Genotype by environment interaction and adaptability of upland rice varieties in northweatern Ethiopia

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Abstract

Rice is commonly characterized as a semi aquatic crop and well adapted to submerged anaerobic soil culture. There are also varieties adapted to dry land culture on aerobic soils like any other cereal crops. This type of rice variety is called upland rice and it is one of the main staple food crops in inter-tropical highland areas of the world. Nine upland rice genotypes were tested at three different locations in randomized complete block design with three replications in north western Ethiopia to estimate the magnitude of genotype by environment interactions and the adaptability performance of upland rice varieties during 2008 main cropping season. The combined analysis of variance revealed highly significant differences ($P<0.01$) among genotypes and environments for grain yield, number of spikelets per plant, days to heading and maturity and above ground biomass yield. Getachew (5655 kg ha^{-1}), Andasa (5505 kg ha^{-1}), NERICA-4 (5296 kg ha^{-1}) and NERICA-3 (5263 kg ha^{-1}) were genotypes which gave high mean grain yield across locations whereas the early maturing (104 day) genotype, NERICA-10 (3934 kg ha^{-1}) was the least yielding. The AMMI1 biplot showed that genotypes Superica-1 and Getachew were specifically adapted to Metema and Pawe areas, and NERICA-4 and Andasa were specifically adapted to Woreta area whereas NERICA-3 was adapted to all locations. However, further study is required on multi-locations for a number of years to generate confidential information that enables appropriate recommendations to be made.

Introduction

Rice belongs to the genus *Oryza* and most probably originated in India or south eastern Asia. It is the world's second most important cereal crop next to wheat. Rice is commonly characterized as a semi aquatic crop and well adapted to submerged anaerobic soil culture (Stoskopf, 1985). There are also varieties adapted to dry land culture on aerobic soils like any other cereal crops. These types of rice varieties can be defined as rice grown on both flat and sloping fields that are not bunded and called upland or dry land rice variety (IRRI, 1975). Upland rice is one of the main staple food crops in inter-tropical highland areas and much of the future expansion of the world's rice land will probably be in upland rice because most of the land suited to irrigated paddy culture is already allotted to lowland rice.

Eventhough, rice was introduced and tested initially in different areas of Ethiopia such as Gambella, Pawe, Woreta in the beginning of 1970s, due attention was not given prior to the mid 1990s (Wolelaw, 2005). At present, rice is becoming an important crop in the country and it is the first by the average productivity (2.9 t ha^{-1}) among cereals (CSA, 2008) followed by maize (2.1 t ha^{-1}). Since the mid of 1990s, however, about 10 upland rice varieties including four NERICA varieties have been released. Currently, the released varieties, especially NERICAs, have been under dissemination and expansion in diverse agro-ecologies of the country from lowlands of 750 m a.s.l to areas of about 2000 m a.s.l elevations by different governmental and non-governmental organizations. However, there is no sufficient information on the genotype by environment interaction effects and adaptability performance of varieties for specific locations. Therefore, this experiment was executed to estimate the magnitude of genotype by environment interactions and adaptability performance of upland rice varieties for specific and multi locations.

Materials and methods

Field experiment was conducted on nine upland rice genotypes (Kokit (IRAT-209)), NERICA-3, NERICA- 4, Superica-1, Getachew (AD-01), Andasa (AD-012),NERICA-1, NERICA-10 and Tigabe (IREM-194)) in north western Ethiopia at Metema, Pawe and Woreta during 2008 main cropping season. The design was randomized complete block design with three replications. Each experimental plot had a total area of 6 m^2 (1.2 m x 5 m) with six rows at 0.2 m interval. There was a 0.5 m distance between two consecutive plots within a replication. Seeds were sown in rows with manual drilling at a rate of 60 kg ha^{-1}. The fertilizer application was at a rate of 64/46 kg ha^{-1} N/P_2O_5. Nitrogen was applied three times in the form of urea. All P_2O_5 and one-third N were applied during planting. The second and the third one-third splits were applied at tillering and at panicle initiation stages, respectively. Data were collected on plot and plant basis. The data on plot basis were taken from the central four rows i.e., number of days to head and mature. The number of tillers per plant, number of effective tillers per plant, number of spikelets per panicle, panicle length and plant height were taken on the main tiller of five plants. The grain yield of each plot was taken after final cleaning, adjusted to 14% moisture level and then converted into kg ha^{-1}. Finally, the collected data were analyzed using different statistical software packages and some data were transformed using square root to stabilize coefficient of variation. Genstat (2007) and IRRISTAT (2005) were used for additive main effect and multiplicative interaction (AMMI) analysis and plotting genotype and environment means over the IPCA values, respectively.

Results and discussion

The AMMI analysis showed that there were significant differences among genotypes and environments for yield and yield related traits (Table 1). The highly significant genotype differences among these upland rice genotypes could be due to differences in their genetic make up and diverse nature of origins. Getachew, Andasa, NERICA-4 and NERICA-3 gave higher mean grain yield across locations whereas NERICA-10, NERICA-1, Kokit and Tigabe produced grain yield below the grand mean (Table 2). Locations differed in their grain yield potentioal (P<0.01). The average grain yield across locations was 4899 kg ha^{-1}. The highest mean grain yield was recorded at Metema (5305 kg ha^{-1}) followed by Pawe (5040 kg ha^{-1}). At Woreta, grain yield (4351 kg ha^{-1}) was recorded below the grand mean (Table 3).

Table 1. AMMI analysis of variance for grain yield (kg ha^{-1}) of upland rice genotypes tested at three locations during 2008 main cropping season.

Sources of variation	Degree of freedom	Sum of squares	Mean squares	Sum of square explained	
				% total	% GxE
Environment	2	13097169	6548584**	18.55	
Rep.within E	6	922013	153669		
Genotype	8	26494041	3311755**	37.53	
GxE	16	23382054	1461378**	33.12	
IPCA 1	9	21795675	2421742**	30.87	93.22
IPCA 2	7	1586379	226626^{ns}	2.25	6.78
Error	48	6700999	139604		
Total	80	70596276			
Grand Mean = 4898.92			CV (%) = 7.6		

*and ** = significant difference at P<0.05 and P<0.05, respectively. ns- non significant difference, GxE = Genotype by environment interaction, IPCA = Interaction principal component axis.

The number of tillers per plant was high at Woreta and relatively low at Metema and Pawe whereas for the number of spikelets per panicle and thousand kernels weight the reverse was noted. At Woreta, the relatively high number of tillers per plant, the lower number of spikelets per panicle and small thousand kernel weight was because of the scarcity of rainfall for some days starting from the beginning of September in which most genotypes could start to initiate panicles and flowers. Early stress during vegetative growth can interrupt floret initiation while drought during flowering causes spikelet sterility and terminal drought influences grain filling rate (Botwright *et al.*, 2008). Saini and Westgate (2000) have also underlined that water stress during flower initiation in cereals slows the rate of floral development, leading to a delay or even a complete inhibition of flowering.

AMMI analysis for grain yield

The additive main effects and multiplicative interaction analysis of grain yield showed that all the components of the treatment combination, namely environment, genotype, and genotype by environment interaction were highly significant ($P<0.01$) and accounted for 18.55%, 37.53%, and 33.12% of the total sum of squares, respectively. Most of the total sum of squares of the model (56.08%) was attributed to the main effects of environment and genotype, while 33.12% was found to be for the interaction effect (Table 1). Similar results of large main effects (60.30%) were also reported for upland rice varieties by Lafitte and Courtois (2002). The interaction sum of squares was partitioned into the interaction principal component axes (IPCA 1 and IPCA 2) but it was for the first IPCA that its mean square was highly significant with 9 degrees of freedom. These IPCAs explained 93.22% and 6.78% percent of the interaction sum of squares, respectively. The mean square of the second IPCA was not significant and it was treated as an AMMI residual.

Table 3. Mean values for grain yield and yield related traits of upland rice genotypes over three locations in 2008.

Location	GY	DH	DM	PL	PH	BY	HI	TKW	HLW	NTPP	NETPP	NSPP
Metema	5305	76.93	97.41	24.34	114.19	11777.9	45.43	28.29	54.08	9.06 (3.07)	8.42(2.98)	166.4(12.85)
Pawe	5040	77.56	107.00	21.05	101.79	5040.0	42.69	28.91	55.19	7.29 (2.78)	6.12(2.56)	111.8(10.50)
Woreta	4351	96.33	132.82	21.29	88.14	10972.2	39.3	26.99	54.82	11.5 (3.45)	11.01(3.38)	127(11.26)
Mean	4899	83.61	112.41	22.23	101.37	9263.37	42.47	28.06	54.7	9.28 (3.10)	8.52(2.97)	135.06(11.53)
CV (%)	7.6	1.4	0.5	6.6	5.1	6.6	5.6	5.3	3.3	8.2	8.4	6.9
SE±	71.91	0.224	0.119	0.281	0.994	147.357	0.457	0.288	0.351	0.049	0.048	0.048
LSD (5%)	204.45	0.638	0.338	0.798	2.827	419.01	1.30	0.818	0.998	0.138	0.137	0.435

GY = Grain yield, DH = Days to heading, DM = Days to mature, PL = Panicle length, PH = Plant height, BY = Biomass yield, HI = Harvest index, TKW = Thousand kernel weight, HLW = Hectoliter weight, NTPP = Number of tillers per plant, NETPP = Number of effective tillers per plant, NSPP=Number of spikelets per panicle.

The environment and the genotype means were plotted against the first IPCA which helped in the interpretation of the interaction effects among genotypes and environments and in the assessment of the adaptability of genotypes (Fig. 1).

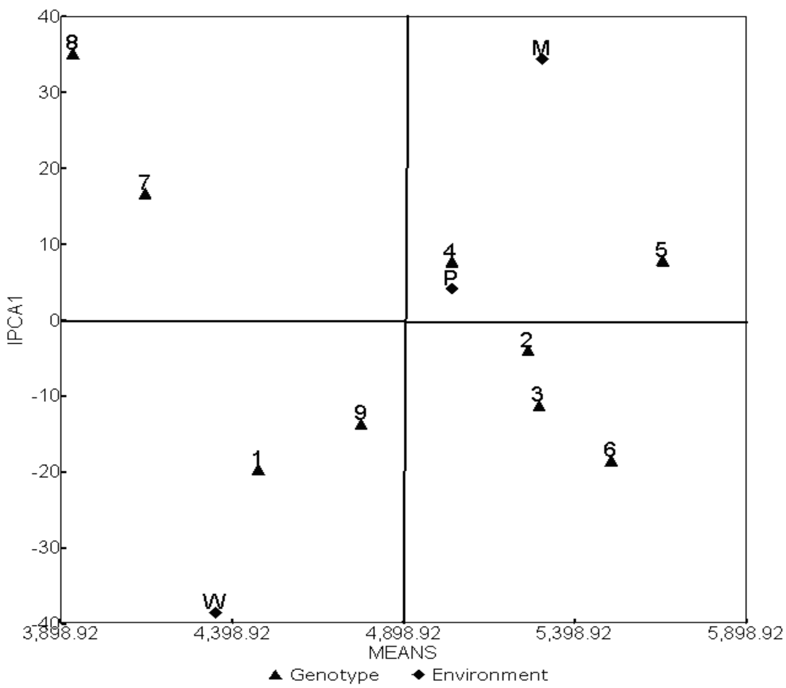

Fig. 1. AMMI1 biplot for grain yield (kg ha^{-1}) of upland rice genotypes tested at three locations in 2008.

Designations: 1-9 for genotypes and letters in upper cases for locations where: 1-kokit, 2=NERICA-3, 3=NERICA-4, 4=Superica-1, 5=Getachew, 6=Andasa, 7=NERICA-1 8=NERICA-10, 9=Tigabe, M- Metema, P- Pawe and W-Woreta. IPCA- interaction principal component axis, AMMI- additive main effect and multiplicative interaction

In the AMMI1 biplot, if genotypes have a zero or nearly zero IPCA 1 scores, then they are stable across their testing sites. If a genotype is farther from zero, it is highly responsive and does not perform consistently across environments (Samonte *et al.*, 2005)**.** If a genotype and an environment have similar signs on the principal component axis, then the interaction between them is positive and this genotype is well adapted to this environment. However, if they have opposite sign of IPCA 1 scores, their interaction is negative and the environment is not favorable to this genotype (Crossa *et al.*, 1990; Zobel *et al.*, 1988). In the AMMI1 biplot

(Fig. 1), there were differences among genotypes both for the interaction effects and mean grain yields i.e., the variation for main effect (mean grain yield) and interaction effect could be simply read across the abscissa and the ordinate, respectively. There were also differences among the locations for both cases.

Woreta was different from other locations in both the interaction and for the main effects. It had mean grain yield below the grand mean and negative score while the other two locations possessed positive environment scores (Table 4) and mean grain yield above the grand mean. Location Pawe had near zero environmental score when compared with others and then it had relatively small interaction effects indicating that it was suitable for the performance of all genotypes. The near zero genotype scores for genotypes NERICA-3, Superica-1 and Getachew were also an indication of their adaptability, particularly NERICA-3, to the three location regardless of the environmental effect.

Table 4. Mean grain yield (kg ha^{-1}) and environment and genotype IPCA 1 scores for nine upland rice genotypes tested at three locations in 2008.

No.	Genotypes	Locations			Genotype	
		Metema	Pawe	Woreta	Mean	IPCA 1
1	Kokit	4166	4599	4665	4476	-19.73
2	NERICA-3	5452	5527	4812	5264	-3.97
3	NERICA- 4	5376	5283	5228	5296	-11.28
4	Superica-1	5729	5186	4205	5040	7.73
5	Getachew	6447	5630	4889	5655	7.8
6	Andasa	5189	5707	5618	5505	-18.6
7	NERICA-1	4888	4760	2785	4144	16.69
8	NNERICA-10	5638	4068	2095	3934	35.07
9	Tigabe	4863	4601	4865	4776	-13.7
Env.	Mean	5305	5040	4351	4899	
	IPCA 1	34.44	4.18	-38.62		

*and ** denote significant and highly significant differences at P<0.05 and P<0.001, respectively, ns denotes non significant difference. GxE = Genotype by environment interaction, IPCA = Interaction principal component axis, and Env. = Environment.

Similar sign for IPCA 1 scores of the genotypes Superica-1 and Getachew and locations Metema and Pawe implied that their interaction was positive and the higher yields of these genotypes were found in particular at these locations. These two genotypes scored mean grain yield above the grand mean and hence they were found to be the best adapted genotypes for Metema and Pawe. These locations were again considered as the favorable environments for these two genotypes.

The genotypes Kokit, NERICA-4, Andasa and Tigabe and Woreta had positive interaction effects as they all owned similar (negative) IPCA 1 scores indicating that these genotypes performed well at Woreta. Genotypes NERICA-4 and Andasa had mean grain yield above the grand mean and they were found to be suitable for Woreta.

Conclusion and recommendation

There were significant differences among rice genotypes and locations for grain yield and other traits. The first IPCA of the AMMI analysis explained large portion of the interaction sum of squares (93.22%). The plotting of environment and genotype means against the first IPCA for grain yield helped in the interpretation of the interaction effects among genotypes and environments as well as the adaptability of the genotypes. Getachew, Andasa, NERICA-4 and NERICA-3 were the genotypes with high mean grain yield across locations. Among locations, the highest mean grain yield (5305 kg ha^{-1}) was recorded at Metema followed by at Pawe (5040 kg ha^{-1}). NERICA-3 had less response to all locations indicating that it was widely adapted genotype. Metema was found to be the most favorable environment for genotypes Superica-1 and Getachew. On the other hand, Woreta was found to be favorable to NERICA-4 and Andasa. This study gave an insight for consideration of the dissemination of upland rice varieties to different agro-ecologies of the country since the upland rice genotypes were found to have different responses to the environments considered. However, further study is required on multi-locations for a number of years to generate confidential information that enables appropriate recommendations to be made.

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