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EFFECT OF GENOTYPE-ENVIRONMENT INTERACTION ON GRAIN YIELD OF EXOTIC RICE (*ORYZA SATIVA* L.) HYBRIDS

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Abstract

Genotype by environment interaction (GEI) is a major complication in plant breeding. Authors used additive main effects and multiplicative interaction (AMMI) to evaluate the effects of GEI in hybrid rice genotype and their adaptation in three years at four locations. Among rice hybrid genotypes ACI93024 was stable in all environments with high yield potential. Using 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. ACI-2, LP-70 and Mayna were specifically adapted to the environment of Rangpur, Jessore and Gazipur, respectively. Comilla was identified as stable environment for all the genotypes.

Introduction

Rice (*Oryza sativa* L.) is the world's most important food crop. In order to achieve the uphill task of feeding the burgeoning population, exploitation of hybrid vigor through heterosis breeding is being recognized as a readily-available means to raise the genetic yield ceiling in areas where yields have already reached their potential (Virmani 1996). In Bangladesh, hybrid rice technology offers considerable opportunity to increase the productivity of rice. For expansion of hybrid rice, the major limitation faced, however, is the lack of male fertility restoration as well as the stability in performance of the hybrids in the diversified environmental conditions of the country. Cytoplasmic male sterile line is not adapted to Bangladesh condition. So, we need special breeding programme that will emphasize the identification of stable male sterile lines adapted to Bangladesh conditions, the development of hybrids and the multi-location testing of their performance. In this approach, developing highly-heterotic rice hybrids for yield performance and evaluating them across environments is mandatory.

In most of the plant breeding programs, GE interaction effects are of special interest for identifying the most stable genotypes, mega-environments and other adaptation targets. Various methods for yield stability analysis are based on different stability concepts and can be classified accordingly (Flores *et al.* 1998). Univariate methods such as stability variance (Shukla1972) and joint regression (Eberhart and Russell 1966) have some limitations that can be overcome by using the multivariate statistical methods.

Gauch (1988) and Zobel *et al.* (1988) proposed the additive main effects and the multiplicative interaction (AMMI) model for analyzing multi-environment, and the multiplicative

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effect of GE interaction, and thus can explain more information compared to other methods. The first interaction principal component analysis (IPCA 1) is usually superior to linear regression in accounting for the GE sum squares (Gauch and Zobel 1996).

The objectives of this study were: (i) To estimate yield stability of improved rice hybrid genotypes and (ii) explore the advantages and disadvantages of AMMI stability parameters in selecting more stable rice hybrid genotypes.

Materials and Methods

The experiments were conducted in Hybrid Rice division of Bangladesh Rice Research Institute (BRRI) at four different agro-ecological zones in the country for three planting seasons (2007-08, 2008-09, 2009-10). Thirteen (HS-273, LP-70, Heera-2, Doel, Mayna, LP-05, Aloron-HB09, ACI93024, BRRI hybrid dhan1, HG-101, ACI-2, HRM-02, WBR-5, BRRI dhan28 and BRRI dhan29) commercial rice hybrid varieties including two checks BRRI dhan28 and BRRI dhan29 were evaluated. HS-273, LP-70, Heera-2, Doel, Mayna, LP-05, Aloron-HB09, ACI93024, HG-101, ACI-2, HRM-02, WBR-5 genotypes are imported from China. The experiments were carried out in a randomized complete block design, with three replications. Each experimental plot was comprised of 5 × 6 m. Standard agronomic practices were followed and plant protection measures were taken as required. Two border rows were used to minimize the border effects. Growth duration was measured by counting days i.e. duration of life time. The grain yield (t/ha) data was estimated and corrected at 14% moisture.

AMMI model (Gauch 1988 and Zobel *et al.* 1988) was used to quantify the effect of different factors (genotype, location) of the experiment. The AMMI statistical model is most appropriately termed as a hybrid model. It makes use of standard ANOVA procedures to separate the additive variance from multiplicative variance (genotype by environment interaction). Then it uses a multiplicative procedure- PCA to extract the pattern from the G × E portion of the ANOVA (Zobel *et al*. 1988). Thy hybrid 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 environment (e), μ = Grand mean, α_g = Genotype mean deviation, β_2 = Environment mean deviation, N = No. of IPCAs (Interaction principal component axis) retained in he model. λn = Singular value for IPCA axis **n,** γ_{gn} = Genotype Eigen vector values for IPCA axis **n,** δ_{en} = Environment Eigen vector values for IPCA axis **n,** ρ_{ge} = The residuals.

The model further provides graphical representation of the numerical results (Biplot analysis) with a straight-foreword interpretation of the underlying causes of G × E according to Gauch (1988), Kempton (1984) and (Bradu and Gabriel 1978).

Results and Discussion

Contribution of GE interaction effect for yield and growth duration studied in different environments. GE interaction makes difficult to select the best performing and most stable genotypes. The AMMI model used in the present investigation for selecting suitable genotypes.

Stability parameters like phenotypic index (Pi), regression coefficient (bi) and deviation from regression (S^2di) of the genotypes were estimated following AMMI (Additive main effect and multiplicative interaction) model. Genotypes giving insignificant bi and S^2di are considered to be adapted to all environments. While those bi exhibit significant value and S^2di exhibit insignificant value are considered to possess stability performance for favorable environment.

Mean performance of genotypes, their response and stability parameters phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) for growth duration are presented in Table 1. Result showed for days to maturity the genotypes HS273, Heera2, Doel, standard check variety BRRI dhan29 and BRRI hybrid dhan1 showed negative phenotypic index (Pi), insignificant regression coefficient (bi) and deviation from regression (S^2di) indicating stability of genotypes over all environments with shorter growth duration (Table 1). On the other hand, Mayna, LP 05, standard check variety BRRI dhan28 and HB09 showed the negative phenotypic index (Pi), significant regression coefficient (bi) and non significant deviation from regression (S^2di) indicating shorter growth duration and highly responsive to the favorable environment of Gazipur first year, second year, Comilla second year, Jessore second year, third year and Rangpur first year and second year. Shorter growth duration is desirable for hybrid rice. Aditya *et al*. (2010) observed the genotype BRRI dhan29-SC3-28-L3 was short growth duration and stable over locations. AMMI model has a strong linear relationship between variety performance and environmental factors (Mclaren and Chaudhary 1998).

The environmental mean and genotypic mean of grain yield ranged from 5.702 to 7.230 t/ha and 4.616 to 7.569 t/ha, respectively. Seven genotypes showed positive phenotypic index, while the other genotypes had negative phenotypic index for grain yield (Table 2). This positive phenotypic index indicated the higher yield and negative indicated the lower yield among the genotypes. Again, positive and negative environmental index (I_j) reflects the rich or favorable and poor or unfavorable environments, for this character, respectively. The environmental index (I_j) directly reflects the poor or rich environment in terms of negative and positive environmental index (I_j), respectively. Thus the environment of Gazipur second and thired year, Jessore second and thired year, Rangpur second year locations were identified as poor and other locations were identified as rich environments for rice hybrid production.

Among the genotypes, ACI93024 showed highest yield as well as stable over the environments. HS273, Heera-2, ACI2 and HRM-02 were highly stable with moderate yield potential. The hybrids LP-70 and Doel were higher yielding but had significant regression coefficient (bi) and non significant deviation from regression (S^2di) which means they were not stable variety and responsive to the favorable environments. Prediction of genotypes with high grain yield also varied within environments. The genotype ACI93024 (7.569 t/ha) was predicted as the best yielding cultivar out of 12 environments by AMMI model. AMMI analysis increased the accuracy of yield predictions in diverse crop genotypes. The grain yield was sensitive and highly influenced by environment resulting in higher G × E interaction under stress environments in rainfed ecosystem as reported earlier (Ouk *et al.* 2007).

The AMMI biplot analysis graphic of the 15 cultivars in 12 environments, over three agricultural years is shown in Fig. 1. In AMMI biplot, the usual interpretation of a biplot assay is that if a genotype or an environment has an IPCA1 scores of nearly zero, it has small interaction is positive, if different, there interaction is negative. Mahalingam *et al.* 2006 reported that genotypes occurring close together on the plot will tend to have similar yields in all environments, while genotypes for apart may either differ in mean yield or show a different pattern of response over the environments. The AMMI biplot clearly indicated that all the 15 genotypes studied differed from each other and not only for mean yields, but also for their interaction effects. However, the environments studied differed only for their interaction effects and they exhibited less difference

Table 1. Stability analysis for growth duration (days) of 13 commercial rice hybrids and two inbreed check varieties over 12 environments.

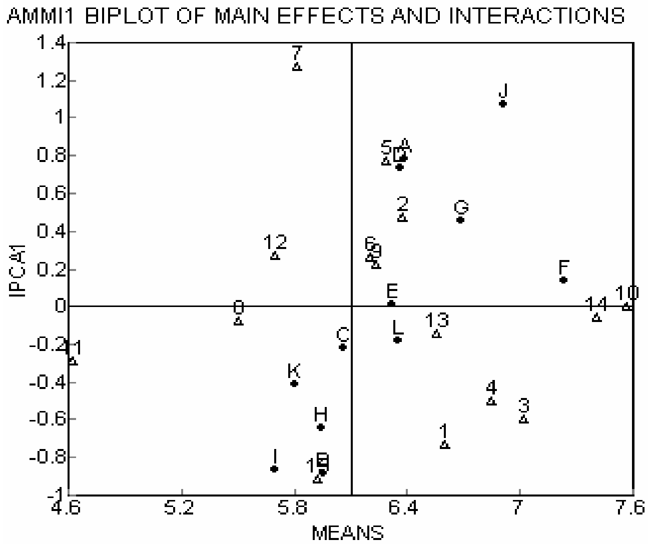
Genotypes	Environments												Overall mean	Pi	bi	S^2di
	A	B	C	D	E	F	G	H	I	J	K	L				
HS-273	134.7	136.7	144.7	140.0	138.0	143.3	138.3	135.3	135.0	132.0	134.0	145.7	138.1	-3.3	0.879	10.00
LP-70	139.0	139.7	147.3	149.0	144.3	150.3	140.0	135.3	137.7	138.7	136.7	148.0	142.2	0.8	1.143	11.21
Heera-2	139.3	134.0	146.3	148.0	131.7	147.7	143.0	135.7	138.7	139.3	133.7	149.0	140.5	–0.9	1.475	8.82
Doel	140.3	133.3	148.3	147.0	131.7	143.7	141.3	133.0	140.0	139.3	133.0	153.7	140.4	–1.0	1.635	12.76
Mayna	140.7	130.0	148.0	149.0	128.0	143.0	141.3	128.7	142.3	140.7	130.7	148.7	139.3	–2.1	1.820*	19.16
LP-05	140.3	132.3	148.7	146.0	130.7	142.7	143.7	131.3	130.0	140.0	130.7	149.3	138.8	–2.6	1.922*	5.23
BRRI dhan28	139.7	133.0	147.3	148.0	130.3	146.0	145.0	131.7	138.0	137.7	131.7	143.3	139.3	–2.1	1.611*	8.32
BRRI dhan29	135.7	131.7	151.3	141.0	131.3	147.3	140.7	133.7	144.7	136.3	130.3	149.0	139.4	–2.0	1.392	30.01
Aloron-HB09	138.0	131.0	151.3	147.0	131.7	143.7	143.7	130.0	138.7	138.0	130.7	140.3	138.7	–2.7	1.651*	11.91
ACI93024	141.0	149.7	146.0	144.3	151.7	136.7	141.7	152.0	137.3	140.3	148.0	144.0	144.4	3.0	-0.443*	26.96
BRRI hybrid dhan1	134.0	134.3	141.0	139.0	136.0	144.3	135.7	136.0	138.0	133.3	133.3	142.7	137.3	–4.1	0.602	9.78
HG-101	146.3	142.3	148.0	155.0	142.3	146.3	150.0	140.7	144.0	147.0	141.3	143.3	145.6	4.2	0.879	7.15
ACI-2	140.0	152.0	148.7	142.0	141.0	152.0	142.3	134.0	147.3	140.3	146.3	140.7	143.9	2.5	0.109	32.07
HRM-02	151.0	156.0	140.0	155.0	162.3	128.7	158.0	146.0	126.7	158.0	147.7	142.3	147.6	6.2	0.047	145.46
WBR-5	155.0	143.3	134.0	157.0	155.0	128.3	156.0	147.0	125.7	153.3	147.0	143.0	145.4	4.0	0.279	130.82
Mean	141.0	138.6	146.1	147.2	139.1	142.9	144.1	136.7	137.6	141.0	137.0	145.5	141.4			
Ei(Ij)	–0.4	–2.8	4.7	5.8	–2.3	1.5	2.7	–4.7	–3.8	–0.4	–4.4	4.1				
LSD (0.05)	1.15	3.85	2.46	0.25	2.90	2.86	1.61	4.48	2.63	1.26	4.47	7.56				

A = Gazipur 1st year, B = Gazipur 2nd year, C = Gazipur 3rd year, D = Comilla 1st year, E = Comilla 2nd year, F = Comilla 3rd year, G = Jessore 1st year, H = Jessore 2nd year, I = Jessore 3rd year, J = Rangpur 1st year, K = Rangpur 2nd year, L = Rangpur 3rd year, Pi = Phenotypic index, bi = Regression coefficient, S^2di = Deviation from regression

Table 2. Stability analysis for yield of 13 commercial rice hybrids and two inbreed checks varieties over 12 environments.

Genotype	Environments												Over all mean	Pi	bi	S^2di
	A	B	C	D	E	F	G	H	I	J	K	L				
HS-273	5.046	6.793	6.867	5.550	6.513	7.929	7.290	6.667	6.333	7.010	6.510	6.669	6.598	0.288	0.696	0.50
LP-70	6.872	5.897	6.474	6.383	6.700	7.473	6.873	5.850	4.730	7.560	5.343	6.380	6.378	0.068	1.652*	0.12
Heera-2	6.783	7.550	6.417	6.007	7.627	7.807	6.823	7.797	6.420	7.693	7.213	6.153	7.024	0.714	0.391	0.46
Doel	6.884	6.627	7.101	6.520	6.633	7.595	7.090	6.437	7.330	6.677	6.313	6.907	6.843	0.533	0.348*	0.13
Mayna	6.953	4.797	5.892	7.073	6.647	7.260	6.910	6.483	4.816	7.577	5.043	6.037	6.291	–0.019	1.763	0.32
LP-05	6.961	5.057	5.890	6.350	6.853	7.341	6.393	6.550	4.937	6.497	5.230	6.307	6.197	–0.113	1.298	0.26
BRRI dhan28	6.266	4.450	5.402	6.570	5.483	7.662	6.720	4.180	4.037	8.220	5.020	5.757	5.814	–0.496	2.693*	0.26
BRRI dhan29	4.887	4.627	5.979	5.120	5.227	7.986	6.710	4.860	4.243	5.197	5.040	6.217	5.508	–0.802	1.706	0.53
Aloron-HB09	6.788	6.277	4.180	6.470	6.383	6.333	6.930	6.143	5.318	7.370	6.047	6.537	6.231	–0.079	0.991	0.51
ACI93024	7.628	7.473	7.166	7.670	7.353	7.865	7.843	7.673	6.333	8.510	7.737	7.570	7.569	1.259	0.741	0.16
BRRI hybrid dhan1	4.738	4.257	4.367	4.640	4.870	5.234	4.533	4.347	4.733	4.900	4.477	4.300	4.616	–1.694	0.431*	0.05
HG-101	6.473	4.893	6.489	6.477	4.693	6.417	5.977	4.187	6.503	6.420	4.117	5.733	5.698	–0.612	0.969	0.79
ACI-2	7.045	6.757	5.160	6.763	6.727	6.534	7.163	5.123	6.658	6.850	7.637	6.230	6.554	0.244	0.261	0.59
HRM-02	7.201	7.600	7.418	8.027	7.673	7.637	7.793	6.327	7.326	8.005	6.533	7.322	7.405	1.095	0.671	0.20
WBR-5	5.230	6.267	6.100	5.802	5.500	7.376	5.170	6.563	5.807	5.221	4.753	7.232	5.918	–0.392	0.388	0.72
Mean	6.384	5.955	6.060	6.361	6.326	7.230	6.681	5.946	5.702	6.914	5.801	6.357	6.310			
Ei(Ij)	0.074	–0.355	–0.25	0.051	0.016	0.92	0.371	–0.364	–0.608	0.604	–0.509	0.047				
LSD (0.05)	0.42	0.63	0.70	0.42	0.42	0.46	0.41	1.23	0.48	0.43	0.56	0.35				

A = Gazipur 1st year, B = Gazipur 2nd year, C = Gazipur 3rd year, D = Comilla 1st year, E = Comilla 2nd year, F = Comilla 3rd year, G = Jessore 1st year, H = Jessore 2nd year, I = Jessore 3rd year, J = Rangpur 1st year, K = Rangpur 2nd year, L = Rangpur 3rd year, Pi = Phenotypic index, bi = Regression coefficient, S^2di = Deviation from regression for the main effect (Fig.1). The IPCA1 component accounted with mean yield thus the AMMI biplot gave a model fit of 75.6%. The genotypes BRRI dhan29, ACI2, HRM-02 and ACI93024 had IPCA1 scores near zero and hence had small interaction effects indicating that these varieties were less influenced by the environments. Among these four genotypes HRM-02 and ACI93024 were found to have highest yielded. On the other hand the variety BRRI dhan29 was lower yielded along with IPCA1 scores close to zero, it was adjusted as the stable genotypes and had of IPCA1 scores for both genotype and environment implies positive interaction and then higher yield of the genotypes at that particular locations.



A = Gazipur 1st year, B = Gazipur 2nd year, C = Gazipur 3rd year
D = Comilla 1st year, E = Comilla 2nd year, F = Comilla 3rd year
G = Jessore 1st year, H = Jessore 2nd year, I = Jessore 3rd year
J = Rangpur 1st year, K = Rangpur 2nd year, L = Rangpur 3rd year

1 = HS-273, 2 = LP-70, 3 = Heera-2, 4 = Doel, 5 = Mayna, 6 = LP-05, 7 = BRRI dhan28, 8 = BRRI dhan29, 9 = Aloron-HB09, 10 = ACI93024, 11 = BRRI hybrid dhan1, 12 = HG-101, 13 = ACI-2, 14 = HRM-02, 15 = WBR-5.

Fig. 1. Biplot of the first AMMI interaction (IPCA 1) score (Y-axis) plotted against mean yield (X-axis) for 13 hybrid rice genotypes and two check inbreed varieties in 12 environments.

The location Rangpur among the environments and hybrid ACI2 had slightly negetive IPCA1 score and registered above average yield, hence this genotype are identified as specifically adapted culture to the Rangpur location and this environment was considered as the suitable environment for this genotype. The Jessore location and hybrid LP-70 exhibit positive IPCA1 score with above average yield, so LP-70 is specifically adapted to Jessore region, Gazipur and Comilla region are highly adapted for the hybrid Mayna. BRRI dhan28 are larger positive IPCA1 score which are mostly unstable. The remainng eight genotypes which scattered slightly in the biplot, differed from each other both in mean and interaction effects. Among the environmental conditions, Comilla 3rd year, Jessor 1st year and Rangpur 1st year had high mean with high positive interaction, Gazipur 2nd year and 3rd year, Jessore and Rangpur 2nd year, had low mean yield but Comilla 2nd year showed negligible interaction with average yield. So Comilla is stable environment for all the genotype. The genotypes were stable if it was located around the origin. Mattjik and Sumertajaya

2002 stated that AMMI model increased the accuracy of the prediction of genotype and environment interaction response. The effectiveness of AMMI procedure has been clearly demonstrated by Zaval-garcia *et al.* (1992) in rice; Vijayakumar *et al*. (2001) in rice hybrid, Nahief (2013) in wheat, Xu Fei-fei *et al.* (2014) in rice genotypes, Nassir (2013) in upland rice, respectively using multilocational data. Genotypes (or environments) with large IPCA1 scores (either positive or negative) have high interactions, whereas genotypes (or environments) with IPCA1 scores near zero have small interactions.

Finally, the AMMI model analysis was as an effective tool in understanding complex GE interactions in multi-environment trials of rice hybrid. We can explain the positive outcome of this study the genotypes BRRIdhan29, ACI 2, HRM-02 and ACI93024 had relatively stable with broad adaptation across environments. Comilla was stable environment for all the genotypes. The genotypes ACI 2, LP 70 and Mayna are specifically adapted to the environment Rangpur, Jessore and Gazipur, respectively.

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