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Interpreting Genotype×Environment Interaction in Rice (*Oryza sativa* L.) Using Eberhart and Russell Model

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ABSTRACT

The experiment was laid during *kharif* (June–November, 2022) in three paddy growing regions of Middle Gujarat, India to determine the magnitude of G×E interaction and detect stable high-yielding and specifically performed genotypes for target environment(s). Thirty-two rice genotypes including the standard checks were evaluated for fifteen yield and their attributing characters at three locations (Nawagam, Dabhoi and Thasara) in Randomized Block Design. The results revealed that the mean sum of squares due to genotypes was significant for all of the traits evaluated in all individual environments indicating a sufficient amount of diversity among the different genotypes tested. The linear component of G×E interaction was found significant for days to 50% flowering, productive tillers plant^{-1}, panicle weight, number of grains panicle^{-1}, grain yield plant^{-1} and harvest index, which indicated linear response of genotypes to changing environments and hence genotype performance would be predictable for those characters. The predominance of linear components suggested that linear regression accounted for a large portion of the G×E interaction for these traits and may help in the accurate forecasting of genotype performance across environments. Four genotypes i.e., IET-28354, IET-29538, IET-29774 and IET-28703 were found stable in all the environments with wider adaptability for grain yield plant^{-1}.

KEYWORDS: Rice, environmental index, G×E interaction, stability and adaptability

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1. INTRODUCTION

Rice (*Oryza sativa* L.) serves as a fundamental dietary component for around 3.5 billion individuals, serving as the main calorie source for over half of the global population (Muthayya et al., 2014). This crop offers the benefit of being rich in carbohydrates and packed with essential nutrients like vitamins, antioxidants, and minerals, making it a wholesome and nutritious choice (Fukagawa and Ziska, 2019; Sen et al., 2020). In India, it is extensively grown food crop, occupying an area of 47.7 mha with production of 136 million tonnes with an average productivity of 2.89 tonnes ha^{-1} (Anonymous, 2022). The total rice occupying area in Gujarat is 892 thousand ha, production is 2115 thousand tonnes and yield is 2607 kg ha^{-1}. (Anonymous, 2021). The rice growing area of the state comes under the districts of Ahmedabad, Anand, Vadodara, Kheda, Anand, Panchmahal, Dahod, Narmada, Valsad, Navsari, Dang, Surat and Bharuch.

Rice productivity is a multifaceted agricultural characteristic influenced by three key elements: the number of panicles unit^{-1} area, spikelet panicle^{-1}, and grain weight (Sakamoto et al., 2008). In the past, plant breeding initiatives have employed diverse strategies to enhance yield potential and cultivate high-yielding varieties. Yet, recent breeding approaches, amidst rapidly changing climates, underscore the significance of ensuring cultivar stability and adaptability across diverse environmental contexts (Li et al., 2019). The challenge of climate change affects the stability and long-term viability of rice production. It is an environmental shift driven by rising levels of greenhouse gases (Cassia et al., 2018; Karbi and Chemke, 2023; Simmer et al., 2023). Although rice originates from the tropics, temperatures above 35°C during reproductive stages significantly reduce yields, particularly when flowering coincides with heat stress (Umarani et al., 2020). A 1°C rise in the growing-season minimum temperature has been shown to lower rice grain yield by 10%. Climate change has caused unpredictable rainfall patterns, leading to conditions like drought and water stress. As a result, the performance of different varieties or genotypes varies depending on the environment.

G×E is defined as a phenomenon that phenotypes respond to genotypes differently according to different environmental factors. A genotype is considered stable when it shows minimal environmental variance. The performance of a trait depends on the genotype, the environment, and their interaction, which helps identify genotypes adapted to specific environments. Grain yield stability is influenced by the capacity of a genotype to react to environmental conditions, which is determined by the genotype's genetic composition. Environmental factors often account for a significant portion of the total variation observed in traits (Blanche et al., 2009). The previous studies reported the G×E interaction for rice in middle Gujarat conditions (Parmar et al., 2012; Bhatt et al., 2015; Parmar et al., 2016) using different stability models. Bhatt et al., 2015 in middle Gujarat climatic zone screened the genotypes using the Eberhart and Russell (1966). This is method commonly used for analysis of G×E interaction is the linear regression model in which the bi (regression) values give information about adaptability and S^2di is used as measure of stability of performance. An ideal genotype should have both high mean yield performance and high stability across environments (Gedif and Yigzaw, 2014). G×E interaction, linked with high yield suggests the suitability of variety in varying environments. But this ideal condition is rare and the varieties with high stability generally show low yield capacity and vice versa. Evaluating genotypes under various contrasting environments within certain variation is a recognized approach for choosing stable genotypes. This study constructed with aim to dissect the G×E interaction and identify the stable genotypes for general cultivation.

2. MATERIALS AND METHODS

2.1. *Experimental sites*

The experiment was conducted in three different environments viz., Main Rice Research Station, Anand Agricultural University, Nawagam (E_1), Paddy Research Station, Anand Agricultural University, Dabhoi (E_2), Agricultural Research Station for Irrigated Crops, Anand Agricultural University, Thasra (E_3), during the year *kharif* (June–November) 2022 at Gujarat, India.

2.2. *Experimental material*

The experimental material was comprised of 32 diverse genotypes of rice. All the experiments were conducted in Randomized Complete Block Design with three replications. Each genotype was planted in a single row of 3.0 m length, 20 cm apart, with a 15 cm plant-to-plant spacing. The recommended agronomical and plant protection practices were followed for the successful raising of the crop.

2.3. *Observations recorded*

Five plants were randomly selected from each experimental unit of each replication and used to record observations for the grain yield as well as its component characters. Observations were recorded on fifteen different characters of rice i.e., days to 50% flowering, plant height (cm), productive tillers plant^{-1}, panicle length (cm), panicle weight (g), number of grains panicle^{-1}, test weight (g), grain yield plant^{-1} (g), harvest index (%), hulling (%), milling (%), grain L:B ratio (mm), head rice recovery (%), alkali spreading value and amylose content (%).

2.4. Statistical analysis

The mean value of each experimental unit for various traits was computed. These calculated mean values for the various characters were used for statistical analysis. The statistical analysis for the G×E interaction and stability parameters were estimated using the procedure given by Eberhart and Russell (1966). The genotype mean across all environments, the regression coefficient, and the deviation from regression are the three main stability parameters. The genotype means across all environments ($\bar{x}_i$), provides a comparative evaluation of each individual genotype. The regression coefficient (b_i) is the regression of the performance of each genotype in different environments on the environmental index, which is a measure of response of particular genotype to environments. The deviation from regression (S^2d_i) is considered as a measure of the stability of an individual genotype, accounting for unpredictable irregularities in genotype response to various environments.

These parameters were estimated as:

a) Mean ($\bar{x}_i$): The mean value of ith genotype over all the environments for each genotype was calculated using following formula: $\bar{x}_i = \sum^n_{j=1} Y_{ij}/n$

b) Environmental index (I_j): Environmental index was calculated as the mean of all genotypes in the jth environment minus the grand mean for all the environments.

$I_j = [\sum^n_{j=1} Y_{ij})/n] - [(\sum^g_{i=1} \sum^n_{j=1} Y_{ij})/gn]$

Where, $\sum^n_{j=1} I_j = 0$, g = Number of genotypes, n = Number of environments

c) Regression coefficient (b_i): The regression coefficient (b_i) for each genotype was calculated using following formula:

$b_i = (\sum^n_{j=1} Y_{ij} I_j / \sum^n_{j=1} I^2_j$

d) Mean square deviation from linear regression (S^2d_i): The mean square deviation from linear regression (S^2d_i) *i.e.* non-linear component of Genotype×environment interaction for each genotype was calculated using following formula:

$S^2d_i = (\sum^n_{j=1} \delta^2_{ij}/n-2) - (\sigma^2_e/r)$

$$\sum_{j=1}^{n} \delta^2_{ij} = [\sum_{j=1}^{n} Y^2_{ij} - \frac{Y^2_i}{n}] - [\frac{(\sum^n_{j=1} Y_{ij} Ij)^2}{\sum^n_{j=1} I^2_j}]$$

Where, r=Estimate of pooled error, n=Number of environments, r = Number of replications, g=Number of genotypes.

e) Test of significance

- Test of significance among genotype mean was done using null hypothesis as given below:

$H_0 = \mu_1 = \mu_2 = \mu_3 = \ldots\ldots = \mu_n$

The 'F' test for testing significance:

$F = MS_1/MS_3$

- To test the differences among genotypes for their regression on environmental index, the hypothesis was as follow:

$H_0 = b_1 = b_2 = b_3 = \ldots\ldots = b_n$

The 'F' test for testing significance:

$F = MS_2/MS_3$

If mean square for pooled deviation (MS_3) is non-significant, then MS_4 is used as the denominator and if MS_3 is significant, then MS_3 itself is used as the denominator to test the significance in 'F' test.

- To test the deviation of individuals from linear regression (b_i)

The regression coefficient (b_i) for each genotype was tested using 't' test as given below: Here, to test the significance of b_i from zero:

$t_{(n-2)} = |b_i - 0| / S.E.\ \text{of}\ b_i$

Where, $S.E.\ (b_i) = \sqrt{}\sum^n_{j=1} \delta^2_{ij})/(n-2)/\sum^n_{j=1} I^2_j$

Where,

The significance of the deviation from linear regression (S^2d_i) for each genotype was tested using 'F' test:

$F = (\sum^n_{j=1} \delta^2_{ij}/(n-2))/$Pooled error mean square (M'_e)

Where, Pooled error mean square (M'_e) $= \sigma^2_e/r$

3. RESULTS AND DISCUSSION

3.1. Analysis of variance (ANOVA)

The analysis of variance of all the fifteen traits for each environment is revealed that the mean squares due to genotypes were significant for all of the traits evaluated in all individual environments, which suggested the presence of a sufficient amount of variability in the material evaluated for grain yield and its contributing traits. The wide range of diversity allows plant breeders to select superior and desired genotypes for further crop improvement.

3.2. Pooled analysis of variance (ANOVA)

The analysis of variance for stability analysis showing the mean sum of squares due to various sources of variations for different characters investigated are presented in Table 1. The mean squares due to genotypes over environments were found significant for all the characters studied. It indicated the presence of a considerable amount of variability among the genotypes for various characters under study. Environments significantly differed for all the characters, except test weight and grain L:B ratio, which indicated the significant influence of environment on the expression these characters under investigation. The G×E interaction was highly significant for most of the traits except, test weight, hulling, milling, head rice recovery, grain L:B ratio, amylose content and alkali spreading value. These results revealed

Table 1: Analysis of variance for stability analysis showing the mean sum of squares for various characters (Eberhart and Russell, 1966)

Source	d.f.	Days to 50% flowering	Plant height (cm)	Productive tillers plant^{-1}	Panicle length (cm)	Panicle weight (g)	No. of grains panicle^{-1}	Grain yield plant^{-1} (g)	Harvest index (%)
Genotypes (G)	31	238.59**	260.72**	1.02**	7.04**	0.50**	8579.50**	23.44**	71.82**
Environments (E)	2	230.23**	1897.43**	12.02**	33.54**	4.84**	2066.69**	651.38 **	55.58**
Genotypes×Environments	62	4.67**	28.65**	0.49**	1.18**	0.13**	103.52*	6.96 **	22.29**
Environments+(G×E)	64	11.71**	87.05**	0.85**	2.19	0.28**	164.87**	27.10**	23.33*
Environments (linear)	1	460.46**	3794.85**	24.04**	67.08**	9.69**	4133.37**	1302.76**	111.16**
G×E (linear)	31	5.97*	30.49	0.61*	0.89	0.17*	155.26*	8.94*	31.76**
Pooled deviations	32	3.26**	25.97**	0.36	1.42**	0.09**	50.16	4.83*	12.43**
Pooled error	186	0.74	5.68	0.31	0.57	0.04	74.13	2.85	5.96

*, ** Significant at (p=0.05) and (p=0.01) level of significance, respectively

the differential behaviour of the genotype over location for all the characters except the one quantitative and six quality traits mentioned above. The findings were in conformity for significance of G×E interaction with Gaballah et al. (2016) for panicle weight; Jain et al. (2019) for number of grains panicle^{-1}; Prajapati and Kathiria (2018), Rawte et al. (2021), Nayak et al. (2022) for grain yield plant^{-1}.

3.3. Eberhart and russell ANOVA

The further partitioning of G×E interaction was done as per Eberhart and Russell's model (1966) in order to determine the magnitude of linear and non-linear components of variation, that provide information on predictable and unpredictable sources of variation, contributing to Genotype×Environment interactions for all traits, respectively. The values of mean square due to Environments+(Genotypes×Environments) were found to be significant for all the characters except panicle length, which suggested variable response of genotypes to changing environments. Mean square due to Environments (linear) was found highly significant for all the characters, which suggested that environments varied considerably among different location for all the traits investigated. The higher magnitude of mean squares for Environments (linear) compared to Genotypes×Environments (linear) indicated that linear response of environment accounted for the major part of the total variation for all the traits under investigation.

The mean squares due to Genotypes×environments (linear) were found significant for traits such as days to 50% flowering, productive tillers plant^{-1}, panicle weight, number of grains panicle^{-1}, grain yield plant^{-1} and harvest index, which indicated linear response of genotypes to changing environments and hence genotype performance would be predictable for those characters. The present findings agree with Saidaiah et al. (2010) for panicle weight; Jain et al. (2019) for number of grains panicle^{-1}; Shinde and Patel (2014), Gaballah et al. (2016), Parimala et al. (2019) for grain yield plant^{-1}. While the linear component of G×E interaction was found non-significant for the traits like plant height, panicle length.

The non-linear component of G×E interaction i.e., pooled deviation was found significant for most of the characters i.e., days to 50% flowering, plant height, panicle length, panicle weight, grain yield plant^{-1} and harvest index. The findings are in conformity with Pandey et al. (2020) for panicle weight; Prajapati and Kathiria (2018), Rawte et al. (2021), Nayak et al. (2022) for grain yield plant^{-1}. While pooled deviation was found non-significant for productive tillers plant^{-1} and number of grains panicle^{-1}. The results are in confirmation with Gaballah et al. (2016), Vanisri et al. (2016) for productive tillers plant^{-1}.

Both linear as well as the non-linear component of G×E interaction found significant for the traits like days to 50% flowering, panicle weight, grain yield plant^{-1} and harvest index. Which indicated that performance of genotypes for these traits was partly predictable and partly unpredictable in nature. The findings are in conformity with Pandey et al. (2020) for days to 50% flowering; Saidaiah et al. (2010), for panicle weight; Shinde and Patel (2014), Gaballah et al. (2016), Parimala et al. (2019) for grain yield plant^{-1}.

The linear component of the G×E interaction was higher than the non-linear component i.e., pooled deviation for days to 50% flowering, panicle weight, harvest index and grain yield plant^{-1}. Thus, predominance of linear components suggested that linear regression accounted for a large portion of the G×E interaction for these traits. The reported predominance of linear components may help in accurate forecasting of genotype performance across environments.

3.4. Environmental index

The environmental indices calculated for all the fifteen characters investigated are presented in Table 2 and Figure 1 indicating both the favourable and unfavourable environments for all the component traits. Computation of environmental indices revealed that in Nawagam (E_1) there was a substantial increase in the values of the environmental index, which indicated that it was a favourable environment for grain yield plant^{-1} (I_1=4.608) and yield attributes viz., productive tillers plant^{-1} (I_1=0.622), panicle length (I_1=1.139), panicle weight (I_1=0.342), number of grains panicle^{-1} (I_1=8.242) and test weight (I_1=0.071). As earliness is considered best for developing early maturing varieties, Nawagam (E_1) was considered the most compatible environment for days to 50% flowering (I_1=-0.003). Likewise, low alkali spreading value is also desirable for rice, Thasra (E_3) environment was considered as the most appropriate environment for alkali spreading value (I_3=-0.101).

Table 2: Estimation of the environmental index (Ij) for each character under different environments

Sl. No.	Characters	E_1	E_2	E_3	$\sum Ij^2$
1.	Days to 50% flowering	-0.003	2.684	-2.681	14.389
2.	Plant height (cm)	8.811	-5.439	-3.372	118.589
3.	Productive tillers plant^{-1}	0.622	-0.603	-0.018	0.751
4.	Panicle length (cm)	1.139	-0.296	-0.843	2.096
5.	Panicle weight (g)	0.342	-0.423	0.081	0.303
6.	No. of grains panicle^{-1}	8.242	-7.813	-0.429	129.168
7.	Grain yield plant^{-1} (g)	4.608	-4.409	-0.200	40.711
8.	Harvest index (%)	-0.439	-1.042	1.481	3.474

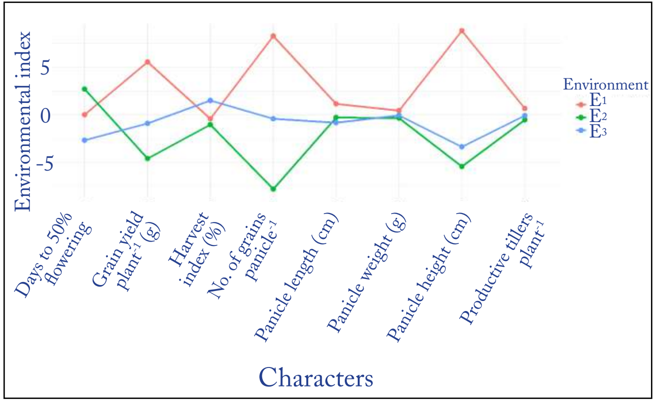

Figure 1: Character variation across environments using environmental index

While, the environment E_2 (Dabhoi) was the unfavourable environment among all the environments under investigation for most of the yield and its attributes viz., grain yield plant^{-1} (I_2=-4.409), productive tillers plant^{-1} (I_2=-0.603), panicle length (I_2=-0.296), panicle weight (I_2=-0.423), number of grains panicle^{-1} (I_2=-7.813) and test weight (I_2=-0.118). As in environment E_2 (Dabhoi), most of the genotypes were found very late in flowering, it was considered the most unfavourable environment with respect to the characters days to 50% flowering (I_2=2.684). In contrast it showed favourable response for plant height (I_1=-5.439).

The methodology developed by Eberhart and Russell (1966) for studying cultivar adaptability and stability consists essentially of a simple linear regression analysis of a dependent variable for each genotype, in our instance the yield in each environment and in relation to the environmental index, it is calculated from the mean of all genotypes in the environment. The superiority of an environment at a specific location or in a specific season is revealed by the environmental index. The use of environmental index to discriminate the favourable and unfavourable environments was done by Ghazy et al. (2024) and El-Aty et al. (2024) to interpret the results of regression model. According to Breese (1969), the estimates of the environmental index can provide the basis for identifying the superior environment for the expression of the genotype's maximum potential. The positive and negative values of the environmental index indicate the superior and inferior situations for each character, respectively. The selection of genotypes should be based on the its performance in all environment; however, the environmental index helps in site specific genotypes selection.

3.5. Stability parameters

The Genotype×environment interaction measures the differential response of genotypes to environmental changes. This interaction could mitigate the progress of selection and cause difficulty in the identification of stable cultivars. Eberhart and Russell (1966) defined genotypes with higher mean values ($\bar{x}_i$), unit regression coefficients (b_i=1), and non-significant deviation from linear regression (S^2d_i=0) to be stable and adaptable to different environmental conditions. Genotypes with a higher mean value and regression coefficient greater than unity (b_i>1), as well as a non-significant deviation from linear regression, were regarded as responsive and suitable for favourable environmental conditions. Furthermore, genotypes with higher mean values and regression coefficients less than unity (b_i<1) or negative and non-significant deviations from linear regression were considered to be best suitable for unfavourable environmental conditions. Likewise, all the genotypes were classified as being suitable for different environmental conditions. The regression analysis was not performed for seven characters *i.e.*, test weight, hulling (%), milling (%), head rice recovery, grain L: B ratio, amylose content and alkali spreading value, as the G×E interaction was found non-significant for those traits. Once it is confirmed that genotypes interact significantly with the environment, the next step is to identify the most desirable genotypes. In this paper we have discussed the stability parameters of rice grain yield.

A graph prepared on the bases of stability parameters for grain yield plant^{-1} is depicted in Figure 2. In the graph, the b_i values of different genotypes are plotted against their corresponding mean yields ($\bar{Y}_i$). Then the line-pair $y=\bar{b}\pm SE(b_i)$ parallel to X-axis (the yield axis) and the pair $x=\bar{Y}..)\pm SE(\bar{Y}_i)$ parallel to Y-axis are drawn, thus enclosing the points plotted earlier into different regions.

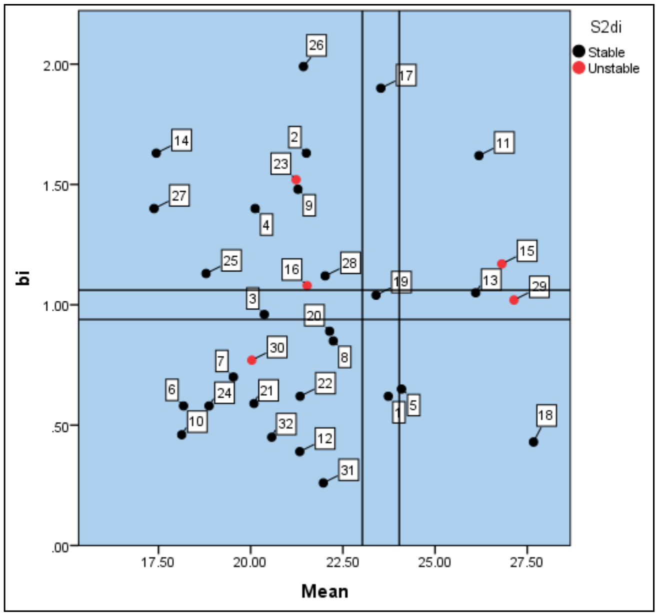

Figure 2: Graph depicting stability parameters (Mean-regression coefficient (bi)) for grain yield plant^{-1}

The stability analysis for grain yield plant^{-1} revealed that the mean performance of 11 genotypes was higher than the overall mean (21.76) for this trait. Genotypes IET-29970, IET-28354, IET-29774, Gontra Bidhan 3, IET-29238 and others, which had a higher mean than the overall mean were considered desirable genotypes. The minimum and maximum grain yield plant^{-1} were 17.38 (IET-28792) and 27.67 (IET-28757), respectively [Table 3, Figure 2].

The further examination of data for this trait demonstrated that a non-significant deviation from regression (S^2d_i=0)

Table 3: Stability parameters (Eberhart and Russell, 1966) for grain yield plant^{-1} in rice

Sl. No.	Genotypes	Grain yield plant^{-1} (g)		
		Mean	bi	S^2d_i
1.	IET-29970	23.73	0.62 ** @@	-2.78
2.	IET-28343	21.51	1.63 ** @@	-2.63
3.	IET-30221	20.37	0.96 **	-2.29
4.	Shobini	20.12	1.40 ** @	-1.51
5.	IET-28354	24.09	0.65 **	-1.22
6.	IET-27823	18.18	0.58 ** @	-1.15
7.	IET-28329	19.53	0.70 **	-0.66
8.	IET-29774	22.24	0.85 **	-2.45
9.	IET-29814	21.28	1.48 **	2.68
10.	IET-29219	18.13	0.46 * @@	-1.22
11.	Gontra Bidhan 3	26.19	1.62 ** @@	-2.77
12.	Karjat 7	21.33	0.39	4.72
13.	IET-29238	26.10	1.05	5.87
14.	NDR 359	17.44	1.63 ** @	0.45
15.	IET-27077	26.81	1.17	18.04
16.	IET-30116	21.53	1.08	17.53
17.	IET- 28730	23.53	1.90 ** @@	-1.20
18.	IET-28757	27.67	0.43	-0.39
19.	IET-29538	23.40	1.04 **	-1.37
20.	IET-28746	22.14	0.89 ** @@	-2.84
21.	IET-29482	20.09	0.59 ** @	-1.43
22.	IET-29469	21.34	0.62 ** @@	-2.80
23.	IET-30120	21.23	1.52 **	10.93
24.	IET-30132	18.87	0.58 ** @	-1.49
25.	IET-29465	18.79	1.13 ** @@	-2.83
26.	IET-30149	21.43	1.99 ** @@	-2.40
27.	IET-28692	17.38	1.40 **	0.52
28.	IET-28703	22.02	1.12 **	-1.32
29.	IET-27984	27.14	1.02	26.76
30.	GR 21 (C)	20.03	0.77	9.10
31.	GAR 22 (C)	21.97	0.26	-0.73
32.	GAR 14 (C)	20.57	0.45	4.27
	General mean	21.76	-	-
	Standard error	1.27	0.06	-

*, ** Significant at (p=0.05) and (p=0.01) level of significance when Ho: b_i=0; @, @@ significant at (p=0.05) and (p=0.01) level of significance when Ho: bi=1; #, ## Significant at (p=0.05) and (p=0.01) level of significance

was found only in 27 genotypes out of the 32 genotypes under study, thus the performance of these genotypes can be predicted. Whereas, significant deviation from regression (S^2d_i=0) was found in the rest of the 5 genotypes, which indicated that their performance cannot be predicted.

The 22 genotypes, which had a non-significant deviation from regression (S^2d_i=0) also exhibited a significant regression coefficient at b_i=0, showing their proneness to changing environments. The higher mean estimates than the overall mean, regression coefficient nearly equal to unity (b_i=1) and non-significant deviation from regression (S^2d_i=0) was displayed by only four genotypes viz., IET-28354, IET-29774, IET-28703 and IET-29538, which indicated that this was the only genotype found stable and well adapted under all the environmental conditions.

The two genotypes IET-28730 and Gontra Bidhan-3 were considered stable and specifically adapted to favourable environments, as they showed a higher mean than the overall mean, regression coefficient greater than unity (b_i>1) and non-significant deviation from regression (S^2d_i=0). While IET-29970 and IET-28746 were found with a higher mean value than the overall mean, regression coefficient below unity (b_i<1) and non-significant deviation from regression (S^2d_i=0), therefore this genotype was specifically adapted to unfavourable environment.

Stability parameters computed for different rice genotypes revealed that four genotypes i.e., IET-28354, IET-29538, IET-29774 and IET-28703 were found stable in all the environments with wider adaptability for grain yield plant^{-1}. Out of these four, IET-28354 (24.09 g) was the best yielder and also found stable in all environments for plant height, number of grains panicle^{-1} and harvest index. It was also found stable and adapted to unfavourable environment (E_3: Thasra) for panicle length and panicle weight. Therefore, it was identified as the best genotype to grow across the environments. Another genotype IET-29538 was found with 23.40 g of grain yield as well as stable for number of productive tillers plant^{-1}. It was also found stable and specifically adapted to the un-favourable environment (E_2: Dabhoi) for panicle weight. The genotype IET-29774 (22.24 g) also produced grain yield higher than the general mean over environments. The best feature of this genotype was that it remained stable for days to 50% flowering. Also, two genotypes viz., IET-28730 and Gontra Bidhan 3 were found stable and specifically adapted to the favourable environment i.e., E_1: Nawagam. Further two genotypes IET-29970 and IET-28746 were found stable and specifically adapted to the unfavourable environment i.e., E_2: Dabhoi [Table 4].

It is difficult to generalize stability for all genotypes relative

Table 4: List of the genotypes which were stable and well adapted to all environments or specifically adapted to favourable environments or unfavourable environments for various characters

Sl. No.	Character	Stable and widely adapted to all environments	Stable and specifically adapted to the favourable environment	Stable and specifically adapted to the unfavourable environment
1.	Days to 50% flowering	4 genotypes	E_3-Thasra (5 genotypes)	E_2-Dabhoi (2 genotypes)
		IET-29774, Gontra Bidhan-3, Karjat-7	IET-29814, IET-30116, IET-30132, IET-30149, IET-28692	IET-29970, GR-21
2.	Plant height	5 genotypes	E_2-Dabhoi (1 genotype)	E_1-Nawagam (1 genotype)
		IET-28343, IET-28354, IET-28329, Gontra Bidhan-3, IET-30132	IET-29482	NDR-359
3.	No. of productive tillers plant^{-1}	7 genotypes	E_1-Nawagam (2 genotypes)	E_2-Dabhoi (3 genotypes)
		IET-29814, IET-29238, IET-29219, IET-29538, IET-29746, IET-30132, IET-30149	IET-29469, IET-29465	IET-29970, IET-28757, GR-21
4.	Panicle length	2 genotypes	E_1-Nawagam (1 genotype)	E_3-Thasra (1 genotype)
		IET-28343, IET-29814	IET-29469	IET-28354
5.	Panicle weight	5 genotypes	E1-Nawagam (5 genotypes)	E2-Dabhoi (2 genotypes)
		IET-28343, IET-30221, IET-29814, IET-28757, IET-28354,	Shobini, IET-28730, Gontra Bidhan-3, IET-30149, IET-28692	IET-29538, IET-27984

Table 4: Continue...

Sl. No.	Character	Stable and widely adapted to all environments	Stable and specifically adapted to the favourable environment	Stable and specifically adapted to the unfavourable environment
6.	No. of grains panicle^{-1}	5 genotypes	E_1-Nawagam (2 genotypes)	E_2-Dabhoi (0 genotype)
		Shobini, IET-28354, IET-29814, Gontra Bidhan-3, IET-28730	GR-21, GAR-14	-
7.	Grain yield plant^{-1}	4 genotypes	E_1-Nawagam (2 genotypes)	E_2-Dabhoi (2 genotype)
		IET-28354, IET-29774, IET-28703, IET-29538	IET-28730, Gontra Bidhan-3	IET-29970, IET-28746
8.	Harvest index (%)	2 genotypes	E_3-Thasra (5 genotypes)	E_2-Dabhoi (1 genotype)
		IET-28343, IET-28354	IET-29238, IET-27077, IET-30116, IET-28730, IET-28757	GR-21

to all observations as because the genotypes used in this study did not exhibit a uniform stability and response pattern for different observations (Muthuramu, 2023). As the environment and environment linear is significant with linear genotype and environment interaction, the genotype performance can be predicted. Wasan et al. (2018) identified seven genotypes (Jaowmong 1, Neawmong 1, Neawdum 1, Leamna, Prayaleamkang, Kunwang 2, and Kunwang 3) that showed great yield stability over five locations using stability parameters. Similarly, the genotypes, DRR Dhan 48 and HURZ-3 showed good mean values for all the traits and stability for grain zinc, yield per hectare, 1000 grain weight in research study by Pandey et al. (2020) using linear G×E interaction. Recently Muthuramu (2023) used the landraces and identified Sivappuchithiraikar and Mysore malli with highest grain yield and general stability. Therefore, stability parameters could be used reliably for predicting genotypes performances.

4. CONCLUSION

The study provided dissection of genotype and environment interaction. The tested genotypes ranked differently across three environments. After confirmative testing, the promising stable genotypes viz., IET-29538, IET-28354, IET-29774 and IET-28703 can be rerecommended for general cultivation.

5. REFERENCES

Anonymous, 2021. Crop-wise final advance estimate of area, production and yield of food grains, oilseeds and other crops for Gujarat State, Director of Agriculture Gujarat state, Gandhinagar. Available at https://dag.gujarat.gov.in/Home/AreaProductionAndYield accessed on 14th March 2022.

Anonymous, 2022. International Production Assessment Division, Foreign Agriculture Service, U. S. Department of Agriculture. https://ipad.fas.usda.gov/countrysummary/Default.aspx?id=IN&crop=Rice. accessed on: 7th August 2023.

Bhatt, J.P., Nanavati, J.I., Mehta, A.M., 2015. Stability analysis and G×E interactions in lowland rice promising genotypes. ORYZA-An International Journal on Rice 52(3), 217–221.

Blanche, S.B., Utomo, H.S., Wenefrida, I., Myers, G.O., 2009. Genotype×environment interaction of hybrid and varietal rice cultivars for grain yield and milling quality. Crop Science 49(6), 2011–2018.

Breese, E.L., 1969. The measurement and significance of genotype×environment interactions in grasses. Heredity 24, 27–44.

Cassia, R., Nocioni, M., Correa-Aragunde, N., Lamattina, L., 2018. Climate change and the impact of greenhouse gasses: CO_2 and NO, friends and foes of plant oxidative stress. Frontiers in Plant Science 9. doi: www.doi.org/10.3389/fpls.2018.00273.

Eberhart, S.T., Russell, W.A., 1966. Stability parameters for comparing varieties. Crop Science 6(1), 36–40.

El-Aty, M.S.A., Abo-Youssef, M.I., Sorour, F.A., Salem, M., Gomma, M.A., Ibrahim, O.M., El-Tahan, A.M., 2024. Performance and stability for grain yield and its components of some rice cultivars under various environments. Agronomy 2024, 14, 2137.

Fukagawa, N.K., Ziska, L.H., 2019. Rice: importance for global nutrition. Journal of Nutritional Science and Vitaminology (Tokyo) 65, S2–S3. doi: www.doi.org/10.3177/jnsv.65.S2.

Gaballah, M.M., Hassan, H.M., Shehab, M.M., 2016. Stability parameters for grain yield and its components in some rice genotypes under different environments. Paper presented at 6th Field Crops conference, FCRI, AEC, Giza, Egypt, 3–14.

Gedif, M., Yigzaw, D., 2014. Genotype by environment interaction analysis for tuber yield of potato (*Solanum tuberosum* L.) using a GGE biplot method in Amhara region, Ethiopia. Agricultural Sciences 5, 239–249. www.doi.org/10.4236/as.2014.54027.

Ghazy, M.I., Abdelrahman, M., El-Agoury, R.Y., El-Hefnawy, T.M., El-Naem, S.A., Daher, E.M., Rehan, M., 2023. Exploring genetics by environment interactions in some rice genotypes across varied environmental conditions. Plants 13(1), 74.

Jain, B.T., Sarial, A.K., Kaushik, P., 2019. Understanding G×E interaction of elite basmati rice (*Oryza sativa* L.). genotypes under north Indian conditions using stability models. Applied Ecology and Environmental Research 17(3), 5863–5885.

Karbi, I., Chemke, R., 2023. A shift towards broader and less persistent Southern Hemisphere temperature anomalies. NPJ Climate and Atmospheric Science 6, 1–7. doi: www.doi.org/10.1038/s41612-023-00526-9.

Li, R., Li, M., Ashraf, U., Liu, S., Zhang, J., 2019. Exploring the relationships between yield and yield-related traits for rice varieties released in China from 1978 to 2017. Frontiers in Plant Science 10, 543.

Muthayya, S., Sugimoto, J.D., Montgomery, S., Maberly, G.F., 2014. An overview of global rice production, supply, trade, and consumption. Annals of The New York Academy of Sciences 1324(1), 7–14.

Muthuramu, S., 2023. Stability analysis in rice landraces grown under dry Direct seeded condition. Bangladesh Journal of Botany 52(4), 941–948.

Nayak, G.P., Sujatha, M., Chandra, M.Y., Saida, N.D., Kiran, B.T., 2022. Stability analysis for grain yield and yield contributing traits in hybrid rice. Biological Forum-An International Journal 14(1), 1230–1234.

Pandey, V., Singh, S.K., Korada, M., Singh, D.K., Khaire, A.R., Habde, S., Majhi, P.K., 2020. Stability analysis in rice (*Oryza sativa* L.) genotypes with high grain zinc. Indian Journal of Agricultural Research 54(6), 689–698.

Parimala, K., Surender, R.C., Sudheer, K.S., Narender, R.S., 2019. Stability analysis over different environments for grain yield and its components in hybrid rice (*Oryza sativa* L.). Electronic Journal of Plant Breeding 10(2), 389–399.

Parmar, D.J., Patel, J.S., Mehta, A.M., Makwana, M.G., Patel, S.R., 2012. Non-parametric methods for interpreting genotype×environment interaction of rice genotypes (*Oryza sativa* L.). New Facets of 21st Century. Plant Breeding 5(1), 18.

Parmar, D.J., Patel, J.S., Motak, G.N., Vaishnav, P.R., Mehta, A.M., 2016. Study of genotype x environment interaction in rice (*Oryza sativa* L.) by stability estimates. ORYZA-An International Journal on Rice 53(2), 144–150.

Prajapati, K.N., Kathiria, K.B., 2018. Genotype×environment interactions and stability for grain yield and its components in WBPH tolerant rice (*Oryza sativa* L.). International Journal of Bio-resource and Stress Management 9(1), 137–141.

Rawte, S., Saxena, R.R., Verulkar, S.B., 2021. Analysis of yield stability of rice (*Oryza sativa* L.) landraces under drought conditions with three different approaches. Indian Journal of Genetics and Plant Breeding 81(2), 236–244.

Saidaiah, P., Sudheerkumar, S., Ramesha, M.S., 2010. Stability analysis of rice (*Oryza sativa* L.) hybrids and their parents. Indian Journal of Agricultural Sciences 81(2), 111–115.

Sakamoto, T., Matsuoka, M., 2008. Identifying and exploiting grain yield genes in rice. Current Opinion in Plant Biology 11(2), 209–214.

Sen, S., Chakraborty, R., Kalita, P., 2020. Rice-not just a staple food: A comprehensive review on its phytochemicals and therapeutic potential. Trends in Food Science & Technology 97, 265–285. doi: www.doi.org/10.1016/j.tifs.2020.01.022.

Shinde, D.A., Patel, P.B., 2014. Genotype and environment interaction and stability analysis for yield and its contributing traits in rice. Oryza 51(3), 195–203.

Simmer, R.A., Jansen, E.J., Patterson, K.J., Schnoor, J.L., 2023. Climate change and the sea: A major disruption in steady state and the master variables. ACS Environmental Au 3, 195–208. doi: www.doi.org/10.1021/acsenvironau.2c00061.

Umarani, E., Hemalatha, V., Saritha, A., Ramanjaneyulu, A.V., 2020. Impact of high temperature stress in rice. International Journal of Economic Plants 7(3), 108–110. https://doi.org/10.23910/2/2020.0366.

Vanisri, S., Raju, S., Raju, D., Reddy, P.R., Suryanarayana, Y., 2016. Genotype×environment interaction and stability analysis of promising rice cultures under different sowing dates during *kharif*. Electronic Journal of Plant Breeding 7(3), 794–798.

Wasan, J., Tidarat, M., Sompong, C., Bhalang, S., Jirawat, S., 2018. Evaluation of stability and yield potential of upland rice genotypes in North and Northeast Thailand. Journal of Integrative Agriculture 17(1), 28–36.