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Estimation of G x E Interaction by AMMI Model in 'Antenna Panel' Genotypes of Rice [*Oryza sativa* L.]

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HIGHLIGHTS

- IRRI has launched their flagship project-4 consisting of '*Antenna Panel*'.
- 'Antenna panel' genotypes characterize evolving climate-dynamics through crop's eye.
- SAHEL 108 is the most superior genotype for grain yield over all the three environments of testing.

Abstract: G × E interaction is major cause of discrepancy in crop yield under different environments. International Rice Research Institute (IRRI) launched their fourth flagship project on Global Rice Array (GRA-IV) to identify climate resilient rice genotypes. The G x E interaction was studied in 'Antenna Panel' genotypes Of rice using AMMI model. The results indicated that main effects as well as interactive G x E effects were significant for most of the traits. Major portion of the G x E was contributed by the genotypes. AMMI model having two principle components axis was found as the best predictive model. On the basis of biplots and ASV score SAHEL 177 for days to 50% flowering, SADRI for plant height; FEDEARROZ 50 for panicle length; CT11891-2-2-7-M for number of grains panicle^{-1} and SAHEL 108 for grain yield were considered as most stable genotypes in all the consecutive three environments. Moreover Yield Stability Index (YSI) supported the results that SAHEL 108 is the most superior genotype for grain yield over all the three environments of testing. Findings from this study are expected to help breeders to select suitable genotype on the basis of its performance and stability over locations. which can provide a head start to the rice improvement programmes for Indo-gangetic Plains and *Hilly Tarai regions* of India.

Keywords: AMMI; G x E interaction; Rice; stability.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important grain crops which fulfills the calorific needs of above half of the total population on earth. Approximately 20% of global (total) energy intake is met by rice. Moreover, there is a necessity to increase rice production by 8–10 million tons annually to meet future needs [1]. Rice in India feeds 70% of the population fulfilling 43% of calorific needs [2]. There's an urgency of upscaling of nearly a 50% increase in rice production over the short span of next few decades and to achieve this goal, improving productivity is critical need [3,4]. Over 50% of the Indian population is somehow dependent on rice for their calorific needs [5]. India holds 2nd global rank among all the rice producing countries. In recent times, degrading crop-environment and changing climatic conditions is posing serious treats to rice production in the Indian sub-continent [6]. Globally, about 1/3rd of the rice yield fluctuations is caused by the climate variability [7]. This prevailing situation in the rice production scenario warrants efficient scouting for genotypes with high adaptation capabilities towards a wide range of environments and climatic conditions to fulfill specific social and economic needs. The genotype x environment interaction is an important part of plant breeding [8]. A variety is said to be stable high-yielder when it exhibits lower interactive GxE effects and higher mean yield when cultivated under wide range of growing conditions. Simultaneous consideration of both yield and stability is important to ensure precise and reliable selection of genotypes [9]. Becker and Leon (1988) defined a stable genotype as “one possessing a constant performance irrespective of any change in environmental conditions” [10].

Several researchers use the additive main effects and the multiplicative interaction analysis (AMMI) model to decipher the interactive G x E effects in different crops [11,12]. This model gained popularity among breeders as it can make precise yield predictions in Multi-Environment Trials (METs- over locations or over years) and can also clearly demarcate the interactive effects and main effects by combinatorial principal component analysis (PCA) with analysis of variance (ANOVA)[13-16]. Stability as a sole criterion to scout the desirable genotypes is not meaningful because the most stable genotype is not necessarily a high-yielding one [17]. So, a selection criterion that can accommodate yield performance and stability into a single definitive index should be used for selection of desirable genotypes [18-20]. Keeping these points in mind a study was conducted in three different locations in the Northern India during *Kharif* 2021 to identify the stable breeding lines of rice from the global exotic germplasm for yield and important yield components. Once stability of such genotypes is established then they can enhance our gene pool and simultaneously can be used in future breeding programmes to meet specific needs.

MATERIAL AND METHODS

The present study was conducted in three different locations in the Northern India [Figure 1] during *Kharif* 2021. The three locations are namely, Kashipur, Pantnagar and Majhera. Norman E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar falls in Tarai region of Uttarakhand state is having subtropical and humid climate. It is situated in the foot hills of Himalayas at an altitude of 243.84 m above mean sea level at 29.01° N latitude and 79.48° E longitude. Sugarcane Research Centre of Govind Ballabh Pant University of Agriculture and Technology. Kashipur falls in Western part of Uddham Singh Nagar district of Uttarakhand state. It is situated at an altitude of 218 m above mean sea level at 29.18° N latitude and 78.99° E longitude. Majhera Krishi Vigyan Kendra of Govind Ballabh Pant University of Agriculture and Technology situated at Dhari Tehsil of Nainital District of Uttarakhand state and has a cool climate. It is situated at an altitude of 989 m above mean sea level at 29.50° N latitude and 79.47° E longitude. Weather data for the three experimental locations are provided In supplementary Table 4 at the end of the text. Field evaluation and phenotyping were carried out during kharif 2021.

The experimental material comprised of fifteen genotypes namely, *viz*., IRRI 154, IR 78222-20-7-148-2-B-B-B-B, IR 69726-116-1-1, IRRI 146, SWARNA, SADRI, KHAO HLAN ON, IR13L493, IR6, ZANTON::IRGC 52785-1, SAHEL 108, SAHEL 177, FEDEARROZ 50, CT11891-2-2-7-M and ORYZICA SABANA 10 that includes genotypes from the ‘Antenna Panel’ of Global Rice Array-IV, one of the flagship the project of IRRI, Philippines. ‘*Antenna Panel*’ genotypes are actually superior genotypes nominated by several South-East Asian nations to constitute a panel which can help in understanding the climate dynamics. The experiment was laid down in a Randomized Block Design (RBD) with three replications in all the locations during *kharif* 2021 following the recommended package of practices to raise a normal and healthy crop. The observations were recorded on Days to 50 percent flowering, Plant height at maturity (cm), Number of tillers plant^{-1} at maturity, Panicle length (cm), Grains panicle^{-1}, Thousand grains weight (g) and Grain yield (Kgh^{-1}). The AMMI model was used to decipher the interactive G x E effects [14] over all the three diverse locations. The test of significance of main effects as well as the interactive effects was carried out by an F-test devised by Gollob (1968) [21]. GEA-R (2017) Version 4.1 software available at www.cimmyt. Org, was used for all the statistical analyses and simultaneous construction of biplots [22]. Further estimation of the AMMI stability values (ASV) was carried out to rank the genotypes according to their stability [23]. A unique selection criterion/Index *viz.,* Yield Stability Index (YSI) which can factor-in both mean yield performance and stability in a single indices and it was employed to identify superior genotypes from the global ‘*Antenna Panel*’[19-20; 24].

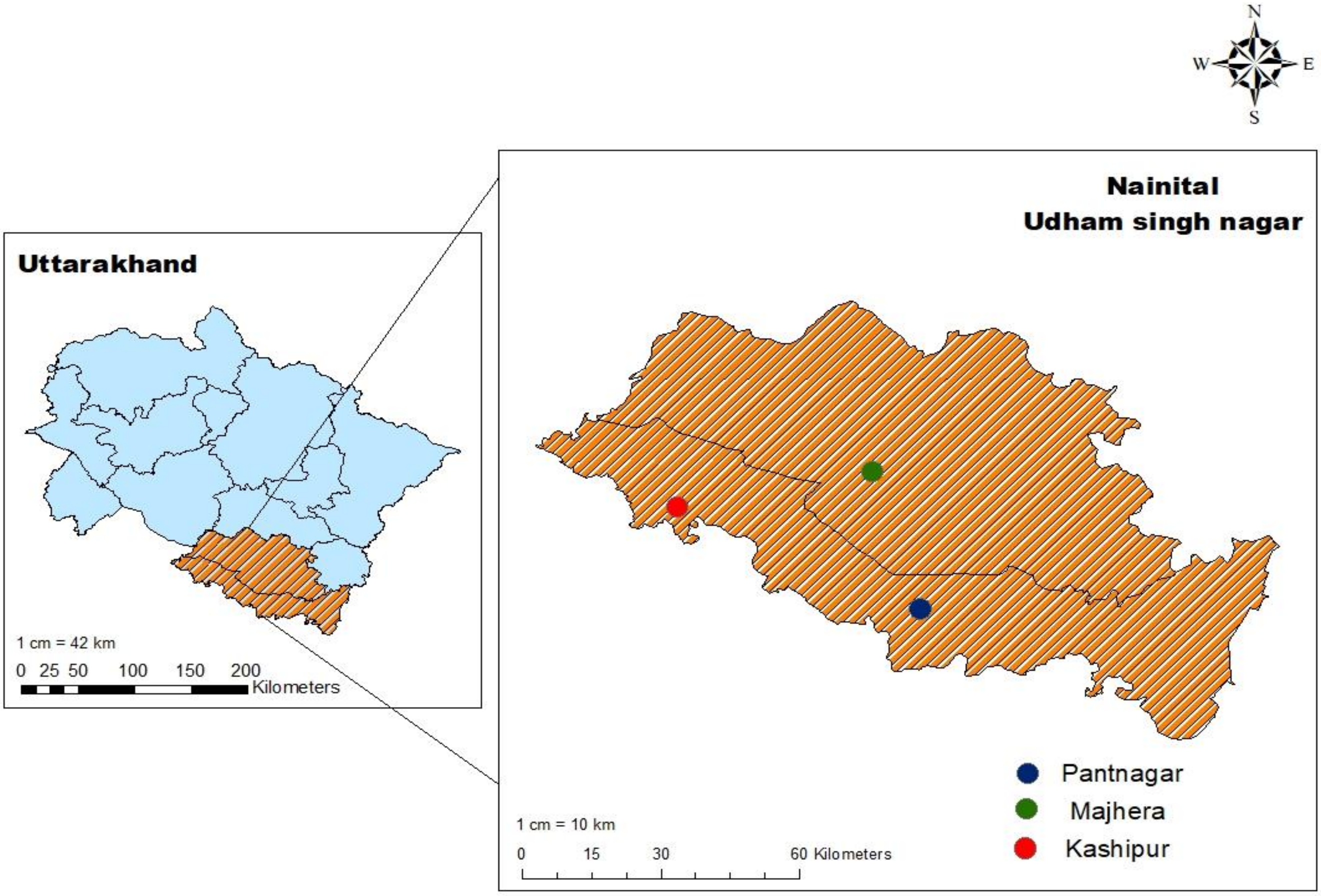


Figure 1. Map of Uttarakhand State of India showing the three growing environments. Blue dot for Pantnagar, Green Dot for Majhera and Red Dot for Kashipur.

RESULTS AND DISCUSSION

Analysis of Variance (ANOVA) of AMMI Model

The ANOVA revealed that for all the traits under study, the G x E interaction was found to be significant except for- number of tillers plant^{-1} and 1000-grain weight (Table 1). There's a clear-cut indication that the diverse growing conditions influence the rice grain yield to a large extent. The significance of main effects namely, environment and genotype and the significance of the interactive GxE effects shows that the genotypes and their traits are under the influence of both main as well as interactive effects. Due to non-significance of the interactive GxE effects the traits namely, number of tillers plant^{-1} and 1000-grain weight were not analysed further. In cereals, the significance of main effects (environment and genotype) as well as G x E interaction effects for yield and various yield contributing traits were reported by several researchers namely, Tarakanovas and coauthors 2006; Katsenios and coauthors 2021; Hilmarsson and coauthors 2021; Nhantumbo and coauthors 2021 [25-28], followed by genotypic effects indicating that the environments in which the genotypes were grown were highly diverse, also the genotypes under study were diverse and both the large differences between environmental means and genotypic means resulted in variation in the traits. But, the interactive GxE effects cannot be ignored at all as all the studied traits except number of tillers plant^{-1} and 1000-grain weight have significant interactive GxE effects. The effects by environment were large as compared to genotype for the traits like Plant height, Panicle length, Number of tiller plant^{-1}, Grains panicle^{-1} and Grain yield indicating that the environments under study were highly variable.

For a better understanding of the stability scenario the sum of squares due to Interactive GxE effects were further partitioned. The aforementioned interactive effects for all the traits were further divided into principal components namely, IPCA I and IPCA II. These two principal component axis uses all of the degrees of freedom available in the interaction and also the 100% of the sum of squares available in the interaction. Zobel and coauthors (1988) in their study emphasized that AMMI model partitioned into two principal component axis is the best predictive model for stability and henceforth in the present study similar approach was adopted [29]. The detailed discussion of ANOVA for different yield and yield attributing traits is presented in Table 1. In general, it is evident from the Table 1 that major portion of total sum of squares (TSS) was contributed by environmental main effects followed by genotypic effects indicating that the environments in which the genotypes were grown were highly diverse. However significant contribution of interactive G x E effects was also seen. In all the studied traits AMMI having two principal component axis (IPCA I and IPCA II) was found as best predictive model with IPCA I accounting for major portion of G x E sum of squares. As far as grain yield is concerned, a close perusal of the Table 1 also revealed that for grain yield (Kgh^{-1}) 37.61% of TSS was attributable to genotypic effects, 23.87% to Interactive G x E effects and 98.53% to environmental effect. The IPCA I accounted for 76.98% of the Interactive G x E effects while the IPCA II accounted for 23.02% of Interactive G x E effects. AMMI analysis was effectively used by several researchers for selecting stable and superior genotypes for a particular growing or environmental conditions [30-32].

Table 1. ANOVA of AMMI consisting of source of variations and the percent (%) contribution of each source.

Source of Variation	Degrees of Freedom	Days to 50% flowering		Plant Height		Number of Tillers per Plant		Panicle Length		Grains per Panicle		1000-grain weight (g)		Grain yield (Kg/h^{-1})	
		MSS	**Explained (%)**	**MSS**	**Explained (%)**	**MSS**	**Explained (%)**	**MSS**	**Explained (%)**	**MSS**	**Explained (%)**	**MSS**	**Explained (%)**	**MSS**	**Explained (%)**
Environment	2	443.25**	4.99	33310.97**	60.11	939.34	63.36	745.08**	61.48	140812.54**	47.07	6.67993	1.20	46616716.78**	38.53
Genotype	14	688.86**	54.28	2364.11**	29.86	46.20	21.82	44.56**	25.74	10205.93**	23.88	37.2662	46.79	6500623.81**	37.61
G x E	28	258.43**	40.73	397.03**	10.03	15.70	14.83	11.07**	12.79	6207.25**	29.05	20.7146	52.01	2062718.31**	23.87
PC 1	15	324.69**	67.31	629.76**	84.98	25.55	87.20	13.10**	63.38	8702.64**	75.11	24.11271	62.36	2963977.82**	76.98
PC 2	13	181.96**	32.69	128.48**	15.02	4.33	12.80	8.73**	36.62	3327.95**	24.89	16.7937	37.64	1022803.49**	23.02
Error	90	11.53	0.00	53.01	0.00	19.52	0.00	4.14	0.00	955.22	0.00	16.163	0.00	177910.08	0.00

[1]where, SS = Sum of Square; MSS = Mean Sum of Square, PC = Principle Component, **significant at 1%, *significant at 5% level

Table 2. IPCA I and IPCA II values of genotypes along with AMMI stability value (ASV) for different traits

Genotype	Days to 50% flowering				Plant Height				Panicle Length			
	IPCA1	IPCA2	ASV	RANK	IPCA1	IPCA2	ASV	RANK	IPCA1	IPCA2	ASV	RANK
IRRI 154	-0.05	-0.01	0.10	1	-0.27	0.34	1.59	12	0.03	-0.13	0.14	2
IR 78222-20-7-148-2-B-B-B-B	-0.08	0.21	0.28	3	-0.14	-0.11	0.82	8	0.39	-0.27	0.72	12
IR 69726-116-1-1	-0.11	0.20	0.31	6	0.04	-0.08	0.26	2	-0.29	0.13	0.51	9
IRRI 146	-1.00	0.57	2.14	15	-0.34	-0.14	1.93	14	0.23	-0.24	0.47	8
SWARNA	-0.75	-0.81	1.75	14	-0.08	0.08	0.45	3	-0.18	0.11	0.33	6
SADRI	-0.10	-0.21	0.30	5	0.00	0.10	0.10	1	0.32	-0.01	0.55	10
KHAO HLAN ON	0.38	0.48	0.92	13	0.11	-0.03	0.63	6	0.25	0.35	0.56	11
IR13L493	0.32	-0.28	0.72	11	-0.09	0.01	0.52	4	0.18	-0.01	0.32	5
IR6	0.34	-0.05	0.71	10	-0.16	-0.31	0.98	9	-0.19	-0.17	0.38	7
ZANTON::IRGC 52785-1	0.25	0.08	0.52	8	1.00	0.11	5.66	15	0.01	0.80	0.80	14
SAHEL 108	0.24	-0.06	0.50	7	-0.18	-0.03	1.04	10	0.14	0.07	0.25	3
SAHEL 177	0.12	0.11	0.27	2	0.13	-0.21	0.76	7	-0.18	-0.04	0.31	4
FEDEARROZ 50	0.26	0.03	0.54	9	0.09	-0.31	0.62	5	-0.02	0.14	0.14	1
CT11891-2-2-7-M	0.31	-0.37	0.75	12	0.19	0.21	1.07	11	0.31	-0.49	0.72	13
ORYZICA SABANA 10	-0.13	0.11	0.29	4	-0.29	0.37	1.70	13	-1.00	-0.24	1.75	15
Environment 1 Kashipur (*Kharif* 2021)	-1.00	-0.34	2.09	3	0.44	-0.58	2.57	1	-0.79	-0.61	1.50	2
Environment 2 Pantnagar (*Kharif* 2021)	0.14	0.89	0.94	1	0.56	0.54	3.20	2	-0.21	0.90	0.97	1
Environment 3 Majhera (*Kharif* 2021)	0.86	-0.55	1.85	2	-1.00	0.04	5.66	3	1.00	-0.29	1.76	3

Table 2 (Continued) IPCA I and IPCA II values of genotypes along with AMMI stability value (ASV) for different traits and Yield Stability Index (YSI) for Grain yield plant^{-1}

Genotype	Number of Grains Panicle^{-1}				Grain yield plant^{-1} (**Kg/h**)				
	IPCA1	IPCA2	ASV	RANK	IPCA1	IPCA2	ASV	RANK	YSI
IRRI 154	-0.27	-0.08	0.82	10	-0.11	-0.23	0.43	5	2
IR 78222-20-7-148-2-B-B-B-B	0.10	-0.09	0.32	3	-0.13	-0.10	0.43	6	5
IR 69726-116-1-1	0.39	0.04	1.19	13	0.31	-0.22	1.06	12	8
IRRI 146	0.03	0.38	0.39	4	0.58	-0.25	1.94	14	6
SWARNA	0.00	0.11	0.11	1	0.04	0.31	0.35	3	9
SADRI	0.32	0.29	1.02	12	0.49	-0.18	1.65	13	7
KHAO HLAN ON	0.12	0.21	0.42	5	0.26	-0.17	0.87	10	12
IR13L493	0.53	-0.22	1.62	14	-0.30	-0.08	1.02	11	13
IR6	0.13	-0.26	0.48	7	-1.00	-0.38	3.37	15	15
ZANTON::IRGC 52785-1	-0.27	0.05	0.82	9	-0.02	0.42	0.43	4	10
SAHEL 108	0.17	-0.24	0.56	8	0.01	-0.03	0.05	1	1
SAHEL 177	-1.00	-0.18	3.02	15	-0.24	0.16	0.83	9	14
FEDEARROZ 50	-0.02	-0.44	0.44	6	0.16	0.06	0.55	7	3
CT11891-2-2-7-M	0.01	-0.14	0.15	2	-0.13	0.61	0.76	8	11
ORYZICA SABANA 10	-0.25	0.57	0.94	11	0.08	0.06	0.26	2	4
Environment 1 Kashipur (*Kharif* 2021)	-1.00	-0.05	3.02	3	1.00	-0.17	3.35	3	
Environment 2 Pantnagar (*Kharif* 2021)	0.56	-0.63	1.80	2	-0.69	-0.56	2.38	2	
Environment 3 Majhera (*Kharif* 2021)	0.44	0.68	1.50	1	-0.31	0.72	1.25	1	

Stability analysis on basis of AMMI biplots and ASV values

Interactive GxE effects are analysed by rsearchers graphically with the help of AMMI biplots. The biplots hence obtained help in diagnosing, inspecting and interpreting the Interactive GxE effects, visually [33]. AMMI I and AMMI II are the two main types of AMMI biplots, where the former is obtained by plotting main effects namely, genotype and environment on the X-axis and then plotting the IPCA I score of them on the Y-axis. Similarly, when the genotypic and environmental IPCA I score is plotted against genotypic and environmental IPCA II score then AMMI II biplots are obtained [34]. Higher order of interactions and less stability is indicated when the IPCA 1 scores are large for a said genotype or environment irrespective of positive sign or negative sign of the value. But, IPCA I scores for genotypes which are nearer to zero indicates lesser interactions between the genotype and the environment, tagging it to be ‘stable’. In the case of AMMI II biplots, the genotypes that gets plotted near the intersection of the X-axis and Y-axis are considered more stable. On the other hand, the least stable genotypes are those that appear farther away from the origin (i.e., the intersection of the X-axis and Y-axis). Positive Interactive effects or high mean performance in a given environment is indicated when the genotypic and environmental IPCA I scores are having same sign (both positive and both negative). Similarly, if the genotypic and environmental IPCA I scores are having opposite sign (one positive and other negative or vice-versa) then it indicates that the genotypes had a low mean performance in that given environment due to negative interactive effects. Purchase and coauthors 2000 in their study ranked different genotypes for yield stability on the basis of AMMI stability values (ASV), where a genotype in question having minimum ASV value is most ‘stable’ and vice-versa [23]. Another technique known as Yield stability index was used to identify high yielding and stable genotypes. The genotype with lowest YSI is considered to be most stable with high grain yield [24].

In case of Days to 50% flowering on basis of low IPCA I score, near to origin position of genotypes on AMMI II biplot and least ASV value, genotype IRRI 154 (IPCA I, -0.05; ASV, 0.10) was ranked as best in terms of stability, while genotype SAHEL 177 (IPCA I, 0.12; ASV, 0.27) ranked second for Days to 50% flowering (Table 2; Figure 2 a1 & a2). Considering the IPCA-I score and the mean values- Sahel 177 (mean 92.22 days) is identified as most desirable genotypes as it took less days than average mean for Days to 50% flowering as compared to general mean (mean 98.97 days) along with second ASV rank indicating the stability of the genotype Sahel 177. Environment-1(Kashipur, *Kharif*-2021) reported negative IPCA I score while environment 2 (Pantnagar, *Kharif*-2021) & 3 (Majhera, *Kharif*-2021) reported positive IPCA I scores (Table 2). Among the genotypes, Sahel 177 and in case of environments, the environment 2 (Pantnagar, *Kharif*-2021) reported positive IPCA I scores along with low average mean for days to 50% flowering. Hence environment 2 (Pantnagar, *Kharif*-2021) can be considered as favorable environment for the genotype SAHEL 177.

For Plant height, genotype SADRI (IPCA I, 0.00; ASV, 0.10) ranked as most stable while IR 69726-116-1-1 (IPCA I,0.04; ASV, 0.26) ranked as second most stable genotype. If the mean values along with the IPCA I score is also considered then the genotypes – SADRI (mean 95.41 cm) is identified as most desirable genotypes as its mean for plant height is lower than the general genotypic mean (101.28) along with least IPCA I score. Environment-3 (Majhera, *Kharif*-2021) reported negative IPCA I score while environment-1(Kashipur, *Kharif*-2021) & 2(Pantnagar, *Kharif*-2021) reported positive IPCA I scores (Table 2; Figure 2 b1 & b2). Among the genotypes, both SADRI and IR 69726-116-1-1 reported positive IPCA-I scores along with low average mean for Plant Height indicating the suitability of the genotypes in those particular environments.

For Panicle length, genotype FEDEARROZ 50 (IPCA I,-0.02; ASV, 0.14) ranked first in terms of stability while genotype IRRI 154 (IPCA I, 0.03; ASV, 0.14) ranked second and SAHEL 108 (IPCA I, 0.14; ASV, 0.25) ranked third (Table 2; Figure 2 c1 & c2). If mean values along with the IPCA I score is also considered, the genotypes FEDEARROZ 50 (mean 26.61) is identified as most desirable genotypes as its mean for panicle length is higher than the general mean (25.01) along with smaller IPCA-I score. Environment-3 (Majhera, *Kharif*-2021) reported positive IPCA-I score while environment-1(Kashipur, *Kharif*-2021) & 2(Pantnagar, *Kharif*-2021) reported negative IPCA-I scores (Table 2). Among the genotypes, FEDEARROZ 50 reported negative IPCA-I scores along with high average mean for panicle length.

With regard to Number of grains panicle^{-1}, the genotypes SWARNA (IPCA I, 0.00; ASV, 0.11) ranked first in terms of stability while CT11891-2-2-7-M (IPCA I, 0.01; ASV, 0.15) ranked as second most stable genotype (Table 2; Figure 2 d1 & d2). CT11891-2-2-7-M (mean 222.56) was identified as most desirable genotypes as Number of grains panicle^{-1} in CT11891-2-2-7-M was higher than the general mean (155.85) along with small IPCA I score. Among different environments, the IPCA-I score was minimum for Environment-3 (Majhera, *Kharif*-2021). The IPCA-I score for Environment-3 (Majhera, *Kharif*-2021) was 0.44 and thus it was considered as most stable environments for genotypes. Environment-1 (Kashipur, *Kharif*-2021) is the most unstable environment as the IPCA-I value for it was -1.00. Higher mean performance by a genotype in a given environment is indicated by IPCA-I score of a given genotype and the given environment possessing same sign (Positive interaction effects). Signs being opposite indicates towards negative interactions and results in lower mean performance in that given environment. The positive IPCA-I scores were reported for the genotypes- IR 78222-20-7-148-2-B-B-B-B (0.10), IR 69726-116-1-1 (0.39), IRRI 146 (0.03), SWARNA (0.00), SADRI (0.32), KHAO HLAN ON (0.12), IR13L493 (0.53), IR6 (0.13), SAHEL 108 (0.17) and CT11891-2-2-7-M (0.01) while the negative IPCA-I score was reported for the genotypes- IRRI 154 (-0.27), ZANTON::IRGC 52785-1 (-0.27), SAHEL 177 (-1.00), FEDEARROZ 50 (-0.02) and ORYZICA SABANA 10 (-0.25). Environment-3 (Majhera, *Kharif*-2021) and Environment- 2(Pantnagar, *Kharif*-2021) reported positive IPCA-I score while environment-1(Kashipur, *Kharif*-2021) reported negative IPCA-I scores (Table 2). Among the genotypes, CT11891-2-2-7-M reported positive IPCA-I scores along with high average mean for number of grains panicle^{-1}. If the growing environmental conditions are diverse, then it is of great significance in identifying a stable genotypes for that crop. It is well-established in many studies that environments have direct correlation with the selection of genotypes having maximum yield in a particular environment g 0,4 [35].

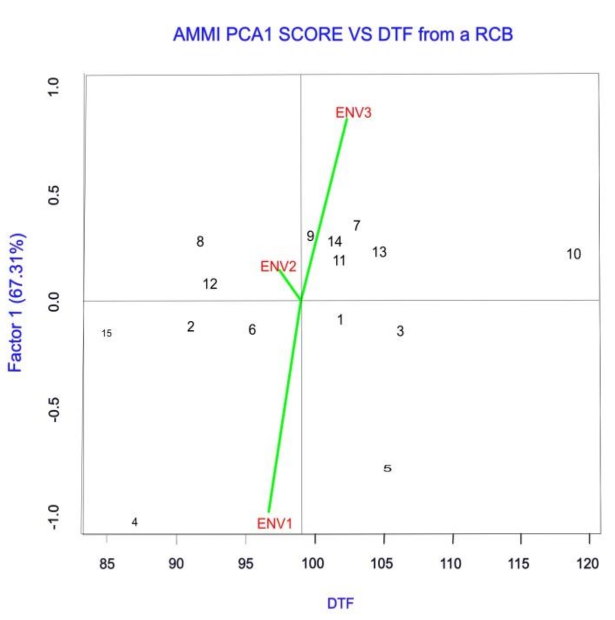
For Grain yield plant^{-1}, genotype SAHEL 108 (IPCA I, 0.01; ASV, 0.05) was identified as most stable genotype (Table 2; Figure 2 e1 & e2). Considering the mean values along with the IPCA I score, genotype SAHEL 108 (3395.67 Kgh^{-1}) was marked as most desirable genotypes as its mean for Grain yield plant^{-1} was high than the general mean 2667.34 Kgh^{-1} along with top most ASV rank. The genotypes *viz*., SAHEL 108 and FEDEARROZ 50 and the Environment 1 Kashipur had high mean for Grain yield plant^{-1}along with positive IPCA I score (Table 2). Hence environment 1 is identified as favourable for the genotypes, SAHEL 108 and FEDEARROZ 50. Stability of the genotypes are only indicated by the AMMI Stability Values but such stable genotypes may or may not possess high mean yield. Henceforth, the analysis of yield stability index (YSI) suggested that the genotype SAHEL 108 has the Minimum YSI score of 1 and hence this genotype had the high and stable seed yield across the studied environments (Table 2). The environment E II was found as somewhat stable and high yielding environments for Grain yield plant^{-1}. Although the Environment 3 Majhera Was the most stable environment for the present study but the mean yield on that environment was found to be very less when compared with the other two growing environments. On the basis of AMMI biplot I & II, ASV (AMMI Stability Value), and Yield Stability Index (YSI) scores, the genotype SAHEL 108 was identified as most stable and high yielding genotype for Grain yield plant^{-1} across three studied environments. SAHEL 108 also ranked 3rd for panicle length in terms of stability. In all the studied traits, AMMI having two principle components axis (IPCA I & IPCA II) is found as the best predictive model and AMMI biplot I & II were constructed by using these two scores. These two principal component axis contributes 100 per cent of the G x E interaction sum of squares and used entire degrees of freedom available in the interaction. On the basis of biplots and ASV score SAHEL 177 for days to 50% flowering, SADRI for plant height; FEDEARROZ 50 for panicle length; CT11891-2-2-7-M for number of grains panicle^{-1} and SAHEL 108 for grain yield were considered as most stable genotypes in all the consecutive three locations/ environments (Table 3).

Table 3. List of most superior and desirable genotypes identified for different traits based on IPCA scores, ASV rankings and mean values.

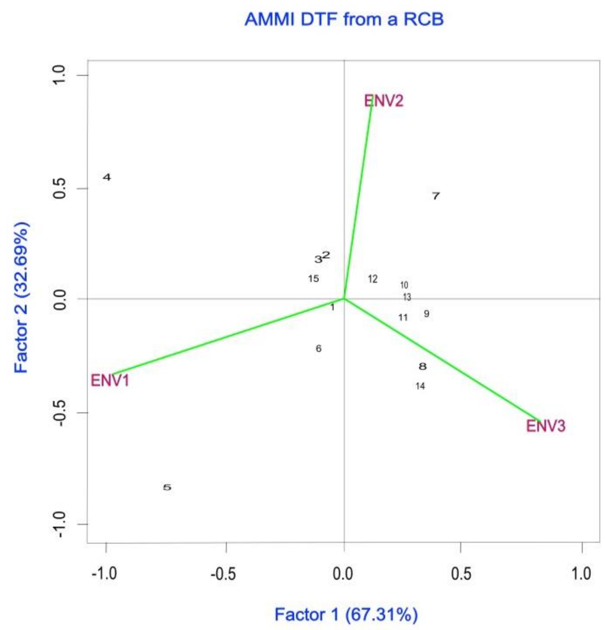
Character	Genotype	Mean	General mean	IPCA 1 score	ASV Value	ASV Rank
DTF	SAHEL 177	92.22	98.97	0.12	0.27	2
PH	SADRI	95.41	101.28	0.00	0.10	1
PL	FEDEARROZ 50	26.61	25.01	-0.02	0.14	1
GPP	CT11891-2-2-7-M	222.56	155.85	0.01	0.15	2
Yield	SAHEL 108	3395.67	2667.34	0.01	0.05	1

CONCLUSION

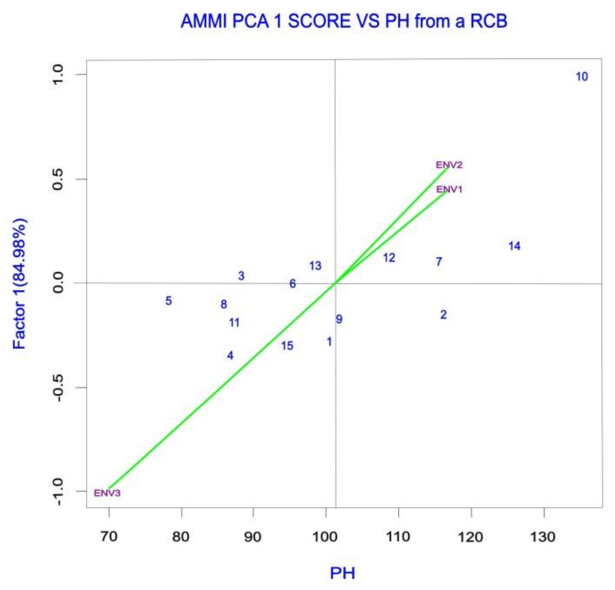
Thus in this study it was found that by employing AMMI-based multivariate stability model and finally, employing YSI, the genotype Sahel 108 was found to be the most stable and desirable genotype. Such an integrated Index approach selection will help also choose a variety that can be specifically adapted to the environmental conditions of the Indo-Gangetic Plains and can help breeders in ensuring sustainable rice production in near future.



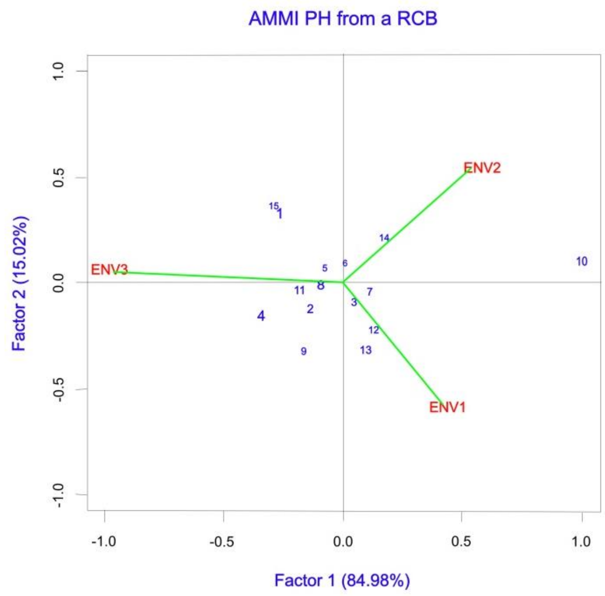
(a1) AMMI-I biplot for Days to 50% flowering



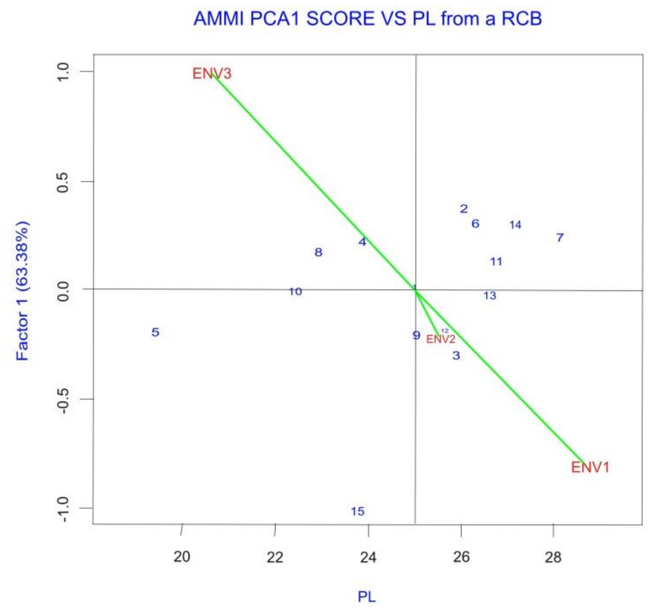
(a2) AMMI-II biplot for Days to 50% flowering



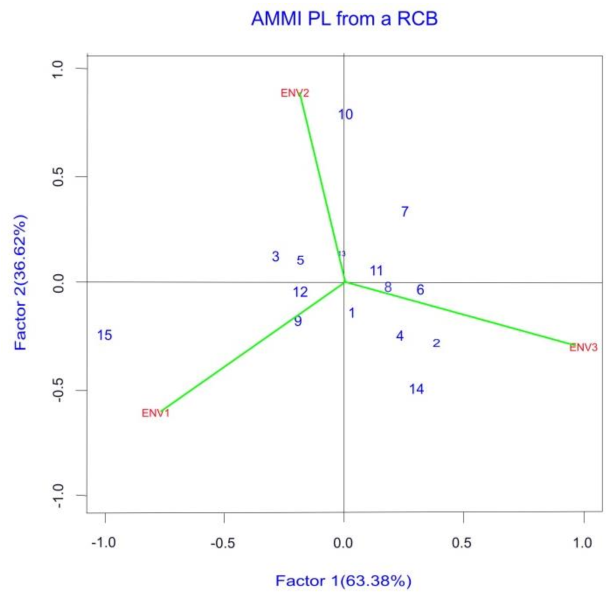
(b1) AMMI-I biplot for Plant Height



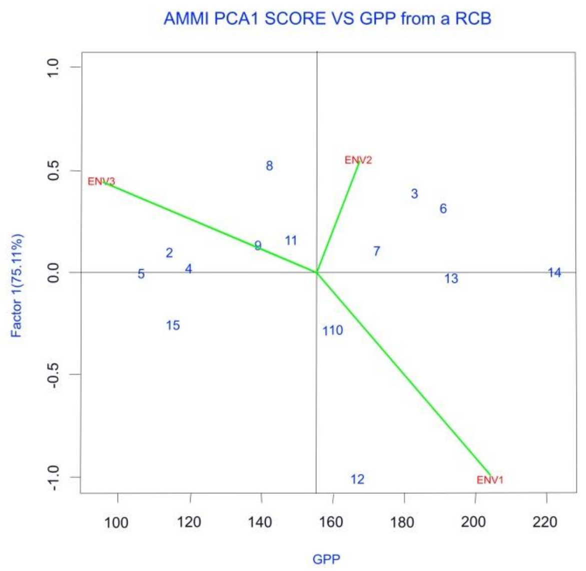
(b2) AMMI-II biplot for Plant Height



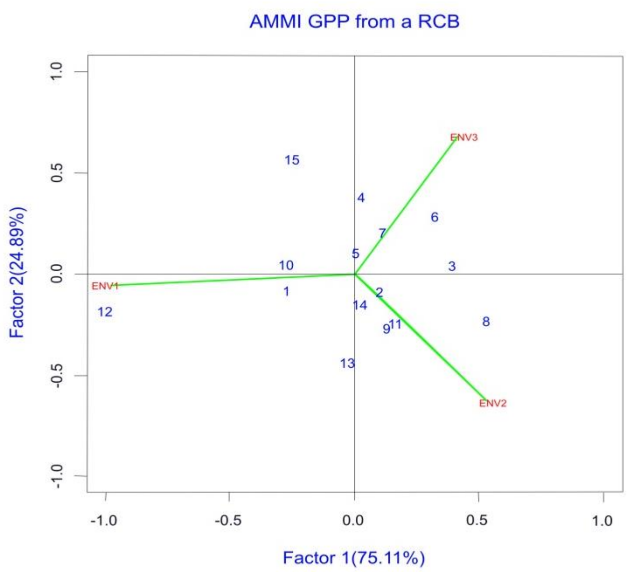
(c1) AMMI-I biplot for Panicle Length



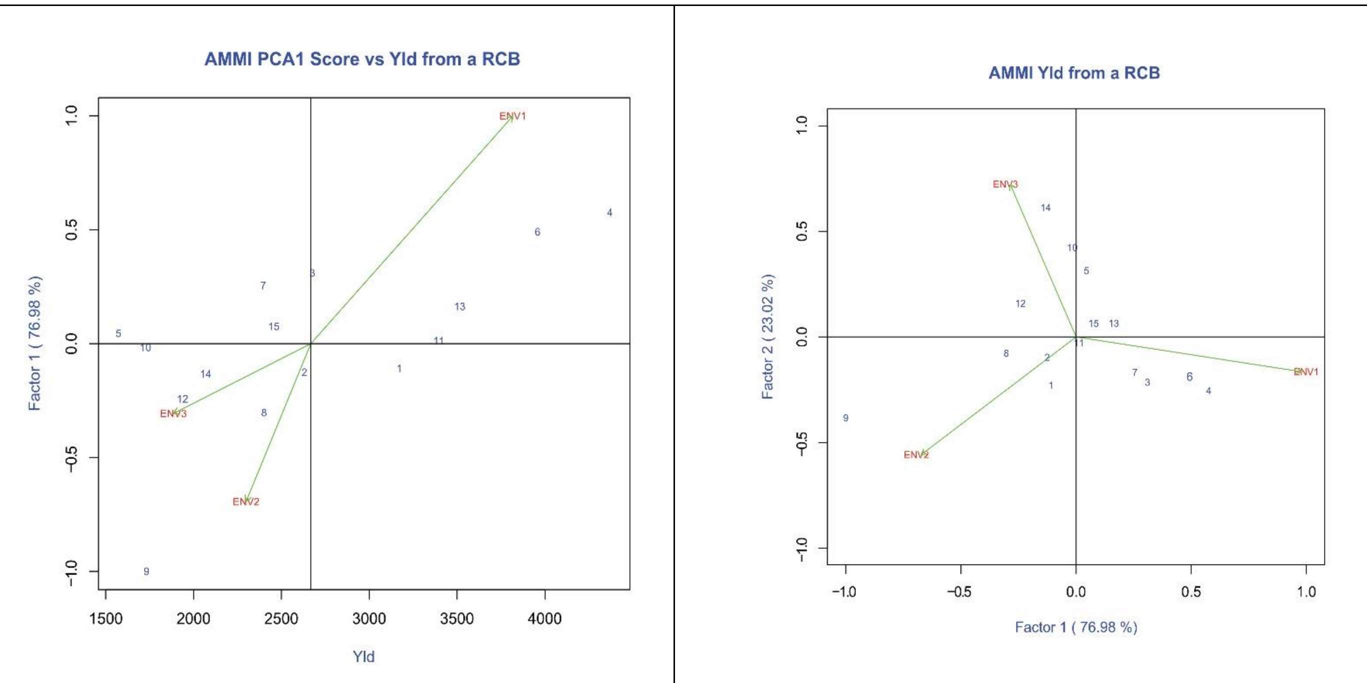
(c2) AMMI-II biplot for Panicle Length



(d1) AMMI-I biplot for Grains Per Panicle



(d2) AMMI-II biplot for Grains Per Panicle



(e1) AMMI-I biplot for Grain Yield **e2) AMMI-II biplot for Grain Yield**

Figure 2. AMMI-I and AMMI-II biplots for a1 & a2 for Days to 50% flowering (DTF), b1 & b2 for Plant Height (PH), c1 & c2 for Panicle Length (PL), d1 & d2 for Grains per Panicle (GPP) and e1 & e2 for Grain Yield, respectively. Numbers plotted in the biplots indicates the genotypes namely, IRRI 154 (1), IR 78222-20-7-148-2-B-B-B-B (2), IR 69726-116-1-1 (3), IRRI 146 (4), SWARNA (5), SADRI (6), KHAO HLAN ON (7), IR13L493 (8), IR6 (9), ZANTON::IRGC 52785-1 (10), SAHEL 108 (11), SAHEL 177 (12), FEDEARROZ 50 (13), CT11891-2-2-7-M (14) and ORYZICA SABANA 10 (15).

Table 4. Mean values for temperature and rainfall at all the three experimental sites during June-November, 2021.

Locations	June		July		August		September		October		November	
	Temp(ºC)	Rain (mm)	Temp(ºC)	Rain (mm)	Temp(ºC)	Rain (mm)	Temp(ºC)	Rain (mm)	Temp(ºC)	Rain (mm)	Temp(ºC)	Rain (mm)
Kashipur	31.1	257	29.2	233.7	32.2	313.7	28.9	308.8	25.1	6.2	25	0
Pantnagar	35.7	85.8	36.4	236	33.7	303.5	31	36.6	29	427.5	26	00
Majhera	22	274.2	21	190	22	118.7	20	57.1	18	461.7	16	30

[1] This table is placed at the end as weather data is supplementary in this research.

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