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GENOTYPE-ENVIRONMENT INTERACTION AND STABILITY ANALYSIS IN HYBRID RICE: AN APPLICATION OF ADDITIVE MAIN EFFECTS AND MULTIPLICATIVE INTERACTION

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Abstract

Genotype-environment interaction and stability performance were investigated on amylase, protein and grain yield with 13 hybrid rice promising combinations in five environments. The combined ANOVA showed that the mean sum of square due to genotype (G), environment (E) and G × E interaction were significant for amylose content, protein content and grain yield. This suggests a number of variabilities among the genotypes and environments as and the indicated genotypes interacted significantly with environments. The Additive Main Effects and Multiplicative Interaction (AMMI) biplot for yield clearly indicated that the hybrids BR10A/BR12R, II32A/BR15R, II32A/BR16R, II32A/BR10R, BR9A/BR15R, BRRI hybrid dhan2 and BRRI hybrid dhan3 were high yielding, stable and had general adaptability at all locations. The AMMI estimation had a profound effect in producing sharp and stratified ranking patterns and on this basis BRRI hybrid dhan2 would be considered more adapted to a wide range of environments than the rest of the genotypes. The biplot technique was used to identify appropriate genotype to special locations. This consideration on the basis of average yield for specific genotype to the specific location. The hybrid combination II32A/BR12R was more suitable for Gazipur location and the hybrid combination BR10A/BR13R was considered for Comilla region. Barisal was more stable site than other location for grain yield due to IPCA score near zero which had no interaction effect.

Introduction

Rice is consumed mainly as whole grains and its amylose and protein content are considered an important component compared to any other food crop. The quality preference of rice varies widely. For instance, countries consuming japonica type rice, low amylose is preferred since after cooking it is soft and sticky. However, in indica type rice consuming countries, intermediate amylose is preferred since it is soft and fluffy after cooking.

Amylose content is one of the important chemical properties of hybrid rice because it is the indicator of stickiness or non stickiness of cooked rice. More than 25% amylose content gives non sticky cooked rice, 20 - 25% amylose rice gives soft and comparatively sticky cooked rice (Kumar and Khush 1986). Protein is a nutritional quality indicator in rice. Protein content of the varieties varied from 7.5 - 8.8%. Phenotypically stable varieties are usually sought for commercial production of crop plants. In any breeding program it is necessary to screen and identify phenotypically stable genotypes, which could perform more or less uniformly under different environmental conditions. Considering this fact in mind, the present investigation was carried out to collect information on newly developed genotypes of rice hybrids which may be of great use in launching a dynamic and efficient breeding program.

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The AMMI model (Gauch 1993) is more efficient in determining the most stable and high yielding genotypes in multi-environment trials compared to earlier procedures (Finlay and Wilkinson 1963, Eberhart and Russel 1966). Biplot analysis is possibly the most powerful interpretive tool for AMMI models. Biplots are graphs where aspects of both genotypes and environments are plotted on the same axes so that interrelationships can be visualized. The AMMI biplot where the main effects (genotype mean and environment mean) in X axis and IPCA1 scores for both genotypes and environments are plotted in Y axis. The effectiveness of AMMI procedure has been clearly demonstrated (Crossa *et al.* 1991, Das *et al.* 2009, Tarakanovas and Ruzgas 2006).

The main objectives of the present investigation is to identify high yielding stable hybrids and to determine the areas where rice hybrids would be adapted and produce economically competitive yields with high protein and amylose content.

Materials and Methods

The experiments were conducted under Plant Breeding Division of Bangladesh Rice Research Institute (BRRI) at five different agro-ecological zones (AEZ) in the country. Eleven (9 test and 2 released hybrids) rice hybrids developed at the Bangladesh Rice Research Institute with two popular check variety BRRI dhan28 and BRRI dhan29 were used as experimental materials.

The experiments were carried out in a randomized complete block design, with three replications. Each experimental plot was comprised of 30 m^2. Standard agronomic practices were followed and plant protection measures were taken as required. Two border rows were used to minimize the border effects. Characters studied were amylose and protein contents and grain yield. Ten randomly selected samples were used for recording observations on amylose and protein content. Amylose content was determined after Juliano (1971). Protein contents were calculated from nitrogen and was determined by Micro Kjeldahl method (Lynch and Barbana 1999). Amylose and protein content are measured in percentages. The grain yield (g/plant) data were estimated and corrected at 14% moisture.

ANOVA was used and the GEI was estimated by the AMMI model (Zobel *et al.* 1988). In this 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 stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russell (1966). Significance of differences among bi value and unity was tested by t test, between S^2di and zero by F test (Eberhart and Russell 1966). All the data were subjected to analysis using statistical analysis package software Cropstat version 7.2 (AMMI, SSA and ANOVA models) after Zobel *et al.* (1988).

Results and Discussion

The combined analysis of variance showed that mean sum of square due to genotypes and environment was significant for amylose content, protein content and grain yield, indicating the presence of variability among the genotypes and environments. These results are in agreement with Wanjari *et al.* (1988), Desai *et al.* (1991) and Dahiya *et al.* (1993). Also showed the GE interaction was significant, it was possible to proceed further and calculate phenotypic stability (Farshadfar and Sutka 2003). ANOVA based on AMMI model for grain yield is presented in Table 1. The effects of genotype × environment interaction could be divided into four components, i.e. IPCA1, IPCA2, IPCA3 and IPCA4 where IPCA1, IPCA2 and IPCA3 were significantly different while IPCA4 was not significantly different.

Table 1. Analysis of variance of the G × E interaction of hybrid rice.

Source of variation	df	Mean sum of squares			
		Milling yield (%)	Amylose content (%)	Protein content (%)	Yield (gm/plant)
Genotypes (G)	12	50.820***	16.681***	1.262***	32.586***
Environment (E)	4	75.135***	54.386***	7.387***	23.319***
Replication	2	43.648***	4.446***	0.314***	1.841
Interaction G × E (GEI)	48	10.459***	0.491***	0.316***	2.249***
AMMI component 1	15	18.861***	0.837***	0.460***	3.865***
AMMI component 2	13	7.829***	0.741***	0.398***	2.100***
AMMI component 3	11	7.865***	0.830***	0.272***	1.850***
AMMI component 4	9	3.427***	0.509**	0.114	0.260
G × E (Linear)	12	20.620***	1.015**	0.576***	3.117***
Pool deviation	36	7.072***	0.316	0.402***	1.960***
Pooled error	96	0.206	0.342	0.224	0.479

**, ***Significant at 0.1 and 0.1% level, respectively.

Amylose content of milled rice varied from low to intermediate. Most of the genotype showed low amylose, only four showed intermediate amylose content. BR1A/BR12R, BR10A/BR12R, II32A/BR15R, II32A/BR16R, II32A/BR10R, II32A/BR12R, BR10A/BR13R, BR10A/BR15R and BRRI hybrid dhan3 showed negative phenotypic index (Pi), non significant regression coefficient (bi) and deviation from regression (S^2di) indicating stable genotype over all environments with low amylose content. BR9A/BR15R, standard check variety BRRI dhan28 and BRRI dhan29 showed positive Pi, non significant bi and S^2di were stable over all environments with high amylose content. BRRI hybrid dhan2 showed positive Pi, significant bi and non significant S^2di indicating the highly responsive to the environments Gazipur, Shatkhira and Comilla (Table 2). According to the annual report of BRRI 2009, the amylose content of 20 BRRI varieties grown at seven locations, BR16 showed highest amylose content (28.7%) and BR2 showed the lowest amylose content (22.1%).

Protein content in grain determines the nutritional value. The genotypes BR1A/BR12R, II32A/BR15R, BR10A/BR13R, BRRI hybrid dhan2, BRRI dhan28 and BRRI hybrid dhan3 showed positive phenotypic index (Pi), non significant bi and S^2di indicating stable genotype over all environments (Table 3). As per the annual report of BRRI 2009, the protein content of 20 BRRI varieties grown at nine locations, BR6 showed highest protein content of 6.47% and BRRI dhan29 showed lowest protein content 6.12%. BR24, BR26 and BRRI dhan28 possessed high mean and phenotypic index and was considered to be stable with high percentage of protein content (Sarker and Ferdous 2002). Protein content shows stable performance in genotype × seedling age at different environments.

The genotypes BR10A/BR12R, II32A/BR15R, II32A/BR16R, II32A/BR10R, II32A/BR12R, BR10A/BR13R, BR9A/BR15R, BRRI hybrid dhan2 and BRRI hybrid dhan3 showed positive phenotypic index (Pi) with insignificant regression coefficient (bi) and deviation from regression (S^2di) which indicated that these genotypes were stable over the environments (Table 4). The superior over all mean of genotype indicates its superiority across the environments. RF55-254, RF55-198 and RF-53-253-3-I topped for productivity over all the six environments, indicating their superior performance (Hanamaratti *et al.* 2009). Silveira and Vencovsky (1983) also reported stable rice cultivar with high yield. Standard check variety BRRI dhan28 possessed lower mean, negative phenotypic index (Pi) with significant regression coefficient (bi) and insignificant deviation from regression (S^2di) which indicated that this variety was suitable for poor environments of Barisal and Rangpur.

The AMMI analysis provides a graphical representation or biplot (Fig. 1) to summarize information on the main effects and the first principal component scores of the interactions (IPCA1) of both genotype and environments, simultaneously (Kempton 1984). Displacement along the abscissa reflected differences in main effects, where as displacement along the ordinate exhibited differences in interaction effects. The AMMI expected yield for any genotype and environment combination can be calculated from Fig. 1 following standard procedures suggested by Zobel *et al.* (1988).

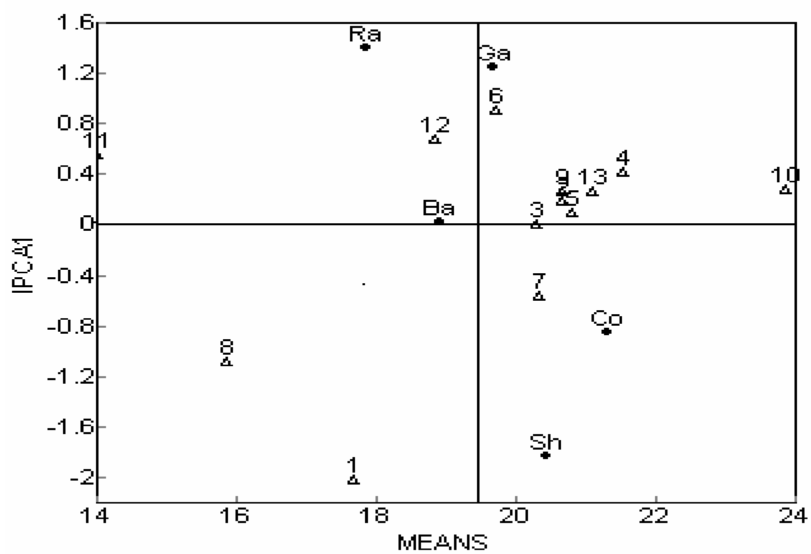

Fig. 1. Biplot of the first AMMI interaction (IPCA 1) score (Y axis) plotted against mean yield (X axis) for 13 hybrid rice genotypes. Ga = Gazipur, Ba = Barisal, Sh = Shatkhira, Co = Comilla and Ra = Rangpur, 1 = BR1A/BR12R, 2 = BR10A/BR12R, 3 = II32A/BR15R, 4 = II32A/BR16R, 5 = II32A/BR10R, 6 = II32A/BR12R, 7 = BR10A/BR13R, 8 = BR10A/BR15R, 9 = BR9A/BR15R, 10 = BRRI Hybrid dhan 2, 11 = BRRI dhan 28, 12 = BRRI dhan 29, and 13 = BRRI hybrid dhan 3, Δ = Hybrid combination (genotypes), ● = Environments (5)

The AMMI1 biplot gave a model fit of 91.6%. Genotypes and environments on the same parallel line, relative to ordinate, have similar yields and a genotype or environment on the right side of the midpoint of this axis has higher yields than those on the left hand side. Consequently, the genotypes BR10A/ BR12R, II32A/BR15R, II32A/BR16R, II32A/BR10R, BR9A/BR15R, BRRI hybrid dhan2 and BRRI hybrid dhan3 were generally high yielding, with BRRI hybrid dhan2 being the over all best. In contrast, BR1A/BR12R, BR10A/BR15R, BRRI dhan28 and BRRI dhan29 were generally low yielding genotypes. The AMMI1 estimation had a profound effect in producing clear and stratified ranking patterns and on this basis BRRI hybrid dhan2 would be considered more adapted to a wide range of environments than the rest of the genotypes. Dixon and Nukenine (1997) and Crossa *et al.* (1991) obtained a similar stratification in cassava

Table 2. Stability analysis for amylase content (%) of 13 promising hybrid rice in five environments (boro 2009-2010).

En. No.	Hybrids	Locations						Phenotypic index (Pi)	bi	S^2di
		Gazipur	Barisal	Shatkhira	Comilla	Rangpur	Overall mean			
1	BR1A/ BR12R	19.53	16.00	19.41	22.14	19.05	19.23	–1.9	1.066	0.02
2	BR10A/ BR12R	20.20	18.38	21.00	24.14	21.25	20.99	–0.14	0.984	0.41
3	II32 A/ BR15R	20.30	17.57	20.61	23.62	20.42	20.50	–0.63	1.043	0.05
4	II32 A/ BR16R	22.27	16.05	21.50	24.07	18.64	20.50	–0.63	1.426	2.02
5	II32 A/ BR10R	19.27	16.19	18.81	22.32	19.07	19.13	–2.0	1.057	0.09
6	II32 A/ BR12R	19.17	16.92	19.44	22.00	19.00	19.31	–1.82	0.879	0.05
7	BR10A/ BR13R	20.03	17.15	20.46	22.78	20.15	20.11	–1.02	0.973	0.06
8	BR10A/ BR15R	20.03	17.00	19.97	23.10	21.14	20.25	–0.88	1.040	0.51
9	BR9A/ BR15R	23.00	20.00	23.03	26.50	23.01	23.11	1.98	1.120	0.06
10	BRRI hybrid dhan 2	24.00	22.40	23.38	24.00	22.33	23.22	2.09	0.293*	0.42
11	BRRI dhan 28	24.00	21.09	24.29	27.00	24.02	24.08	2.95	1.022	0.02
12	BRRI dhan 29	24.00	21.07	24.01	27.08	24.15	24.06	2.93	1.035	0.05
13	BRRI hybrid dhan 3	20.60	17.00	20.23	23.12	19.95	20.18	–0.95	1.062	0.03
	Mean	21.26	18.22	21.24	23.99	20.94	21.13			
	E index (Ij)	0.13	–2.91	0.11	2.86	-0.19				
	CV (%)	1.07	2.09	3.85	2.86	3.68				
	LSD (0.05)	0.38	0.64	1.38	1.16	1.30				

* Indicates slopes significantly different from the slope for the overall regression which is 1.00.

Table 3. Stability analysis for protein content (%) of 13 promising hybrid rice in five environments (boro 2009 - 2010).

En. No.	Hybrids	Locations						Phenotypic index (Pi)	bi	S^2di
		Gazipur	Barisal	Shatkhira	Comilla	Rangpur	Overall mean			
1	BR1A/ BR12R	7.800	6.300	7.600	8.400	7.367	7.493	0.566	1.003	0.03
2	BR10A/ BR12R	6.700	5.633	6.833	7.733	6.200	6.620	–0.307	1.013	0.04
3	II32 A/ BR15R	7.333	6.167	7.333	8.267	7.200	7.260	0.333	0.987	0.00
4	II32 A/ BR16R	7.100	5.167	6.967	7.533	6.200	6.593	–0.334	1.162	0.13
5	II32 A/ BR10R	6.400	5.033	6.067	7.133	6.533	6.233	–0.694	0.962	0.10
6	II32 A/ BR12R	6.800	5.700	7.033	7.800	6.800	6.827	–0.1	0.985	0.02
7	BR10A/ BR13R	7.000	6.067	7.200	8.167	6.900	7.067	0.14	0.988	0.01
8	BR10A/ BR15R	6.200	5.167	6.333	7.267	6.100	6.213	–0.714	0.987	0.01
9	BR9A/ BR15R	6.800	5.767	6.800	7.867	6.633	6.773	–0.154	0.988	0.00
10	BRRI hybrid dhan 2	7.700	6.600	7.167	8.633	7.033	7.427	0.5	0.973	0.09
11	BRRI dhan 28	7.900	6.900	8.000	9.000	7.900	7.940	1.013	0.980	0.01
12	BRRI dhan 29	6.700	5.600	6.800	7.700	6.500	6.660	–0.267	0.993	0.00
13	BRRI hybrid dhan 3	6.900	6.033	6.800	8.133	6.800	6.933	0.06	0.979	0.04
	Mean	7.026	5.856	6.995	7.972	6.782	6.927			
	E index (Ij)	0.099	–1.071	0.068	1.045	-0.145				
	CV (%)	0.72	2.62	3.11	2.25	2.23				
	LSD (0.05)	0.09	0.26	0.37	0.30	0.25				

Table 4. Stability analysis for yield (g/plant) of 13 promising hybrid rice in five environments (boro 2009 - 2010).

En. No	Hybrids	Locations						Phenotypic index (Pi)	bi	S^2di
		Gazipur	Barisal	Shatkhira	Comilla	Rangpur	Overall mean			
1	BR1A/BR12R	15.29	16.82	22.09	21.24	12.93	17.67	–1.97	2.588	4.37
2	BR10A/ BR12R	20.82	19.34	20.83	22.91	19.33	20.65	1.01	1.008	0.44
3	II32 A/ BR15R	20.55	18.20	20.68	23.31	18.65	20.28	0.64	1.371	0.97
4	II32 A/ BR16R	23.20	17.74	22.54	23.23	20.93	21.53	1.89	1.056	4.48
5	II32 A/ BR10R	21.07	21.43	20.94	22.29	18.29	20.81	1.17	0.923	0.96
6	II32 A/ BR12R	21.10	19.24	19.37	19.69	19.11	19.70	0.06	0.159	0.81
7	BR10A/ BR13R	18.99	19.91	20.36	24.91	17.44	20.32	0.68	1.826	2.45
8	BR10A/ BR15R	14.81	15.51	20.33	15.75	12.86	15.85	–3.79	1.256	6.31
9	BR9A/ BR15R	20.57	19.61	21.00	22.33	19.81	20.66	1.02	0.748	0.25
10	BRRI hybrid dhan 2	23.45	23.24	23.77	25.79	22.94	23.84	4.2	0.729	0.44
11	BRRI dhan 28	14.36	14.06	13.74	14.85	13.03	14.01	–5.63	0.405*	0.23
12	BRRI dhan 29	19.62	19.63	18.11	19.45	17.37	18.84	–0.8	0.348	1.14
13	BRRI hybrid dhan 3	21.85	21.00	22.04	21.25	19.38	21.10	1.46	0.583	0.67
	Mean	19.67	18.90	20.45	21.31	17.85	19.64			
	E index (Ij)	0.03	–0.74	0.81	1.67	-1.79				
	CV (%)	3.32	2.97	5.18	4.67	3.28				
	LSD (0.05)	1.10	0.95	1.78	1.68	0.99				

* Indicates slopes significantly different from the slope for the overall regression which is 1.00.

and wheat genotypes, respectively. Genotypes with IPCA1 scores near zero had little interaction across environments and *vice versa* for environments (Crossa *et al.* 1991).

Environment Barisal with IPCA1 scores near zero had no interaction effects, genotype II32A/BR12R and environment Gazipur combinations with IPCA1 scores of the same sine produced positive specific interaction effects.

Four groupings were evident from the biplot (Fig.1) BR1A/BR12R and BR10A/BR15R generally low yielding and unstable (high negative IPCA1 score); BRRI dhan28 and BRRI dhan29 were low yielding and moderately stable across environments (low positive IPCA1 scores); BR10A/BR12R, II32A/BR15R, II32A/BR16R, II32A/BR10R, BR9A/BR15R, BRRI hybrid dhan2 and BRRI hybrid dhan3 were high yielding and stable (had high positive IPCA1 scores); BR10A/BR13R was high yielding and moderately stable across environments (low negative IPCA1 scores).

The AMMI statistical model has been used to diagnose the G × E interaction pattern of grain yield of hybrid rice. The hybrids BRRI 10A/BRRI 12R, II32A/BRRI 15R, II32A/BRRI 10R, BRRI 9A/BRRI 15R, BRRI hybrid dhan2 and BRRI hybrid dhan3 were hardly affected by the G × E interaction and thus will perform well across a wide range of environments. Locations, such as Barisal, that could be regarded as a good selection site for rice hybrid improvement due to stable yields observed were also identified.

References

Crossa J, Fox PN, Pfeiffer WH, Rajaram S and Gauch HG 1991. AMMI adjustment for statistical analysis of an international wheat yield trial. Theor. Appl. Genet. **81**: 27-37.

Dahiya SK, Singh S and Singh M 1993. A study of G × E interaction in advanced lines of pigeonpea. Int. J. Tropical Agril. **11**: 276-279.

Das S, Misra RC and Patnaik MC 2009. G×E interaction of mid-late rice genotypes in LR and AMMI model and evaluation of adaptability and yield stability. Environment and Ecology **27**: 529-535.

Desai NG, Bharodia PS and Kukadia MU 1991. Study of genotype × year interaction in pigeonpea. Int. Pigeonpea Newslett,. **13**: 14-15.

Dixon AGO and Nukenine EN 1997. Statistical analysis of cassava yield trials with the additive main effects and multiplicative interaction (AMMI) model. Afr. J. Root Tuber Crops **3**: 46-50.

Eberhart SA and Russel WA 1966. Stability parameters for comparing varieties. Crop Sci. **6**:36-40.

Farshadfar E and Sutka J 2003. Locating QTLs controlling adaptation in wheat using AMMI model. Cereal Res. Comm. **31**: 249-255.

Finlay KW and Wilkinson GN 1963. The analysis of adaptation in a plant breeding program. Australian J. Agril. Res. **14**:742-754.

Gauch, HG 1993. Matmodel Version 2.0: AMMI and related analysis for two-way data matrices. Micro computer Power, Ithaca, New York, USA.

Hanamaratti NG, Salimath PM, Vijayakumar CHM, Ravikumar RL, Kajjidont ST and Chetti MB 2009. Genotypic stability of superior near isogenic introgression lines for productivity in upland rice. Karnataka J Agric. Sci. **22**(4): 736-740.

Juliano BO 1971. A simplified assay for milled rice amylose. Cereal Sci. Today **16**(10): 334-340.

Kempton RA 1984. The use of biplots in interpreting variety by environment interactions. J. Agril. Sci. **103**: 123-135.

Kumar I and Khush GS 1986. Gene dosage effect of amylase content in rice endosperm. Jpn. J. Genet. 61: 559-568.

Lynch JM and Barbana DM 1999. Kieldahl nitrogen analysis as a reference method for protein determination in dairy products. J. AOAC Int. **82**: 1389-1398.

Sarker U and Ferdous N 2002. Genotype × Seedling age interaction in rice (*Oryza sativa* L.). Pakistan J. Biol. Sci. **5**(3): 375-277.

Silveira EP and Vencovsky R 1983. Grain yield stability of upland rice (*Oryza sativa* L.) in Sao Paulo State. Ciencia-e-Cultura. **35**: 971-977.

Tarakanovas T and Ruzgas V 2006. Additive main effect and multiplicative interaction analysis of grain yield of wheat varieties in Lithuania. Agro. Res. **4**: 91-98.

Wanjari KB, Patil AN, Fulzele GR and Ghavghave PB 1988. A note on stability analysis in pigeonpea *Cajanus cajan* L. Millsp. Ann. Plant Physiol. **2**: 113-114.

Zobel RW, Wright JM and Gauch JH 1988. Statistical analysis of yield trial. Agron. J. **80**: 388-393.

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