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Genotype x Environment Interaction and Yield Stability in Improved Rice varieties (Oryza sativa L.) Tested Over Different Locations in Western Oromia, Ethiopia

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Abstract
Eleven rice genotypes were evaluated at 6 environments in Western Ethiopia during 2015 and 2016 main cropping season. The objective of the study was to determine the magnitude of genotype x environment interaction and performance stability in the rice genotypes. The study was conducted using a randomized complete design with 3 replications. Genotype x environment interaction and yield stability were estimated using the additive main effects and multiplicative interaction and site regression genotype plus genotype x environment interaction bi plot pooled analysis of variance for grain yield showed significant (P<0.01) to significant (P<0.05) differences among genotypes, environment, genotype x environment interaction effects. This indicates that genotypes differentially respond to the change in test environments or the test environments differentially discriminated the genotypes or both. Environment accounted for 69.39%, of the total yield variation, genotype for 8.50% and genotype x environment for 3.90%, indicating the need for spatial and temporal replication of the trials. Regression and AMMI analysis were employed in order to determine the stability of genotypes. The two models regression analysis and AMMI revealed similar result in that Adet and Hidassie were stable and widely adapted genotypes. Adet and Hidassie varieties were the most stable and high yielding genotype and was therefore recommended for commercial production in the western Ethiopia upland rice growing areas.
Keywords: Rice, genotype x environment interaction, stability parameters, yield

ITRODUCTION

More than half of the world's population depends on rice for its major daily source of food energy and protein and thus the importance of rice in relation to food security and socio-economic stability is self-evident (FAO, 2003). Rice is the fastest growing source of food in Africa. During the past three decades rice grain has seen a steady increase in consumption and demand given its important place in the strategic food security planning policies of many African countries (Norman and Otoo, 2003; Africa Rice Center, 2007; Forum for Agricultural Research in Africa, 2009). Rice is proven to be one of the potential strategic commodity crops that can assure food security and poverty reduction in Ethiopia (Seyum and Gebrekidan,2005; Gebrekidan and Seyoum, 2006; Zenna *et al*., 2008). Moreover, rice could also be considered as one of the best and cheapest alternative technology available to small-scale farmers for improving productivity of grain yields in flooded and swampy environments through efficient utilization of land and water (Gebrekidan and Seyoum, 2006).

The recent surge in demand triggered by soaring import price, consumer preference in urban areas, population growth and rapid urbanization forced the country to expand small-scale and commercial rice production in various agro-ecologies (Zenna *et al*., 2008). As a result of which, rice production is escalating rapidly from year to year (Gebrekidan and Seyoum, 2006; Aredo *et al*., 2008; Zenna *et al*., 2008). Nevertheless, the challenges facing the successful development of the rice sector are huge and includes: lack of adequate rice milling facilities, lack of improved varieties and recommended crop management practices for different rice ecosystems, and biotic and a biotic stresses; low agricultural inputs (fertilizer, improved rice varieties seed, agro-chemicals…etc), poor mechanization and lack of adequate human resource in the value chain (MoARD, 2010).

Western Oromiya is one of the potential areas where rice is recently introduced and being produced mainly in rain fed upland ecology. However, improved rice varieties and development out puts are very limited in the area to satisfy the growing demand of large and small-scale farmers for improved rice varieties. Grain yield depends on genotype, environment and management practices and their interaction with each other (Messina *et al*., 2009). Under the same management conditions, variation in grain yield is principally explained by the effects of genotype and environment (Dingkuhn *et al*., 2006). So information of genotype × environment interaction leads to successful evaluation of stable genotype, which could be used for general cultivation.

The level of performance of any character is a result of the genotype (G) of the cultivar, the environment in which it is grown (E), and the interaction between G and E (GEI). Interaction between these two explanatory variables gives insight for identifying genotype suitable for specific environments. The environmental effect is typically a large contributor to total variation (Blanche *et al*., 2009). Moreover, G x E interactions greatly affect the phenotype of a variety, so the stability analysis is required to characterize the performance of varieties in different environments, to help plant breeders in selecting desirable varieties. Mosavi (2013) observed significant yield differences among rice genotypes, environment and genotype by environment interaction. Therefore, the major objective of present study was to evaluate and select high yielding improved rice varieties for upland ecology of western Oromiya.

2. Materials and Methods

Eleven rice (***Oryza sativa* L.**) varieties including standard check (*Chewaqa)* were tested at Bako, Chewaqa, Uke and Guttin for three cropping seasons (2015-2016). Genotypes were planted in a completely randomized block design with three replications in which each plot comprises of six rows having 5 m length. The spacing between rows was 20 cm and the seed was drilled in rows. A 100/100 kg P2O5 and urea per hectare (ha-1) fertilizer was used. Urea was split appliad half at planting and half at panicale initiation. Management practices were done according to the recommendations for the particular crop and/or location. The middle 4 rows were harvested and the grain yield was adjusted to 14% seed moisture content before data processing for analysis. Grain yield analysis was carried out using regression (Eberhart and Russell, 1966) and AMMI models in Agrobase software (Agrobase, 2000). The linear model proposed by Eberhart and Russell (1966) is:

$$Y_{ij} = \mu_i + b_i I_j + S^2 d_{ij}$$

where Yij is the mean performance of the ith variety (I = 1, 2, 3…, n) in the jth environment; is the $S^2 d_{ij}$ mean of the ith variety over all the environments; bi is the regression coefficient which measures the response of ith variety to varying environments; S2dij is the deviation from regression of ith variety in the jth environment and Ij is the environmental index of the jth environment. Similarly, the AMMI model (Gauch and Zobel, 1996) is:

$$Y_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda n \gamma_{gn} \delta_{en} + \rho_{ge}$$

where Y_{ger} is the observed yield of genotype g in environment e for replication r; Additive parameters:μ is the grand mean; α_g the deviation of genotype g from the grand mean and β_e is the deviation of environment e; the multiplicative parameters:λ_n is the singular value for interaction principal component axis (IPCA) n,Y_{gn} is the genotype eigenvector for axis n, and δ_{en} is the environment eigenvector; ρ_{ge} PCA residuals (noise portion) and ε_{ger} is error term.

Table 1.Characteristics of rice varieties Tested

No	Variety name	Year of Release	Rain fall (mm)	Ecosystem	Days to maturity	Yield (ton ha^{-1})	
						On-farm	**On-station**
1	Adet	2014	800-1400	Upland	112-120	2.4	4.2
2	NERICA 13	2014	650-800	Upland	104	3.3	3.8
3	Getachew	2007	800-1400	Upland	97-125	2.1	3.0
4	Andassa	2007	800-1400	Upland	111-135	2.5	3.8
5	Chewaqa	2013	800-1200	Upland	160	3.3	4.2
6	Hidassie	2012	800-1400	Upland	100-130	2.2-3.2	3.0-4.2
7	Tana	2007	800-1400	Upland	109-135	2.4	4.4
8	NERICA-2	2007	Intermitte irrigation	Irrigated upland	80-90	3.5	5.5
9	NERICA-4	2006	800-1400	Upland	110	3.0	4.8
10	Tana	2007	800-1400	Upland	109-135	2.4	4.4
11	SUPERICA-1	2006	800-1400	Upland	115	2.3	5.1

3. RESULTS AND DISCUSSION

Combined analysis of variance

Table 1 presents the combined analysis of variance. Genotype (G), environment (E) and genotype × environment interaction (GEI) were highly significant (P<0.001) for grain yield (Table 1). The factors explained showed that rice grain yield was affected by genotype (69.39%), environment (8.50%) and their interaction (3.90%). In general, a wide genetic diversity for maximum traits existed in the rice materials used in this study and this may be due to their diverse origins. The effects of G and E as shown in their highly significant mean square (MS) for maximum traits reflected genotypic differences towards adaptation to different environments. Thus the highly significant G × E effects suggest that the genotypes may be selected for adaptation to specific environments. This is in harmony with the findings of Aina *et al*., (2009) and XuFei-fei *et al.,* (2014) in G × E interaction effects of cassava genotypes. The significant genotype × environment interaction effects demonstrated that genotypes responded differently to the variation in environmental conditions of locations. This is indicative of the necessity of testing rice varieties at multiple locations. This also attests to the difficulties encountered by breeders in selecting new varieties for release. The large sum of squares for genotypes indicated that the genotypes were diverse, with large differences among genotypic means causing most of the variation in grain yield, which is harmony with the findings of Misra *et al.* (2009) and Fentie *et al.,* (2013) in rice production.

3.1 Regression Analysis Based on Eberhart and Russell Model

Mean square due to genotypes and interaction of genotype x environment (linear) were found to be highly significant ($P < 0.01$ (Table 2). The significance of genotypes x environments (linear) showed there is differences in yield performance among the genotypes under different environments. In line with the findings of this study, Chaudhary *et al.* (1994) reported highly significant for genotypes and Genotype x environment (Linear) in field pea.

The mean performance, regression coefficient (b_i) and squared deviation (s^2d_i) from the regression values are presented in Table 3. According to Ebrehart and Russell (1996) genotypes with high mean yield and regression coefficient (b_i) equal to unity and deviation from regression (s^2d_i) approach to zero. The genotypes *Adet and Hidassiei* have mean yields higher than the average, (b_i) did not differ significantly from unity and (s^2d_i) approaching zero. This implied that these genotypes were stable and widely adapted.

Table 2. ANOVA From Means Table (Eberhart-Russell Regression Model)

Source	df	SS	MS
Varieties	10	28.343	2.83**
Env.+ in Var.x Env.	55	180.693	3.28
Env. in linear	1	115.656	
Var. x Env. (linear)	10	33.272	3.32**
Pooled deviation	44	31.765	0.722
Residual	132	24.543	0.186

Grand mean = 4.055 R-squared = 0.8242 C.V. = 18.42%

Table 3. Stability anaylsis in rice tested in western Ethiopia during 2015-2016

Genotype	Regression coefficient (b_i)	Squared deviation from regression (s^2d_i)	Grain yield (tons ha-1)
Adet	1.1557**	0.5429	6.04
Kokit	0.1276	0.1786	3.59
Hidassies	1.6541**	0.7949	4.58
Nerica 13	1.3815**	0.4985	3.62
Superica 1	1.4781	0.2417	4.52
Nerica 2	1.2338*	0.3501	4.1
Getechew	0.9989	0.1523	3.88
Andassa	1.1494	0.0452	3.28
Nerica 4	0.861	0.2812	3.72
Tana	1.183*	0.4536	3.33
chewaqa	0.0321*	2.3569	4.37
	Mean		**4.09**

3.2 Stability analysis by AMMI model

The mean grain yield value of 11 rice vareties averaged over six environments presented in Table 4, which showed that the varieties Adet and Hidassie had the highest 8.2 t ha-1 and 8.1 t ha-^{1} and lowest 4.58t ha-1 and 3.37 t ha-1 respectively. Different genotypes showed inconsistent performance across all the environments. The variety Adet (6.04) was the top performers, while variety Andassa 3.28 t ha-1 and Tana 3.33 t ha-1, were the poorest yielders.

Table 4. Mean grain yield of rice across years (2015/16-2016/17) and locations (Uke, Chewaqa, Bako & Guttin).

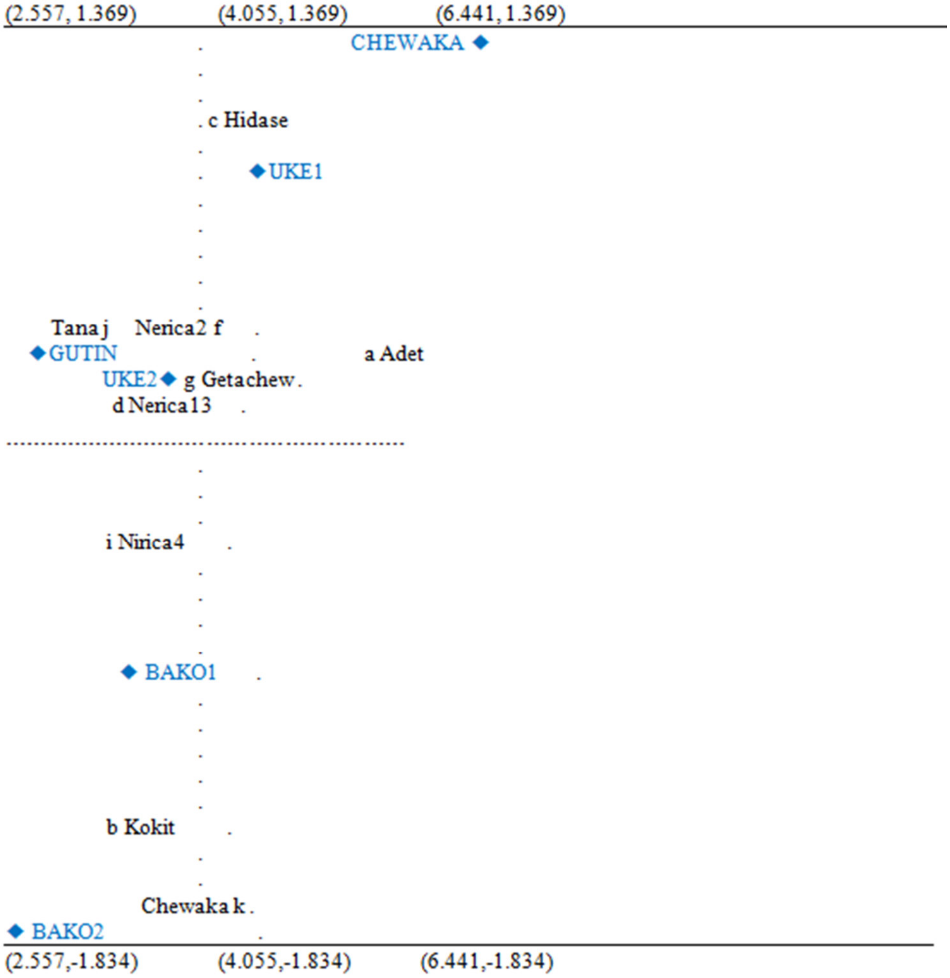
		Mean grain yield (ton ha-1)							
		2015/16			2016/17				
No	Genotype	Uke	Chewaqa	Bako	Bako	Uke	Guttin	Meam	Rank
1	Adet	6.89	8.23	4.96	6.07	5.52	4.58	6.04	1
2	Kokit	3.50	3.22	4.00	4.31	3.85	2.66	3.59	8
3	Hidassies	6.61	8.10	3.37	1.14	4.55	3.69	4.58	2
4	Nerica 13	4.29	7.32	3.82	2.37	2.36	1.58	3.62	9
5	Superica 1	6.21	7.73	3.50	1.62	4.48	3.58	4.52	3
6	Nerica 2	5.30	7.31	3.63	2.04	3.61	2.74	4.10	5
7	Getechew	4.98	6.35	3.40	2.09	3.70	2.75	3.88	6
8	Andassa	4.67	5.57	2.68	1.18	3.24	2.31	3.28	11
9	Nerica 4	4.18	6.35	3.61	2.76	3.20	2.23	3.72	7
10	Tana	4.75	5.67	2.48	1.05	3.52	2.54	3.33	10
11	chewaqa	3.59	4.98	5.69	6.07	3.45	2.42	4.37	4
	Mean	5.00	6.44	3.74	2.79	3.77	2.82	4.09	

Source	**df**	**MS**	**% Genotype x Environment interaction explained**
Total	197		
Environments	5	69.393**	
Reps within Env.	12	1.146	
Genotype	10	8.503*	
Genotype x Env.	50	3.902**	
IPCA 1	14	10.245**	73.52
IPCA 2	12	1.901**	11.69
Residual	120	0.499	

3.3 AMMI biplot display

Among the varieties Adet and Hidassie were generally exhibited high yield with high main (additive) effects showing positive IPCA1 score, but variety Adet being the overall best. Hence, variety Adet was identified as specially adapted to the environments of Uke and Chewaqa and these two environments were considered as the wide range suitable environments for this variety.

Fig. 1. AMMI biplot for grain yield (t ha-1) of 11 rice genotypes (G) and four environments (E) using genotypic and environmental IPCA scores.



4. CONCLUSSION

The present studies revealed that rice yield were liable to a significant fluctuation with changes in the growing environments, G x E interaction effect being almost eight times higher than that of genotype effect. This study also clearly demonstrated that the regression and AMMI analyses models were found to be effective for determining the magnitude and pattern of genotype x environment interaction effect in the rice genotypes. From the regression and AMMI analyses, therefore, *Adet and Hidassie varieties were* the most stable and high yielding genotype and as a result, these were recommended for commercial use for the western Ethiopia upland rice growing areas.

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