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Stability analysis for grain yield and quality traits in selected traditional and improved varieties of rice over different Zones of Karnataka

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ABSTRACT

Traditional rice varieties (TRVs) form important components of genetic reservoir. TRVs used in study viz., Rajamudi, Ratnachoodi and Jeerigesanna are photosensitive. They may exhibit Genotype by Environment (G×E) interactions for grain yield and quality traits. Hence, present experiment was conducted to understand responses of yield and quality traits in selected traditional along with improved varieties of rice over five different locations of Karnataka using additive main effects and multiplicative interaction (AMMI) model and bi-plots were developed following GGE bi-plot methodology. AMMI analysis revealed that there existed significant GE interaction among ten rice varieties and genotypes and environments were diverse in nature. IPCA1 and IPCA2 together explained more than 75% of GE interaction for yield and quality traits and maximum GE interaction was explained by IPCA (Interaction Principle Component Analysis) 1. BR-2655 and Ratnachoodi were found to be most stable varieties and Mugadsiri was found to be most unstable variety for grain yield. Jeerigesanna and BPT-5204 were stable for gel consistency and amylose content respectively. Among rice varieties used, BR-2655 was found to be the best variety since it recorded highest grain yield and also it was stable performer for grain yield and also amylose content across five different locations.

Key words: *Rice, stability analysis, AMMI model, GGE bi-plot, grain yield, grain quality*

INTRODUCTION

Rice (*Oryza sativa* L., 2n=24) belonging to the family Gramienae, is the world's most important food crop and a primary food source for more than one third of world's population. Traditional Rice varieties (TRVs) are valuable genetic reservoirs as they harbor time tested traits. Hence, TRVs are given more importance by farmers because of their better grain quality. Each TRV show adaptation to specific ecosystem (Rajanna et al., 2014). Among such TRVs grown in Karnataka, Rajamudi, Rathnachoodi and Jeerigesanna are the three popular ones, but are photosensitive. These TRVsare being cultivated in old Mysore region of the state (selected taluks in Hassan, Mandya, Mysore, Chamarajanagara and Coorg districts). Medium slender grain, good cooking quality properties and higher straw yield are few important characters for which these varieties are being liked by farmers (Rajanna et al., 2014).

Yield is an important trait considered in any given variety of rice. Along with yield, grain quality and cooking parameters are also important for the popularity of a variety in any location. Cooking quality of rice is influenced by chemical parameters like amylose content, gel consistency, gelatinization temperature and alkali spreading value. Gelatinization temperature determines the time required for cooking milled rice, whereas amylose content influences texture of rice after cooking. Gel consistency measures the tendency of cooked rice to harden after cooling. Within the same amylose group, varieties with a softer gel consistency are preferred and the cooked rice has a higher degree of tenderness. Harder gel consistency is associated with harder cooked rice and less sticky (Juliano et al., 1964).

Expression of better yield and quality is influenced by genotypes, environment and interaction between genotype and environment. Genotype×Environment interactions can be quantified using several procedures based on evaluations of genotypes under multi environmental trials (METs). Various efforts were made to characterize the behavior of genotypes in response to varying environments. Earlier biometricians used ANOVA (Allard, 1960) and linear regression (Finlay and Wilkinson, 1963; Eberhart and Russel; Perkins and Jinks, 1968), which explain G×E interactions in a single dimension. However, in nature, complex G×E occurs which can now be explained by the development of multiplicative models like Additive Main Effect and Multiplicative Interaction (AMMI) model and Genotype and Genotype by Environment bi-plot (GGE-bi-plot). These statistical methods help breeders in identifying a stable genotype that can perform well in variable environmental conditions and also identifying locations where selected varieties can perform well for gran yield and quality traits (Elias, A. A. et al., 2016). Among these models, AMMI model and GGE bi-plots serve as best methods to understand GE interactions. AMMI analysis has been reported to have significantly improved the probability of successful selection (Gauch and Zobel, 1988) and has been used to analyze genotype × environment interaction with greater precision in many crops (Gauch, 1992; Crossa et al., 1991). The model combines the conventional analysis of variance for genotype and environment main effects with principal components analysis to decompose the genotype × environment interaction into several Interaction Principal Component Axes (IPCA).

Yan et al. (2000) proposed another methodology known as a GGE-bi-plot for graphical display of GEI pattern of multi-environmental trial data. It applies the bi-plot technique for graphical display of the GGE of a multi-environmental trial data, hence the term GGE bi-plot. This GGE bi-plot is constructed by using the first two principal components (PC1 and PC2) also referred to as primary and secondary effects, respectively, derived from subjecting environment centered yield data (Yan et al., 2000). The GGE bi-plot can be used effectively to identify the GEI pattern of the data. It clearly shows which genotype won in which environments simplifying mega environment identification.

The present study was undertaken to understand the influence of different agro-climatic zones (environments) on yield and cooking quality parameters in selected TRVs and improved varieties of rice and to identify locations that are well suited for their better yield and good cooking quality.

MATERIAL AND METHODS

Experimental material consisted of four traditional rice varieties (TRVs) *viz.*, Rajamudi white, Rajamudi red, Rathnachoodi, Jeerigesanna, two farmers varieties (FVs) *viz.*, BKB, PUB and four high yielding varieties (HYVs) *viz.*, BR 2655, Tunga (IET13901), BPT-5204, MGD 101(MugadSiri). These rice varieties were grown in five locations of Karnataka *viz.*, Zonal Agricultural Research Station (ZARS), V.C. Farm, Mandya (Zone 6), Agriculture Research Station (ARS), Gunjevu, Holenarasipurataluk (Zone 7), Agriculture and Horticulture Research Station(AHRS), Navile, Shivamogga (Zone7), Agriculture Research Station (ARS), Gangavathi (Zone 3), Agriculture Research Station (ARS), Malagi (Zone 9) during *kharif* (wet season) 2017.

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications in all five locations selected under study. Nursery was raised during July-August, 2017 and 25-30 days old seedlings were transplanted and 20cm×10cm spacing was followed in all locations. Recommended package of practices for rice cultivations in respective locations were followed. Samples were harvested at the time of maturity. They were threshed, cleaned, dried and weighed.

The following quality parameters were estimated for all the seed samples collected from all test locations as per Standard Evaluation System of Rice (IRRI, 1996).

i) Alkali Spreading Value (ASV)

Alkali spreading value was determined by the method of Bhattacharya et al., 1971. The degree of alkali disintegration was visually rated according to Standard Evaluation System of Rice (IRRI, 1996). Ten polished rice grains in triplicates were soaked in 10ml of 1.7% KOH solution and kept in incubator at 30^0C for 23hrs. The degree of grain disintegration was estimated according to Standard Evaluation System of Rice (IRRI, 1996)

ii) Gelatinization Temperature (GT)

Gelatinization temperature was determined based on alkali score according to Little et al., 1958. Gelatinization temperature (GT) = 74.8- 1.57×Alkali score

iii)Amylose content % (AC)

Amylose content of rice was estimated according to the procedure suggested by Juliano et al., 1981. Amylose content was calculated as;

Amylose content (%) =

$$\frac{\text{Sample OD value x weight of the amylose taken x 1 ml x 100}}{\text{Standard OD value} \times \text{weight of the sample taken (mg)} \times \text{5ml}}$$

Average of three replications was taken as amylose content (%) in each rice sample.

iv) Gel consistency

Gel consistency was determined by the procedure of Cagampang et al., 1973. Gel consistency measured as the length of the gel of l00mg rice flour taken in triplicates in 2.0 ml 0.2 N KOI in 100 x 13mm testtubes after lh in a horizontal position. Length of the gel flow was measured and gel consistency data were classified according to Juliano, 1990 as soft (10cm), medium (4-6cm) and hard (2.5-4 cm).

Statistical analysis

AMMI analysis

The G X E interaction of ten rice genotypes over five locations were assessed by AMMI model as proposed by Gauch and Zobel, 1988, using the statistical program GenStat 18th edition. First, an ANOVA model was used with main effects of genotype and environment (without the interaction), then a principal component analysis (PCA) was fitted using the standardized residuals. These residuals include the experimental error and the effect of the G×E interaction. The equation was:

$$Y_{ij} = « + G_i + E_j + \text{p}^{\text{a}}{}_{k}\sim_{ik}¥_{jk} + e_{ij}$$

Where, Y_{ij} is the observed mean yield of the i^{th} genotype in the j^{th} environment. μ is the general mean, G_i and E_j represent the effects of the genotype and environment, respectively. λ_k is the singular value of the k^{th} axis in the principal component analysis. α_{ik} is the eigen vector of the i^{th} genotype for the k^{th} axis γ_{jk} is the eigen vector of the j^{th} environment for the k^{th} axis. nis the number of principal components in the model. e_{ij} is the average of the corresponding random errors.

Stability parameters

Two stability parameters were calculated *viz*., AMMI stability value (ASV) and genotypic stability index (GSI). The AMMI model does not make provision for a quantitative stability measure, and as such a measure is essential in order to quantify and rank genotypes in terms of yield stability (Gauch and Zobel, 1996; Gauch, 1992). Therefore, the AMMI stability value (Purchase et al., 2000) was used to quantify and rank genotypes based on their stability for a trait. AMMI stability value (ASV) is the distance from zero in a two dimensional scatter diagram of IPCA1 scores against IPCA2 scores. AMMI stability value was calculated using sum of squares and scores of both IPCA1 and IPCA2. The genotype recording the lowest ASV was the most stable one across the tested environments and genotype recording highest ASV was the most unstable across the tested environments.In the same manner, the genotype having IPCA2 score near zero reveals more stability while large values indicate more responsive and less stable genotypes. Genotypic selection index (GSI), also called Yield Stability Index (YSI) (Farshadfar, 2011) was used for simultaneous selection for stability and performance of the genotypes. Low values of GSI show desirable genotypes with high mean yield and stability (Farshadfar, 2008). AMMI stability value (ASV) and Genotypic stability index (GSI) were calculated (Purchase, 2000) as;

$$\text{ASV} = \sqrt{\left[\frac{SS_{\text{IPCA1}}}{SS_{\text{IPCA2}}}\right]^2 + [\text{IPCA2 score}]^2}$$

Where SS_{IPCA1} and SS_{IPCA2} are the sum of squares of IPCA1 and IPCA2 respectively. IPCA1 score and IPCA2 score are the scores of the genotype in those particular PCAs.

$$GSI = R_{ASV} + RY$$

Where, R_{ASV} is the rank of AMMI stability value, and RY is the rank of mean yield of genotypes (RY) across environments.

GGE bi-plot analysis

GGE bi-plot methodology, which is a combination of AMMI bi-plot and GGE concepts (Yan et al., 2000), was used for visual interpretation of patterns of GEI. Polygon view of GGE biplot based on symmetrical scaling for determining 'which-won-where' pattern of genotypes with test locations and average-environment coordination (AEC) view of bi-plot based on environment-focused scaling for interpreting mean performance of the genotypes vs. their adaptability patterns were used to understand the pattern of genotype-environment interaction.

RESULTS AND DISCUSSIONS

Mean yield performance of all ten varietiesover five locationsfor grain yield and quality parameters are represented in Table 1 and Table 2 (a and b) respectively.

i) Yield

Analysis of variance as per AMMI model revealed that there was significant contribution for variation by main effects (genotypes and environments) and interaction effects for yield (Table 3). Significant mean sum of squares due to genotypes indicate that there existed genotypic differences and significance of environment explains that environmental effects differ across different locations and test locations were diverse. Further, G×E interaction effects signify that genotypes behave differently across different environments.

Large sum of squares due to environments for yield indicated that differences among environmental means were very high and environments were diverse in nature (Zobel et al., 1988). It was found in present study that environmental mean variations were very higher than genotypic mean variations for yield (Table 3). Hence, test locations were diverse. Present results are in harmony with results of Adesole and Yetunde (2016) who evaluated fifteen upland rice varieties in two locations in South-Western Nigeria and concluded that environmental mean variations were more for grain yield and panicle characteristics. In contrast to this, Akter et al. (2015) observed that mean sum of square due to genotype main effect was high for grain yield when rice genotypes were evaluated in different growing seasons. These results suggest that variations in environment means are majorly due to location differences than seasonal variations.

The multiplicative variance of the treatment sum of squares due to GE interaction was further partitioned into two principle components IPCA1 and IPCA2. Two principle components were highly

Table 1. Mean yield performance of varieties in five locations.

Varieties code	Characters	Grain yield q/ha.					
	Varieties	Mandya	Gunjevu	Shivamogga	Gangavathi	Malagi	Mean
1	BKB	61.20	64.00	53.20	71.60	40.80	58.16
2	PUB	59.20	66.00	80.00	73.60	42.00	64.16
3	Tunga	52.40	88.00	82.00	101.20	50.40	74.80
4	Rajamudi Red	48.00	74.00	86.80	91.20	66.80	73.36
5	Mugadsiri	46.00	64.80	95.60	97.20	95.20	79.76
6	Rajamudi White	50.80	79.20	102.00	86.40	73.60	78.40
7	BPT-5204	68.00	52.00	69.60	83.60	46.40	63.92
8	Ratnachoodi	52.00	61.60	82.00	76.80	60.80	66.64
9	BR-2655	67.20	77.20	93.20	88.80	80.80	81.44
10	Jeerigesanna	46.40	44.40	51.20	65.20	42.40	49.92
	Mean	55.12	67.12	79.56	83.56	59.92	69.06
	SEm±	3.90	4.80	4.38	4.84	3.80	
	CD @ 5%	11.50	14.32	13.00	14.38	11.32	
	CV %	12.10	12.44	9.53	10.03	11.02	

q/ha= quintal per hectare, CD= critical difference, CV= coefficient of variation, SEm±= standard error of mean

Table 2a. Mean performance of varieties for amylose content and gelatinization temperature in five locations

Varieties codes	Characters	Amylose content (%)					Gelatinization Temperature (^0C)				
	Varieties	Mandya	Gunjevu	Shivamogga	Gangavathi	Malagi	Mandya	Gunjevu	Shivamogga	Gangavathi	Malagi
1	BKB	26.6	28.42	25.92	26.2	26.9	65.38	65.38	66.95	66.95	66.95
2	PUB	25.5	21.7	21.95	25.9	26.5	66.95	66.95	66.95	68.52	66.95
3	Tunga	27.8	22.7	29.18	26.8	30.8	66.95	66.95	66.95	68.52	66.95
4	Rajamudi Red	25.6	25.6	29.59	26.4	26.7	66.95	66.95	68.52	68.52	66.95
5	Mugadsiri	24.5	25.6	29.08	25.7	26.9	65.38	65.38	66.95	66.95	66.95
6	Rajamudi White	23.3	22.5	22.78	23.5	25.3	66.95	66.95	66.95	68.52	68.52
7	BPT-5204	23.1	23.6	26.72	25.5	24.9	66.95	66.95	66.95	66.95	66.95
8	Ratnachoodi	21.4	24.5	29.25	21.1	24.3	66.95	66.95	68.52	66.95	66.95
9	BR-2655	23.3	25.2	24.49	27.7	25.7	68.52	68.52	68.52	66.95	68.52
10	Jeerigesanna	25.2	24.4	21.83	21.9	26.4	68.52	68.52	66.95	68.52	66.95
	SEm±	0.17	0.094	0.18	0.12	0.17	0.0023	0.0015	0.003	0.005	0.0035
	CD @ 5%	0.5	0.28	0.54	0.36	0.49	0.01	0.01	0.05	0.03	0.07
	CV %	1.2	0.67	1.21	0.84	1.099	0.1	0.01	0.23	0.3	0.3

CD= critical difference, CV= coefficient of variation, SEm±= standard error of mean

Table 2b. Mean performance of varieties for gel consistency and alkali spreading value in five locations

Characters	Gel consistency (cm)					Alkali Spreading Value				
Varieties	Mandya	Gunjevu	Shivamogga	Gangavathi	Malagi	Mandya	Gunjevu	Shivamogga	Gangavathi	Malagi
BKB	8.9	8.1	8.1	7.1	7.9	6	6	5	5	5
PUB	9.7	9.1	10.4	10.2	9.9	5	5	5	4	5
Tunga	8.8	8.8	7.7	8.2	9	5	5	5	4	5
Rajamudi Red	9.03	8.5	10.03	9.1	8.9	5	5	4	4	5
Mugadsiri	7.9	7.2	8.8	9.9	8.7	6	6	5	5	5
Rajamudi White	8.7	9.5	6.6	7.8	8.7	5	5	5	4	4
BPT-5204	9.8	9.6	10.3	10.1	10.1	5	5	5	5	5
Ratnachoodi	9.96	10.3	10.2	8.4	10	5	5	4	5	5
BR-2655	9.03	8.3	8.1	10.4	9.7	4	4	4	5	4
Jeerigesanna	9.43	9.2	9.1	9.1	10.3	4	4	5	4	5
SEm±	0.07	0.068	0.1	0.065	0.068	0.0023	0.0015	0.003	0.005	0.0035
CD @ 5%	0.21	0.202	0.3	0.19	0.2	0.01	0.01	0.05	0.03	0.07
CV %	1.35	1.33	1.94	1.25	1.25	0.1	0.01	0.23	0.3	0.3

CD= critical difference, CV= coefficient of variation, SEm±= standard error of mean significant for grain yield. The per cent contribution of each of the IPCAs to the sum of squares of the genotype × environment interaction for grain yield is tabulated in Table 3. IPCA1 explained maximum percent of genotype-environment interaction (60.5 %). Zobel et al. (1988) proposed that two IPCAs for AMMI model were sufficient for a predictive model. Therefore, the interaction of ten rice genotypes evaluated over five different environments were best predicted by the first two principle component axes that explained about more than 75% of the interaction sum of squares. The rest of the variations were taken as residual effect.

Quality parameters

Quality of rice is the second most important character after yield and expression of quality parameters are also influenced by genotype, environment and interaction between genotype and environment. Hence, stability analysis was done for important quality parameters that determine cooking quality of rice to identify locations that are well suitable for better cooking quality of rice varieties used in present investigations. The results show that there existed significant GE interactions for amylose and gel consistency parameters which implies that genotypes behaved differently over different environments for these quality parameters.

Therefore, this study helps to identify locations that are suitable for better expression of quality in selected rice varieties.

In the present study, significant effect of GE interaction on chemical quality parameters like amylose content (Table 4a) and gel consistency (Table 4b) was observed. GE interaction was found to be non-significant for alkali spreading value and gelatinization temperature (Table 4c). Large genotype sum of squares were found for all four quality parameters indicating that genotypes were diverse for these parameters. Results are in accordance with Abeysekera et al. (2016) who evaluated different rice varieties over different seasons and observed that both variety and the variety×

Table 3. ANOVA table for AMMI model for grain yield (q/ha.)

Source	d.f.	Sum of squares	Mean squares	F ratio	%TSS	G*E %
Total	149	51135	343.2	6.01	100	
Treatments	49	45491	928.4***	16.26	88.963	
Genotypes	9	14218	1579.8***	27.67	27.805	
Environments	4	18064	4516***	79.089	35.326	
Block	10	504	50.4	0.88	0.9856	
Interactions	36	13210	366.9***	6.43	25.834	
IPCA 1	12	7988	665.7***	11.66	15.621	60.5 %
IPCA 2	10	3164	316.4***	5.54	6.1875	23.95 %
Residuals	14	2057	146.9	2.57	4.0227	
Error	90	5140	57.1		10.052	

***Significance @ p=0.001, q/ha.= quintal per hectare, %TSS= % of total sum of squares, IPCA= interaction principle component axes, %G*E= % of genotype and environment interaction

Table 4a. AMMI ANOVA for amylose content

Source	d.f.	Sum of squares	Mean squares	F ratio	%TSS	G*E %
Total	149	783.3	5.26		100	
Treatments	49	777.3	15.86***	264.3333	99.23401	
Genotypes	9	271.9	30.21***	503.5	34.71212	
Environments	4	95.6	23.9***	398.3333	12.20477	
Block	10	0.6	0.06	1	0.076599	
G*E Interaction	36	409.8	11.38***	189.6667	52.31712	
IPCA1	12	225.5	18.79***	313.1667	28.78846	54.95 %
IPCA2	10	109	10.9***	181.6667	13.91549	26.59 %
Residuals	14	75.3	5.38***	89.66667	9.613175	
Error	90	5.4	0.06			

***Significance @ p=0.001, %TSS= % of total sum of squares, IPCA= interaction principle component Axes, %G*E= % of genotype and environment interaction.

Table 4b. AMMI ANOVA for Gel Consistency

Source	d.f.	s.s.	m.s.	F ratio	%TSS	%G*E
Total	149	133.17	0.894	52.588235	100	
Treatments	49	131.29	2.679***	157.58824	98.588271	
Genotypes	9	67.75	7.527***	442.76471	50.874822	
Environments	4	4.19	1.048***	61.647059	3.1463543	
Block	10	0.34	0.034	2	0.2553128	
GE Interactions	36	59.36	1.649***	97	44.574604	
IPCA 1	12	34.53	2.877***	169.23529	25.929263	58.16 %
IPCA 2	10	21.41	2.141***	125.94118	16.077195	36.06 %
Residuals	14	3.42	0.244***	14.352941	2.568146	
Error	90	1.54	0.017	1	1.1564166	

***Significance @ p=0.001, %TSS= % of total sum of squares, IPCA= interaction principle component Axes, %G*E= % of genotype and environment interaction.

season interaction effects were highly significant. Endosperm starch amylose content is influenced by ambient temperature. High ambient temperature decreases the amylose content, while cool temperature during grain development increases the amylose content (Juliano et al., 1981). Other than temperature, genetics also play a major role in the amylose content of rice. The level of waxy gene protein increases in lower temperatures resulting in high amylose content in mature seeds (Suzuki et al., 2003). The waxy gene located in rice chromosome 6, encodes the enzyme granule bound starch synthase (GBSS) which plays a key role in amylose synthesis. In addition to the major effect of the waxy gene, minor genes also affect rice amylose content (Suzuki et al., 2003). Juliano et al. (1964) documented that variations in amylopectin fractions and nitrogenous fertilization at heading stage affect gel consistency in rice genotypes. Presence of GE interactions in gel consistency and amylose content in present study may be correlated with differences in soil fertilization and temperature across locations. Mahalingam et al. (2013) also recorded similar findings in their study.

Table 4c. AMMI ANOVA for alkali spreading value and gelatinization temperature.

Source	Alkali spreading value	Gelatinization temperature (^{0}C)
Total	0.3221	0.794
Treatments	0.9796	2.415
Genotypes	2.2667***	5.587***
Environments	1.35	3.328
Block	0.0001	0.0002
Interactions	0.6167	1.520
IPCA1	0.8	1.972
IPCA2	0.8643	2.130
Residuals	0.2826	0.697
Error	0.0002	0.0002

***Significance @ p=0.001, IPCA= interaction principle component axes.

The two principle components were highly significant for amylose and gel consistency. IPCA1 explained 54.95 % and 58.16 % for amylose and gel consistency (Table 4a and Table 4b).

Stability parameters

Yield

According to ASV, Ratnachoodi was the most stable genotype for yield since it recorded lowest ASV with mean yield of 66.64 q/ha. BR-2655 was the stable genotype recording highest mean yield (81.44 q/ha.) among all genotypes next to Ratnachoodi. The least stable genotype was Mugadsiri since it recorded highest ASV (11.57) with mean yield of 79.76 q/ha (Table 5). Among TRVs, Ratnachoodi, Jeerigesanna and Rajamudi red varieties were found to be stable for yield since TRVs harbor time tested traits that enable stable performance across a range of environments (Rajanna et al., 2014). According to GSI, BR-2655 was found to be the best variety since it recorded higher mean yield and was stable for yield across locations, since GSI was found lower for it.

Quality traits

According to ASV, Jeerigesanna was the most stable for gel consistency since it recorded least ASV value, followed by BPT-5204 and Tunga. Most unstable genotype for gelconsistency was Rajamudi white as it recorded highest ASV value and it showed a specific

Table 5. AMMI Stability parameters for grain yield (q/ha.)

Genotype	IPCAg1	IPCAg2	ASV	Rank ASV	Mean	Rank of mean	GSI
BKB	3.28376	0.54742	8.31	9	58.16	9	18
PUB	1.74449	-0.73497	4.47	5	64.16	7	12
Tunga	1.13058	-4.07731	4.98	6	74.8	4	10
Rajamudi red	-1.35812	-1.3305	3.68	4	73.36	5	9
Mugadsiri	-4.54528	1.4749	11.57	10	79.76	2	12
Rajamudi white	-2.29367	-1.42322	5.96	7	78.4	3	10
BPT-5204	2.4275	2.04801	6.46	8	63.92	8	16
Ratnachoodi	-0.70114	0.54597	1.85	1	66.64	6	7
BR-2655	-0.91629	1.15866	2.59	2	81.44	1	3
Jeerigesanna	1.22816	1.79103	3.58	3	49.92	10	13

q/ha= quintal per hectare, ASV= AMMI stability value, GSI= genotypic selection index, IPCA= interaction principle component axes

adaptation. Similarly, BPT-5204 was most stable for amylose content, followed by Rajamudi white and BR-2655. Least stable for amylose content was Ratnachoodi (Table 6). Most appropriate amylose content for better cooking quality is intermediate amylose content (20-25%) which was observed in varieties *viz.*, PUB (24.31%), Rajamudi white (23.47%), Ratnachoodi (24.13%), Jeerigesanna (23.94%) and BPT-5204 (24.77%). But these varieties except BPT-5204 were unstable for expression of amylose content across locations since they recorded higher GSI values. BPT-5204 also had stable and good performance with respective to gel consistency across test locations under present study

Understanding pattern of genotype-environment interaction display using graphical tool

A polygon is drawn on the genotypes that are farthest from the bi-plot origin so that all other genotypes fall within the polygon. The perpendicular lines starting from GGE bi-plot origin are drawn to each side of the polygon. The perpendicular lines are equality lines between adjacent genotypes on the polygon. The genotypes located on the vertices of the polygon perform either the best or poorest in one or more locations (Yan et al., 2000). The equality lines divide the bi-plot into sectors. The vertex genotype in each sector is the winning genotype at locations whose markers (points) fall into the respective sector (Yan et al., 2000). Locations within the same sector share the same winning genotype, and locations in different sectors have different winning genotypes. Thus polygon view of a GGE bi-plot indicates presence or absence of cross-over GEI (Yan and Rajcan, 2002).

'Which won where' pattern of GGE biplots for grain yield of selected varieties is given in Fig. 1. Genotypes BKB, BPT-5204, Mugadsiri, Rajamudi white and Tunga were found to be responsive genotypes and unstable for grain yield since they were located on vertices of the polygon. Malagi and Shivamogga shared Mugadsiri and Rajamudi white as their winning genotypes since they fall in the same sector of polygon. Similarly, BPT-5204 was winning genotype in Mandya and Tunga was winning genotype in Gunjevu and Gangavathi. Rest of the genotypes were found to be

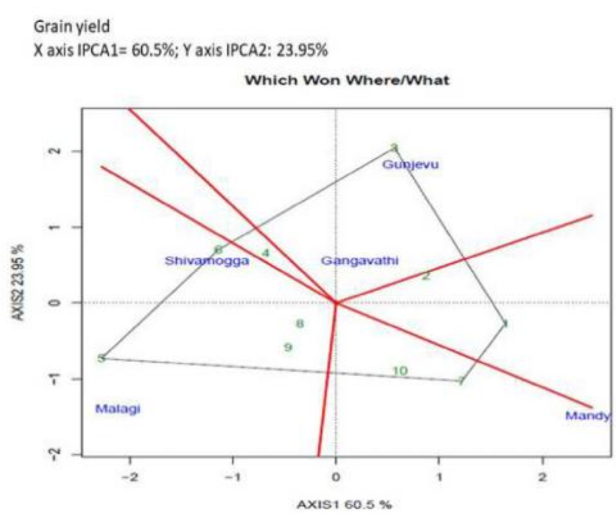

Fig. 1. Polygon view of GGE bi-plot based on the symmetrical scalling for 'which-won-where' pattern of genotypes and locations for grain yield. (1=BKB, 2= PUB, 3= Tunga, 4= Rajamudi red, 5= Mugadsiri, 6= Rajamudi white, 7= BPT-5204, 8= Ratnachoodi, 9= BR-255, 10= Jeerigesanna)

Table 6. AMMI stability parameters for gel consistency and amylose content.

Genotype	Gel consistency (cm)							Amylose content (%)						
	IPCAg1	IPCAg2	ASV	Rank ASV	Mean	Rank of mean	GSI	IPCAg1	IPCAg2	ASV	Rank ASV	Mean	Rank of mean	GSI
BKB	0.454	-0.468	0.87	6	8.013	10	16	0.28322	-1.2267	1.27	7	26.8	2	9
PUB	-0.468	-0.304	0.81	4	9.860	2	6	1.47439	0.46596	1.70	8	24.31	7	15
Tunga	0.416	0.334	0.75	3	8.500	7	10	0.20281	1.87275	1.89	9	27.47	1	10
Rajamudi red	-0.353	-0.607	0.83	5	9.127	5	10	-0.7413	0.16622	0.84	4	26.79	3	7
Mugadsiri	-1.019	0.198	1.65	9	8.500	8	17	-0.80363	0.03812	0.89	5	26.37	4	9
Rajamudi white	0.977	0.742	1.74	10	8.260	9	19	0.56502	-0.01315	0.63	2	23.47	10	12
BPT-5204	-0.214	-0.192	0.39	2	9.980	1	3	-0.44432	0.05402	0.50	1	24.77	6	7
Ratnachoodi	0.601	-0.679	1.18	7	9.787	3	10	-1.89733	-0.14	2.11	10	24.13	8	18
BR-2655	-0.507	0.886	1.21	8	9.087	6	14	0.41971	-0.66354	0.81	3	25.29	5	8
Jeerigesanna	0.111	0.089	0.20	1	9.427	4	5	0.94143	-0.55367	1.18	6	23.94	9	15

ASV= AMMI stability value, GSI= genotypic selection index, IPCA= interaction principle component axes

stable according to GGE biplots since they are located near origin.

According to polygon view for gel consistency (Fig. 2), Rajamudi red, Rajamudi white, Ratnachoodi, BR-2655 and Mugadsiri were unstable for gel consistency and show specific adaptation. Accordingly, Rajamudi white show specific adaptation to Gunjevu, Mandya and Malagi, whereas Rajamudi red and BR-2655 show specific adaptation to Shivamogga and Gangavathi respectively and are winning genotypes in respective locations. Similarly in Fig. 3, for amylose content, BKB was winning genotype in Gunjevu, PUB in Mandya and Gangavathi, Tunga in Malagi and Ratnachoodi in Shivamogga.

Winning genotypes does not always mean best genotype in respective location. For example, intermediate amylose content (20-25%) is regarded as better for good texture after cooking. Though BKB was a winning genotypeGunjevu, it recorded higher amylose content (28.42%, Table 2a) which is not

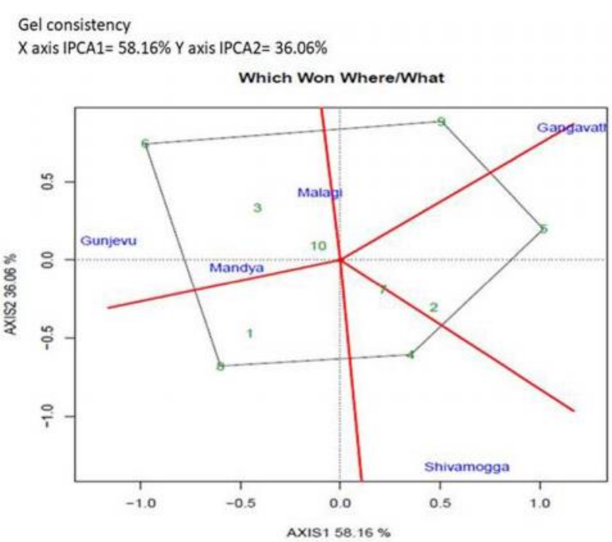

Fig. 2. Polygon view of GGE bi-plot based on the symmetrical scalling for 'which-won-where' pattern of genotypes and locations for gel consistency. (1=BKB, 2= PUB, 3= Tunga, 4= Rajamudi red, 5= Mugadsiri, 6= Rajamudi white, 7= BPT-5204, 8= Ratnachoodi, 9= BR-255, 10= Jeerigesanna)

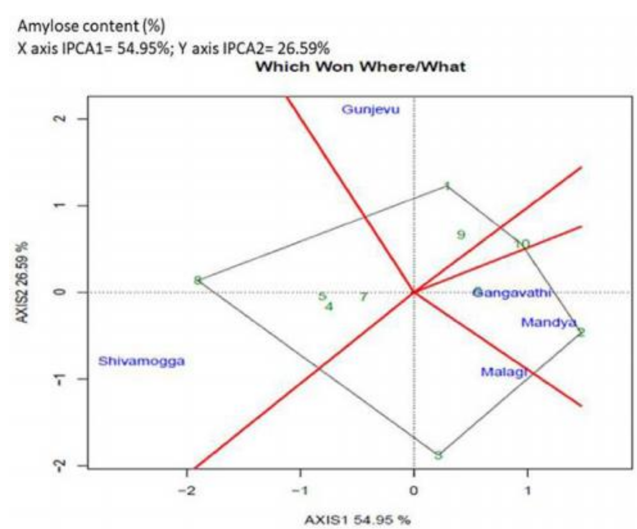

Fig. 3. Polygon view of GGE bi-plot based on the symmetrical scalling for 'which-won-where' pattern of genotypes and locations for amylose content. (1=BKB, 2= PUB, 3= Tunga, 4= Rajamudi red, 5= Mugadsiri, 6= Rajamudi white, 7= BPT-5204, 8= Ratnachoodi, 9= BR-255, 10= Jeerigesanna)

preferred for good cooking quality.

Results of biplots were found to be similar to AMMI stability parameters. But, GGE biplots could explain the relationship between environments and varieties and could explain the pattern of GE interactions. Similar findings were obtained by Ogunbayo et al., 2014.

CONCLUSION

Genotype-Environment (GE) interaction is a complex phenomenon in nature which needs to be understood by breeders in order to identify locations that are suitable for better yield of a given variety. It was revealed by AMMI analysis in present investigation that there existed significant GE interaction among ten rice varieties evaluated across five different locations. Genotypes and environments were diverse. IPCA1 and IPCA2 together explained more than 75% of GE interaction for yield and quality traits and maximum GE interaction was explained by IPCA 1. GGE biplots provided an excellent graphical tool to understand pattern of GE interaction and helped in identifying mega-environments and locations that are suitable for better yield of a given variety.

Analysis revealed that BR-2655 and Ratnachoodi were found to be most stable varieties and Mugadsiri was found to be most unstable variety for yield. Jeerigesanna and BPT-5204 were stable for gel consistency and amylose content respectively. Among test varieties used under investigation, BR-2655 was found to be best variety since it recorded highest grain yield and also it was stable performer for grain yield across five different locations. It was also nearly stable for amylose content across locations. Hence, BR-2655 can be considered as best variety with stable yield and stable cooking quality across locations. AMMI model and GGE biplots were found to be excellent tool to understand GE interactions. But, GGE biplots could provide more meaning information with reference to relationship between genotypes and environments.

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