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Comparison of parametric stability models for genotype x environment interaction in cold tolerant genotypes of rice (*Oryza Sativa* L.) for vigour index

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ABSTRACT

Evaluation of promising rice genotypes in multi-environmental situations takes into consideration the genotype by environment interaction as a key step. This study was performed to spot stable, cold tolerant genotypes for seedling cold stress with attributes for future breeding programs. Thirty-eight rice genotypes were screened for cold stress under laboratory conditions to determine their stability and adaptability with various stability models, viz., Wricke's Ecovalence, Coefficient of Variation, Tai Stability Analysis, Shukla's Stability Variance, Superiority Measure, Perkins and Jinks and Eberhart-Russell method. The G×E interaction effects explained the trait vigour index to be contributed mainly by the environmental component. The vigour index was positively correlated with Superiority measure and Perkins and Jinks stability models. Among all the genotypes, VIVEKDHAN-85, SKAU-389, RAJENDRA, K-429, RP-2421 and HPR 2336 were found to be promising by having wider adaptability in different environmental conditions and could serve as reliable donors in the target environments offering a vital source for expanding the genetic base of cold stress tolerance and development of adapted genotypes.

Keywords- *Rice, Coefficient of Variation, Cold tolerance, Genotype x environment interaction, Shukla's Stability Variance, Superiority Measure, Tai Stability Analysis, vigour index, Wricke's ecovalence.*

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Introduction

Rice (*Oryza sativa* L.) is a means of subsistence as a food crop across Asia where half of the world's poorest people reside. The crop is unique because it can be cultivated in wet conditions which may not be possible for other crops to survive. To combat the elevating food demand, breeding for high yielding varieties of rice coupled with tolerance to abiotic stresses is extremely important. Among the abiotic stresses, cold stress is a highly significant factor that disturbs the rice development and metabolism cultivated in temperate and high-elevated regions. It interferes with the development of plant morphologically and reduces the yield performance. When seedlings are prone to cold, improper seed germination, injury to seedlings, weak crop stand coupled with diminishing productivity and stability of yield is witnessed. Even rolling of leaves, yellowing, necrosis and dwarfing of seedlings were reported [1]. In north-eastern India, rice cultivation during the winter season is frequently subjected to cold stress affecting the seed growth, tillers formation, fertility and ultimately the yield [2]. In Telangana, especially during the *Rabi* season, the productivity of rice in northern districts is hampered by cool temperatures of <10°C during December and January resulting in stunted growth and poor tillering of the seedlings. Thus, under such conditions, cultivation of cold tolerance genotypes will be useful in producing optimum yield. Since cold tolerant genotypes normally belong to *japonica* subspecies of rice, the need for the development of cold tolerance in *indica* lines suited to rabi and higher-latitude zones persists.

On the other hand, seedling vigour is the product of size of seedling, internal condition, and rate of development related to genetic and environmental impacts. It is regarded as a main element in seed standards that deciphers precise information on the field performance potential of seed lots. Coupled with cold stress, low vigour in seeds may aggregate reduced speed of germination with low seedling emergence uniformity, affecting the initial and final crop establishment, consequently minimizing the seed production [3]. Since the seed health and quality are highly influenced by the time of sowing, edapho-climatic factors, growing environment, the genetic architecture of species [4], the search for greater adaptable cultivars may hasten the performance of rice seeds with good physiological functioning.

For assessment of stability, optimum performance of cultivars is very much necessary [5]. A cultivar could be considered superior with an ability to perform well in a favorable climate coupled with phenotypic stability. Selection and evaluation of plant cultivars are usually influenced by the interaction of Genotype and environment (G x E). There have been several statistical techniques employed for Genotype by Environment interaction analysis [6]. However, the most commonly followed techniques rely on the statistics of regression, parameters of variance along with non-parametric approaches. Preliminary base for considering regression model being a technique of stability assessment was put forward [7], and it was revamped [8]. Tai with his companions assessed phenotypic stability with the help of regression coefficient (b) and deviations of mean square from the regression (s^2d) for some key characters as an altered model of what Eberhart and Russell (1966) procured [9]. The ecovalence as a measure of stability which includes genotype's role in the total sum of squares of Genotype by Environment interaction [10]. Shukla gave the famous parameter of 'stability variance' (S^2) by altering the Wricke's ecovalence model for the purpose of providing an impartial outcome of the Genotype by Environment variance pertaining to all genotypes [11]. Francis and Kannenberg considered the coefficient of variation measure (cv*i*) for every cultivar as a parameter of adaptation [12], while it was recommended as a superiority index (*Pi*) measure, by taking in account the average of squared interval in between the cultivar's reaction and the average of highest response accounted from all the environmental conditions [13]. However, among all these stability models, Eberhert and Russell's statistic (1966) is extensively used since it considers both the linear as well as non-linear parts of GEI for determining stable genotypes. As per this stability statistic, cultivar having top mean performance, coefficient of regression being unity and deviation from regression not differing from zero is considered more stable. Thus, an experiment comprising of 38 rice genotypes was performed under low temperature stress at the germination stage in four different experimental conditions to determine the stability and G x E interactions using various parametric stability models.

MATERIALS AND METHODS

Plant material

A collection of 38 cold tolerant genotypes (Table 1) procured from Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Regional Research Station, Palampur and Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir in addition to three checks that were used as a basic material for the study.

Cold tolerance

The cold tolerance experiment was taken up under controlled conditions at Quality control Lab, PJTSAU, Rajendranagar, Hyderabad [14]. Twenty seeds of each genotype were initially rinsed with 70% aqueous ethanol (30 sec) accompanied by soaking in 5% aqueous solution of sodium hydrochlorite (20 min) to avert any microbial risk. Then the seeds were rinsed with distilled water allowed to grow in petri plates with double layered germination paper dipped in distilled water. Genotypes were tested for cold tolerance by germinating them in a BOD seed germinator at different experimental temperatures *viz.,* 28°C for a week (control), 13°C and 8°C for a period of 28 days (treatments) and during Rabi season. By employing the mean data of seedling length (cm) and germination (%), seedling vigour index was calculated.

Parametric stability models

Various parametric stability models were utilized for detecting stable genotypes grown at different temperature conditions as follows:

[10] conceptualized the contribution of every cultivar to the total mean squares of GEI as the ecovalence. Ecovalence or stability (Wi) is determined as the association of ith cultivar with environment described as:

$$W_i = \left[\overline{Y_{ij}} - \overline{Y_{i.}} - \overline{Y_{.j}} - \overline{Y_{..}}\right]^2$$

In which, Yij is overall mean performance of cultivar (i) in jth environmental condition, Yi. With Y.j are the deviations of cultivar and environmental means and Y.. is overall mean. Because of it, cultivars having a lower Wi ecovalence are supposed to have minimum deviations from the environmental means and thus regarded as highly stable.

Coefficient of Variation stability parameter (CVi) was deciphered with combination of coefficient of variation statistic and overall mean performance of cultivar [12].

$$CV_i = \left(\sqrt{S_i^2}/\overline{X}_{i.}\right) \times 100$$

Splitting up the effect of GEI of ith genotype into important Tai's measures, *viz*., α and λ, that measure genotype's linear type of response to the effects of environment and the amount of deviation from the linear response, using the component of GE interaction.

Superiority Index (Pi) value was computed [13].

$$P_i = \sum_{j=1}^{n} (X_{ij} - M_j)^2/2E$$

In which, Xij is performance of cultivar (i) in jth environment, Mj being the high performance of cultivar in (j) environment and E is total number of environmental conditions.

The variance of cultivar's stability as its performance across environmental conditions following the elimation of environmental mean main effects [11].

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)}\left[G(G-1)\sum_j\left(Y_{ij} - \overline{Y}_{i.} - \overline{Y}_{.j} + \overline{Y}_{..}\right)^2 - \sum_i\sum_j\left(Y_{ij} - \overline{Y}_{i.} - \overline{Y}_{.j} + \overline{Y}_{..}\right)^2\right]$$

In which, Yij is overall mean performance of (ith) cultivar in (jth) environment, Yj. is mean of the genotype i in all environments, Y.j is mean of all genotypes in jth environments and Y.. is mean of all genotypes in all environments.

A stability parameter to quantify non-linear sensitivity to the environmental variations was given by Perkins and Jinks with consideration on the GEI constituent of every cultivar as a linear function of additive environmental variation. In 1966, Eberhart and Russell described combining the environmental mean sum of squares and GE interactions and partitioning it into a linear effect between environments and for G by E interaction. For determining index of stability from regression statistic, residual mean sum of squares pooled over all environmental conditions is considered with a stable variety as the cultivar which has less deviation from regression mean squares (Sdi^2). The equation depicting Eberhart and Russell's model includes:

$$Y_{ij} = m + b_i I_j + \delta_{ij} \qquad (i = 1, 2, \ldots, t \text{ and } j = 1,2, \ldots, s).$$

In which, Yij is mean value of cultivar (ith) in environment (jth), m is overall means of all cultivars over entire environmental conditions, bi is regression coefficient of cultivar on the environmental index, Ij is environmental index, which is the mean deviation of performance of all the varities from the total mean value and δij is deviation from regression.

RESULTS AND DISCUSSION

Mean performance of genotypes

Seed vigour is a prime characteristic feature of seed health, determining effective germination of the seed, seedling growth, seed perpetuity and hardening to adverse conditions [15]. High vigour index containing seeds can notably revamp the uniformity and speed of germination leading to an increased field emergence. This, in turn, paves the way for better performance of crop eventually producing higher yield under various situations. In this study, mean vigour index (Table 3) ranged from 5.90 (VL DHAN-221) to 81.60 (HPR-2336). Twenty-two genotypes in *Rabi,* 20 at 28 °C, 20 at 13°C and 18 genotypes at 8°C showed above average mean vigour index. Among the environments, 13°C and 8°C conditions were far below the average vigour index. The highest vigour index was recorded at 28°C followed by *Rabi* with a mean value of 94.86 and 60.54 respectively. Nineteen genotypes (SKAU-382, JHELUM, SKAU-5, SKAU-389, CHENAB, HIMALAYA-1, HIMALAYA-741, HIMALAYA-2216, RP-2421, HPR-1068, SUKARADHAN-1, HPR-2336, VIVEK DHAN-82, VIVEK DHAN-62, VIVEK DHAN-65, VL DHAN-86, V L DHAN-206, VL DHAN-207, VL DHAN-209) have recorded higher individual mean vigour index as compared to the overall genotype mean vigour index across environments of which HPR-2336 and RP-2421 were the best ones which are expected to tolerate temperatures, humidity and produce a good yield.

Analysis of G×E Interaction

Genotype × environment interaction effects are accorded exceptional attention for recognizing the most adaptable cultivars befitted to suitable environmental conditions. A genotype is represented as stable if it performs statically across different environments. Combined Analysis of Variance (ANOVA) for Vigour index across four environmental conditions exhibited highly significant differences for mean squares ($P < 0.01$) in terms of genotype, environment as well as for GE interaction suggesting variable behaviour of genotypes coupled with a wider range of diversity across the tested environments (Table 2). Vigour index was comparatively more affected by environment, which explained 70.79% of overall variation in contrast with genotypes describing 20.13% and GE interaction interpreting 8.86% of the entire variation. The high sum of squares of environment pointed that environmental conditions were distinct with huge variations in mean of environments contributing majority of vigour index variation. The first and second interaction Principal Component Axis explained most of the variation, 78.18% and 19.6%, respectively, while the remaining residuals were not significant. Therefore, IPCA1 and IPCA2 together predicted the total variation among the tested genotypes. Environmental sum of squares was 3.5 times larger than the genotype sum of squares, while the magnitude of the GEI sum of squares was twice smaller than that for genotypes, suggesting smaller variations in response of genotypes. The small mean square error of combined ANOVA signifies that almost all of the variation was accounted. For estimating the magnitude of GEI, though the standard ANOVA procedure is useful, but the relative contribution of each and every genotype to the total GE interaction cannot be known [16]. Thus, in order to dissect the contribution of individual genotypes to the total GEI, various statistical parameters have been deployed to study the adaptability and stability of genotypes.

Stability Statistics

Different parametric based stability models were utilized for identifying stable genotypes for vigour index. Wricke's Ecovalence considers GEI mean square as the thumb-rule for the assessing the stability of genotypes in addition to the relative proportion of each cultivar to the overall interaction of genotype by environment [10]. Lower the Wi^2 values, higher is the stability of genotypes. The ecovalence values (Wi^2) for 38 cold resistant rice genotypes over four environments were presented in Table 3, which ranged from 3.52 for the genotype RAJENDRA to 2825.79 for VL DHAN-221. Since cultivars with the least ecovalence (W_i^2) values are regarded as stable, RAJENDRA was designated as highly stable, followed by K-429. Though genotypes were stable for ecovalence, they had average vigour index values than overall mean index indicating that stability for this parameter is not highly correlated with vigour index. Cultivar general superiority also known as superiority measure was given by Lin and Binns, 1988. It explains the mean square distance between the responses of genotypes to the peak response over varied environmental conditions. This parametric measure largely focuses on genotype's performance rather than a stability measure over environments. Lesser the superiority measure, shorter is the way to the genotype, leading to the emergence of promising genotype with maximum vigour index. Genotypes are identified as adaptable and desirable if they possess a lower superiority measure value. This stability measure described the highly stable genotypes (Table 3) for Pi and vigour index being HPR-2336 followed by the genotypes RP-2421 and HPR-1068, which ranked second and third respectively. This parameter was hugely associated with vigour index, since, genotypes with high vigour index were also observed to be possessing high stability, according to this parameter.

More stable are those varieties with low environmental variance (S^2_i) and coefficient of variation (CV_i) as proposed by Francis and Kannenberg in 1978. In this study, VIVEKDHAN-65, TELLAHAMSA, SKAU-341, and CHINA-1039 genotypes had lesser values for environmental variance (S^2_i) with coefficient of variation (CV_i) compared to the remaining for the vigour index indicating their high adaptability (Table 3, Fig. 1). On the other hand, genotypes SUKARADHAN-1, CHINA-988 and VL DHAN-209 had higher rank for CV_i, thus were classified to be unstable coupled with their lower vigour index. In Shukla's stability variance, with regard to each and every genotype, the Genotype by Environment sum of squares is divided into variance components (σi^2). A genotype is supposed to be adaptable and stable with its stability variance value (σi^2) being close to the variance of environment (σo^2) on the basis of the variance components which indicated by Sh-σi^2 equal to zero. Stable genotypes have smaller stability variance (σi^2), while higher value points the lesser stability of genotypes. This stability parameter aids in the recognition of factors of environment that provides contribution to the heterogeneity in GEI and thus is considered practically important. Results of the present study revealed that RAJENDRA, K-429 and CHINA-1007 were the highly stable genotypes concerning their rank. For this parameter, the stable genotypes had moderate vigour index indicating that high vigour index is always not related to the stability of genotypes.

Two of the genotypic stability statistics that were put forward by Tai (1971) include linear response of environmental effects as quantified by α while the divergence from linear response of the error variance magnitude is reflected by λ. The distribution of 38 rice genotypes on the Alpha-Lambda space depicting distinct regions of stability was shown in Figure 2 with the horizontal axis as lambda (λ) and the vertical axis as alpha (α). Perfect stable genotype has consistent across all environments which is equivalent to determine $\alpha = -1$ and $\lambda = 1$. Genotypes with $\alpha = 0$ and $\lambda = 1$ are regarded as moderately stable, $\alpha > 0$ and $\lambda = 1$ as below average stable, while with $\alpha < 0$ and $\lambda = -1$ are determined to be having above average stability. HPR-2336, RP-2421, HIMALAYA-2216 and VIVEKDHAN-62 were average stable cultivars according to this model. Numerous reasons are responsible for the dissimilarity between the results of Tai's and Shukla's parameters. Shukla's method is considered only when there are a large number of genotypes and is dependent on interaction totals, while Tai's model utilizes the interaction means for the purpose of analysis. By taking into account the GEI constituent of every genotype as a linear function of the additive environmental constituent, a statistical analysis to quantify the non-linear response to the varaiations of environment was given by Perkins and Jinks. In this stability model, for each genotype and environment, the fixed effect is considered as the deviation from regression line with $\beta i = 0$ and $\sigma^2 i = 0$ as stable. In the current study, genotypes HPR1068, HPR2336 and RP-2421 were regarded as stable. The genotypes with lesser b values were least responsive to environmental fluctuations with least environmental correlations.

Cultivars possessing higher mean performance, coefficient of regression (bi) near to one and deviation from regression (S^2di) close to zero are regarded as stable [8]. The values of regression coefficient for genotypes varied from 0.134 to 1.581 (Table 3, Fig. 3). Nineteen genotypes were with bi-values greater than unity (> 1.0), indicating better buffering of these genotypes to rich environments and might be sensitive to environmental changes. The remaining 19 genotypes had bi scores smaller than unity (< 1.0), suggesting specific adaptability to low and poor performing environments as suggested by Das *et al*., 2010. On the other hand, some genotypes namely, VIVEKDHAN-85, SKAU-389, HIMALAYA-741, VLDHAN-209, MTU-1010 and VIVEKDHAN-62 had bi-values close to or equal with unity, indicating wide adaptability to the environmental conditions. Further, considering mean vigour index and bi value of the genotypes jointly, four genotypes (VIVEKDHAN-85, SKAU-389, SKAU-339, SHALIMAR-1 and HPR-2513) were found to be having greater buffering and adaptability to the environment. The deviation from regression (S^2di) value among the genotypes ranged from 1.060 to 246.72. Of the total 38 genotypes, none of them had deviation from regression (S^2di) value equal with zero showing poor adaptability of these genotypes in different environments. Overall, when the combined adaptability statistics of higher mean vigour index, coefficient of regression along with mean square deviation were taken into account, VIVEKDHAN-85, SKAU-389, SKAU-339, SHALIMAR-1 and HPR-2513 of the entire genotypes exhibited general adaptability.

Ranking of genotypes based on vigour index and stability parameters was given in the Table 4.

A cultivar that delivers good performance and is consistent in environmental fluctuations is said to be adapted [17]. This capacity in a stable cultivar is a consequence of perfect combination of variable characters that help to perform coordinately in difficult situations. Thus, the current study identified the genotypes RAJENDRA, K-429 to be stable according to Shukla's Stability Variance and Wricke's Ecovalence, RP-2421, HPR 2336 genotypes adaptable as per Superority measure, Tai Stability Analysis and Perkins and Jinks model. Of all the genotypes, VIVEKDHAN-85, SKAU-389, SKAU-339, SHALIMAR-1 and HPR-2513 emerged as stable cultivars according to Eberhart and Russell model. The genotype was VL DHAN-221 found to be least stable from all the stability models.

CONCLUSION

From the present investigation multiple models were fitted to assess the level of adaptability, which compiled with vigour index mean analyses, deciphered a satisfactory understanding of the stability level of rice genotypes in varied environmental conditions. Vigour index stability across different environments varied among the rice genotypes. It was highly correlated with Superiority measure and Perkins and Jinks stability models. On the whole from the study, it was evident that among the promising genotypes that were identified, RAJENDRA, K-429, RP-2421 and HPR 2336, were more stable for most of the stability statistics in union with high vigour index which could be utilized as a germplasm collection for upcoming breeding programmes. But as per Eberhart and Russell model, VIVEKDHAN-85, SKAU-389, SKAU-339, SHALIMAR-1 and HPR-2513 were found to be having wider adaptability to the environmental conditions, while VL DHAN-221 was found to be least stable with least vigour index. Thus, the current study was useful for identifying potentially well performing and stable cold tolerant rice genotypes for vigour index through genotype x environment interactions.

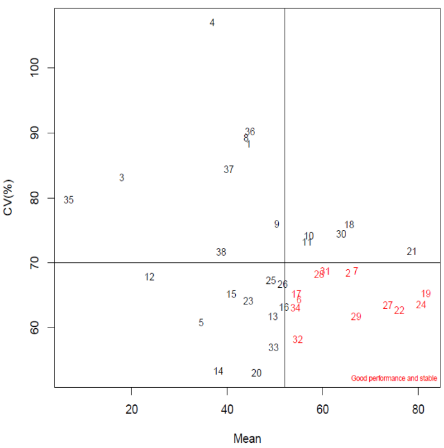

Figure 1. Distribution of 38 rice genotypes on the basis of coefficient of variation (CV%)

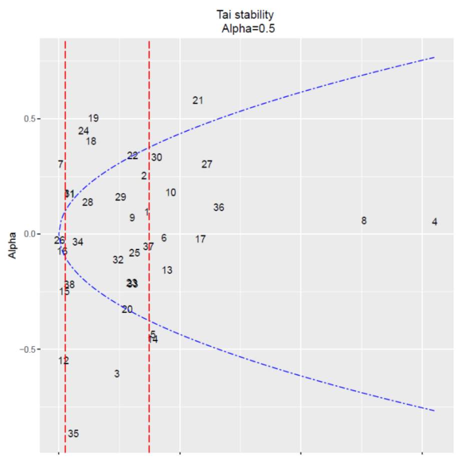

Figure 2. Allotment of the 38 genotypes of rice on Alpha-Lambda space showing different stability regions according to Tai method

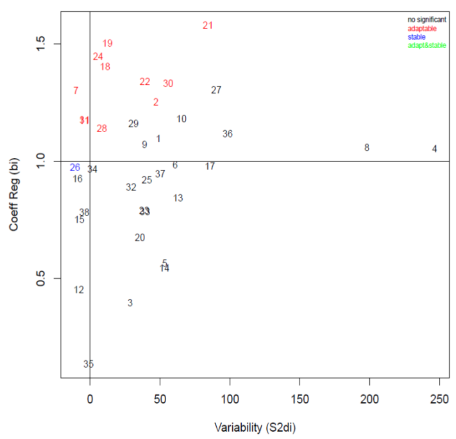

Figure 3. Distribution of of stable genotypes of rice as per Eberhart and Russell model

Table 1. List and codes of 38 genotypes of rice evaluated in the study

S. No	Germplasm lines	Code	Source
1	CHINA-1039	G1	KUAST, Khudwani, Kashmir
2	SKAU-382	G2	

3	K-116	G3	SKUAST, Khudwani, Kashmir
4	K-475	G4	
5	CHINA-988	G5	
6	JHELUM	G6	
7	SKAU-5	G7	
8	CHINA-1007	G8	
9	SHALIMAR-1	G9	
10	SKAU-389	G10	
11	CHENAB	G11	
12	K-332	G12	
13	SKAU-339	G13	
14	SKAU-341	G14	
15	K-429	G15	
16	HIMALAYA-1	G16	KVV, Malan, Himachal Pradesh
17	HIMALAYA-741	G17	
18	HIMALAYA-2216	G18	
19	RP-2421	G19	
20	HPR-2143	G20	
21	HPR-1068	G21	
22	SUKARADHAN-1	G22	
23	HPR-2373	G23	
24	HPR-2336	G24	
25	HPR-2513	G25	
26	VIVEK DHAN-85	G26	VPKS, Almora, Uttarakand
27	VIVEK DHAN-82	G27	
28	VIVEK DHAN-62	G28	
29	VIVEK DHAN-65	G29	
30	VL DHAN-86	G30	
31	VL DHAN-206	G31	
32	VL DHAN-207	G32	
33	VL DHAN-208	G33	
34	VL DHAN-209	G34	
35	VL DHAN-221	G35	
36	MTU 1010	G36	APRRI, Maruteru, Andhra Pradesh
37	TELLAHAMSA	G37	IRR, Rajendranagar, Hyderabad, Telangana
38	RAJENDRA	G38	

Table 2: Combined stability analysis of variance for vigour index across four environments

	Source	**DF**	**SS**	**MSS**	**Explained (%)**	**Cumulative value**
Vigour Index	**Treatments**	151	602462	3990		
	Genotypes	37	123274	3332	20.13	20.13
	Environments	3	426506	142169	70.79	90.92
	G x E Interactions	111	52682	475	8.6	99.52
	IPCA1	39	41192	1056	78.18	78.18
	IPCA2	37	8076	218	19.6	97.78
	Error	296	9453	32		
	Total	455	612175	1345		

Table 3. Comparison of different stability parameters for each genotype in rice

S.No.	Genotype	VI	Wi2	pi	CV(%)	Sh-σi 2	bi	S2di	PJ
1	HPR2336	81.603	992.162	17.190	65.223	344.542	1.503	12.403	0.503
2	RP2421	81.384	784.656	26.252	63.560	271.531	1.448	5.809	0.448
3	HPR1068	78.613	1457.537	50.663	71.720	508.286	1.582	84.420	0.582
4	HIMALAYA2216	65.848	536.167	83.697	62.740	184.100	1.341	39.279	0.341
5	SKAU382	65.471	546.979	129.201	63.467	187.904	1.303	90.404	0.303
6	SKAU389	57.146	181.771	266.832	61.704	59.405	1.161	31.042	0.161
7	CHENAB	56.725	345.076	216.019	68.746	116.864	1.303	10.064	0.303
8	JHELUM	55.379	652.558	229.932	75.850	225.052	1.403	10.736	0.403
9	HIMALAYA741	54.063	355.697	275.868	68.404	120.601	1.253	47.119	0.253
10	HIMALAYA1	52.018	548.334	293.188	74.415	188.381	1.333	55.899	0.333
11	SKAU339	50.393	131.608	400.279	68.734	41.755	1.177	3.828	0.177
12	SHALIMAR1	50.306	112.659	452.939	68.209	35.088	1.140	8.490	0.140
13	HPR2513	48.193	276.198	513.335	74.131	92.629	1.181	65.396	0.181
14	HPR2143	46.643	126.242	504.165	73.153	39.867	1.173	4.099	0.173
15	MTU1010	45.260	145.575	652.072	64.311	46.669	0.983	60.852	-0.017
16	CHINA1039	44.404	126.756	711.218	58.175	40.048	0.890	29.336	-0.110
17	HPR2373	44.179	196.024	689.307	65.155	64.420	0.979	85.778	-0.021
18	CHINA1007	43.870	30.311	673.128	63.099	6.113	0.967	1.717	-0.033
19	K429	41.398	25.069	776.987	63.117	4.269	0.926	9.046	-0.074
20	RAJENDRA	38.652	3.528	757.168	66.714	3.310	0.975	10.811	-0.025
21	VIVEKDHAN85	38.000	119.804	762.101	75.939	37.601	1.071	39.024	0.071
22	SKAU341	37.677	275.442	962.249	56.917	92.363	0.784	39.255	-0.216
23	K475	37.091	240.447	928.790	61.772	80.050	0.843	62.849	-0.157
24	VIVEKDHAN82	37.000	127.778	895.830	67.221	40.407	0.920	40.613	-0.080
25	VIVEKDHAN65	36.000	491.800	1178.609	53.014	168.489	0.674	35.673	-0.326
26	CHINA988	35.060	271.123	969.062	90.181	90.844	1.117	98.508	0.117
27	VIVEKDHAN62	35.000	156.081	982.375	88.273	50.366	1.097	48.975	0.097
28	VLDHAN86	34.000	266.481	1165.513	64.093	89.210	0.789	38.735	-0.211
29	VLDHAN209	33.000	432.397	1059.707	89.239	147.588	1.059	198.214	0.059
30	VLDHAN208	32.000	238.032	1335.188	65.116	79.200	0.752	7.675	-0.248
31	VLDHAN207	31.000	133.893	1240.198	84.360	42.559	0.947	50.202	-0.054
32	VLDHAN206	30.000	191.211	1407.825	71.625	62.726	0.783	4.105	-0.217
33	TELLAHAMSA	28.000	902.740	1648.256	53.343	313.079	0.545	53.138	-0.455
34	SUKARADHAN1	27.000	527.201	1390.943	107.053	180.945	1.054	246.721	0.054
35	SKAU5	26.000	840.002	1810.007	60.712	291.005	0.564	53.408	-0.436
36	K332	22.933	1125.341	2524.396	67.865	391.402	0.453	8.122	-0.547
37	K116	17.324	1448.086	2969.008	83.137	504.960	0.395	28.642	-0.605
38	VLDHAN221	5.904	2825.793	4103.909	79.714	989.709	0.134	1.060	-0.866

Table 4. Ranking of genotypes based on vigour index and stability parameters

S. No.	Genotype	VI Rank	Wi2 Rank	pi Rank	CV(%) Rank	Sh-σi 2 Rank	S2di Rank	PJ Rank
1	HPR2336	1	34	1	17	34	14	2
2	RP2421	2	31	2	12	31	6	3
3	HPR1068	3	37	3	26	37	33	1

4	HIMALAYA2216	4	27	4	8	27	22	5
5	SKAU382	5	28	5	11	28	35	7
6	SKAU389	6	13	8	6	13	17	13
7	CHENAB	7	22	6	24	22	11	8
8	JHELUM	8	30	7	30	30	12	4
9	HIMALAYA741	9	23	9	22	23	24	9
10	HIMALAYA1	10	29	10	29	29	29	6
11	SKAU339	11	9	11	23	9	3	11
12	SHALIMAR1	12	4	12	21	4	9	14
13	HPR2513	13	21	14	28	21	32	10
14	HPR2143	14	6	13	27	6	4	12
15	MTU1010	15	11	15	14	11	30	20
16	CHINA1039	16	7	18	4	7	16	27
17	HPR2373	17	15	17	16	15	34	21
18	CHINA1007	18	3	16	9	3	2	23
19	K429	19	2	21	10	2	10	25
20	RAJENDRA	20	1	19	18	1	13	22
21	VIVEKDHAN85	21	5	20	31	5	20	17
22	SKAU341	22	20	24	3	20	21	30
23	K475	23	17	23	7	17	31	28
24	VIVEKDHAN82	24	8	22	19	8	23	26
25	VIVEKDHAN65	25	25	29	1	25	18	33
26	CHINA988	26	19	25	37	19	36	15
27	VIVEKDHAN62	27	12	26	35	12	25	16
28	VLDHAN86	28	18	28	13	18	19	29
29	VLDHAN209	29	24	27	36	24	37	18
30	VLDHAN208	30	16	31	15	16	7	32
31	VLDHAN207	31	10	30	34	10	26	24
32	VLDHAN206	32	14	33	25	14	5	31
33	TELLAHAMSA	33	33	34	2	33	27	35
34	SUKARADHAN1	34	26	32	38	26	38	19
35	SKAU5	35	32	35	5	32	28	34
36	K332	36	35	36	20	35	8	36
37	K116	37	36	37	33	36	15	37
38	VLDHAN221	38	38	38	32	38	1	38

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