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SHORT RESEARCH ARTICLE

Stability analysis of popular short grain aromatic rice for yield component traits in Gangetic alluvial zone of India (*Oryza sativa* L.)

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Abstract

The present study aimed at investigating genotype × environment interaction and stability performance for yield component traits of sixteen aromatic rice genotypes over six *kharif* seasons to find agronomically stable genotypes. The analysis of variance for yield component traits revealed highly significant ($p < 0.01$) variation among genotypes, environments and their interactions for yield traits. Based on univariate analysis of *YSi* and Eberhert and Russel model for grain yield genotypes, Kalabati (G5), Dudheswar (G1), Mohan Bhog (G6), Krishna Bhog (G7), Dehradun Gandeswary (G8), Ramachandra Bhog (G9), Katharibhog (G11) and Tulaipanji (G13) exhibited high mean as compare to population mean. The highest ranked and *YSi* score genotypes G11 and G5, were found best for the yield component traits. Based on the AMMI biplot technique, the genotypes G13, G2 (Lal Badsha Bhog), and G7 were most appropriate in the entire environment (season), while the GGE biplot indicated that G5 was the most suitable for grain yield.

Keywords: Rice, aromatic, AMMI analysis. G x E interaction, stability

Aromatic rice is a special class of rice produced all over the country and has a huge market demand due to its pleasant fragrance and good cooking qualities. The aroma in rice is due to the presence of large chemical compounds in endosperm but primarily 2-acetyl-1-pyrroline (2-AP) is the main source of fragrance (Poonlaphdecha et al. 2016) and its controlled by both genetic and environmental factors. In the Indian subcontinent, aromatic rice is grouped into two categories with long grained basmati type (L/B ratio >3 mm), and small and medium-grained (L/B ratio <3 mm) non- Basmati type. India had exported 17.78 million tonnes of non-Basmati rice to the world for a worth valued at $6.35 billion during 2022-23 (APEDA 2023). West Bengal signifies a hotspot of short grain aromatic rice and three popular cultivars, Tulaipanji, Gobindabhog and Kalonunia of this state have already been granted for geographical indication (GI) tagged in India.

Plant breeders select stable genotypes for their breeding programs based on genotype × environment interactions. Stability analysis of yield traits for different environment can be evaluated in both univariate and multivariate (AMMI and GGE analysis) statistics approaches helps to recognize the genetic components that confer wide or specific. Realizing the importance of aromatic rice, the present study was carried out to evaluate sixteen promising aromatic rice (non-

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Table 1. Description of the aromatic rice genotypes used for the study

Genotype code	Name of Genotypes	Description of the genotypes	Native place of growing
G1	Dudheswar	Strong aroma, fine, small grain, photo-period sensitive, long duration, tall, short bold grain, good eating quality, protein (5.87%), amylose content (13.27%), starch (79.44%), glycemic index (63.66%) (Mondal et al. 2021).	Northern part of West Bengal
G2	LalBadsha Bhog	Strong aroma, small grain, fine rice, short bold, greyed-yellow kernels, awnless, protein (6.8%) (Pandey et al. 2013).	Malda, West Bengal
G3	Tulsi Mukul	Mild aroma, photo-period sensitive, long duration, tall, medium slender grain, awnless, chocolate brown hull, light colour culm.	Northern part of West Bengal
G4	Gopal Bhog	Strong aroma, small grain, fine rice, greyed-yellow kernels, white colour grain, tall statured, long duration, photo-period sensitive, awnless.	Nadia, West Bengal
G5	Kalabati	Strong aroma, bold scented, tall statured, used as parboiled rice, anthocyanin colouration on leaf blade, sheath, nodes and internodes, purple culm, black to purple kernels.	Nadia, West Bengal
G6	Mohan Bhog	Strong aroma, small grain, fine rice, greyed-yellow kernels, white colour grain, photo-period sensitive, awnless.	Nadia, West Bengal
G7	Krishna Bhog	Strong aroma, small grain, fine rice, greyed-yellow kernels, white colour grain, photo-period sensitive, awnless.	Nadia, West Bengal
G8	Dehradun Gandeswary	Strong aroma, small grain and white colour, fine rice, short-slender, greyed-yellow kernels, photo-period sensitive, awnless.	Nadia, West Bengal
G9	Ramachandra Bhog	Strong aroma, small grain, fine rice, photo-period sensitive, awnless, short-bold grain, brownish yellow hull, light colour culm.	Nadia, West Bengal.
G10	Malsira	Mild aroma, small grain, tall statured, photo-period sensitive, awnless, short-bold grain.	Northern part of West Bengal
G11	Katharibhog	Moderate aroma, medium slender, photo-period sensitive, long duration, tall statured, slender grain, protein (6.43%), amylose content (20.43%), starch (54.57%), glycemic index (45.72%) (Mondal et al. 2021).	DakshinDinajpur, West Bengal
G12	Kalolunia	Strongly aroma, awnless, Brown kernels, protein rich, photo-period sensitive, long duration, tall, lodging susceptible, medium slender grain, protein (6.2%), amylose content (21.60%) (Pandey et al. 2013), starch (72.49%), glycemic index (66.85%) (Mondal et al. 2021), GI registered in 2023.	Northern part of West Bengal
G13	Tulaipanji	Very strongly aroma, soft kernel, digestive, photo-period sensitive, long awn, lodging susceptible, late maturity (140–150 days) and tall statured with no anthocyanin colouration, kernels medium slender and white in colour, protein (6.1%), amylose content (20.50%) (Pandey et al. 2013), starch (68.99%), glycemic index (67.38%) (Mondal et al. 2021), GI registered in 2017.	Uttar Dinajpur and Dakshin Dinajpur, West Bengal
G14	Gobindabhog	Very strongly aroma, soft kernel, white non-Basmati type, buttery, short- grain rice, long duration, photo-period sensitive,short bold, protein (7.2%), amylose content (22.50%)(Pandey et al. 2013), starch (73.39%), glycemic index (66.14%), (Mondal et al. 2021), GI registered in 2017.	Nadia, West Bengal
G15	Radhunipagal	Mild aroma, greyed-yellow kernels,awnless,photo-period sensitive, long duration, tall statured, lodging susceptible, leaf anthocyanin colour distribution on tips of leaf, short-slender grain, zinc (23.74 ppm), iron (2.91 ppm), protein content (6.57%), amylose content (16.39%) (Akhtar et al. 2022).	Nadia, West Bengal
G16	Chinikamini	Strong aroma, small grain, fine rice, greyed-yellow kernels, awnless, very sweet taste, used as whole grain, tall statured, long duration, photo-period sensitive.	Nadia, West Bengal

basmati) genotypes for yield stability analysis in Gangetic plain Old Alluvial Region of West Bengal, India (latitude 25°19′ N and longitude 88° 46′ E).

For stability analysis, sixteen short-grain aromatic rice germplasm (Table 1) were evaluated during six *kharif* seasons (2016-2021). About 25-day-old seedlings of each genotype were transplanted in the main field and sown in a plot size of 4 m^2 with a 20 x 20 cm spacing. The experiments were carried

Table 2. Selection of genotypes according to Eberhert and Russell stability parameter for yield component traits across six environments(seasons)

Stability parameters	FF	PH	PNPP	PL	NGP	SYPP	TW	LBR	GY
Above average mean	G5, G2, G10, G1, G3, G4 (lower than average mean)	G5, G3, G7, G9, G2, G1, G15, G6	G4, G8, G12, G14	G14, G7, G3, G6, G4, G5, G11, G13, G15	G3, G6, G8, G9,	G5, G4, G11, G8, G13	G5, G10, G7, G14, G13, G9	G13, G12, G11, G5, G2, G1	G5, G8, G11, G1, G10
High mean bi = 1 S^2di = 0 or minimum	Gopal Bhog (G4)	Mohan Bhog (G6)	Dud heswar (G1), Lal Badsha Bhog (G2)	Tulsi Mukul (G3)	Tulsi Mukul (G3)	Tulaipanji (G13), Dehradun Gandeswary (G8)	Kalabati (G5)	Tulaipanji (G13), Mohan Bhog (G6), Lal Badsha Bhog (G2),	Kalabati (G5), Kathari bhog (G11), Ramachandra Bhog (G9)

FF = 50% flowering, PH = plant height (cm), TPP = tiller plant^{-1}, PNPP = panicle number plant^{-1}, PL= panicle length (cm), NGP = number of grain plant^{-1}, TW = test weight (gm), LBR = Length/breadth ratio, GY = grain yield (t hac^{-1}); *bi* = Regression coefficient; S^2_{di}= Deviation from regression; *Low mean is desirable for days to 50% flowering

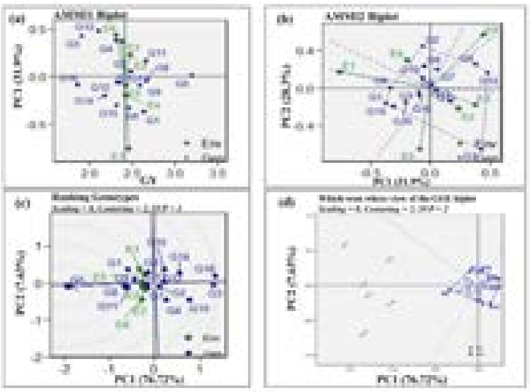

Fig. 1. AMMI and GGE biplot for grain yield (GY); a) AMMI 1 biplot for the primary component of interaction (PC1) and mean of grain yield of rice genotypes across environment; b) AMMI2 biplot for grain yield reflects interaction of IPCA2 against IPCA1 scores across six environment; c) Ranking genotypes for grain yield performance of test genotypes in comparison to an estimated average environment and ideal genotype and d) Polygon views of the GGE biplot based on symmetrical scaling for 'which-won-where' pattern of rice genotypes of GY

out in a randomized complete block design with three replications. The combined analysis of variance for yield component traits were measured at genotype, environment and G × E interaction across the environments/seasons. The univariate stability analysis for yield component traits for all six seasons were estimated following yield-stability (*YSi*) statistic (Kang 1993) and regression coefficient over environment according procedure of Eberhart and Russell (1966) model. The multivariate stability analysis for grain yield was assessed using AMMI analysis (Yan et al. 2007).

Combine analysis and univariate stability of yield component traits of aromatic rice

Pooled analysis of variance of six environmental (seasons) data showed significant genotypic and genotype × environment interactions (p > 0.05) for all the yield component traits (Supplementary Table S1). A significant G x E interaction for yield component traits of rice cultivars were detected earlier (Hashim et al. 2021). Based on a combined analysis of yield and stability using the *YSi* statistic, it was observed that G5 was the most stable genotype in the selection ranks for GY, followed by G11, G8, G9, and G1, respectively (Supplementary Table S2). Using *YSi* scoring, eight genotypes were determined to be better for GY, DF, and PH; seven for PNPP, PL, TW, and LBR; nine for NGP, and five for SYP, based on high trait mean and stability, respectively.

According to the Eberhert and Russell (1966) model, the genotypes exhibited a higher mean value than the overall mean, with the regression coefficient approximating unity (bi = 1) (P < 0.01) and a non-significant deviation from regression (S^2di = 0), regarded as "average stability" across a wide range of environment. Therefore, in this study, the most stable genotype was considered as G4 for FF; G6 for PH; G1 and G2 for PNPP; G3 for PL; G3 for NGP; G13, G8 for SYPP; G5 for TW; G13, G6 and G2 for LBR; G5, G11 and G9 for GY, respectively (Table 2).

AMMI and GGE biplot analysis

Biplot abscissa and ordinate showed the grain yield main effect and the first principal component (PC1) in AMMI1 (Fig. 1a). The presence of GEI was clearly demonstrated by the AMMI2 biplot model, when the partitioning of the first two principal component interaction account for 60.2% of the genotype and genotype by environment variation for GY (Fig. 1b). Based on the AMMI biplot technique, G13, G2 and G7 were found suitable for grain yield and general adaptation to all the environments. The low contribution of environments and considerable G × E interaction for grain yield were noted through AMMI analysis, allowing for the genotype selection for a given location/environment (Dwivedi et al. 2020). According to the GGE biplot-polygon view graph for GY (Fig. 1c), close to the "ideal genotype," G5 was the most suitable genotype in the entire environment (season). On the other hand, the poor-performing genotypes G3, G16 and G10 for GY were treated as abominable because they are located distantly from the Ideal genotype. For GY, it explains the suitability to select the top-performing aromatic rice genotypes G5 (vertex genotype), G9, G13, G8 and G11 in six mega-environments or genotype specific adaptation (Fig. 1d). The mega-environments stability for grain yield also reported previously in rice (Hashim et al. 2021).

In this study, ideal genotypes were chosen using univariate and multivariate stability analyses for agronomic parameters, with a focus on improving aromatic rice production. According to a yield stability statistics study, G11 (Kathari Bhog) performed the best steadily for PNPP, PL, SYP, NGP, LBR, and GY. AMMI and GGE biplots found that G5 (Kalabati) was the most stable genotype for GY throughout the seasons. The yield component traits of the study's winning genotypes (G11, G5, and G7) required additional testing in multilocation trials. Additionally, Tulaipanji (G13), Kataribhog (G11), and Kalonunia (G12) were extensively cultivated and found to have stable genotypes that consumers highly valued as preferred for good fragrances; nevertheless, the average yield was low, making them peculiar to a specific location. These genotypes could be beneficial for donor parents to improve other cultivars as well as for direct cultivation.

Supplementary material

Supplimentary Tables 1 and 2 are provided, www.isgpb.org

Authors' contribution

Conceptualization of research (BD, RB, JK); Designing of the experiments (SM, PM); Execution of field/lab experiments and data collection (PP, SM, AB); Analysis of data and interpretation (BD, AD, DK); Preparation of the manuscript (BD, DK,BP).

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Supplementary Table S1. Combined analysis of variance (ANOVA) of yield-component traits and grain yield of aromatic rice

Source	DF	FF		PH		PNPP		PL		NGP		SYPP		TW		LBR		GY	
		MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)	MS	ESS (%)
E	5	60.77	2.66	70.70	0.68	6.40	0.96	7.73	1.85	209.2	0.38	142.72	2.21	22.75	2.22	0.045	0.58	0.158	1.68
Rep (E)	12	8.20	0.86	7.54	0.17	7.17	2.60	0.39	0.23	20.3	0.09	5.31	0.20	1.81	0.42	0.006	0.18	0.042	1.08
G	15	604.0**	79.33	3234.95**	93.03	153.74**	69.59	99.09**	71.35	15498.3**	83.50	1944.16**	90.42	224.10**	65.59	2.30**	90.37	1.88**	60.07
GEI	75	15.13**	9.93	26.25**	3.78	6.15**	13.92	6.21**	22.34	504.8	13.60	13.58**	3.16	18.30**	26.78	0.019	3.67	0.125*	19.89
Residuals	180	4.58	7.22	6.79	2.34	2.38	12.93	0.49	4.22	37.7**	2.44	7.19	4.01	1.42	4.99	0.011	5.20	0.045	17.27
Min		105.6		137.93		11.28		19.47		117.17		23.39		10.88		2.14		1.859	
Max		123		175.27		21.06		26.87		220		51.04		23.69		3.41		3.199	
OV mean		115.95		157.38		14.50		23.39		163.46		32.92		15.73		2.62		2.41	
CV (%)		1.845		1.66		10.64		2.99		3.76		8.15		7.58		4.02		8.84	
P value (Shapiro -Wilk)		0.087		0.057		0.061		0.332		0.473		0.062		0.076		0.247		0.505	

FF= 50% flowering, PH= plant height (cm), TPP = tiller plant^{-1}, PNPP= panicle number plant^{-1}, PL= panicle length (cm), NGP= number of grain plant^{-1}, TW= test weight (gm), LBR= Length/breadth ratio, GY= grain yield (t hac^{-1}); E= environment; Rep= replication; G= genotype; GEI= Genotype × environment interaction; DF= degrees of freedom, MS= mean square, CV= Coefficient of Variation (%),OVmean=Overall mean,ESS (%)= proportion of explained sum of squares, *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

Supplementary Table S2. *YSi* ranking of each genotype based on trait meansand significance

GEN	FF	PH	PNPP	PL	NGP	SYPP	TW	LBR	GY	Rank sum	YSiSum
G1	-6	6+	1	0	5+	-7	-5	12+	13+	67	19
G2	-10	7+	14+	2	4+	-2	-9	14+	7	62	27
G3	-7	10+	-4	17+	10+	-1	-2	-2	-9	65	12
G4	-4	-7	11+	15+	-5	8+	0	7	2	79	27
G5	-9	11+	-4	4	-6	11+	11+	16+	19+	100	53
G6	14+	4+	0	8+	11+	-6	-1	0	10+	83	40
G7	8+	9+	-6	10+	-9	-3	8+	8	11+	89	36
G8	3+	-5	10+	-10	9+	9+	-4	4	15+	87	31
G9	11+	8+	-3	-9	8+	-4	7+	1	14+	87	33
G10	-8	-10	1	1	-8	-5	10+	6	-3	52	-16
G11	1	-8	5+	13+	6+	10+	0	17+	16+	91	60
G12	9+	-3	9+	-5	-7	0	5+	18+	5	89	31
G13	-2	-4	8+	1	-10	7+	12+	19+	12+	85	43
G14	7+	-9	3+	11+	7+	-2	14+	1	2	79	34
G15	5+	5+	-2	12+	2+	-1	-7	9+	6	63	29
G16	10+	-6	-9	-4	-4	0	-8	-1	-2	45	-24
Ysi Mean	1.37	0.57	2.12	4.12	0.812	0.875	1.93	8.06	7.37		

Adjustment of +1 for mean yield ≥ overall mean yield (OMY), +2 for mean yield ≥ 1LSD above OMY, +3 for mean yield ≥ 2LSD above OMY, 1 for mean yield ≤ OMY, 2 for mean yield ≤ 1LSD below OMY, and 3 for mean yield ≤ 2LSD below OMY. *$P < 0.05$, **$P < 0.01$.Stability ratings were computed as follows: −8, −4, and −2 for stability measures significant at $P < 0.01$, 0.05, and 0.10, respectively; and 0 for the non-significant stability measure. + selected genotype