_2 is the ideal genotypes followed by G_{10} because there is smaller distance from the genotypes to the virtual ideal genotype. Similarly the inferior genotypes were G_1, G_{13}, G_6 and G_9 as indicated in fig 3.

It is possible to identify an ideal environment to genotypes based on the projection of ideal environment on the ATC horizontal axis which is equal to the longest vector of all environments. The closer environments to the virtual ideal environment indicated that the environment is suitable to test the genotypes. Hence, season 1 is more suitable followed by season 2 and season 3 respectively. Season 3 was located far from the ideal environment and genotypes tested in this season showed lowest performance in average grain yield.

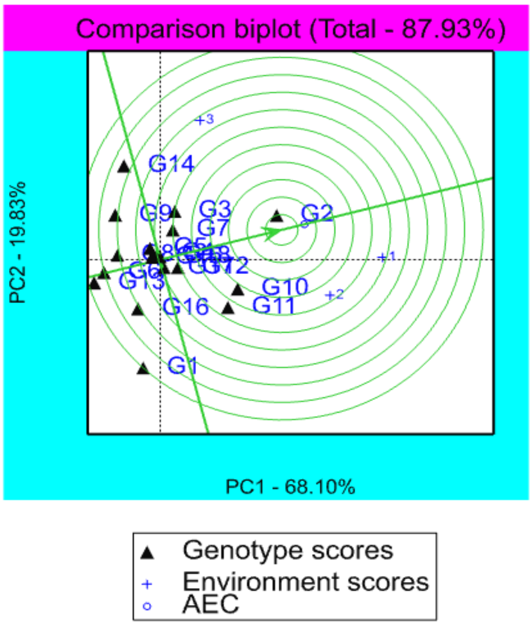

Fig. 3. GGE biplot of ideal genotype and comparison of the genotypes with the ideal genotype

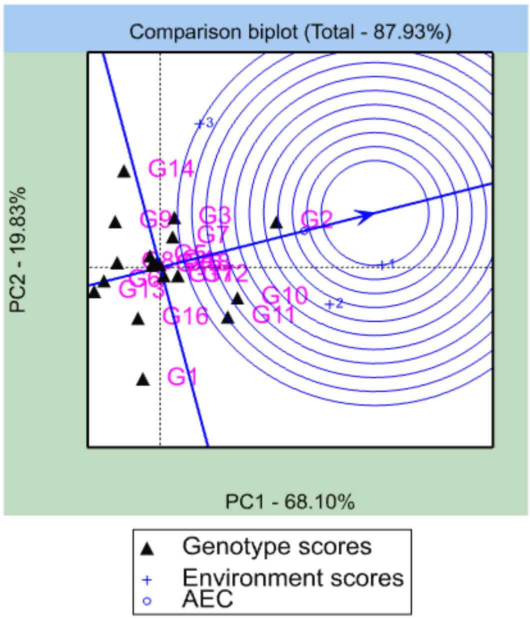

Fig. 4. GGE biplot of ideal environment and comparison of the environment with the ideal environment

CONCLUSION

Evaluation of three years early matured rice genotypes showed variations in performance and stability. Performance variation of each rice genotypes were the result of the genetic constitution of the genotype, the environment and the interaction of both genotype and environment (Gauch and Zobel., 1996). From the research result G_2 and G_{10} showed closer stability for both environments but other genotypes (G_6 and G_{13}) showed highest stability but poor in grain yield performance. There were also genotypes (G_1 and G_{14}) which had very unstable performance over seasons. It was observed that genotype with a constant performance in three growing seasons but the yield potential was lower. The presences of such genotyeps are important because it has significant role for the concept ecovalence because it has a contribution to the total GE interaction sum of squares (Wricke *et a*t 1962).

Among the tested rice genotypes G_2 (YUNJING 23) was the most favorable genotype and showed better performance in season one and season two followed by G_{10} (IR8322-F11-66). Additionally, G_2 and G_{10} had showed better grain yield performance as compared to the standard check of G_{18} (EDGET). So that both genotypes should be released for lowland rice ecosystem and believed to increase production and productivity for rice producers. Furthermore, GGE biplot analysis was the most powerful method to analyze, visualize and interpret the genotype and environment interaction. It was also a convenient procedure to genotypes stability studies and environments that have to be applied in plant breeding program.

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