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GENETICS AND PLANT BREEDING

Additive Main Effects and Multiplicative Interactions Analysis of Plant Height in Basmati Rice

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ABSTRACTS

Thirty six basmati rice genotypes were evaluated under four production systems *viz.* Transplanted rice (TPR), System of rice intensification (SRI), Chemical free cultivation (CFC) and Wet direct seeded rice (Wet DSR) at RRS, Kaul, and RRS, Uchani (Karnal), CCS HAU, Hisar, Haryana during *Kharif* season of 2016 and 2017. The experiment was conducted using Randomized Complete Block Design with three replications. Yield stability and adaptability of plant height were analyzed by Eberhart and Russell's and additive main effects and multiplicative interaction (AMMI) model. The environment, genotype main effects, and the GEI were all highly significant. The study indicated that the tested genotypes, such as Pusa 1734-8-3-85, SJR-70-3-2, PAU 6297-1, Pusa 1656-10-705, Pusa 1884-3-9-175, and Pusa-1884-9-12-14 had dwarf plant height, which indicated these genotypes adapted to favorable environments. Based on AMMI biplot analysis, the genotypes, Improved Pusa Basmati 1 and HUBR-16 with low mean and IPCA1 score close to zero, were identified as stable genotype and had general adaptation to all the environments.

Highlights

- The genotype x environment interaction is important for plant breeding because it affects the genetic gain and selection of cultivars with wide adaptability.
- Numerous methods have been developed to reveal patterns of G x E interaction, However, additive main effects and multiplicative interaction (AMMI) model is widely used in the multi-environment cultivar trials as it quantify the genotype environment interaction through PCA and graphical representation.
- Based on AMMI analysis genotypes Improved Pusa Basmati 1 and HUBR-16 were identified as stable adaptable to all the environments for plant height.

Keywords: Adaptability, AMMI, Eberhart and Russsell's, Rice and Stability

Rice is the second largest cereal crops and is the staple food of nearly one-half of the world population. Developing countries account for 95% of the total production, with china and India alone responsible for nearly half of the world output. It belongs to family poaceae. Rice is also known as 'model crop' due to its diploid nature (2n=24), relatively small genome size (Kurata *et al.* 1994; Xu *et al.* 2005), a significant level of polymorphism (McCouch *et al.* 1997), and its adaptations to wide range of geographical, ecological and climatic regions. It is grown over 163.1 million ha. area with production of 748 m.t. of paddy and an average productivity of 4.59 t/ha (FAO, 2016) (www.fertilizer.org). In India, it is cultivated on about approximate 44.1 m. ha area with production of 165.3 m.t. paddy and productivity 3.78 t/ha (Anonymois (2016). Haryana occupies an area of 12.28 lakh ha with production of 39.98 lakh tones and productivity 3.25 t/ha (Anonymous, 2013-14).

Now days, conventional method of rice cultivation viz., puddled transplanted rice is facing severe constraints because of water and labour scarcity coupled with climatic changes. Therefore, necessitating to search alternative methods with good potential to save water, reduce labour requirement, mitigate green-house gas emission and adapt to climatic risks. In recent years, there has been a shift from conventional to non-conventional cultivation techniques namely direct seeded rice (DSR) & system of rice intensification (SRI) in several countries of Southeast Asia (Pandey and Velasco, 2002). Direct-seeding of rice has the potential to provide several benefits to farmers and the environment over conventional practices of puddling and transplanting. Direct seeding helps reduce water consumption by about 30% (0.9 million liters acre^{-1}) as it avoids nursery raising, seedling uprooting, puddling and transplanting, and thus reduces the labour requirement (Pepsico International, 2011). Similarly, system of rice intensification (SRI) originated serendipitously in Madagascar and first used by Father Henri de Laulanı´e in 1983 is a new method gaining popularity in many countries to increase the rice production. It is a new methodology of rice cultivation that can raise rice output by reducing water requirements and external inputs (Uphoff *et al.* 2002). This method increases yield by over 30%, while using 40% less water than conventional methods. Evaluation of different genotypes performance under different production systems is required for the optimization of the genetic potential of different genotypes under diverse edaphic conditions.

Plant growth is greatly affected by environmental fluctuations due to significant genotype and environment interaction (Reddy *et al.* 2011). The most efficient way to assess the genetic potential and adaptability of genotype is to grow it in multiple environments for several years (Gauch and Zobel 1996; Epinat-Le Signor *et al.* 2001). The evaluation of genotypes to suitable testing locations is crucial to the success of a plant breeding program. Now a day an additive main effect and multiplicative interaction (AMMI) model is commonly used to measure G x E interaction during yield trials. Understanding of G x E interaction is very important for evaluating the adaptability and stability of cultivars. AMMI can detect GE interaction in a multi-dimensional space and present the interaction using a biplot. Thus, the present study was conducted to assess to 36 basmati rice genotypes for their yield stability over the environments.

MATERIALS AND METHODS

A field experiment was conducted during the *Kharif* season of 2016 and 2017 at two locations, Rice Research Station Kaul and Regional research station, Uchani under CCSHAU, Hisar Haryana, India. The experiments were carried out in a Randomized Block Design (RBD) with three replications in a total sixteen environments under four production systems (Table 1). The plant material used in the present study was consisted of 36 basmati rice genotypes. The analysis of variance of the present investigation was carried out as per the standard procedures of Panse & Sukhatme (1985) for plant height. The data of 36 genotypes across 16 environments were analyzed by using stability models *viz;* (1) Eberhart & Russel (1966), (2) Additive Main effects and Multiplicative Interaction (AMMI) (Gauch & Zobel 1989).

RESULTS AND DISCUSSION

Eberhart and Russel's (1966)

Analysis of variance

The results of pooled analysis of variance for stability as devised by Eberhart and Russell (1966) are presented in Table 2. The genotypes, environments

Table 1: Description of environments

Environments							
Chemical Free Cultivation (CFC)				**Direct Seeded Rice (DSR)**			
E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
CFCK16	CFCK17	CFCU16	CFCU17	DSRK16	DSRK17	DSRU16	DSRU17
System of Rice Intensification (SRI)				**Transplanted Rice (TPR)**			
E9	**E10**	**E11**	**E12**	**E13**	**E14**	**E15**	**E16**
SRIK16	SRIK17	SRIU16	SRIU17	TPRK16	TPRK17	TPRU16	TPRU17

K16-*Kaul 2016***; K17-***Kaul 2017***; U16-***Uchani 2016 and* **U17-** *Uchani 2017.*

and genotype × environment interaction components showed significant differences for plant height when tested against pooled deviation revealed that the selected genotypes are rich in variation, micro-environments created through production systems were different from each other and wide differential behavior of genotypes in changing environments. Mean sum of squares due to environments + (genotypes × environments) were highly significant for plant height depicted the distinct nature of environments and genotype × environment interaction on phenotype expression. Significance of environment (linear) component for plant height indicated that the genotypes responded linearly for most of the characters under study. Significance for mean squares for genotype × environments (linear) indicates variation in the performance of genotype is due to the regression of genotypes on environments and the performance is predictable in nature. The high and significant pooled deviations indicated the performance of genotypes is entirely unpredictable in nature. Similar results were also reported by Meena *et al.* (2016), Kulkarni *et al.* (2018) and Manjunatha *et al.* (2018).

Table 2: Pooled analysis of variance for plant height in rice over 16 environments (Eberhart and Russell, 1966 model)

Source of variation	df	SS	MS
Genotype	35	145598.25	4159.95**
Environment	15	5245.50	349.70**
Genotype × Environment	525	3087.00	5.88**
Environment + Genotype × Environment	540	8332.20	15.43**
Environment (Linear)	1	5245.10	5245.10**
Environment × Genotype (Linear)	35	233.80	6.68
Pooled deviation	504	2852.64	5.66*
Pooled error	1120	5017.60	4.48

Stability parameters

The mean value for plant height ranged from 86.83 (Pusa-1475-03-42-45-119-1) cm to 144.02 (Taraori basmati) cm with an overall mean of 113.10 cm (Table 4). Among the genotypes tested, except Pusa 1475-03-42-45-119-1 and UPR-386-9-1-1, the remaining 34 genotypes exhibited non-significant deviations from the regression (S^2di) as such their performance can be predicted in the varying environments. The genotypes Pusa 1734-8-3-85 (μ= 104.63, bi= 1.39***, S^2di= 4.77), SJR-70-3-2 (μ= 109.38, bi= 1.13***, S^2di= -0.96), PAU 6297-1 (μ= 104.42, bi= 1.26***, S^2di=-2.59), Pusa 1656-10-705 (μ= 103.75, bi= 1.18***, S^2di= -1.23), Pusa 1884-3-9-175 (μ= 98.13, bi= 1.36***, S^2di= -0.75), Pusa-1884-9-12-14 (μ= 106.60, bi= 1.35***, S^2di= -1.77) with low mean value than overall mean, significant regression coefficient more than unity and non-significant deviation from regression was observed to be suitable for favorable environment. Genotypes, Pusa Sugandh 3 (μ= 109.73, bi= 0.72***, S^2di= 0.44), Pusa Sugandh 5 (μ= 103.10, bi= 0.97***, S^2di= -0.54), Pusa Sugandh 6 (μ= 89.13, bi= 0.89***, S^2di= -1.18), Pusa basmati 1 (μ= 104.71, bi= 0.95***, S^2di= 0.75), Improved Pusa Basmati 1 (μ= 101.19, bi= 0.99***, S^2di= -3.02), Pusa-1826-12-2-71-4 (μ= 98.56, bi=0.86***, S^2di=1.11), CSR TPB 1 (μ= 96.17, bi= 0.99***, S^2di= 0.58), Pusa 6295-2 (μ= 87.81, bi= 0.88***, S^2di= 0.14), Pusa 1637-2-8-20-5 (μ= 101.50, bi= 0.83***, S^2di= -2.22) with low mean value than overall mean, significant regression coefficient less than unity and non-significant deviation from regression was found suitable for unfavorable environment. The genotypes showing unpredictable performance with highly significant deviation from regression were Pusa 1475-03-42-45-119-1 (μ= 86.83, bi= 0.80, S^2di= 14.58***) and UPR-386-9-1-1 (μ= 107.90, bi= 1.30***, S^2di= 8.77***). Madhukar and Raju (2013) identified HRI-157 suitable for favorable and NLR34449 for poor environment. Similarly, RNR 2465 by Swapna *et al.* (2014); PRH-10, PA 6129 and PSD-3 by Meena *et al.* (2016); KRH-2 by Munisonappa *et al.* (2004); RPHP87 and RPHP 114 by Ajmera *et al.* (2017); and BPT 2411, BPT 3291 and BPT 2231 by Laxmi *et al.* (2014) was identified as stable genotypes for plant height. The environment, E16 most favorable environment for tall plant height as indicated by environmental index (4.20), whereas E1 resulted in dwarf ness (environmental Index -5.27).

AMMI (Gauch, 1988)

Analysis of variance

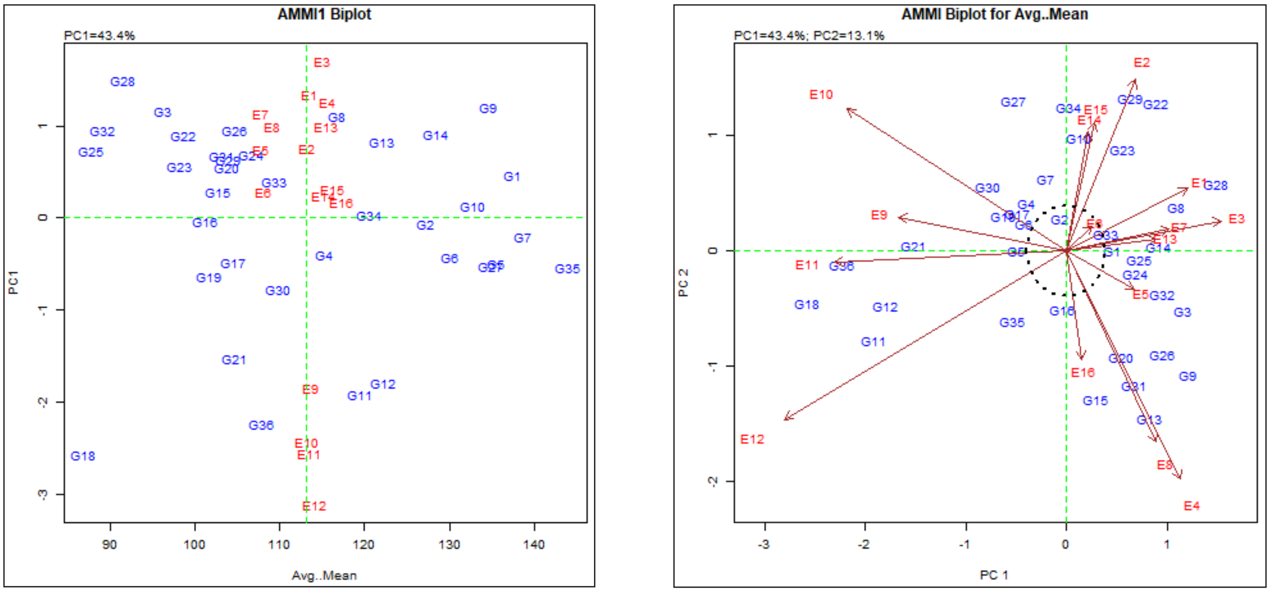
The combined analysis of variance showed that mean sum of squares due to genotypes and environments were significant for plant height (Table 3). This indicated the presence of variability among the genotypes and environments. The AMMI analysis of variance (Table 4) for plant height across

Table 3: Pooled analysis of variance for plant height in rice over 16 environments (Gauch, 1988)

Source of variation	df	SS	MS	% explained	Cumulative
Trials	575	153927.50	267.70		
Genotypes	35	145598.25	4159.95**	94.59	94.59
Environments	15	5245.50	349.70**	3.41	98
G*E Interaction	525	3087.00	5.88**	2.00	100
PCA I	49	1327.90	27.10*	43.40	43.40
PCA II	47	405.61	8.63*	13.10	56.50
Pooled error	45	328.50	7.30*		

Table 4: Mean performance and stability parameters for plant height in rice over 16 environments

Sl. No.	Genotypes	Mean	bi	S2di
1	Basmati 370	137.52	1.21***	0.59
2	CSR-30	127.19	0.92***	-1.40
3	CSR TPB-1	96.17	0.99***	0.58
4	Haryana Basamti 1	115.17	1.01***	-2.27
5	Haryana Mahek 1	135.52	0.86***	-3.11
6	HKR -11-509	130.08	1.09***	-2.73
7	HKR 03-408	138.73	0.84***	-0.56
8	HKR 06-417	116.79	0.93***	4.76
9	HKR 06-434	134.67	0.76	1.63
10	HKR 06-443	132.83	1.07***	1.17
11	HKR 06-487	119.50	1.20***	6.16
12	HKR 08-425	122.15	1.41***	5.44
13	HKR 11-447	121.98	0.70	1.51
14	HKR 98-476	128.48	1.00***	0.06
15	HUBR-16	102.73	0.74	1.23
16	Improved Pusa Basmati 1	101.19	0.99***	-3.02
17	PAU-6297-1	104.42	1.26***	-2.59
18	Pusa 1475-03-42-45-119-1	86.83	0.80	14.58***
19	Pusa 1637-2-8-20-5	101.50	0.83***	-2.22
20	Pusa 1656-10-705	103.75	1.18***	-1.23
21	Pusa 1734-8-3-85	104.63	1.39***	4.77
22	Pusa 1826-12-271-4	98.56	0.86***	1.11
23	Pusa 1884-3-9-175	98.13	1.36***	-0.75
24	Pusa 1884-9-12-14	106.60	1.35***	-1.77
25	Pusa 6295-2	87.81	0.88***	0.14
26	Pusa Basmati 1	104.71	0.95***	0.75
27	Pusa Basmati 1121	134.88	1.26***	1.80
28	Pusa Basmati 1509	91.50	0.79	5.29
29	Pusa Sugandh 2	103.85	0.72	4.45
30	Pusa Sugandh 3	109.73	0.72***	0.44
31	Pusa Sugandh 5	103.10	0.97***	-0.54
32	Pusa Basmati 6	89.13	0.89***	-1.18
33	SJR-70-3-2	109.38	1.13***	-0.96
34	Super Basmati	120.46	0.84***	0.83
35	Taraori Basmati	144.02	0.81***	0.52
36	UPR-386-9-1-1	107.90	1.30***	8.77***
Mean		**113.10**		



(a) (b)

Fig. 1 (a): AMMI 1 Biplot for plant height of 36 Basmati rice genotypes (G) and 16 environments (E) using genotypic and environmental scores **(b)** AMMI 2 Biplot for plant height showing the interaction of IPCA2 against IPCA1 scores of 36 Basmati rice genotypes (G) in 16 environments (E)

G1	Basmati 370	G19	Pusa 1637-2-8-20-5	E1	Chemical Free Cultivation K 16
G2	CSR-30	G20	Pusa 1656-10-705	E2	Chemical Free Cultivation K17
G3	CSR TPB-1	G21	Pusa 1734-8-3-85	E3	Chemical Free Cultivation U 16
G4	Haryana Basamti 1	G22	Pusa 1826-12-271-4	E4	Chemical Free Cultivation U17
G5	Haryana Mahek 1	G23	Pusa 1884-3-9-175	E5	Direct Seeded Rice K 16
G6	HKR -11-509	G24	Pusa 1884-9-12-14	E6	Direct Seeded Rice K17
G7	HKR 03-408	G25	Pusa 6295-2	E7	Direct Seeded Rice U 16
G8	HKR 06-417	G26	Pusa Basmati 1	E8	Direct Seeded Rice U17
G9	HKR 06-434	G27	Pusa Basmati 1121	E9	System of Rice Intensification K 16
G10	HKR 06-443	G28	Pusa Basmati 1509	E10	System of Rice Intensification K17
G11	HKR 06-487	G29	Pusa Sugandh 2	E11	System of Rice Intensification U 16
G12	HKR 08-425	G30	Pusa Sugandh 3	E12	System of Rice Intensification U17
G13	HKR 11-447	G31	Pusa Sugandh 5	E13	Transplanted Rice K 16
G14	HKR 98-476	G32	Pusa Basmati 6	E14	Transplanted Rice K17
G15	HUBR-16	G33	SJR-70-3-2	E15	Transplanted Rice U 16
G16	Improved Pusa Basmati 1	G34	Super Basmati	E16	Transplanted Rice U17
G17	PAU-6297-1	G35	Taraori Basmati		
G18	Pusa 1475-03-42-45-119-1	G36	UPR-386-9-1-1		

the environments showed that 94.59% of the total variation was attributed to genotypic effects, 3.41% to environmental effects and 2.00 % to genotype × environment interaction effects. The presence of GEI was clearly demonstrated by the AMMI model, indicating the substantial differences in genotypic response across the environments. The G × E interaction was portioned among the first two interaction principal component axis (IPCA), as they were 43.40 and 13.10% respectively; and the cumulative variance was about 56.50% for PCAI and PCA II. This implies that the interaction of the 36 basmati rice genotypes with sixteen environments was predicted by the first two components of genotypes and environments. Similar results were also observed by Akter *et al.* (2014) for grain yield, Jain *et al.* (2017) for harvest index and test grain weight and Jain *et al.* (2018) for days to 50% flowering and days to maturity in rice.

Stability parameters

Genotypes or environments with large IPCA1 scores, either positive or negative had large interactions (and are specific adaptation of a genotype to certain environments), whereas genotypes with IPCA1 score of zero or nearly zero had smaller interactions (Crossa *et al.* 1990). The locations E16, E14, E15 and E6 had IPC1 score near zero and hence had small interaction effects (and considered as stable) indicating that all the genotypes performed well in these locations (Fig. 1a). But E16, E14 and E15 were found to have above overall mean. So, these locations were not suitable by keeping in view the importance dwarf plant height. Similarly, the genotypes Improved Pusa Basmati 1, Super Basmati, CSR-30, HKR 06-443, HKR 03-408 and HUBR-16 had near zero score on the first IPCA1 indicating that these genotypes were less influenced by the environments (stable genotypes). Out of these, Improved Pusa Basmati 1 and HUBR-16 registered below overall mean along with the IPCA1 score close to zero, they stable genotype and had general adaptation to all the environments. Similar signs of IPCA 1 score for both genotype and environment implies positive interaction and if different, their interaction is negative and thus it attributes at that particular environment. Genotypes, SJR-70-3-2; HKR 06-417; and Pusa 1884-9-12-14, Pusa Sugandh 2 were identified as specifically adapted to the E6; E4 and E13; and E5 respectively and these environments were considered as the favorable environments for these genotypes. Similar findings were also reported by Laxami and Kumar (2017) and Rajaram and Waghmode (2017 for plant height in rice. In AMMI 2 biplot, (Fig. 1b) the environmental scores are joined to the origin by side lines. Sites with short spokes do not exert strong interactive forces. Those with long spokes exert strong interaction. The E6, E5 and E13 had short spokes and they do not exert strong interactive forces while E7, E16, E9, E14, E15, E1, E8, E4, E3, E11, E10, E2 and E12 with long spokes were more differentiating environments. The genotypes near the origin are not sensitive to environmental interaction and those distant from the origins are sensitive and have large interaction. In the present study, CSR-30, SJR-70-3-2, Basmati 370, Haryana Mahek 1, HKR -11-509, Haryana Basmati 1, PAU-6297-1 and Improved Pusa Basmati 1 were close to the origin and hence they were non sensitive to environmental interactive forces whereas Pusa Basmati 1509, Pusa 1884-3-9-175, Pusa 1826-12-271-4, Pusa Sugandh 2, HKR 06-443, Super Basmati, Pusa Basmati 1121, UPR-386-9-1-1, Pusa 1475-03-42-45-119-1, HKR 08-425, HKR 06-487. HKR 11-447, HUBR-16, Pusa Sugandh 5, Pusa 1656-10-705, HKR 06-434 and Pusa Basmati 1 found more responsive since they were away from the origin. Genotypes that are close to each other tend to have similar performance and those that are close to environment indicates their better adaptation to that particular environment. In this case, the best adapted genotypes for E11 was UPR-386-9-1-1; for E6 was SJR-70-3-2: for E13 was HKR 98-476; for E1 were HKR 06-417 and Pusa Basmati 1509; for E2 were Pusa 1826-12-271-4 and Pusa Sugandh 2; for E14 was HKR 06-443.

CONCLUSION

The genotype x environment interaction (GEI) has beenan important and challenging issue for plant breeders in testing the performance of crop varieties. The GEI reduces association between phenotypic and genotypic values and leads to bias in the estimates of gene effects and combining ability for various characters that are sensitive to environmental fluctuations. Such traits are less amenable to selection. AMMI statistical model could be a great tool to select the most suitable and stable genotypes for specific as well as for diverse environments. In the present study, AMMI model has shown that the largest proportion of the total variation in grain yield was attributed to environments. AMMI biplot analysis identified Improved Pusa Basmati 1 and HUBR-16 as adaptable genotype to all the environments for dwarf plant height.

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