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Stability analysis of elite rice (*Oryza sativa* L.) genotypes under diverse situations

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Abstract
Stability analysis identifies the adaptation of a crop genotype in different environments. The present study was undertaken to evaluate the stability of thirteen genotypes for yield and yield contributing characters in rice over three different locations in Karnataka state of India during Kharif, 2019. The highly significant differences among rice genotypes for grain yield and yield contributing characters over environments and genotype × environment interaction were observed. The rice genotype BD-08 (12.55g/hill) was found as the most promising stable genotype for grain yield as indicated by their higher mean performance across diverse locations. The genotype BD-07 performed well under better environmental conditions for grain yield, while the genotype BPT-5204 performed well under adverse environmental conditions for grain yield. Hence, the genotypes BD-08 can be directly used in various breeding programs for enhancing rice productivity and also can be released as a variety.

Keywords: rice, stable, genotype, environment

1. Introduction
Rice (*Oryza sativa* L.) is one of the most important food crops in the world. It is an excellent source of complex carbohydrates and the best source of energy. It is the primary staple food for millions of people; more than two billion people in Asia and a hundred million in Africa and Latin America depend on rice for food. Globally, rice is cultivated in an area of about 165.25 million hectares with an annual production of 787.29 million metric tons and productivity of 4.76 metric tons per hectare. In India, rice is grown on 46.38 million hectares with an annual production of about 195.42 million metric tons and productivity of about 4.21 metric tons per hectare (FAO, 2021). The above statistics indicate that the productivity of the country is far less than the world's average. Since rice is grown in diverse agro-climatic conditions ranging from upland to lowland and irrigated to rainfed situations, their phenotypic responses vary greatly by the environment. It is important to have continuous and concerted efforts to evolve stable cultivars with high-yield potential. Assessing the stability of genotypes across the seasons is an important parameter in deciding the superiority of a particular genotype in a particular environmental condition. Information on genotype × environment interaction leads to the successful evaluation of stable genotypes, which could be used for general cultivation. For developing stable varieties, Finlay and Wilkinson (1963) and Eberhart and Russell (1966) have provided models for some stability analysis, which have been used in the identification of stable genotypes. Therefore, the present investigation was carried out to identify stable genotypes with high yield using the Eberhart and Russell model for the Northern Transition Zone and Hilly Zone of Karnataka state.

2. Material and Methods
The experiment was conducted on thirteen genotypes, ten of which were biofortified and drought-tolerant advanced breeding lines obtained from a cross between the drought-tolerant genotype D6-2-2 (selected from the local landrace Doddiga) and the superior rice grain quality genotype BPT-5204. These lines were designated as BD-01, BD-02, BD-03, BD-04, BD-05, BD-06, BD-07, BD-08, BD-09, and BD-10. The experiment also included the two parents of the cross, BPT-5204, and D6-2-2, as well as the local check MGD-101. The evaluation was carried out for grain yield and yield contributing characters during the Kharif season of 2019 at AICRIP (All India Coordinated Rice Improvement Project) Mugad, which is located in the Northern Transition Zone of Karnataka (Zone-8), ARS (Agriculture Research Station), Sirsi, which belongs to the Hilly zone with a high rainfall area of Karnataka (Zone-9), and ARS Malagi, which belongs to the Hilly zone with a low rainfall area of Karnataka (Zone-9).

The advanced breeding materials were developed at ARS Sirsi. The evaluating genotypes were sown in raised beds, and 25-day-old seedlings were transplanted into the main field under puddled conditions. The main field was puddled thrice until a fine tilth of soil was obtained, and the crop was raised under irrigated conditions during Kharif 2019. The experimental layout was a Randomized Block Design, consisting of five rows of 5.0 m in length, with a spacing of 20 cm between rows and 10 cm between plants in two replications, and a single seedling hill-1 of genotype was planted. Recommended management practices and intercultural operations were followed. Observations were made on randomly selected five plants per plot for grain yield and other yield-related characters *viz.*, days to 50 percent flowering, number of panicles hill-1, and grain yield hill-1. Stability parameters were estimated following Eberhart and Russell's (1966) model. The analysis of variance for each location was conducted, and the mean genotypic values for each location were taken for analyzing the data over the location. The characters that recorded significant G × E were used for stability analysis. A genotype with a unit regression coefficient (bi=1) and deviation not significantly different from zero (S^2di=0) was considered a stable genotype with the unit response (performance does not change with the change in environment) and are widely adaptable to different environments. If bi is more than unity, it is considered to possess less than average stability and is adaptable to favorable environments, if bi is less than unity, it is considered to possess more than the average stability and is adaptable to poor environments and genotypes with any bi value with significant S^2 di are unstable.

3. Result and Discussion

3.1 Analysis of variance

The analysis of variance (Table 1) showed significant differences among the genotypes for all the characters studied in all the environments. It indicates that there is significant variation among genotypes, which can be further studied for their interaction with different environments to identify their suitability for cultivation.

Table 1: Analysis of variance for yield and yield component characters in all the environments

Source of variation	df	Mean sum of squares at Mugad			Mean sum of squares at Malagi			Mean sum of squares at Sirsi		
		Days to 50% flowering	Number of panicles hill $^{-1}$	Grain yield hill^{-1}	Days to 50% flowering	Number of panicles hill^{-1}	Grain yield hill^{-1}	Days to 50% flowering	Number of panicles hill^{-1}	Grain yield hill^{-1}
Replications	1	0.62	0.89	4.70	0.24	0.32	6.11	0.04	0.08	0.30
Genotypes	12	322.1**	0.31**	6.47**	214.1**	3.79**	28.55**	4610.1**	503.4**	47.02**
Error	12	0.28	0.67	0.91	0.37	0.07	3.77	14.46	1.45	0.34

* and ** Significant at 5% and 1% levels, respectively

3.2 Stability analysis

3.2.1 Pooled analysis of variance

The pooled analysis of variance (Table 2) indicated significant variation among the genotypes for all the characters when tested against pooled error and pooled deviation. It reveals that the selected genotypes are having significant variations for all characters when tested in different environments. The mean squares due to environments were found significant for all the characters when tested against pooled deviation as well as pooled error. It reveals the wide difference between environments. The significance of the Genotype and Environment interaction suggests the differential behavior of genotypes in changing environments. The Environment + (Genotype × Environment) was significant for all the characters when tested against pooled error and pooled deviation. It indicates the distinct nature of environments and Genotype × Environment interactions in phenotypic expression. The significance of the Environment (linear) component for all the characters, when tested against pooled error, indicates the difference between the environments and their influence on genotypes for the expression of these characters. The Genotype × Environment (linear) interaction was significant for all characters except grain yield per plant when tested against pooled error and pooled deviation. This indicated significant differences among the genotypes for linear response to environments (bi) behavior of the genotypes could be predicted over environments more precisely and Genotype × Environment interaction was the outcome of the linear function of environmental components. Hence, the prediction of the performance of genotypes based on stability parameters would be feasible and reliable. The significant pooled deviations for grain yield hill^{-1} and number of panicles hill^{-1}, when tested against pooled error indicated that the performance of genotypes is entirely unpredictable in nature for these two characters. It also indicated the importance of non-linear components in determining the interaction of genotypes with the environment

Table 2: Pooled analysis of variance for stability based on the Eberhart and Russell model

Source of variation	df	Mean sum of squares		
		Days to 50% flowering	Number of panicles hill^{-1}	Grain yield hill^{-1}
Genotypes	12	321.2**	5.12*	8.90*
Environment	2	453.1**	202.08**	290.06**
Genotype × Environment	24	69.49**	9.6**	4.28*
Environment+ (Genotype × Environment)	26	99.0**	24.4**	26.26**
Environment (Linear)	1	906.2**	404.1**	580.12**
Genotype × Environment (Linear)	12	138.9**	16.67**	2.91
Pooled Deviation	13	0.000	2.4**	5.21**
Pooled Error	36	0.31	0.143	0.722
Total	38	6429.298	18.3	20.78

* and ** Significant at 5% and 1% levels, respectively

3.2.2 Stability parameters

Estimation of stability parameters i.e., mean (μ), regression coefficient (bi), and a mean square deviation from regression (S^2di) for all the genotypes were estimated for three characters to assess the relative phenotypic stability of performance over environments, and the results were presented in Tables 3, 4, 5. For grain yield per plant, the genotype, BD-08 (12.55 g), was found stable due to their high grain yield per plant, regression coefficient (bi) near to unity, and non-significant deviation from linear regression (S^2di). while, the genotype, BD-07 (12.49 g), were having more grain yield per plant and had the least deviation from linear regression, but had a regression coefficient (bi >1) and thus, was found to be highly responsive to better environments. while BPT-5204 (10.15 g) had more grain yield per plant with non-significant deviation from regression but had a regression coefficient (bi < 1) that showed an above-average response and high stability under unfavorable environments. The highest-yielding stable genotype, BD-08 was found to be stable for the number of panicles per plant. Based on a low mean, regression coefficient near unity, and non-significant deviation from regression, the genotype BD-09 (109.5 days) was considered stable for early flowering. Several research workers have also reported stability parameters for grain yield and yield contributing characters *viz*., Kumar *et al*., 2006 [9], Arumugam *et al*. 2007 [3], Dushyanthakumar and Shadadshari, 2010 [4], Kumar *et al*. 2010 [10], Vanave *et al*. 2010 [15], Ajmera *et al*. 2017 [1], Oladosu *et al*. 2017 [13], Manjunatha *et al*. 2018 [12], Pandey *et al*. 2020 [14], Kouke *et al*. 2022 [8], Lee *et al*. 2023 [11].

Table 3: Stability parameters for days to 50% flowering across three environments

S. No.	Genotypes	Days to 50% flowering					
		Mugad	Malagi	Sirsi	Mean	b_i	S^2di
1.	BD-01	115.0	110.0	106.0	110.5	0.762	0.008
2.	BD-02	127.0	124.5	122.0	124.5	0.423	2.091
3.	BD-03	138.0	121.0	104.0	121.0	2.879	1.306
4.	BD-04	124.0	120.0	116.0	120.0	0.678	0.699
5.	BD-05	139.0	133.0	127.0	133.0	1.016	0.222
6.	BD-06	131.0	129.5	128.0	129.5	0.254	-0.571
7.	BD-07	131.0	126.5	122.0	126.5	0.762	-0.639
8.	BD-08	130.0	125.0	120.0	125.0	0.847	-0.204
9.	BD-09	116.0	109.5	103.0	109.5	1.101	0.252
10.	BD-10	136.0	108.0	80.0	108.0	4.743	-0.381
11.	D6-2-2	112.0	117.2	122.5	117.3	-0.889	2.605
12.	BPT-5204	118.0	114.0	110.0	114.0	0.678	-0.505
13.	MGD-101	94.0	95.5	97.0	95.5	-0.254	-0.244
General Mean		123.9	118.0	112.1	118.00	1.00	
CD at 5%		1.2	1.3	2.4			
Environmental index		5.9	0.0	-5.9			

* and ** Significant at 5% and 1% levels, respectively

Table 4: Stability parameters for number of panicles hill^{-1} across three environments

S. No.	Genotypes	Number of panicles hill^{-1}					
		Mugad	Malagi	Sirsi	Mean	b_i	S^2di
1.	BD-01	5.9	7.4	10.9	8.06	0.55	3.56**
2.	BD-02	7.3	4.9	17.8	9.98	1.74	0.51*
3.	BD-03	7.2	7.4	13.0	9.20	0.80	1.66**
4.	BD-04	6.8	3.8	11.2	7.27	0.93	0.48*
5.	BD-05	6.4	5.1	14.1	8.53	1.22	0.63*
6.	BD-06	7.7	5.2	13.0	8.63	1.01	-0.048
7.	BD-07	6.1	6.9	12.1	8.37	0.77	2.86**
8.	BD-08	7.8	3.8	18.0	9.87	1.86	-0.12
9.	BD-09	5.6	3.1	14.1	7.60	1.46	-0.017
10.	BD-10	7.3	4.1	22.1	11.17	2.42	1.53**
11.	D6-2-2	7.6	5.9	6.2	6.55	-0.03	1.51**
12.	BPT-5204	10.2	5.2	7.6	7.65	0.14	11.72**
13.	MGD-101	8.9	5.4	7.2	7.17	0.12	5.51**
General Mean		7.3	5.2	12.9	8.46	1.00	
CD at 5%		1.8	0.6	0.8			
Environmental index		-1.2	-3.2	4.4			

* and ** Significant at 5% and 1% levels, respectively

Table 5: Stability parameters for grain yield hill^{-1} across three environments

S. No.	Genotypes	Grain yield hill^{-1} (g)					
		Mugad	Malagi	Sirsi	Mean	b_i	S^2di
1.	BD-01	5.0	13.7	15.6	11.46	1.12	5.804
2.	BD-02	3.9	12.0	10.4	8.76	0.91	-1.945
3.	BD-03	4.6	14.1	9.6	9.46	0.96	2.163
4.	BD-04	3.7	13.5	9.6	8.93	1.02	0.281
5.	BD-05	3.7	12.5	14.1	10.13	1.12	4.438
6.	BD-06	4.4	16.6	10.7	10.55	1.23	5.628
7.	BD-07	6.2	18.4	12.9	12.49	1.24	3.712
8.	BD-08	6.3	16.7	14.7	12.55	1.17	-1.942
9.	BD-09	6.3	9.2	13.7	9.74	0.53	12.923**
10.	BD-10	2.4	12.5	12.2	9.05	1.19	-0.401
11.	D6-2-2	2.9	11.9	7.1	7.28	0.88	3.672
12.	BPT-5204	7.3	10.1	13.1	10.15	0.45	5.454
13.	MGD-101	0.9	12.4	7.4	6.89	1.18	2.737
General Mean		4.4	13.3	11.6	9.80	1.00	
CD at 5%		2.1	3.9	1.2			
Environmental index		-5.4	3.5	1.8			

and **Significant at 5% and 1% levels, respectively

4. Conclusions

From the foregoing discussion, genotype BD08 was found to be stable for grain yield hill^{-1} and some of the important yield components can be recommended as variety in the Northern Transition Zone and Hilly Zone of Karnataka state and also should be given due importance while formulating breeding program aiming to develop high yielding and stable varieties in rice. The genotype BD09 was found stable for days to 50 percent flowering, hence this can be utilized in the breeding program for the development of early maturing varieties in these zones.

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