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RESEARCH PAPER

Statistical methods to study adaptability of barley genotypes evaluated under multi environment trials

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Abstract : Genotypes G5, G8, G3, G21 and G18 had achieved higher yields besides $b_i > 1.0$. G21 and G3 identified as appropriate one, because had higher yield value than the mean, b_i values near 1.0 and low S^2_{di}. Lower values (W^2_i) resulted for G12, G5, G2, G21 while higher for G5, G3 and G14. Genotypes G12 followed by G2, G20, and G7 had the smallest environmental variance (S^2_{xi}). Smaller values of (CV_i) considered G12, G2, G20, and G10 of stable performance. σ^2_i measure pointed out G12, G7 and G2 with smallest values. Desirable lower P_i values reflected by G18, G5, G21, and G4 while GAI values identified G18, G11, G4 G10 as desirable genotypes. $S_i^{(1)}$ and $S_i^{(2)}$ showed lower values of G12, G2 and G7 genotypes. Significant tests of $S_i^{(1)}$ and $S_i^{(2)}$ proved the highly significant difference in ranks among the 21 genotypes grown in 8 environments. Genotypes G12, G2, and G7 had the lower $S_i^{(3)}$ and $S_i^{(6)}$ values. Yield of genotypes had significant negative correlation with b_i, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and significant positive correlation with GAI, P_i and Rank Sum. Hierarchical cluster analysis classified genotypes into three clusters as largest cluster included genotypes with more than average yield along with high yielders G18, G11, G3, G5, G21 and unstable performance indicated by non parametric measures. Biplot analysis while considering first two significant principal components grouped the parametric and non parametric measures into four groups. The smaller group consisted of b_i and S^2_{di} and adjacent to group of non parametric measures $S_i^{(2)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$.

Key Words : Barley, Parametric, Non-parametric measures, Biplot analysis, Hierarchical clustering

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INTRODUCTION

The high yield and stable performance is required for commercial release of barley cultivars. This task poses a great challenge for the barley improvement programme of the country. Multi-environment trials are conducted to estimate a cultivar's genotypic value and yield performance across number of environments (Kiliç, 2012). Barley besides an important food as well as fodder and income source and estimated demand for barley in the world market is projected to increase substantially (Vaezi *et al*., 2017). GxE interaction is challenging to plant breeders because it complicates the selection of superior genotypes (Khalili and Pour-Aboughadareh, 2016). Significant GxE interaction has led to the development of measures to judge the cultivar

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performance.

Two major approaches have been exploited in literature to study GxE interaction and adaptability of genotypes. First is a parametric or empirical approach, which involves relating observed genotypic responses to a set of environmental conditions. Other approach is the non-parametric or analytical clustering approach, which cluster genotypes according to their similarity of response to a range of environments (Lin *et al.*, 1986). The non-parametric statistics have many advantages over the parametric statistics (Temesgen *et al.*, 2015; Rea *et al.*, 2015). Non parametric measures based on the ranks and stable genotype express relatively consistent ranks across environments (Nassar and Huehn, 1987; Scapim *et al.*, 2010; Thennarasu, 1995 and Kang, 1988).

The objectives of present study were select barley genotypes of high yield and adaptable to different environments of north hills, to study the interrelationships among various parametric and no parametric measures of GxE interaction.

MATERIAL AND METHODS

Twenty one barley genotypes were evaluated at eight locations (Kangra, Majhera, Malan, Bajaura, Shimla, Katrain, Berthin and Ranichouri) during cropping seasons of 2016-2017. Some environmental conditions of the experimental sites reflected in Table C. The attribute evaluated was grain yield expressed in tons per hectare. Additionally, Spearman correlation co-efficients among measures (Piepho and Lotito, 1992) and biplot analysis via principal component analyses (PCA) based on the correlation matrix were calculated to have through understanding of the association among measures. SAS-based computer program SASGESTAB (Hussein *et al.*, 2000) and JMP software's were utilized for the analyses.

Table A : Parametric measures

Finlay and Wilkinson (1963) linear regression co-efficient b_i	$$b_i = 1 + \frac{\Sigma_i (\bar{Y}_{ij} - \bar{Y}i. - \bar{Y}.j + \bar{Y}..)(\bar{Y}.j - \bar{Y}..)}{\Sigma_j (\bar{Y}.j - \bar{Y}..)^2}$$	Value of bi = 1, for average adaptability to environments, bi > 1 better adapted to favourable conditions and bi < 1, better performance in low yielding conditions.
Eberhart and Russell (1966) deviation from regression S^2_{di}	$$S^2_{di} = \frac{1}{E-2}\left[\sum_i (\bar{Y}_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + \bar{Y}..)^2 - (b_i - 1)^2 \sum_j (\bar{Y}.j - \bar{Y}..)^2\right]$$	S^2_{di} > 0 define lower stability.
Lin *et al.* (1986) Environmental variance S^2_{xi}	$$S^2_{di} = \frac{\Sigma (Y_{ij} - \bar{Y}i.)^2}{(E-1)}$$	Minimum variance associated with desirable genotype
Shukla's variance (1972) σ^2_ι	$$\hat{\sigma}^2_i = \frac{1}{(G-1)(G-2)(E-2)}\left[G(G-1)\sum_j (Y_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + \bar{Y}_{..})^2 - \sum_i \sum_j (Y_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + \bar{Y}_{..})^2\right]$$	Large value correlated with unstable performance
Lin and Binns (1988) Superiority index (P_i)	$$P_i = \frac{\sum_{j=1}^{n} (Y_{ij} - M_j)^2}{2E}$$	Genotypes with the largest yield difference in comparison to the reference genotype would have the highest Pi-value
Wricke's ecovalence (1962) W^2_i	$$w^2_i = \sum (Y_{ij} - \bar{Y}_{.i} - \bar{Y}_{.j} + \bar{Y}_{..})^2$$	Greatest stability associated with $W^2_i = 0$.
Francis and Kannenberg (1978) Co-efficient of variation (CV_i)	$$CV_i = (SY_i / \bar{Y}_i) \times 100$$	Low CVs accompanied with high yields for desirable genotype
Mohammadi and Amri (2008) Geometric adaptability index (GAI)	$$GAI = \sqrt[E]{\prod_{i=1}^{E} \bar{Y}i}$$	High value of GAI would be desirable

Table B : Non-parametric measures		
Nassar and Huehn (1987)	$S_i^{(1)} = \frac{2\sum_j^{m-1}\sum_{j'=j+1}^{m}\left\|r_{ij}-r_{ij'}\right\|}{[m(m-1)]}$	$S_i^{(1)}$ mean of the absolute rank differences of a genotype over environments,
	$S_i^{(2)} = \frac{\sum_{j=1}^{m}(r_{ij}-\bar{r}_{i'})^2}{(m-1)}$	$S_i^{(2)}$ variance among the ranks over environments
	$S_i^{(3)} = \frac{\sum_{j=1}^{m}(r_{ij}-\bar{r}_j)^2}{\bar{r}i.}$	$S_i^{(3)}$ sum of the absolute deviations for each genotype relative to the mean of ranks
	$S_i^{(6)} = \frac{\sum_{j=1}^{m}\left\|r_{ij}-\bar{r}_j\right\|}{\bar{r}i.}$	$S_i^{(6)}$ sum of squares of rank for each genotype relative to the mean of ranks
Thennarasu's (1995)	$NP_i^{(1)} = \frac{1}{m}\sum_{j=1}^{m}\left\|r_{ij}^{*}-M_{di}^{*}\right\|$	r^{*}_{ij} was the rank of Y^{*}_{ij}, and $\bar{r}_i$ and M_{di} were the mean and median ranks for original, where $\bar{r}_i^{\ *}$ and M^{*}_{di} were the same parameters computed from the corrected yield values.
	$NP_i^{(2)} = \frac{1}{m}\left(\frac{\sum_{j=1}^{m}\left\|r_{ij}^{*}-M_{di}^{*}\right\|}{M_{di}}\right)$	
	$NP_i^{(3)} = \frac{\sqrt{\sum(r_{ij}^{*}-\bar{r}_{i.}^{*})^2/m}}{\bar{r}_{i.}}$	
	$NP_i^{(4)} = \frac{2}{m(m-1)}\left[\sum_{j=1}^{m-1}\sum_{j'=j+1}^{m}\frac{\left\|r_{ij}^{*}-r_{ij'}^{*}\right\|}{\bar{r}_{i.}}\right]$	
Kang's rank sum (1988)	Combines yield and Shukla's stability variance into one statistic.	Highest yielder assigned rank of 1, lowest variance got rank of 1. Ranks for yield and variance are summed as genotype with lowest rank would be desirable

Results and Discussion

Analysis of variance for yield showed highly significant effects of genotypes, environments and GxE interaction at P<0.01. GxE interaction suggests significant differences in genotypes responses to environments.

Parametric measures:

Average yield of genotypes ranged from 26.8 to 16.9 t/ ha whereas wide variation observed across environments as 36.2 at E-7 to 15.2 at E-5 (Table 1). Considering yield over environments as an important measures, G5, G18, G11, G4, G21, G20, G8, G9, G10, G3, and G4 had yield more than grand mean yield (22.4 t/ ha), while genotypes G14, G19, and G15 had achieved low yield. The results of parametric and non parametric measures along with mean yield are given in Table 1 and ranking of genotypes as per these measures tabulated in Table 2. Measures of adaptability are necessary for general and specific adaptation to environments for promising genotypes. Genotypes G5, G8, G3, G21 and G18 had higher yields along with b_i values greater than 1.0 (Table 1). These genotypes are sensitive to environmental variations and would be suggested for cultivation under favourable conditions, whereas G14, G19, G15 and G13 possessed bi<1 besides lower average yields were poorly adapted across environments and might have specific adaptation to harsh conditions. On the contrary, G10, G11, and G4 had higher grain yields and a co-efficient values near 1.0. These genotypes showed average stability. Among these cultivars G21 and G3 were the most appropriate one, because had higher yield value than the mean, b_i values near 1.0 and low S^2_{di}. Lower values of Wricke's ecovalance (W^2_i) resulted for genotypes G12, G5, G2, G21 and highest for G5, G3 and G14 (Table 2). Good correlation W_i^2 with S^2_{xi} (r = 0.77**) confirmed similar results by these two measures. As per environmental variance (S^2_{xi}), G12 followed by G2, G20, and G7 had the lowest variation across environments and G5 followed by G14, G19, showed the largest variation. Low values of Francis and Kannenberg's co-efficient of variation considered genotypes G12, G2, G20, and G10 of stable performance.

Shukla variance (σ^2_i) revealed that the genotypes G12, G7 and G2 had the smallest variance across the environments, while the genotypes G5, G3 and G14 had the largest σ^2_i. Genotypes of greatest interest would be with the lowest values of Lin and Binns superiority index (Pi), genotypes G18, G5, G21, and G4 have larger yield and the lowest P_i values. GAI measure identified G18 G11 G4 G10 as desirable genotypes.

Non - parametric measures:

Two rank based measures across environments and assign equal weight to each environment ($S_i^{(1)}$ and $S_i^{(2)}$) from Nassar and Huehn (1987). Genotypes with fewer changes in ranking are considered to be more stable (Dehghani *et al.*, 2016). $S_i^{(1)}$ and $S_i^{(2)}$ showed genotypes G12, G2 and G7 had the lowest values; therefore, these genotypes were regarded as the stable genotypes. On the other hand, G18, G11, G4, and G5 had the highest $S_i^{(1)}$ and $S_i^{(2)}$ values; therefore, were of unstable performance. Significant tests of non-parametric measures based on ranks of genotypes $S_i^{(1)}$ and $S_i^{(2)}$ were conducted as suggested by Nassar and Huehn (1987). Individual Z_1 and Z_2 for genotypes were calculated and summed over to obtain Z_1 = 60.72 and Z_2 = 42.99 (Table 1). These values were more than the significant value of χ^2 (0.01, 21) = 38.9. This proved the highly significant difference in ranks among the 21 genotypes grown in 8 environments (Dehghani *et al.*, 2016). Two out of twenty one genotypes showed significantly large values as compared to χ^2 (0.01, 1) = 6.63 this proved the unstable behavior of G21, G15.

Two other nonparametric statistics ($S_i^{(3)}$ and $S_i^{(6)}$) combine yield and stability based on yield ranks of genotypes in each environment (Nassar and Huehn, 1987). $S_i^{(3)}$ and $S_i^{(6)}$ ranged from 9.4 to 59.22 and 1.54 to 7.37, respectively. Genotypes G12, G2, and G7 had the

Table C : Genotype description and environmental characterization of barley multi-environment

Code	Genotype	Parentage	Code	Environments	Latitude	Longitude	Altitude (m)
G 1	BHS 457	AWBLACK/ATHS//ARAR/3/9Cr.279-07/ROHO/4/ALANDA-01	E 1	Kangra	32°10 ' N	76°27 ' E	785.79
G 2	BHS 458	TRA-B/1038//PETUNIA 1/3/PENCO/7/CONGONA/5/CENB /3/ LBIRAN/UNA8217//GLORIABAR/COME/4/SEN/6/QUINA/8/BLLU /RUSSEL// CABUYA/3/ M9846//CCXX14.ARZ/3/PACO CBSS01M00725D-0TOPY -13M -1M-1Y-1M-0Y	E 2	Majhera	29°51 ' N	79°47 ' E	922.39
G 3	BHS 459	LAMONIA94/EXCEL-BAR	E 3	Malan	24°21 ' N	72°44 ' E	230.32
G 4	BHS 460	CLE150/W89o11369//CHERI/3/CANELA	E 4	Bajaura	29°36 ' N	81°31 ' E	1288.60
G 5	UPB 1061	PL 830/BH902	E 5	Shimla	31°10 ' N	77°17 ' E	2196.81
G 6	UPB 1062	INBON-HI-10 (2013-14)	E 6	Katrain	32°13 ' N	77°12 ' E	2400.13
G 7	UPB 1063	DWR 28/(RD 2503/ROBUST/BORR/8/ZARZA 15/GLORIA-BAR/4/ SOTOL//...	E 7	Berthin	31°42 ' N	76°64 ' E	657.60
G 8	VLB 146	INDIANUR-57(2009-10)	E 8	Ranichouri	27°17 ' N	85°98 ' E	518.95
G 9	VLB 149	INDIANUR-51(2009-10)					
G 10	VLB 150	EC667475					
G 11	VLB 151	20thIBON-52					
G 12	VLB 152	PENCO/CHEVRON-AR/3/ATACO/BERMEJO//HIGO/4/PETUNIA 1/5/FRESA					
G 13	VLB 154	ADABELLA/5/LEGACY/4/TOCTE//GOB/HUMAI10/3/ATAH92/AL ELI					
G 14	HBL 764	PETUNIA 2/3/AGA VE/SUMBARD400//MARCO/4/PETUNIA 1/5/TRA-B/1038// PETUNIA 1/3/ PENCO/6/BLLU					
G 15	HBL 765	CI10622/CI5824//PAICO/3/GLORIA-BAR/COPAL/4/BBSC*2/5/ PINON					
G 16	HBL 778	INBYT-HI-2 (2012-13)					
G 17	HBL 780	IBYT-W-18 (2012-13)					
G 18	HBL 113	SELECTION FROM ZYPHYZE					
G 19	BHS 352	HBL240/BHS504//VLB129					
G 20	VLB 118	14th EMBSN-9313					
G 21	BHS 400	34th IBON-9009					

Table 1 : Yield and GxE measures for 21 barley genotypes tested at 8 environments

		Yield	GAI	P_i	S^2_{xi}	CVi	bi	W_i^2	σ^2_i	S^2_{di}	$S_i^{(1)}$	Z_1	$S_i^{(2)}$	Z_2	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Rank
G 1	BHS 457	21.36	19.94	59.75	17.42	19.54	1.10	113.65	17.13	15.03	6.86	0.0084	33.71	0.0480	18.88	3.36	8.125	0.650	0.506	0.643	25
G 2	BHS 458	20.39	19.38	68.42	8.75	14.51	0.96	29.70	3.87	4.40	4.00	4.6499	15.14	2.5519	7.44	1.89	4.000	0.258	0.313	0.406	19
G 3	BHS 459	24.25	22.25	38.51	32.27	23.42	1.28	197.86	30.42	1.54	7.07	0.0040	46.00	0.4798	33.89	4.21	5.750	0.575	0.725	0.910	29
G 4	BHS 460	25.88	24.78	24.62	27.30	20.19	1.02	92.99	13.86	15.28	4.61	2.9503	64.86	4.3775	77.28	9.02	5.500	1.100	1.090	1.410	14
G 5	UPB 1061	26.81	24.19	20.55	58.97	28.64	1.70	255.72	39.56	-152.97	6.46	0.1411	69.14	5.8096	73.06	8.00	8.250	1.375	1.258	1.531	22
G 6	UPB 1062	21.07	19.77	71.37	18.25	20.28	0.87	113.95	17.17	12.59	7.86	0.3980	49.43	0.8971	25.63	3.41	4.750	0.306	0.467	0.577	28
G 7	UPB 1063	19.53	18.17	77.94	13.40	18.75	1.03	28.60	3.70	4.43	4.36	3.6035	20.29	1.4781	9.47	1.73	3.375	0.233	0.289	0.345	19
G 8	VLB 146	24.26	22.61	31.64	24.04	20.21	1.37	140.13	21.31	-31.76	4.75	2.6063	31.14	0.1681	24.56	3.61	3.750	0.417	0.569	0.668	25
G 9	VLB 149	25.14	23.80	26.69	24.18	19.56	1.15	108.29	16.28	9.48	5.61	0.9901	52.29	1.3438	49.63	6.24	5.625	0.662	0.873	1.138	19
G 10	VLB 150	25.27	24.23	26.74	16.04	15.85	1.00	45.49	6.36	7.58	4.14	4.2154	56.57	2.1824	63.36	8.00	4.625	0.771	0.850	1.091	12
G 11	VLB 151	26.15	25.07	25.95	29.27	20.69	0.96	91.49	13.63	14.71	4.00	4.6499	72.29	6.9885	96.38	11.05	4.750	1.056	1.051	1.333	11
G 12	VLB 152	20.88	19.91	64.18	6.14	11.87	0.91	24.95	3.12	1.18	3.39	6.7345	10.00	3.9170	5.33	1.22	2.750	0.212	0.293	0.354	16
G 13	VLB 154	21.31	20.12	64.84	18.26	20.06	0.86	118.57	17.90	11.71	7.43	0.1031	40.57	0.0840	23.18	3.51	5.750	0.383	0.538	0.676	28
G 14	HBL 764	16.93	16.44	132.42	58.52	45.17	0.44	172.27	26.38	-95.78	5.00	2.0557	41.71	0.1403	17.18	2.53	7.000	0.400	0.446	0.567	40
G 15	HBL 765	17.95	17.04	102.45	28.55	29.76	0.82	42.80	5.94	-5.97	2.11	12.4198	39.43	0.0420	15.23	2.48	3.875	0.209	0.274	0.333	24
G 16	HBL 778	21.66	20.13	59.68	13.80	17.15	1.03	92.52	13.79	15.05	7.54	0.1589	39.14	0.0338	21.28	3.34	5.875	0.452	0.483	0.619	20
G 17	HBL 780	18.41	16.83	97.07	37.19	33.13	0.91	134.18	20.37	19.18	6.39	0.1826	33.14	0.0684	15.86	2.60	5.500	0.367	0.459	0.571	34
G 18	HBL 113	26.49	25.37	20.15	33.96	22.00	1.09	102.73	15.40	13.90	4.25	3.9035	76.29	8.6462	104.20	11.71	4.000	0.889	1.003	1.268	13
G 19	BHS 352	17.37	17.00	121.60	50.28	40.82	0.46	151.10	23.04	-92.84	5.46	1.2062	50.00	0.9793	21.05	3.01	6.500	0.342	0.439	0.559	38
G 20	VLB 118	23.37	22.26	46.09	12.63	15.21	0.90	80.55	11.90	9.41	5.50	1.1502	34.00	0.0392	25.73	3.57	4.500	0.429	0.579	0.726	17
G 21	BHS 400	25.51	24.16	24.00	17.18	16.25	1.13	41.91	5.80	0.29	2.93	8.5884	58.86	2.7124	71.65	9.39	4.000	0.667	0.899	1.130	9
	E(s1) =	6.9841	V(s 1) =	1.9151							Sum =	60.72		42.99	χ^2 (0.05,1)	3.84	χ^2 (0.01,1)	6.63			
	E(s 2) =	36.6667	V(s 2) =	181.5437											χ^2 (0.05,21)	32.7	χ^2 (0.01,21)	38.9			

bi= Regression coefficient; S^2_{di}= Deviation from Regression; W_i^2= Wrick's ecovalance; S^2xi= Environmental variance; *CVi*=Coefficient of variation; σ_i^2=Shukla's variance; P_i=Lin and Binns superiority measure; GAI=Genotypic Adaptability Index; $S_i^{(1)}$ average absolute rank dispersion of a genotype over environments; $S_i^{(2)}$ variance among the ranks over environments; Z_1 and Z_2 the standard values of $S_i^{(1)}$ and $S_i^{(2)}$ respectively, for χ^2 test; $S_i^{(3)}$ and $S_i^{(6)}$ the sum of absolute deviations and sum of squares of ranks for each genotype relative to the mean of ranks respectively, NP nonparametric stability parameters

Table 2 : Ranks of yield and measures for 21 barley genotypes over 8 environments

		Yield	GAI	Pi	S^2_{xi}	CVi	bi	W_i^2	σ^2_i	S^2_{di}	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Rank-sum
G 1	BHS 457	12	13	12	8	8	16	13	13	18	17	6	7	9	20	14	10	10	15
G 2	BHS 458	16	16	15	2	2	9	3	3	9	5	2	2	3	7	4	4	4	10
G 3	BHS 459	9	10	9	16	16	19	20	20	8	18	12	14	14	16	13	14	14	18
G 4	BHS 460	4	3	4	13	11	12	10	10	20	9	18	19	18	13	20	20	20	5
G 5	UPB 1061	1	5	2	21	17	21	21	21	1	16	19	18	17	21	21	21	21	12
G 6	UPB 1062	14	15	16	9	13	5	14	14	15	21	13	12	10	11	5	8	8	17
G 7	UPB 1063	17	17	17	4	7	13	2	2	10	8	3	3	2	2	3	2	2	10
G 8	VLB 146	8	8	8	11	12	20	17	17	4	10	4	11	13	3	10	12	11	15
G 9	VLB 149	7	7	6	12	9	18	12	12	13	14	15	15	15	14	15	16	17	10
G 10	VLB 150	6	4	7	6	4	11	6	6	11	6	16	16	17	9	17	15	15	3
G 11	VLB 151	3	2	5	15	14	10	8	8	17	5	20	20	20	11	19	19	19	2
G 12	VLB 152	15	14	13	1	1	8	1	1	7	3	1	1	1	1	2	3	3	6
G 13	VLB 154	13	12	14	10	10	4	15	15	14	19	10	10	11	16	8	11	12	17
G 14	HBL 764	21	21	21	20	21	1	19	19	2	11	11	6	5	19	9	6	6	21
G 15	HBL 765	19	18	19	14	18	3	5	5	5	1	9	4	4	4	1	1	1	13
G 16	HBL 778	11	11	11	5	6	14	9	9	19	20	8	9	8	17	12	9	9	11
G 17	HBL 780	18	20	18	18	19	7	16	16	21	15	5	5	6	13	7	7	7	19
G 18	HBL 113	2	1	1	17	15	15	11	11	16	7	21	21	21	7	18	18	18	4
G 19	BHS 352	20	19	20	19	20	2	18	18	3	12	14	8	7	18	6	5	5	20
G 20	VLB 118	10	9	10	3	3	6	7	7	12	13	7	13	12	8	11	13	13	7
G 21	BHS 400	5	6	3	7	5	17	4	4	6	2	17	17	19	7	16	17	16	1

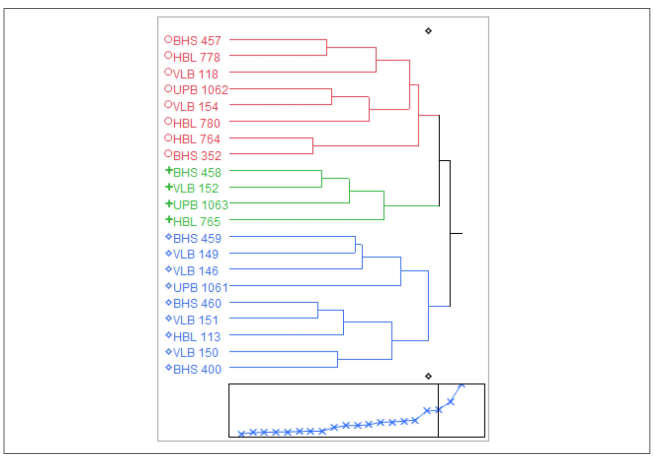

Fig. 1 : Dendogram showing hierarchical classification of 21 barley genotypes based on ranks as per measures

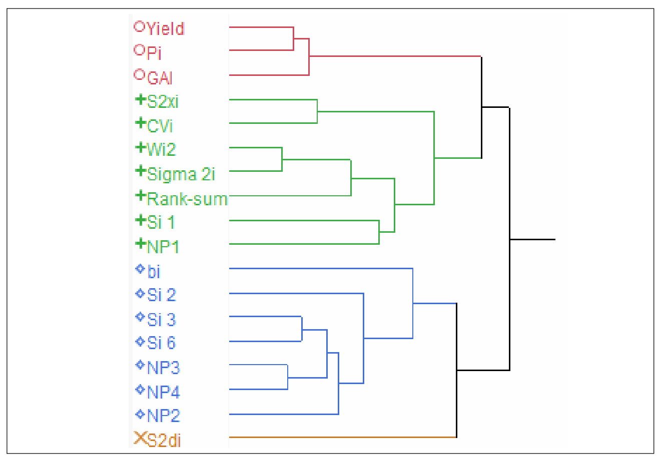

Fig. 2 : Clustering of parametric and non parametric measures by Ward's method

lowest $S_i^{(3)}$ and $S_i^{(6)}$ values hence, these genotypes were characterized as the most stable genotypes, as well as with regard to $S_i^{(3)}$ and $S_i^{(6)}$ statistics (Table 2). While genotypes G18, G11 and G4 were high yielder even unstable genotypes as characterized by $S_i^{(3)}$ and $S_i^{(6)}$ measures (Table 2). Kang rank-sum statistics (Kang, 1988), pointed towards G21 G11 G10 G18 genotypes with a lower rank-sum and regarded as the most desirable, whereas genotypes G14, G19 and G17, which had the highest values, were undesirable.

Linear association analysis :

Rank correlations among measures are given in Table 3. Grain yield has significant negative correlation with b_i, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and showed significant positive correlation with GAI, P_i and Rank Sum (P<0.01). Co-efficient of regression (b_i) expressed positive relation with $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and

Table 3 : Rank correlation among measures and yield of barley genotypes over environments

	Yield	GAI	Pi	S^2_{xi}	CVi	bi	W_i^2	σ^2_i	S^2_{di}	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$
GAI	0.9766																
Pi	0.9857	0.9649															
S^2_{xi}	-0.0779	-0.0052	-0.0286														
CVi	0.1805	0.2429	0.2416	0.9429													
bi	-0.7104	-0.6156	-0.7442	-0.0117	-0.1974												
W_i^2	-0.0299	0.0740	0.0351	0.7701	0.7325	0.1091											
σ^2_i	-0.0299	0.0740	0.0351	0.7701	0.7325	0.1091	1.0000										
S^2_{di}	-0.2013	-0.2312	-0.1675	-0.1779	-0.1870	0.0169	-0.1532	-0.1532									
$S_i^{(1)}$	0.0487	0.1409	0.1227	0.1929	0.2201	0.0968	0.6682	0.6682	0.3097								
$S_i^{(2)}$	-0.6623	-0.6597	-0.6143	0.5519	0.3623	0.1987	0.2740	0.2740	0.0610	-0.0136							
$S_i^{(3)}$	-0.8883	-0.8831	-0.8442	0.3429	0.1208	0.4558	0.2351	0.2351	0.1961	0.0656	0.8831						
$S_i^{(6)}$	-0.9214	-0.9162	-0.8877	0.3019	0.0656	0.5097	0.2058	0.2058	0.1929	0.0078	0.8370	0.9825					
$NP_i^{(1)}$	-0.0312	0.0571	0.0286	0.5442	0.4494	0.0364	0.7286	0.7286	0.1143	0.6929	0.3597	0.2247	0.1838				
$NP_i^{(2)}$	-0.8831	-0.8481	-0.8558	0.3234	0.0468	0.5909	0.2584	0.2584	0.2338	0.0968	0.7649	0.8896	0.8994	0.4104			
$NP_i^{(3)}$	-0.9351	-0.9000	-0.9052	0.2961	0.0234	0.5844	0.2636	0.2636	0.2117	0.1097	0.7727	0.9481	0.9565	0.3000	0.9545		
$NP_i^{(4)}$	-0.9260	-0.8935	-0.8935	0.3013	0.0260	0.5649	0.2714	0.2714	0.2338	0.1370	0.7779	0.9442	0.9487	0.3260	0.9506	0.9974	
Rank-sum	0.6513	0.7253	0.6929	0.4188	0.5877	-0.3188	0.7006	0.7006	-0.2110	0.6078	-0.3500	-0.4864	-0.5195	0.4851	-0.4669	-0.4812	-0.4669

Critical values of correlation at 5% and 1% level of significance are 0.4579 and 0.5825, respectively

showed negative with Rank sum. Deviation from regression S^2_{di} exhibited only marginal correlation with considered measures. Ecovalance (W_i^2) and Shukla variance (σ^2_i) expressed same degree of correlation with measures *i.e.* significant positive with $S_i^{(1)}$, $NP_i^{(1)}$ and Kang rank sum. CV also highlighted significant positive with Ecovalance (W_i^2) and Shukla measures (σ^2_i). GAI showed negative correlation of high significance with b_i, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and positive with Pi and Kang rank sum. $S_i^{(1)}$ measure mentioned positive relation with $NP_i^{(1)}$ and Kang rank sum. Measure $S_i^{(2)}$ expressed positive relation with non parametric measures. Similar behavior observed for $S_i^{(3)}$ and $S_i^{(6)}$. $NP_i^{(s)}$ reflected only positive correlation among themselves. Worth to mention the negative correlation of Kang rank sum with non parametric measures.

Clustering pattern of genotypes and measures :

Dendrogram obtained from hierarchical cluster analysis by Ward's method based on the ranks of genotypes as per yields and other measures. Genotypes were classified into three clusters (Fig. 1). Largest cluster (III) included the genotypes with more than average yield along with high yielders G18, G11, G3, G5, G21 and unstable performance indicated by non parametric measures. However, first cluster I included moderately to low yielder genotypes G1, G16, G20, G6, G13 and G19 as moderately ranked by most of non parametric measures. Second cluster (III) consisted of only 4 genotypes G2, G12, G7 and G15 with low yield even than pointed out by parametric and non parametric as desirable genotypes.

Further Ward's method of hierarchical clustering was carried out to find out any relationship among measures Fig. 2. The measures were clustered in four major groups. Parametric measures of yield with GAI and P_i placed in separate group. Non parametric measures of $S_i^{(2)}$ $S_i^{(3)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ along with b_i placed in third group. More over second group comprised mostly of parametric measures S^2_{xi} , CV_i ,W_i^2, σ^2_i, Kang with $S_i^{(1)}$ and $NP_i^{(1)}$. However, S^2_{di} is separated in remaining group with single occupancy.

Biplot analysis of measures :

Principal components analysis (PCA) based on the rank correlation matrix was presented in Fig. 3. As first two PCs jointly approximated 78.3 % (PC1 = 49.8% and PC2 = 28.4%) of the total variation. Graphically biplot

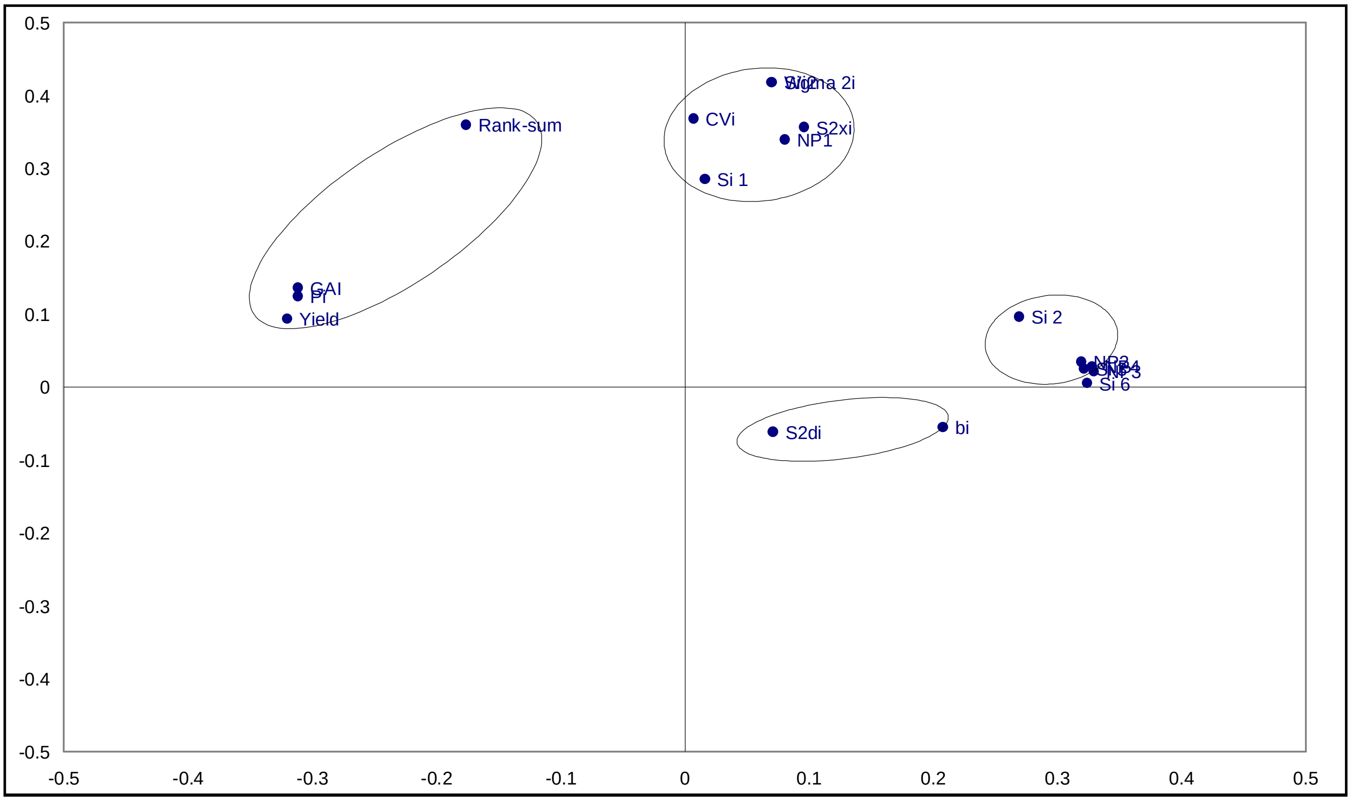

Fig. 3: Biplot of first two principal components of ranks for measures

Table 4 : Loadings of parametric and non parametric measures

Measure	PCA1	PCA2
Yield	-0.3202	0.0936
GAI	-0.3113	0.1361
Pi	-0.3113	0.1245
S^2_{xi}	0.0959	0.3566
CVi	0.0071	0.3681
bi	0.2077	-0.0550
Wi2	0.0700	0.4181
Sigma 2i	0.0700	0.4181
S2di	0.0711	-0.0616
Si 1	0.0163	0.2850
Si 2	0.2692	0.0964
Si 3	0.3214	0.0249
Si 6	0.3239	0.0052
NP1	0.0805	0.3394
NP2	0.3192	0.0344
NP3	0.3294	0.0214
NP4	0.3280	0.0281
Rank-sum	-0.1761	0.3596
% variance explained	49.84	28.43

grouped the measures in four groups. The smaller group consisted of b_i and S^2_{di}. This group is adjacent to group of $S_i^{(2)}$, $S_i^{(6)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, and $NP_i^{(4)}$. Other two groups have placed away from these groups comprised of Rank sum, GAI, Pi and yield in one group and other is of CV_i, W_i^2, σ^2_i, S^2_{xi}, $NP_i^{(1)}$ and $S_i^{(1)}$.

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