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Stability and Adaptability Analysis of BRRI Developed Aus Varieties in Different Locations of Bangladesh

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ABSTRACT

The genotype by environment (G×E) interactions can be observed by differential genotypic responses to varied environmental conditions. Its effect is to limit the accuracy of yield estimates and complicate the identification of specific genotypes for specific environments. The frequently used model additive main effects and multiplicative interaction (AMMI) were used in this study to identify high yielding Aus rice varieties having wide adaptation and or specific adaptation to environment. Multi environment trials on eight Aus rice varieties were conducted at four environmental conditions in 2016. Genotype by environment (G×E) interactions contribution was much higher than the genotypic effect and environmental effect on grain yield. The genotypes BRRI dhan65, BRRI dhan48 and BRRI dhan43 display higher adaptability and stability. Therefore they are included in the study and recommended to be used in all environments. The variety BRRI dhan65 was identified as the most suitable variety with wider adaptability in the region Kushtia followed by BRRI dhan48 and BRRI dhan43. Latest varieties performed better than the oldest ones based on grain yield and could be replaced through ensuring the supply chain of new promising varieties of that locality.

Key words: AMMI model, Aus rice varieties, G × E interaction and stability.

INTRODUCTION

Agro-based developing country like Bangladesh is striving hard for rapid development of its economy. The economic development of the country is mainly based on agriculture. The total cultivable area in Bangladesh is about 8.58 Mha and net cultivated area is 7.95 Mha and 0.22 Mha are cultivable waste (Agriculture Diary 2018). The contribution of agriculture sector in GDP is 14.23 percent in 2017-18. The crop sub-sector dominates with 7.51% of total GDP at constant market price from which rice contributes 46% (National Accounts Statistics 2018). Of all crops, rice plays the leading role by contributing 96% of total food grain production (Bangladesh Food Situation Report 2018). Three major rice crops namely, Aus, Aman and Boro constitute 100% of total rice production and grow in three different seasons. The Aus rice is important crop for drought prone, low water requiring environments in Bangladesh. Also transplanting cost is one of the major resource-consuming activities and it could be reduced through cultivating direct-seeded rice (DSR-Aus). There are two types of Aus rice such as Broadcast/direct seeded Aus also known as upland Aus and partially irrigated Aus or Transplanted Aus (TPR-Aus) in Bangladesh. Aus is typically planted in March-April and harvested in June-July and practically harmonized with the climatic season hot summer (March-May). Aus rice occupies about 12.53% of total cultivable area from where modern varieties cover 10.67% and local varieties cover 1.86 %. About 7.49% of total production comes from Aus rice where

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modern varieties cover 6.87% and local varieties cover 0.62%. The present status of total area and production of Aus rice is 1.08 million ha and 2.71 million MT (BBS, 2018). Research on adaptability of the Aus rice varieties would help farmers to cultivate right varieties in right area as well as the policy makers to formulate decision in this regard.

Genotype × environment (GE) interaction is an important issue faced by plant breeders in crop breeding programme. G×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 varieties. Instability is the result of cultivars response in different environments which usually indicates a high interaction between genetic and environmental factors (Lone *et al.*, 2009). 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). Interactions between these two explanatory variables give insight for identifying genotype suitable for specific environments. The environmental effect is typically a large contributor to total variation (Blanche *et al.*, 2009). Lestari *et al.* (2010) reported that there was significant difference between stability and adaptability of 35 aromatic new plant type rice lines across different environments. Similarly, Sreedhar *et al.* (2011), evaluate 60 hybrid rice cultivars for yield and its component stability across three different agro-climatic zones, and also found that stability in single plant yield was due to plasticity and stability in yield components. In the study of Mosavi (2013) in some promising rice genotypes showed highly significant yield differences among rice genotypes, environment and genotype by environment interaction. Some rice genotypes were adjudged stable when different yield stability parameters were considered. From Hasan (2014) study, GE interaction patterns revealed by AMMI biplot analysis indicated that the hybrid rice genotypes are broadly adapted. Genotypes Jin23A/PR344R, BRRI11A/AGR and IR79156A/BRRI20R showing high yield performance and widely adapted to all environments. Among the hybrids BRRI 10A/BRRI 12R, BRRI 9A/BRRI 15R, BRRI hybrid dhan2, BRRI dhan28 and BRRI dhan29 were found highly stable across the environments. BRRI 10A/BRRI 12R, BRRI 9A/BRRI 15R, II32A/BRRI 15R, II32A/BRRI 10R and BRRI hybrid dhan3 are highly stable as well as high yielder Kulsum (2014). BRRI hybrid dhan2 is also the highest yielder and stable across environment. Several methods of measuring and describing genotypic response across environments have been developed and utilized. For this purpose, multi-location trials, over a number of years are conducted (Luthra *et al.*, 1974).

AMMI model is a hybrid model involving both additive and multiplicative components of two way data structure with biplot facility. The AMMI model uses analysis of variance (ANOVA, an additive model) to characterize genotype and environment main effects and principal component analysis (a multiplicative model) to characterize their interactions (IPCA). The AMMI analysis has been shown to be effective. It captures a large portion of the GE sum of squares, clearly separating the main and interaction effects; and the model often provides an agronomically meaningful interpretation of the data (Gauch *et al.*, 1992). AMMI analysis AMMI 1 biplot showed the genotypes HS-273, Heera-2, ACI-2 and HRM-02 were highly stable with moderate yield potential but the genotype ACI93024 was more adapted to a wide range of environment than the rest of the genotypes, while BRRI dhan28 indices the lowest stability (Kulsum, 2015). Yield data were analyzed to determine the nature and magnitude of G × E interaction effects on grain yield in diverse environments. The multivariate approach, the AMMI model is better for partitioning the G × E into the causes of variation, which is easier to identify environments' potential and used to identify superior genotypes either specific adaptation or wide adaptation. The goal of this study was to evaluate the G × E interaction using AMMI biplot analysis for the grain yield of Aus rice varieties, in order to identify adaptable and stable varieties in different conditions.

MATERIALS AND METHODS

Plant materials and experimental design

Bangladesh Rice Research Institute (BRRI) has developed eight Aus rice varieties for both DSR and TPR-Aus ecosystem. These varieties are early, and growth duration and yield ranges from 99-115 days and 3.0-5.5 t ha^{-1} respectively, with mostly high amylose content (> 25.0%) except BR26 (22.7%) which is preferable trait in the country (Table 1). This shorter duration varieties can also fit in the cropping pattern to increase cropping intensity. In this experiment BRRI released eight rice varieties were tested in four different environmental conditions of Bangladesh during the cropping season Aus 2016. Table 2 shows the description of the four environmental conditions, Gazipur (E1), Kushtia (E2), Rajshahi (E3) and Rangpur (E4).

In each environment, the experiment was carried out in a randomized complete block design, with three replications. Each experimental plot was comprised of 10 m^2 (10 rows, 5 m long, with 20 cm row spacing). Twenty-five-day-old seedlings were transplanted using two seedlings per hill. Standard management practices and plant protection measures were followed for each location as required following the recommendation of *Adhunik Dhaner Chash*, BRRI (2018). Two border rows were used to minimize the border effects. Data were collected on grain yield (tha^{-1}) and R programming language was used for analysis.

Statistical analysis

The combined analysis of variance and Additive Main and Multiplicative Interaction model were performed to look at G × E of the genotypes across all environments. AMMI uses ANOVA to analyze the main effects (additive part) and Principal Component Analysis (PCA) to analyze the non-additive residuals by the ANOVA (Gauch, 1993). The factor explained (%) was calculated comparing sum of square (SS) from AMMI ANOVA. When a genotype and environment have the same sign on their respective first PCA axis, their interaction is positive, if different, their interaction is negative (Tariku *et al.*, 2013).

Table 1. Phenotypic features of different traits of released Aus rice varieties in Bangladesh (BRRI, 2017).

Variety	Genotype code	Growth duration (day)	Plant height (cm)	Grain shape	Amylose (%)	Yield (tha^{-1})	Year of release
BR21	G1	110	100	MB	25	3.0	1986
BR24	G2	105	105	LS	26	3.5	1992
BR26	G3	115	115	LS	22.7	4.0	1993
BRRI dhan27	G4	115	140	MB	27.5	4.0	1994
BRRI dhan42	G5	100	100	LS	26.1	3.5	2004
BRRI dhan43	G6	100	100	MS	26.7	3.5	2004
BRRI dhan48	G7	110	105	MB	26.8	5.5	2008
BRRI dhan65	G8	99	88	MS	26.8	3.5	2014

MB = medium bold, MS = medium slender and LS = long slender.

Table 2. Agro-ecological conditions of different experimental locations (BBS and BMD, 2016).

Location	Agro-ecological condition					
	Latitude	Longitude	Altitude	Annual rainfall (mm)	Mean maximum temperature (°C)	Mean minimum temperature (°C)
Gazipur	23.99	90.41	15	745	33.87	25.88
Khustia	23.90	89.14	17	513	35.26	24.88
Rajshahi	24.37	88.66	20	689	35.50	24.60
Rangpur	25.70	89.27	35	1165	32.22	22.80

The Additive Main and Multiplicative Interaction (AMMI) model

The AMMI model, which combines standard analysis of variance with PC analysis (Zobel *et al.*, 1988), was used to investigate G×E interaction. In AMMI model the contribution of each genotype and each environment to the GEI is assessed by use of the biplot graph display in which yield means are plotted against the scores of the IPCA1 (Zobel *et al.*, 1988).

The AMMI model is:

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

Where, Y_{ge} = yield of the genotype (g) in the environments (e); μ = grand mean; α_g = genotype mean deviation; β_e = environment mean deviation; N = no. of IPCAs (Interaction Principal Component Axis) retained in the model; λn = singular value for IPCA axis n; γ_{gn} = genotype eigenvector values for IPCA axis n; δ_{en} = environment eigenvector values for IPCA axis n and ρ_{ge} = the residuals

AMMI stability value

The principal component analysis (PCA) described by Purchase *et al.* (2000) was calculated as follows:

$$ASV = \sqrt{\left[\frac{IPCA1_{Sumofsquare}}{IPCA2_{Sumofsquare}} \times (IPCA1_{Score})\right]^2 + (IPCA2_{Score})^2}$$

Where, SSIPCA1/SSIPCA2 is the weight given to the IPCA1 value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The higher the IPCA score, either negative or positive, the more a genotype is specifically adapted to certain environments. Lower ASV scores indicate a more stable genotype across environments.

Biplot analysis

Biplot analysis is the most powerful interpretive tool of AMMI models. Biplots are graphs where aspects of both genotypes and environments are plotted on the same axis so that the inter-relationships can be visualized. There are two basic AMMI biplots- the AMMI1 where the main effects (genotype mean and environments) are plotted against each other and the AMMI2 where scores for IPCA 1 and IPCA 2 are plotted.

RESULTS AND DISCUSSION

The AMMI analysis of variance for rice grain yield (t ha^{-1}) of eight genotypes tested in four environments showed that the genotype (G), environment (E) and genotype × environment interaction (GEI) and its first two principal components (PCA1 and PCA2) were significant ($P < 0.001$). From 12.08% of the total sum of squares was attributed to environmental effects, only 26.13% to genotypic effects and 47.65% to genotype × environment interaction effects, which means that rice grain yield was contributed mainly by genotype × environment interaction effects followed by genotype and environment

(Table 3). The environments were diverse and caused the greatest variation in grain yield. The genotype × environment interaction sum of squares was about 1.82 times larger than that for genotypes, which determined significant differences in genotypic response across environments. The first two principal components (PCA1 and PCA2) explained 78.50% and 14.30% of the GEI (Table 3). The mean grain yield of the eight genotypes ranged from 3.12 to 4.85 t ha^{-1}. The highest yielding variety was BRRI dhan65, and the lowest one was BRRI dhan27 (Table 4). Among the four environments, the highest grain yield was obtained from environment E3 (Rajshahi; 4.37 t ha^{-1}), and the lowest from E1 (Gazipur; 3.33 t ha^{-1}).

In the AMMI-1 biplot (Fig. 1), the abscissa represents main effects (G and E) and its ordinate represents IPC1 scores. It thus provides a mean of simultaneously visualizing both mean performance (G) and stability (IPC1) of genotypes. The IPC1 accounted for 78.50% of the GE interaction. The AMMI-1 biplot accounted for 87.45% of the total SS and is thus suitable for interpreting the GE interaction and main effects. Genotypes G6, G7 and G8 with mean yields greater than the overall mean

Table 3. AMMI analysis of variance for rice grain yield of eight genotypes tested in four environments.

Source of variation	df	Sum of squares	Mean squares	F value	P-value	Explained SS (%)
Environment	3	14.12	4.71	20.29	<0.001	12.08
Replication (Environment)	8	1.86	0.23	0.89	0.534	1.59
Genotype	7	30.54	4.36	16.66	<0.001	26.13
GE interaction	21	55.69	2.65	10.13	<0.001	47.65
PC1	9	43.70	4.86	18.54	<0.001	78.50
PC2	7	7.97	1.14	4.35	<0.001	14.30
PC3	5	4.02	0.80	3.07	<0.05	7.20
Residual	56	14.66	0.26			12.55
Total	95	116.86				

Table 4. Grain yield performance, PCA scores of eight genotypes and four environments.

Genotype	Code	Yield (t ha^{-1})	PC1	PC2	PC3
BR21	G1	3.59	0.498	0.499	-0.174
BR24	G2	3.58	-0.059	0.730	0.234
BR26	G3	3.55	0.469	-0.467	0.544
BRRI dhan27	G4	3.12	-1.766	-0.078	-0.028
BRRI dhan42	G5	3.76	0.275	0.396	0.071
BRRI dhan43	G6	4.39	0.038	-0.269	0.218
BRRI dhan48	G7	4.58	0.277	-0.587	-0.014
BRRI dhan65	G8	4.85	0.268	-0.224	-0.851
Gazipur	E1	3.33	0.235	-1.030	-0.313
Kushtia	E2	4.10	0.305	0.033	0.916
Rajshahi	E3	4.37	1.057	0.687	-0.440
Rangpur	E4	3.91	-1.597	0.310	-0.162

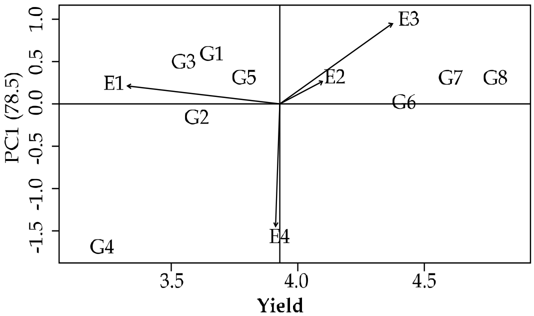

Fig. 1. Interaction of principal component analysis versus grain yield.

and low IPC1 scores had a high combination of yield and stable performances. They indicate that these genotypes are associated with adaptability and stability. The genotype G2 and G5 gave lower yield along with the IPCA1 score close to zero and it was adjudged as the stable genotype. The genotypes G1 and G3 were found to have below average yield and both IPCA1 score close to each other but tended to contribute more to GE interaction. The performances of these genotypes were not decent with respect to yield and stability. On the other hand, the genotype G4 with mean yields less than the overall mean and with the highest distance from the IPC1 = 0 level, tended to contribute highly to GE interaction and accordingly can be regarded as the most unstable genotypes. Among the environments, E2 registered above average yield and had positive IPCA1 score i.e. had small interaction effects indicating that this environment was considered as the suitable environment and all the genotypes performed well in this location. Here the environment E1 was found to have below average yield but had positive IPCA1 score close to zero means favourable environment for all the genotype. And all the genotypes of the study can be grown in this environment. The unfavourable conditions in the E3 and E4 indicate that the genotypes were unstable under those environments.

Figure 2 shows the AMMI2 biplot for grain yield, which accounted for 92.8% of the G×E interaction. Since, PCA2 scores were also important (14.30% of G × E SS) in explaining the genotype × environment interaction, the ballot of the first two PCAs was also used to demonstrate the relative magnitude of the GEI for specific genotypes and environments (Fig. 2). In the AMMI2 biplot points situated nearby to the origin with low scores for two IPCA1 and IPCA2 axes represent stable genotypes and environments. From the study environments E1, E3 and E4 had the highest distance from the origin, so these are sensitive to genotypes changes and have a large G×E interaction. On the other hand, E2 environment was found to be closest to the origin that represent stable environment and also larger mean yield than the average yield (Figs. 1 and 2). This environment showed the smallest scores, thus it has smallest GE interaction effect and were non-sensitive to change in different genotypes and environmental interactive factors. In case of E1 and E4 environments the mean yield less than the average yield and accordingly can be regarded as the most unstable environment. Also E3 situated at the moderate distance from the origin and showed both positive scores of IPCA1 and IPCA2. The specific adaptation indicates a high mean productivity of a genotype in a selected environment. For example, genotype G6, G7 and G8 are adapted to the environments E2 and the genotypes G3 and G7 are adapted to the environment E1, etc (Fig. 2). Regarding the environments, poor contributions were presented by the environments E1, E3 and E4 (Fig. 2). E3 gives the highest mean of productivity (4.37 t ha^{-1}) and E1 gives the lowest mean (3.33 t ha^{-1}).

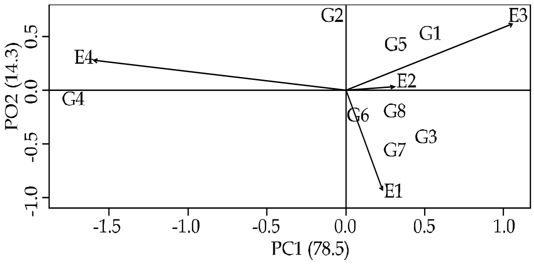

Fig. 2. PCA1 versus PCA2 for grain yield of genotypes.

CONCLUSION

The study revealed that yield was highly influenced by GE interactions followed by the differences among genotypic and environmental effects. Three high yielding genotypes including BRRI dhan65, BRRI dhan48 and BRRI dhan43 were found suitable across environments and considered ideal. Among the environments Kushtia registered above average yield and this environment was identified as the suitable environment for genotypes BRRI dhan43, BRRI dhan48 and BRRI dhan65 due to stable yields.

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