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Plant stature of aromatic rice genotypes in the environment of Bangladesh

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Abstract

Plant stature of a rice crop is an important selection criterion. As plant height is a quantitative trait it is influenced by environmental conditions. A field experiment was conducted with 40 rice genotypes to assess the fluctuation and stability of plant height in a series of 16 environmental situations. The effects of genotype (G), environment (E) and all the components of G×E interaction were highly significant. Among the genotypes, Jamai sohagi was extremely sensitive (bi = 1.37) to environmental changes, and indicating lowest adaptability over the environments. Plant height of seven genotypes *viz.* Basmati PNR346, Benaful, BRRIdhan28, BRRIdhan38, BRRIdhan39, Gandho kasturi and Neimat, having the bi values between 0.59 and 0.72, showed high stability against environmental changes. The other seven genotypes viz. Badshabhog, Basmati Tapl-90, Kamini soru, Khazar, Laljira, Sarwati and Ukni madhu expressed only nonlinear sensitivity (S^2_{di} = 90 – 181)) and thus unpredictable fluctuation. Twenty one genotypes indicated their average stability (bi = 0.91 -1.15) over the environments.

Key words

Plant height, Aromatic rice, G×E interaction, AMMI analysis

Introduction

Rice plant height is a quantitative trait governed by genetic factors but also by environmental conditions (Fang and Wu, 2001). Thus, it tends to show varied degrees of genotype environment interactions. These interactions occur when two or more genotypes perform differently in different environments, and are thus described as differential genotypic sensitivities to environments (Falconer, 1981). Plants, particularly self-pollinated plants, tend to show a high level of G×E interactions that allow better adaptation to their changing environments and the maintenance of genetic variation in populations (Jain and Marshal, 1967). Determination of the magnitude and the nature of genotype and environmental variations present in the plant characters are essential. Additive main effect and multiplicative interaction (AMMI) model has been proved to be a powerful tool for the identification of stable and sensitive genotypes over the range of environments (Dias and Krzanowski, 2006; Sabaghnia *et al*., 2008; Misra *et al*., 2009).

Rice is a major crop that is planted in the most diverse conditions. The geographical distribution of rice growing areas in different parts of the world reveals that rice is cultivated from 50°N to 35°S (Swaminathan, 1999). Adaptability of the rice plant to the environment is determined by its morphology and metabolic activity, which may vary according to the variety and growth stage. Differences in the metabolic pattern insure the pliability of adaptation and are reflected ultimately in the differences in morphological appearance of the plant as a whole (Chu and Tang, 1959). Plant height has been the main target for improvement of lodging resistance. The detection and introduction of semi-dwarf lines was one of the main factors responsible for the higher yields of rice and wheat in "green revolution" (Keller *et al*., 1999; Khush, 1999). The optimum plant height for maximum photosynthetic capacity in a canopy is between 70 and 100 cm in wheat (Flintham *et al*., 1997). New rice cultivars called "New Plant Type" developed for their higher photosynthetic capacity in the canopy are about 100 cm in height (Kumar *et al*., 1999). A reduction in plant height to improve lodging resistance may reduce photosynthetic capacity of a canopy. Plant height of rice is generally considered to be controlled by both qualitative and quantitative genes and gene expression could be modified by environmental factors (Huang *et al*., 1996; Atchley and Zhu, 1997).

Aromatic rices are normally low yielding because of its traditional taller plant type associated with lodging. In the consideration of consumption, aromatic rices constitute a small group of rices. But it is a special group that is regarded as best in quality (Singh *et al*., 2000). Bangladesh occupies an area of 144,863 km^2 lying astride the tropic of cancer between 20°25' – 26°38' N latitudes and 88°01' – 92°40' E longitudes. There is a broad range of agro-ecological environments because of differences in climate, physiography, soil and hydrology (Karim *et al*., 1990). It has a stock of above 7,000 rice germplasm of which around 100 are of aromatic type (Hamid *et al*., 1982). In Bangladesh, aromatic rices are normally transplanted in rainy season (July-August) and most of them are popularly grown in specific location. In Boro season (November - May), rice plant receives more solar energy because of clear sunshine in longer growth duration, and deserves a possibility of higher yield with study plant type. Obviously, genotypic responses in this concern will be different. However, very limited quantitative data are available on genotype (G) $\times$ environment (E) interactions of plant stature. Many workers have performed stability analysis with local and high yielding varieties of rice and other crops (Kaya *et al*., 2002; Sabaghnia *et al*., 2008; Misra *et al*., 2009). However, G×E analysis for plant height of aromatic rices has not yet been done. The present study was undertaken to observe the genotype and environment interaction; and to explore aromatic rice genotypes for stable plant stature over the locations and growing seasons.

Materials and Methods

General experimental details: The experiment was conducted in 2004-05. A total of forty rice germplasm composed of 32 local aromatic, five exotic (V4, V27, V29, V37 and V38) and three non-aromatic (V8, V10 and V30) rice varieties as standard checks, were selected for this research (Table 1). Among the three non-aromatic varieties used, BR28 is a modern Boro, BR39 a modern T.Aman variety and the third one, Nizersail was used as a standard photoperiod sensitive genotype. Exotic genotypes were collected from Pakistan (Basmati PNR346), Nepal (Sarwati and Sugandha-1) and Iran (Khazar and Neimat). The rest of the materials are representing their distribution throughout Bangladesh. Forty rice genotypes formed the treatment variables and were assigned randomly to each unit plot of 5 × 2 m dimension. Seedlings 930 days old) were transplanted in three sets of *Aman* season and 45 day-old seedlings in *Boro* season with a spacing of 20 × 20 cm. A fertilizer rate of 25–35–10–3 kg ha^{-1} of P–K–S–Zn in the form of triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively, was applied as basal dose at final land preparation. The nitrogen was top-dressed as urea in 2–3 splits to the contrary of a common dose with fixed time routine. The amount of urea and time of application were determined with the help of a leaf colour chart (Ladha, *et al*., 1998). A single hill was selected in each plot for plant height data. It was measured as a distance from ground level to the tip of the tallest panicle (Gomez, 1972).

Environmental conditions: The four locations in different parts of Bangladesh were as follows:

B = Benarpota Farm, BRRI Regional Station, Satkhira (22.72°N, 89.08°E).

C = Charchandia Farm, BRRI Regional Station, Sonagazi, Feni (22.84°N, 91.39°E).

D = Domar Seed Production Farm, BADC, Sonaroy, Domar, Nilphamari (26.10°N, 88.84°E).

H = Headquarter Farm, Bangladesh Rice Research Institute, Gazipur (24.00°N, 90.42°E).

Seed was sown in four dates, 3 in T.*Aman* (with an interval of 20 days) and 1 in *Boro* season :

1 = 1st planting in T. *Aman* (Sowing in seedbed on 16th July 2004).
2 = 2nd planting in T. *Aman* (Sowing in seedbed on 5th August 2004).
3 = 3rd planting in T. *Aman* (Sowing in seedbed on 25th August 2004).
4 = Planting in *Boro* season (Sowing in seedbed on 5th November 2004).

The combination of locations × planting times resulted in 16 environmental conditions *viz.* B1, B2, B3, B4, C1, C2, C3, C4, D1, D2, D3, D4, H1, H2, H3 and H4.

Statistical analysis: Stability analysis was done according to the regression model of Eberhart and Russel (1966). The stability parameters viz. regression coefficient (b_i) and deviation from regression (S^2_{di}) were calculated to interpret the results. In addition, the phenotypic index (P_i) was determined following Ram *et al*.(1970). Additive main effect multiplicative interaction (AMMI) model was used to quantify the effect of different factors (genotype, location, planting time) of the experiment (Zobel *et al*., 1988).

Results and Discussion

Stability, response and AMMI studies: Analysis of variance showed high genetic variability among the genotypes. Highly significant mean squares for environments indicated differences among the environments and their immense influences on plant height (Table 2). Similarly, several researchers reported the significant mean squares for genotypes and environments (Naveed *et al*., 2007; Mohammadi *et al*., 2007). The genotype × environment interactions were also highly significant. Thus, the data were extended for analysis of stability indices. Significant genotype × environment

Table -1: Stability and response parameters for plant height (cm) of 40 rice genotypes (aromatic, exotic and standard checks) in Bangladesh.

Sl#	Genotype	Mean (cm)	P_i	b_i	S^2_{di}
V1	Badsha bhog Tapl-63	130.0	11.27	0.78*	98.71*
V2	Baoi jhak	127.1	8.46	0.78*	41.06
V3	Basmati Tapl-90	115.6	–3.10	1.08	96.04*
V4	Basmati PNR 346	87.7	–30.97	0.70*	22.14
V5	Begun bichi	130.7	11.98	1.04	18.40
V6	Benaful	118.5	–0.16	0.65*	70.73*
V7	Bhog ganjia	116.8	–1.93	0.99	57.32
V8	BRRIdhan28	92.4	–26.32	0.62*	40.55
V9	BRRIdhan38	102.2	–16.51	0.72*	75.60*
V10	BRRIdhan39	91.2	–27.48	0.67*	41.23
V11	Chinigura	129.7	10.98	1.30*	57.03
V12	Chinikani	123.2	4.54	0.98	31.58
V13	Darshal	127.5	8.80	1.10	59.15
V14	Doiar guro	123.8	5.14	1.14	32.51
V15	Elai	111.3	–7.35	0.96	46.49
V16	Gandho kasturi	125.1	6.39	0.59*	94.69*
V17	Gandhoraj	125.8	7.13	1.24*	56.50
V18	Hatisail Tapl-101	122.8	4.08	0.91	22.74
V19	Jamai sohagi	128.0	9.33	1.37*	38.00
V20	Jata katari	128.3	9.58	1.15	43.70
V21	Jesso balam Tapl-25	120.0	1.35	1.05	17.40
V22	Jira katari	123.2	4.56	1.18*	16.81
V23	Kalijira Tapl-73	114.4	–4.30	1.17*	40.43
V24	Kalomai	128.7	10.04	1.02	39.39
V25	Kamini soru	131.5	12.85	1.05	103.74**
V26	Kataribhog	124.1	5.39	1.17*	28.54
V27	Khazar	91.2	–7.49	0.77*	181.45**
V28	Laljira Tapl-130	119.8	1.13	1.07	102.94**
V29	Niemat	82.9	–35.81	0.65*	42.89
V30	Nizersail	119.4	0.71	1.00	34.91
V31	Philippine katari	128.1	9.38	0.97	24.11
V32	Premful	127.7	9.05	1.17*	35.66
V33	Radhuni pagal Tapl-77	119.6	0.90	1.20*	55.26
V34	Rajbhog	130.1	11.46	1.05	24.95
V35	Sai bail	129.2	10.50	1.02	59.03
V36	Sakkor khora	120.6	1.96	1.23*	46.71
V37	Sarwati	100.8	–17.90	0.95	90.40*
V38	Sugandha-1	111.6	–7.10	1.01	13.81
V39	Tilkapur	129.1	10.42	1.13	43.73
V40	Ukni madhu	137.7	19.05	1.15	168.55**

P_i = Phenotypic index, b_i = Regression coefficient, S^2_{di} = Deviation from regression

Table - 2: AMMI 4 analysis of variance for the plant height (cm) data of rice genotypes

Source	Df	SS	MS	F
Total	1919	350877	182.8	
Treatments	639	336566	526.7	47.1**
Genotypes	39	116093	2976.7	266.3**
Environments	15	193450	12896.7	1153.5**
G×E interactions	585	41334	70.7	6.3**
IPCA1	53	10381	195.9	17.5**
IPCA2	51	8761	171.8	15.4**
IPCA3	49	4898	100.0	8.9**
IPCA4	47	4367	92.9	8.3**
G×E residual	385	12927	33.6	3.0**
Error	1280	14311	11.2	

df = Degree of freedom; SS = Sum of squares; MS = Mean squares; F = Value of probability; IPCA1, 2, 3, 4 = Interaction principal component axis 1, 2, 3, 4, **Significant at 1% level of probability

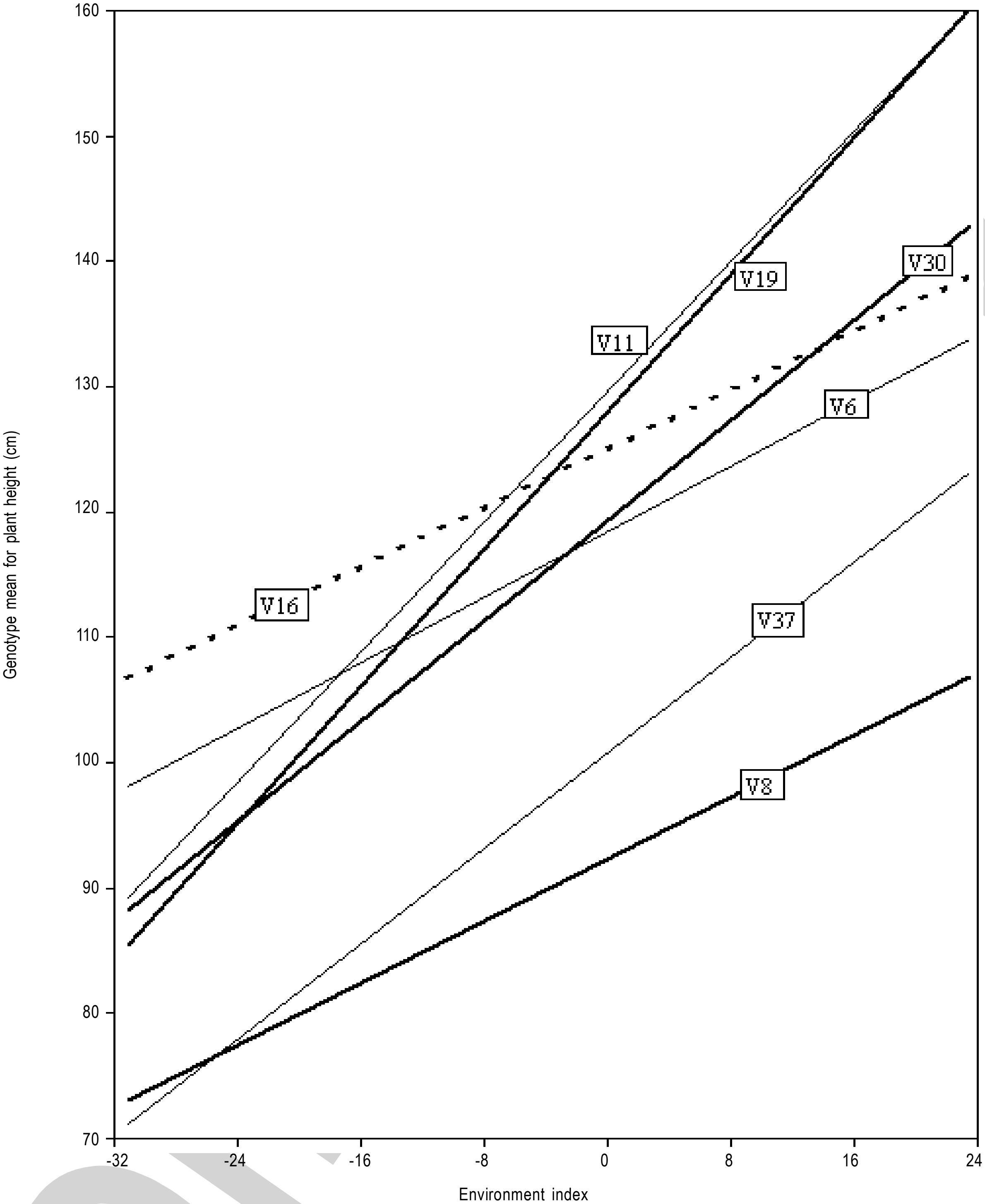

Fig. 1: Linear regression showing the influence of different environments on plant height (cm) of rice genotypes

interactions for different characters in rice were reported by Asenjo *et al*. (2003) and such type of interactions were identified by Hariprasanna *et al*. (2008) for the genotypes of groundnut.

Mean performances of the genotypes, their response and stability parameters for plant height are presented in the Table 1. The range of genotypic means over the environments was found to be 83 to 138 cm. The shortest plant stature was observed in Neimat followed by Basmati PNR346 (88 cm) and BRRIdhan28 (92 cm). The environment means were in the range of 88 – 142 cm. Thirteen genotypes had negative phenotypic indices (P_i) and were dwarf in stature. The remaining 27 genotypes showed positive P_i, signifying relatively taller plant type. The regression coefficients (b_i) of four

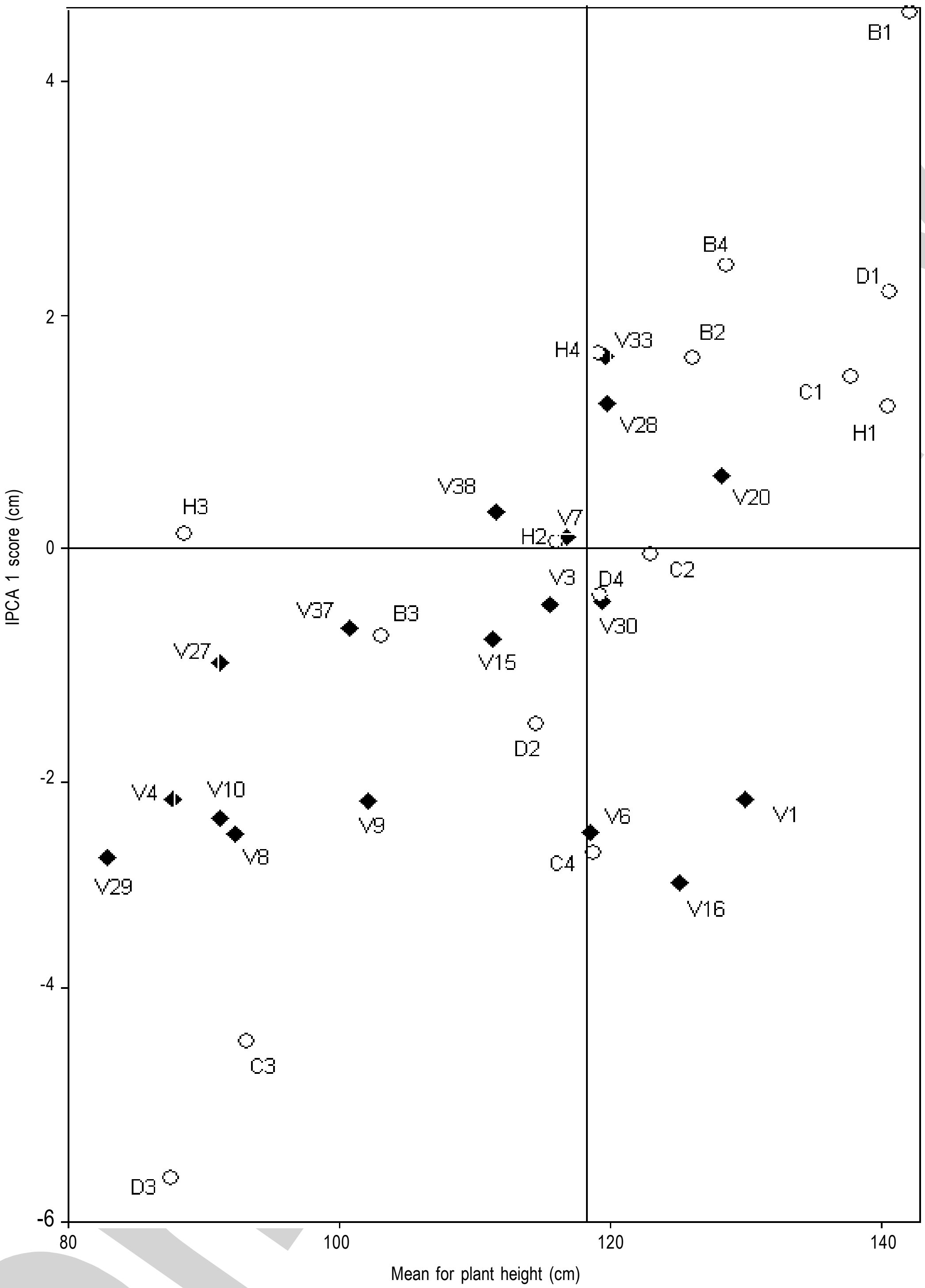

Fig. 2: AMMI 1 model for the plant height data, accounting for 95.1% of the treatment SS

genotypes (V11, V17, V19 and V22) were significant and greater than 1.0 indicating lower adaptability due to their sensitivity to environmental changes. And the prediction was valid since the deviations from regressions (S^2_{di}) of the character were insignificant. The b_i values of seven genotypes (V4, V6, V8, V9, V10, V16 and V29) were significantly lower than unity, indicating better resistance against environmental changes. Moreover, V6, V9 and V16 showed significant S^2_{di} values suggested that both linear and nonlinear components were responsible for plant height in these three genotypes. On the other hand, S^2_{di} of V4, V8, V10 and V29 were insignificant i.e. plant height of these varieties would not be variable in different environments. The seven genotypes (V1, V3, V25,

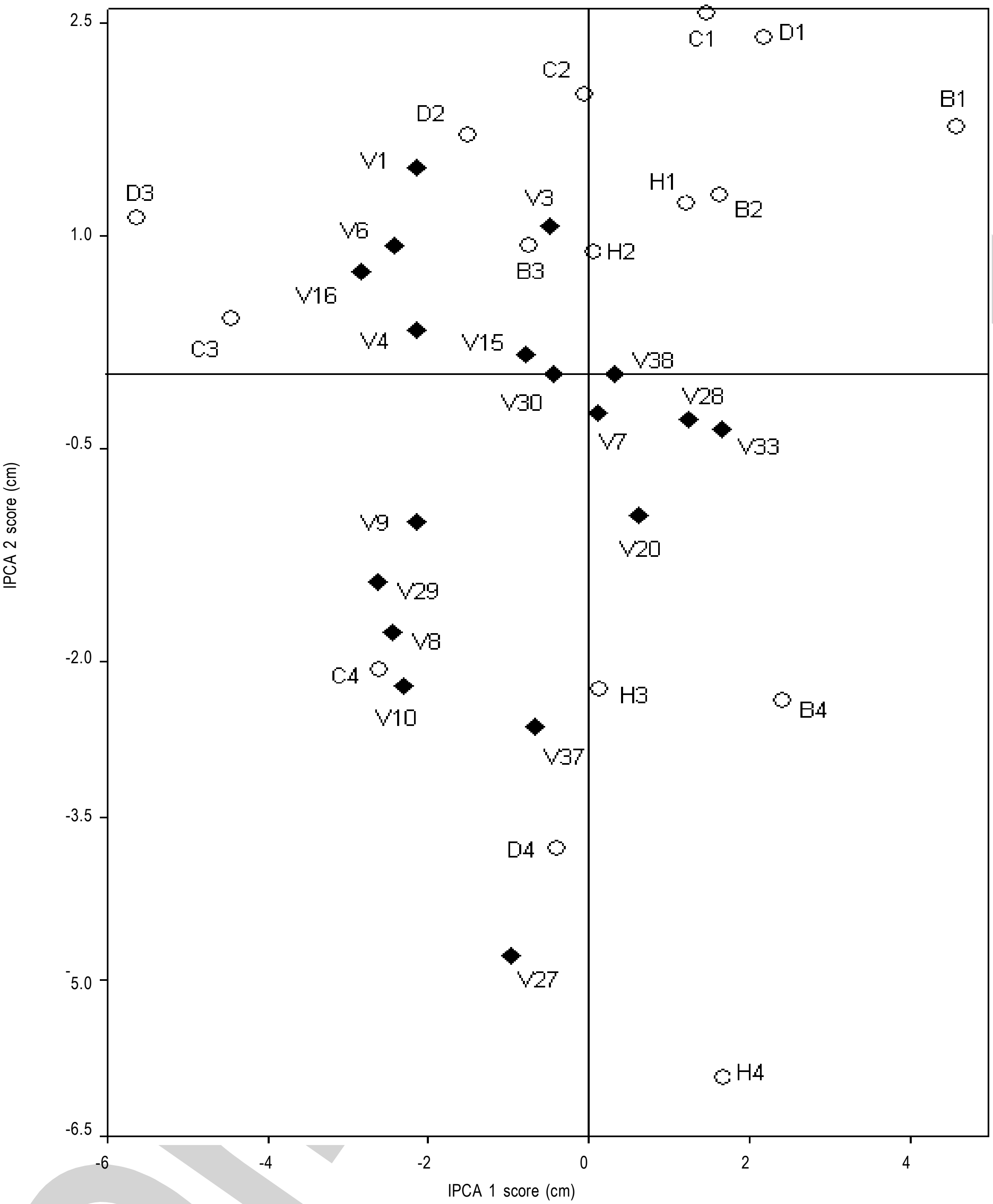

Fig. 3: AMMI 2 model for the interaction of plant height data

V27, V28, V37 and V40) showed only nonlinear sensitivity, so that linear prediction for these genotypes might not be possible. Shadakshari *et al*. (2001) also reported that only non-linear component was significant for plant height of low land rice genotypes under six farming situations. Insignificant values for both b_i (close to unity) and S^2_{di} (lower values) in the other 22 genotypes indicated their average stability for plant stature. Aromatic rices are normally characterized by longer plant height which is susceptible to lodging. So, the genotypes of shorter plant height with minimum b_i values and smaller S^2_{di} estimates would be desirable. The nature of response and stability parameters of seven genotypes are shown with regression lines in Fig. 1. The genotype Jamai sohagi (V19)

Table – 3: AMMI 4 model for the plant height data (grand mean = 118.7 cm) showing the deviation and partition into different principal component axes

Genotypes/ Environments	**Deviation (cm)**	**IPCA score $(\sqrt{\text{cm}})$**			
		IPCA 1	**IPCA 2**	**IPCA 3**	**IPCA 4**
V1	11.27	–2.15	1.48	–0.15	1.62
V2	8.46	–0.85	0.55	–0.75	–0.28
V3	–3.10	–0.48	1.07	3.33	–1.65
V4	–30.97	–2.14	0.34	–1.25	0.27
V5	11.98	–0.17	1.23	–0.45	–0.05
V6	–0.16	–2.42	0.93	2.34	2.09
V7	–1.93	0.10	–0.25	2.30	–0.71
V8	–26.32	–2.44	–1.79	0.40	–0.11
V9	–16.51	–2.16	–1.01	0.15	0.32
V10	–27.48	–2.31	–2.17	0.00	0.30
V11	10.98	2.48	0.72	1.25	–0.11
V12	4.54	–6.15	0.65	0.18	–0.84
V13	8.80	–0.25	2.39	0.16	–0.60
V14	5.14	0.99	1.29	0.29	–0.01
V15	–7.35	–0.78	0.16	0.68	–1.85
V16	6.39	–2.85	0.75	1.95	3.57
V17	7.13	1.80	1.66	1.20	–0.24
V18	4.08	–0.78	0.46	0.36	–0.17
V19	9.33	2.39	0.63	1.49	–1.75
V20	9.58	0.62	–0.97	0.42	–1.59
V21	1.35	0.71	0.47	–0.51	–0.43
V22	4.56	0.98	–0.69	–1.02	–1.11
V23	–4.30	0.64	–0.12	0.56	–2.18
V24	10.04	0.12	1.33	–1.59	–0.46
V25	12.85	0.39	1.17	–3.88	1.18
V26	5.39	1.04	0.51	–1.55	–0.42
V27	–7.49	–0.98	–4.83	–1.22	–1.35
V28	1.13	1.24	–0.29	–0.64	1.81
V29	–35.81	–2.64	–1.44	–0.44	–0.38
V30	0.71	–0.45	0.03	–1.32	–0.45
V31	9.38	–0.56	–0.18	–0.78	–0.91
V32	9.05	1.64	1.08	–0.48	0.90
V33	0.90	1.65	–0.36	1.15	1.01
V34	11.46	0.46	0.59	–0.94	0.03
V35	10.50	0.28	1.54	–2.23	1.30
V36	1.96	2.35	–0.34	–0.64	0.39
V37	–17.90	–0.68	–2.45	–0.39	–1.56
V38	–7.10	0.32	0.03	0.78	0.30
V39	10.42	1.40	0.81	0.27	0.72
V40	19.05	4.10	–4.99	0.98	3.42
B1	23.44	4.58	1.77	–3.71	0.94
B2	7.41	1.63	1.29	–2.70	–0.10
B3	–15.57	–0.75	0.93	–0.17	0.67
B4	9.94	2.42	–2.27	–0.52	–3.75
C1	19.10	1.47	2.56	2.98	–1.37
C2	4.29	–0.05	1.99	2.02	–0.25
C3	–25.48	–4.45	0.42	2.19	–0.48
C4	0.03	–2.60	–2.05	–0.08	–2.95
D1	21.95	2.19	2.39	0.22	–0.50
D2	–4.11	–1.50	1.71	0.86	–2.21
D3	–31.11	–5.63	1.13	–4.24	1.93
D4	0.54	–0.40	–3.72	–2.03	–1.78
H1	21.81	1.21	1.23	1.50	1.25
H2	–2.61	0.06	0.89	0.57	2.86
H3	–30.14	0.13	–2.19	2.09	3.73
H4	0.43	1.67	–6.09	1.02	2.02

IPCA1, 2, 3, 4 = Interaction principal component axis 1, 2, 3, 4 showed the maximum slope indicating the highest sensitivity to environmental changes. Thus, the plant height of V19 is mostly variable in different environments. On the contrary, the lowest slope of V16 (Gandho kasturi) indicated its minimum variability of plant height in wider environmental ranges.

The effect of genotype, environment and components of G×E interactions were highly significant, although the SS for G×E captured only 12% of treatment SS. IPCA1 alone held 25% of G×E SS while IPCA1 and IPCA2 together held 46% of G×E SS. The root mean square (RMS) residuals were examined for model fit. The RMS residual for plant height data in Table 2 was $(12927/1920)^{0.5}$ = 2.59 cm in AMMI 4 model. Similarly, the RMS residual for AMMI 2 was 3.40 cm and 4.02 for AMMI 1 was 4.02 cm. Table 3 listed the additive parameters as deviations and the multiplicative effects as IPCA scores. The first four axes have been computed in the present analysis. It should be noted that first one or two axes were usually considered for interpretation. The AMMI model helped to compute expected plant height (response). For example, the expected plant height of V1 grown in B1 would be 118.70+11.27+23.44+[(–2.15)×4.58] = 143.56 cm in AMMI 1. The observed plant height was 152.47 cm. Thus the AMMI 1 model leaved a residual of 8.91 cm. Moreover, V2 under B1 environment had leaved a residual of 0.46 cm only in AMMI 1 model. It was estimated that AMMI 1 model accounted for 95.1% of the observed data.

In the Fig. 2 it could be clearly observed that the expected plant height considering mean plant height on the abscissa and IPCA1 scores (for genotypes and environments) on the ordinate. Also, straight lines draw attention to the grand mean on the abscissa and to zero on the ordinate. Sixteen environments are shown with open circles. Filled tetragons denoted the genotypes. The genotypes with similar positions did not appear in the graph and thus showed 18 out of 40 genotypes in the AMMI biplot.

The genotypes V3, V15, V27, V30 and V37 showed more or less similar distances from the horizontal reference line. However, series of displacements along the abscissa indicated their differences due to main effects. On the other hand, V6, V28, V30 and V33 are dispersed along the ordinate and apparently they differ only in interaction effects. The genotypes V20 and V27 differ in both; while V3, V7 and V30 were rather similar with respect to both main effects and interaction effects. The main effect for genotypes reflects breeding advances and the main effect for environments characterize the site (Zobel *et al*., 1988). Considering these responses, the three environments viz. C3, D3 and H3 produced remarkably dwarf plants (Table 3 and Fig. 2). On the other hand, C4, D4 and H4 (Boro planting) showed plant height coinciding with grand mean and were much lower than the first planting in T.Aman. Direction and level of interactions of genotypes with environments could be determined from the Fig. 2. For example, V28 and V33 had strong positive interactions with the environments B2, C1, H1 and H4, little interactions with C2, D4, H2 and H3, and negative interactions with C3, C4, D2 and D3. On the other hand, V3, V15, V27 and V37 had positive interactions with B3 and D4, and negative interactions with B1, B4, C3, D1 and D3. In general, local aromatic rice varieties are tall in stature, and hence negative interactions for plant height will be preferred without affecting grain yield.

Further observation of interaction effects exclusively, a different type of biplot had been presented in the Fig. 3. It held IPCA1 on the abscissa and IPCA2 on the ordinate. It captured 46% of the interaction as against 25% of Fig. 2. The Fig. 2 and Fig. 3 together effectively captured 98% of the treatment SS in the AMMI 2 model, leaving a RMS residual of only 3.40 cm, or 2.86% of the grand mean (Table 2). The principles for IPCA1 and IPCA2 biplot graph have been described by several authors (Cornelius and Crossa, 1999; Dias and Krzanowski, 2003, 2006). The genotypes V4, V7, V15, V20, V28, V30, V33 and V38, and the environments B3 and H2 are situated very near the origin (Fig. 3). It indicated a little interaction for the entities (varieties and environments).

Linear regression method identified the most sensitive, average stable and highly stable genotypes over the environments. In the AMMI model, the interaction of 40 genotypes with 16 environments was best predicted by the first 2 principal components of G×E. Consequently, biplot graph generated using the scores of the first two principal components can help breeders have an over all picture of the genotypes and the environments.

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References

Asenjo, C.A., R. Bezus and H.A. Acciaresi: Genotype × environment interaction in rice (*Oryza sativa* L.) in temperate regions using the joint regression analysis and AMMI methods. *Cereal Res. Comm*., **32**, 97-104 (2003).

Atchley, W.R. and J. Zhu: Developmental quantitative genetics, conditional epigenetic variability and growth in mice. *Genetics*, **147**, 765-776 (1997).

Chu, C. and P.S. Tang: Studies on plant respiration. IV. Some morphological, physiological and biochemical changes during germination of rice at different partial pressures of oxygen. *Acta Bot. Sin*., **8**, 201–214 (1959).

Cornelius, P.L. and J. Crossa: Prediction assessment of shrinkage estimators of multiplicative model for multi-environment cultivar trials. *Crop Science*, **39**, 998-1009 (1999).

Dias, C.T.S. and W.J. Krzanowski: Model selection and cross-validation in additive main effect and multiplicative interaction (AMMI) models. *Crop Science*, **43**, 865-873 (2003).

Dias, C.T.S. and W.J. Krzanowski: Choosing components in the additive main effect and multiplicative interaction (AMMI) models. *Sci. Agric. (Piracicaba Braz.)*, **63**, 169-175 (2006).

Eberhart, S.A. and W.L. Russel: Stability parameters for comparing varieties. *Crop Sci*., **6**, 34-40 (1966).

Falconer, D.S.: Introduction to quantitative genetics, 2nd Edn. London and New York (1981)

Fang, P. and Ping Wu: QTL × N-level interaction for plant height in rice (*Oryza sativa* L.). *Plant and Soil*, **236**, 237-242 (2001).

Flintham, J.E., A. Borner, A.J. Worland and M.D. Gale: Optimizing wheat grain yield: Effects of *Rht* (gibberellin-insensitive) dwarfing genes. *J. Agric. Sci.*, **128**, 11-25 (1997).

Gomez, K.A.: Techniques for field experiments with rice. Int. Rice Res. Inst., Los Banos, Laguna, Philippines. p. 46 (1972)

Hamid, A., N. Uddin, M. Haque and E. Haque: *Deshi dhaner jat.* Publication no. 59. Bangladesh Rice Res. Inst. 117 p. (1982).

Hariprasanna, K., C. Lal and T. Radhakrishnan: G x E interaction and stability analysis in large seeded genotypes of groundnut. *J. Oilseeds Res.*, **25**, 126-131 (2008).

Huang, N., B. Courtois, G.S. Khush, H. Lin and G. Wang: Association of quantitative trait loci for plant height with major dwarfing genes in rice. *Heredity*, **77**, 130-137 (1996).

Jain, S.K. and D.R. Marshall: Population studies in predominantly self-pollinated species. X. variation in natural populations of *Avena fatua* and *A. barbata*. *Am. Nat.*, **101**, 19-33 (1967).

Karim, Z., S.G. Hussain and M. Ahmed: Salinity problems and crop intensification in the coastal regions of Bangladesh. BARC Soils publication No. 33. Bangladesh Agric. Res. Council, Dhaka 1215. 63 p. (1990).

Kaya, Y., C. Palta and S. Taner: Additive main effects and multiplicative interactions analysis of yield performance in bread wheat genotypes a cross environments. *Turk. J. Agric.*, **26**, 275-279 (2002).

Keller, M., Ch. Karutz, J.E. Schmid, P. Stamp, M. Winzeler, B. Keller and M.M. Messmer: Quantitative trait loci for lodging resistance in a segregating wheat × spelt population. *Theor. Appl. Genet.,* **98**, 1171-1182 (1999).

Khush, G.S.: Green revolution: Preparing for the 21st century. *Genome*, **42**, 646-655 (1999).

Kumar, A., R.K.S. Tiwari, S.S. Parihar, K.S. Pandya and M.P. Janoria: Performance of prototype rice lines from ideotype breeding. *Int Rice Res Notes*, **24**, 18-19 (1999).

Ladha, J.K., G.J.D. Kirk, J. Bennett, S. Peng, C.K. Reddy, P.M. Reddy and U. Singh: Opportunities for increased nitrogen use efficiency from improved lowland rice germplasm. *Field Crops Res.* **56**, 41-71 (1998).

Misra, R.C., S. Das and M.C. Patnaik: AMMI model analysis of stability and adaptability of late duration finger millet (*Eleusine coracana*) genotypes. *World Appl. Sci. J.*, **6**, 1650-1654 (2009).

Mohammadi, R., A. Mohammad, A. Shabani and A. Daryaei: Identification of stability and adaptability in advanced durem genotypes using AMMI analysis. *Asian J. Plant Sci*., **6**, 1261-1268 (2007).

Naveed, M., M. Nadeem and N. Islam: AMMI analysis of some upland cotton genotypes for yield stability in different milieus. *World J. Agril. Sci.*, **3**, 39-44 (2007).

Ram, J., O.P. Jain and B.R. Murty: Stability performance of some varieties and hybrid derivatives in rice under high yielding varieties programme. *Ind. J. Genet. Plant Breed*., **30**, 187-198 (1970).

Sabaghnia, N., S.H. Sabaghpour and H. Dehghani: The use of an AMMI model and its parameters to analyse yield stability in multi-environment trials. *J. Agric. Sci.*, **146**, 571-581 (2008).

Shadakshari, Y G., H.M. Chandrappa, R.S. Kulkami and H.E. Shashidhar: Genotype × environment interaction in lowland rice genotypes of hill zone of Karnataka. *Indian J. Genet. Plant Breed*., **61**, 350-352 (2001).

Singh, R.K., U.S. Singh and G.S. Khush: Aromatic rices. Oxford and IBH publishing Co. Pvt. Ltd. New Delhi. 292 p. (2000)

Swaminathan, M.S.: Rice in 2000 AD. *In*: Rice – in a variable climate. Ed: Y.P. Abrol and Sulochana Gadgil. APC Publications Pvt. Ltd., Post Box No. 2679, New Delhi-110005, India. pp. 217-238 (1999).

Zobel, R.W., M.W. Wright and H.G. Gauch: Statistical analysis of a yield trial. *Agron. J.*, **80**, 388-393 (1988).