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GENETICS AND PLANT BREEDING

Yield Stability and Association among Parametric and Non-parametric Stability Measures for Wheat (*Triticum aestivum* L.) Genotypes in Northern Region of India

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ABSTRACT

Genotype environment interaction (GEI) is combination of genetic and non-genetic effects which causes differential relative performances of genotypes in different environments. The absence of GEI along with high yield indicates that the genotypes are suitable for general adaptation in those environments. Large number of parametric and non-parametric stability measures exists in literature, but the problem for plant breeder is to decide which of the stability measure is to be chosen for selecting stable genotypes. Several parametric and non-parametric stability measures were employed in the present study for identifying the stable wheat genotypes grown in north India. The measures used in this study included two parametric and eleven non-parametric stability measures. Significant positive correlation was found between all possible pairs of R_S, R_S^2, $S_i^{(6)}$ and grain yield, which suggested that these parameters play similar roles in determining high yielding stable genotypes. Dendrogram based on correlation coefficients between the 13 parametric and non-parametric measures including mean yield of 23 genotypes was used to group the stability measures into clusters. Among the different parametric and non-parametric stability analyzed, the Kang's rank sum (R_S) measure was found to be highly correlated with grain yield. It indicated that, use of to evaluate the stability of wheat genotypes in future selection programs would favor the simultaneous selection of a stable genotype with high yield in northern region of India. The genotypes DPW 621-50, HD 3132 and PBW 698 were found to be the high yielding and most stable genotypes in northern region of India. Genotypes TL 2995, WH 1156 and WH 1138 had very low yield and least stability.

Highlights

- Kang's rank sum (R_S) measure was found to be highly correlated with grain yield
- Genotypes DPW 621-50, HD 3132 were observed to be the most stable genotypes coupled with high yield in northern region of India.
- Genotypes TL 2995, WH 1156 and WH 1157 were found to be the most unstable genotypes and had very low mean yield.

Keywords: Parametric, non-parametric, stability measures, genotype × environment interaction, Spearman's rank correlation

Wheat is the second most important cereal in India after rice. India stands first in area and second in wheat production next to China in the world. The area under wheat cultivation in India is approximately 31.19 million hectares with an annual production of 95.85 million tonnes during year 2013-14. Wheat cultivation in India has been dominated by the northern region of India. The major wheat producing states are Uttar Pradesh, Punjab and Haryana with respective shares of 33.80%, 14.77% and 12.66% in national wheat area. Their share in national wheat production is 33.66%, 21.22% and 12.88% respectively (Anonymous). Developing a crop variety that performs well across varying environmental conditions has long been a major challenge to the plant breeders. Plant breeders have been striving to develop varieties with high grain yield and stability over a wide range of environmental conditions. GE interaction can be defined as the interplay of genetic and non-genetic effects causing differential relative performances of genotypes in different environments. The absence of GEI, coupled with high yield indicates that the genotypes are suitable for general adaptation in the range of environments under consideration. But this is an ideal situation and is rarely encountered practice, because phenotypic stability of a genotype is inversely proportional to the yield. Highly stable varieties are generally low yielders and vice-versa. A balance between yield and stabilityis the goal of any breeding programme for crop improvement.

A number of statistical measures have been developed over the years to analyze GEI and yield stability over environments. These statistical measures are broadly classified as parametric and non-parametric. Parametric measures are based on statistical assumptions about distribution of genotype, environment and GEI effects. These include ecovalence (Wricke 1962), stability variance (Shukla 1972). Non-parametric measures relate environments and phenotypes without making specific distributional assumptions. In general non-parametric measures are less powerful than parametric measures. However, Raiger and Prabhakaran (2000) have shown that when number of genotypes is fairly large, the performance of the non-parametric measures is almost at par with those of parametric measures. There are a large number of parametric and non-parametric stability measures for testing performance of genotypes grown in different environments. It is therefore, useful to study the relationship between the parametric and non-parametric stability measures, and find the most appropriate measure for testing genotypes of a crop grown in various regions in breeding programs. The present study was planned to evaluate performance of various stability measure and find association among them in context of wheat crop for Northern region of India.

MATERIALS AND METHODS

Secondary data on yield of 23 wheat genotypes, evaluated at six locations (Delhi, Haryana, Punjab, Rajasthan, Uttar Pradesh and Uttrakhand) of northern region of India during 2013-14 cropping seasons under irrigated conditions were obtained from All India Coordinated Wheat and Barley Improvement Project Report (2013-2014). Two parametric stability measures viz. Wricke's (1962) ecovalence (W_i) and Francis and Kannenberg's (1978) coefficient of variation (*CV*) and eleven rank based non-parametric measures including Kang's (1988) rank-sum (R_S), Nassar and Huehn's (1987) measures ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$), Thennarasu's (1995) measures ($NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$) and modified rank-sum ($R_S^{(1)}$, $R_S^{(2)}$) introduced by Yue *et al.* (1997) have been used for the present study.

Parametric stability measures

Wricke (1962) proposed the use of genotype environment interaction effects for each genotype, squared and summed across all environments, as a stability measure. This statistic was termed as ecovalence (W_i) and expressed as:

$$W_i = \Sigma_j \left[Y_{ij} - \bar{Y}_{i.} + \bar{Y}_{.j} + \bar{Y}_{..} \right]^2$$

Where, Y_{ij} is the mean performance of i^{th} genotypein the j^{th} environment,

$Y_{i.}$ is the marginal mean of i^{th} genotype,

$Y_{.j}$ is the marginal mean of the j^{th} environment, and

$Y_{..}$ is the overall mean.

Genotypes with a low value of W_i have smaller deviations from the mean across environments and are more stable.

Francis and Kannenberg (1978) proposed coefficient of variation as a stability measure which is given as:

$$CV = \frac{\sqrt{S_i^2}}{\bar{Y}_{i.}} \times 100$$

where, $S_i^2 = \frac{\Sigma_{j=1}^{s} \left(Y_{ij} - \bar{Y}_{i.} \right)^2}{s}$; i = 1, 2, 3… t

Y_{ij} is the mean of the i^{th} genotype in the j^{th} environment, and $Y_{i.}$ is the marginal mean of i^{th} genotype. Genotype with the smallest value of coefficient of variation is considered to be most stable.

Non-parametric stability measures

Kang's (1988) rank sum is a non-parametric stability measure where both yield and Shukla's (1972) stability variance are used for selecting a stable genotype. In this measure, a weight of one is assigned to both yield and stability statistics to identify high-yielding and stable genotypes. The genotype with the highest yield is given a rank of 1 and a genotype with the lowest stability variance a rank of 1. All genotypes are ranked in this way, and the ranks by yield and by Shukla's stability variance were added for corresponding genotype. The genotype with the lowest rank sum is considered most stable.

Nassar and Huehn (1987) proposed 4 non-parametric statistics of phenotypic stability. These are based on the ranking of genotypes in each environment. A stable genotype is the one whose position in relation to the others remains unaltered in the set of assessed environments. Four measures based on yield ranks of genotypes in each environment are given as:

$$S_i^{(1)} = \frac{2\Sigma_j^{s-1}\Sigma_{j=+1}^{s} | r_{ij} - r_{ij} |}{s(s-1)}$$

$$S_i^{(2)} = \frac{\Sigma_{j=1}^{s}\left(r_{ij} - \bar{r}_{i.}\right)^2}{(s-1)}$$

$$S_i^{(3)} = \frac{\Sigma_{j=1}^{s}\left(r_{ij} - \bar{r}_{i.}\right)^2}{\bar{r}_{i.}}$$

$$S_i^{(6)} = \frac{\Sigma_{j=1}^{s} | r_{ij} - \bar{r}_{i.} |}{\bar{r}_{i.}}$$

$S_i^{(1)}$ measures the mean of absolute rank difference of a genotype over environments;

$S_i^{(2)}$ gives the variance among the ranks over environments;

$S_i^{(3)}$ is the sum of square deviations in yield units of each rank relative to the mean rank;

$S_i^{(6)}$ is the sum of absolute deviations in yield units of each rank relative to the mean rank.

For two way data with 't' genotypes and 's' environments, r_{ij} is the rank of i^{th} genotype in the j^{th} environment and r_i is the mean rank of i^{th} genotype across all environments.

Once these four stability measures are computed, genotypes are ranked according to these stability measures. Genotypes having smaller value of these measures are the desirable one and those having larger values are the undesirable ones. Thennarasu (1995) considered adjusted ranks of genotypes within each environment. The ranks obtained from corrected depend only on the genotype x environment interaction and error components. Thennarasu's stability measures are given as:

$$NP^{(1)} = \frac{1}{s}\Sigma_{j=1}^{s} | r_{ij}^{*} - M_{di}^{*} |$$

$$NP^{(2)} = \frac{1}{s}\left[\Sigma_{j=1}^{s} | r_{ij}^{*} - M_{di}^{*} | / M_{di}\right]$$

$$NP^{(3)} = \frac{\sqrt{\Sigma_{j=1}^{s}\left(r_{ij}^{*} - \bar{r}_{i.}^{*}\right)^2 / s}}{\bar{r}_{i.}}$$

$$NP^{(4)} = \frac{2}{s(s-1)}\left[\Sigma_{j=1}^{s-1}\Sigma_{j=j+1}^{s} | r_{ij}^{*} - r_{ij}^{*} | / \bar{r}_{i.}\right]$$

where, r_{ij}^{*} is the rank of i^{th} genotype in the j^{th} environment based on the corrected phenotypic value $Y_{ij}^{*} = Y_{ij} - Y_{i.}$,

r_i and M_{di} are the mean and median ranks respectively of the i^{th} genotype in the j^{th} environment, and $r_{i.}^{*}$ and M_{di}^{*} are obtained from the corrected Y_{ij}.

These measures are obtained simply by adjusting the value of Y_{ij} while ranking is done in same way as for Nassar and Huehn's (1987) stability measures. The genotypes having smaller value of these measures are desirable one.

Modified rank sumstability measures R_s^1, R_s^2 are non-parametric measures given by Yue *et al.* (1997) in which they combined the yield and first two Nassar and Huehn's (1987) non-parametric stability measures. The genotype with the highest yield is given a rank of 1 and the stability measures $S_i^{(1)}$, $S_i^{(2)}$ are also ranked from smallest to largest value. Then there ranks are summed with the ranks according to yield. The genotypes with smaller values are considered as the stable genotypes.

Association among parametric and non-parametric stability measures

The linear relationship between these measures was obtained using the spearman's rank correlation coefficient, which was calculated from the rank of parametric and non-parametric stability measures. If d_i denotes the difference between the ranks of the i^{th} paired observation, then,

$$r_s = 1 - \frac{6\Sigma d_i^2}{n\left(n^2-1\right)}; \qquad i = 1, 2, 3\ldots n$$

The values of r_s ranges from -1 to +1

Dendrogram based on the rank correlation matrix was made for better understanding of the relationship among various stability measures.

RESULTS AND DISCUSSION

Through combined analysis of variance the effects of genotypes, environments and genotype environment interaction were found to be significant. The amount of variance contributed by GEI was larger than that contributed by genotype which indicated that there was a marked GEI effect present in these wheat multi-environment data, leading to the presence of substantial differences in genotypic responses across the test environments and indicating large differences in genotypic performances and their rank orders across environments.

The estimates of two parametric measures of stability (W_i, *CV*), mean grain yield and of eleven non-parametric measures (R_s, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP^{(1)}$, $NP^{(2)}$, $NP^{(3)}$, $NP^{(4)}$, R_s^1, R_s^2) were computed using different software and are presented in Table 1. Stability ranking of various genotypes of wheat computed according to their estimates has been presented in Table 2. These measures of stability are necessary for preferring genotypes in target environments. Spearman's rank correlation was computed between grain yield and the stability parameters. The rank correlations computed between mean yield and each pair of parametric and non-parametric stability measures are presented in Table 3. By looking at the ranking table of genotypes we conclude that the top two highest yielding WH 1105 and PBW 698 are not the stable genotypes. So, the genotypes with the highest grain yield need not to be most stable. We need to select a genotype having high yield as well as having high stability. From the Table 3 of rank correlations we say that the grain yield was positively and significantly correlated with the stability measures R_s, R_s^2 and $S_i^{(6)}$ which indicates that these measures can be used as a tool for simultaneously selecting stable and high yielding wheat genotypes. However, two other

Table 1: Estimates of parametric and non-parametric stability measures for wheat genotypes

Genotypes	YLD	W_i	CV	R_s	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	$R_s^{(1)}$	$R_s^{(2)}$
PBW 697	55.08	151.70	17.37	24	1.33	94.00	22.33	2.94	6.33	0.44	0.82	0.12	27	26
TL 2995	46.83	77.11	8.22	38	0.87	63.20	29.20	5.60	7.00	0.30	0.35	0.04	43	42
WH 1156	51.17	33.16	12.16	25	0.13	31.60	9.38	2.38	4.67	0.29	0.34	0.01	24	23
PBW 681	53.32	36.82	9.18	19	0.60	26.67	9.04	1.72	3.33	0.32	0.43	0.06	27	15
DBW 95	54.87	164.23	11.68	26	0.73	80.27	18.78	2.16	7.67	0.90	0.92	0.08	22.5	26
HD 3128	54.82	169.69	9.47	28	0.13	94.80	22.42	2.54	8.67	1.33	1.03	0.02	10	29
WH 1157	48.83	200.95	19.18	44	0.17	65.18	30.30	3.84	5.92	0.31	0.41	0.01	27	41
WH 1138	53.38	17.22	9.69	14	0.00	32.70	6.90	1.74	4.83	0.42	0.46	0.00	13.5	17
PBW 677	52.70	56.78	12.73	27.5	0.00	39.07	20.26	2.71	4.33	0.29	0.42	0.00	17	24.5
HD 3132	55.63	37.32	8.19	10	0.73	44.57	4.50	1.25	5.83	0.69	0.76	0.09	20.5	14
WH 1154	54.30	40.25	7.68	17	0.73	35.20	11.24	1.96	4.33	0.62	0.64	0.09	26.5	17
PBW 692	53.98	81.82	6.23	27	0.53	53.77	19.00	2.55	6.17	0.65	0.63	0.05	22	22
PBW 698	55.78	52.61	11.01	12	0.93	63.07	14.82	2.09	5.67	0.71	0.78	0.10	23	19.5
HD 3133	46.92	82.79	11.72	40	0.60	54.70	4.68	2.32	5.17	0.25	0.32	0.03	36	35
HUW 675	53.83	44.84	4.73	20	0.50	33.24	13.59	2.22	4.42	0.35	0.50	0.05	22	17
K 1204	51.90	30.58	5.94	22	0.60	31.77	11.29	2.57	4.17	0.30	0.35	0.04	32	22
PBW 695	51.40	55.26	12.19	30	0.73	42.27	17.94	2.77	5.00	0.34	0.43	0.05	36.5	29
HUW 666	52.25	17.59	8.64	20	0.33	33.77	8.00	1.88	4.17	0.29	0.40	0.02	26	24
HD 2967	52.70	64.83	7.54	29.5	0.13	63.07	27.58	3.78	7.00	0.52	0.55	0.01	19.5	33
DPW 621-50	54.80	13.48	7.91	8	0.20	13.77	2.64	0.67	2.83	0.34	0.40	0.02	14	8
WH 1105	56.27	79.07	11.85	17	1.13	62.27	15.41	1.66	6.00	1.14	1.04	0.16	23	17
DBW 88 (I)	52.75	150.58	17.88	33	0.27	56.30	18.94	2.56	5.83	0.63	0.66	0.03	22	28
HD 3086 (I)	54.73	56.89	12.62	21	0.47	58.00	19.12	2.47	6.33	0.74	0.71	0.05	18	23

Table 2: Ranking of wheat genotypes according to parametric and non-parametric stability measures

Genotypes	YLD	W_i	CV	R_s	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	$R_s^{(1)}$	$R_s^{(2)}$
PBW 697	4	20	21	12	23	22	19	20	18.5	13	20	22	18	15.5
TL 2995	23	15	8	21	20	19	22	23	20.5	6	3.5	12	23	23
WH 1156	20	5	17	13	4	3	7	12	8	4	2	3	14	11.5
PBW 681	13	6	10	7	14	2	6	4	2	8	9	17	18	3
DBW 95	5	21	14	14	17.5	21	14	9	22	21	21	18	11	15.5
HD 3128	6	22	11	17	4	23	20	14	23	23	22	6	1	18.5
WH 1157	21	23	23	23	6	20	23	22	15	7	7	4	18	22
WH 1138	12	2	12	4	1.5	5	4	5	9	12	11	1.5	2	5.5
PBW 677	15.5	12	20	16	1.5	9	18	18	5.5	3	8	1.5	4	14
HD 3132	3	7	7	2	17.5	11	2	2	13.5	18	18	20	7	2
WH 1154	9	8	5	5.5	17.5	8	8	7	5.5	15	15	19	16	5.5
PBW 692	10	17	3	15	12	12	16	15	17	17	14	15	9	9.5
PBW 698	2	10	13	3	21	17.5	11	8	12	19	19	21	12.5	8
HD 3133	22	18	15	22	14	13	3	11	11	1	1	10	21	21
HUW 675	11	9	1	8.5	11	6	10	10	7	11	12	13.5	9	5.5
K 1204	18	4	2	11	14	4	9	17	3.5	5	3.5	11	20	9.5
PBW 695	19	11	18	19	17.5	10	13	19	10	10	10	16	22	18.5
HUW 666	17	3	9	8.5	9	7	5	6	3.5	2	5	8	15	13
HD 2967	15.5	14	4	18	4	17.5	21	21	20.5	14	13	5	6	20
DPW 621-50	7	1	6	1	7	1	1	1	1	9	6	7	3	1
WH 1105	1	16	16	5.5	22	16	12	3	16	22	23	23	12.5	5.5
DBW 88 (I)	14	19	22	20	8	14	15	16	13.5	16	16	9	9	17
HD 3086 (I)	8	13	19	10	10	15	17	13	18.5	20	17	13.5	5	11.5

Table 3: Correlations between grain yield, parametric and non-parametric stability measures

	W_i	CV	R_s	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP^{(1)}$	$NP^{(2)}$	$NP^{(3)}$	$NP^{(4)}$	$R_s^{(1)}$	$R_s^{(2)}$
YLD	-.06	.07	.66*	-.35	-.23	.11	.53*	-.23	-.81*	-.86*	-.60*	.49	.56*
W_i	1.0	.46	.68*	.16	.87*	.74*	.54*	.79*	.37	.42	.14	.09	.68*
CV		1.0	.38	-.05	.37	.32	.28	.23	-.01	.13	-.09	.10	.42
R_s			1.0	-.18	.47	.65*	.83*	.44	-.27	-.27	-.36	.34	.93*
$S_i^{(1)}$				1.0	.29	-.03	-.10	.18	.27	.33	.92*	.59*	-.10
$S_i^{(2)}$					1.0	.74*	.48	.90*	.51	.56*	.24	.03	.64*
$S_i^{(3)}$						1.0	.82*	.70*	.24	.28	-.08	.03	.68*
$S_i^{(6)}$							1.0	.44	-.21	-.18	-.27	.31	.82*
$NP^{(1)}$								1.0	.60*	.56*	.17	-.12	.55*
$NP^{(2)}$									1.0	.94*	.50	-.46	-.20
$NP^{(3)}$										1.0	.56*	-.41	-.18
$NP^{(4)}$											1.0	.34	-.31
$R_s^{(1)}$												1.0	.33
$R_s^{(2)}$													1.0

**. Correlation is significant at the 0.01 level*

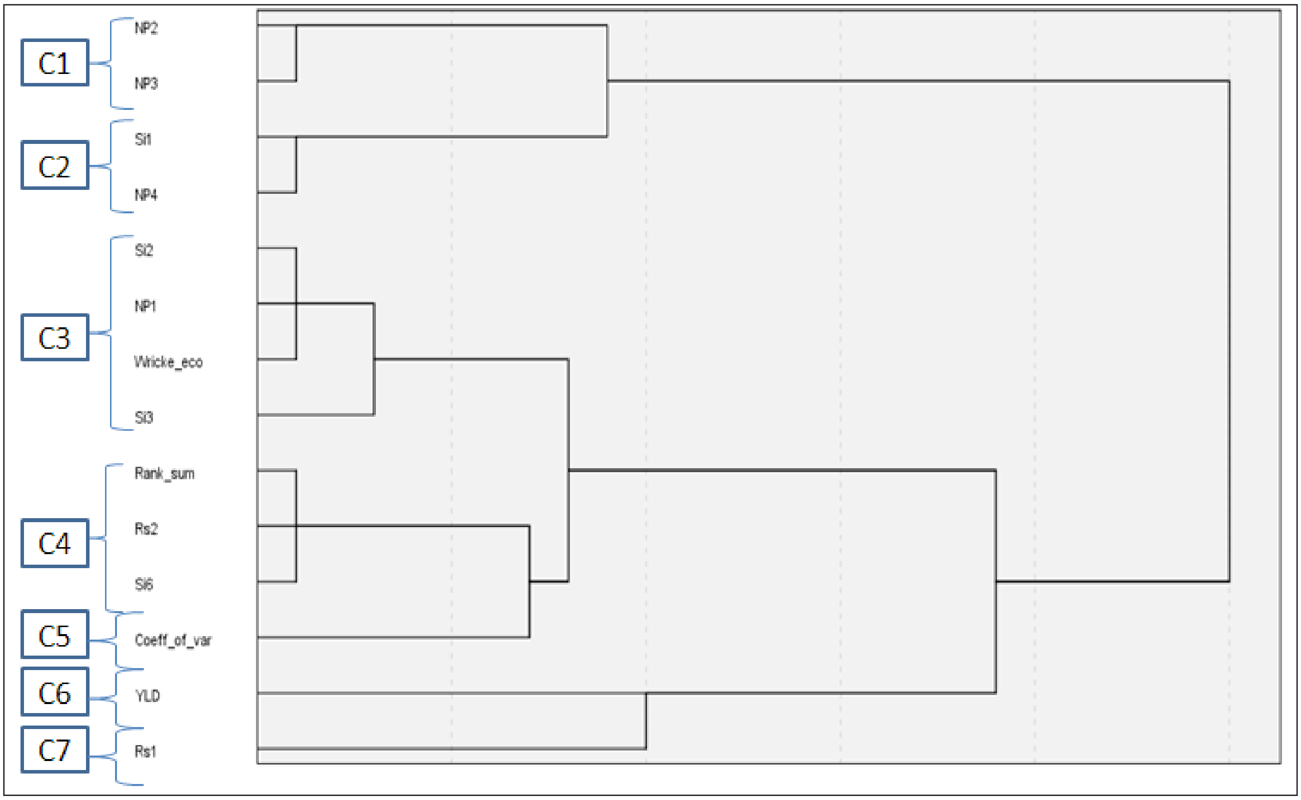

Fig. 1: Dendrogram for correlation between various stability measures indicating similarity between them

stability measures, namely $NP^{(2)}$ and $NP^{(3)}$, showed significant positive correlation with each other and negative correlations with grain yield. Thus, selection based on these stability measures would be less useful when yield is the primary target of selection. Significant positive correlations were obtained between all possible pairs of the stability measures R_s, R_s^2, $S_i^{(3)}$ and $S_i^{(6)}$. The magnitude of correlation between these stability measures varied from the lowest of r = 0.65 between R_s and $S_i^{(3)}$ to the highest of r = 0.93 for R_s and R_s^2. The significant positive correlation between W_i and $S_i^{(2)}$, $NP^{(1)}$ and $S_i^{(2)}$, $NP^{(4)}$ and $S_i^{(1)}$, $NP^{(2)}$ and $NP^{(3)}$ suggests that these parameters would play similar roles in stability ranking of genotypes. Wricke's ecovalence measure had non-significant correlation with the grain yield but had a strong and positive correlation with Kang's rank sum measure, second and third measure of Nassar and Huehn (1987), first measure of Thennarasu (1995) and Yue's second measure. All measures included in this study identify different genotypes as stable. But on an average we concludes a genotype as stable which is having minimum rank for most of the stability measures coupled with average or above average yield.

Dendrogram (Fig. 1) was constructed for grouping various measures using correlation coefficients between the various stability measures including mean yield. It graphically represents the relationship between the various stability measures. Dendrogram shows that seven clusters are formed. First cluster included two stability measures of Thennarasu ($NP^{(2)}$, $NP^{(3)}$) and second cluster included $NP^{(4)}$ and one measure of Nassar and Huehn ($S_i^{(1)}$). These measures were significantly negatively correlated with grain yield. Third cluster included the stability measures $NP^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and W_i which were not significantly correlated with the grain yield but highly correlated with each other. Fourth cluster included the stability measures R_s, $S_i^{(6)}$ and R_s^2 which were significantly and positively correlated with each other and also with the grain yield. Fifth cluster included coefficient of variation which was weakly correlated with grain yield but moderately correlated with fourth cluster measures. Sixth cluster included only the grain yield and seventh cluster included only the measure R_s^1 which was significantly correlated with yield.

CONCLUSION

Kang's rank sum (R_s) measure was found to be highly correlated with grain yield among the different parametric and non-parametric stability analyzed, the. So, R_s use of would favor the simultaneous selection of a stable genotype with high yield in northern region of India. The genotypes DPW 621-50, HD 3132 and PBW 698 were found to be the high yielding and most stable genotypes in northern region of India. Genotypes TL 2995, WH 1156 and WH 1138 had very low yield and least stability.

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