Received: 12 Jan 2022 | Accepted: 13 May 2022 | Online: 06 Jun 2022

Electronic Journal of Plant Breeding

Research Article

Biplot analysis of non parametric measures of stability for long term evaluation of fababean genotypes

RajeshKumar Arya[1], Ajay Verma[2*] and Vandana[1]

[1]Department of Genetics and Plant Breeding, CCSHaryana Agricultural University, Hisar-125004
[2]ICAR-Indian Institute of Wheat & Barley Research, Karnal-132001, Haryana
***E-Mail:** verma.dwr@gmail.com

Abstract
Non parametric measures of stability were compared based on ranks of faba bean genotypes evaluated for the period of long term in the country. High yielding genotypes were HB13-48, HB13-10 and HB13-46 also selected by the Geometric Adaptability Index (GAI) along with larger values of Harmonic means (Har). Measure S_i^{1} selected HB13-11, Vikrant and HB13-48 as opposed to HB13-15, HB13-6 and HB13-9 by S_i^{2} values. Vikrant, HB13-9 and HB13-6 genotypes considered by S_i^{3} and S_i^{4} measure selected HB13-15, Vikrant and HB13-9 faba bean genotypes. The next two S_i^{5}andS_i^{6} pointed towards HB13-15, Vikrant and HB13-49 genotypes, while S_i^{7}pointed for HB13-15, Vikrant and HB13-9 genotypes. Measure based on ranks as per corrected yield of genotypes CS_i^{1} selected HB13-15, HB13-9 and HB13-38, while CS_i^{2} found HB13-15, HB13-9 and HB13-6 as suitable candidates, while values of CS_i^{3} settled for HB13-15 HB13-9 and HB13-6 genotypes. Measure CS_i^{4} identified HB13-15, HB13-9, HB13-6 and CS_i^{5} pointed towardsHB13-15, HB13-38 and HB13-43, while CS_i^{6} observed suitability of HB13-15, HB13-9 and HB13-26 and lastly CS_i^{7} values identified HB13-15, HB13-9 and HB13-38 genotypes. Composite measures consider the ranks of genotypes as per yield and corrected yield simultaneously, values of $NP_i^{(1)}$ measure the observed suitability of HB13-11, HB13-38 and HB13-43.Whereas, as per $NP_i^{(2)}$ valuesHB13-15, HB13-9 and HB13-18 would be genotypes of choice, while $NP_i^{(3)}$ identifiedHB13-15, HB13-9 and HB13-6. $NP_i^{(4)}$ found HB13-9, HB13-6 and Vikrant as suitable genotypes, while values of Z_1 favoured HB13-16, HB13-2 and Vikrant and Z_2 settled for HB13-2, Vikrant, HB13-18. Biplot graphical analysis observed $NP_i^{(1)}$ had maintained a close relationship with CS_i^{3}, CS_i^{6}, CCVR, CSDR, CS_i^{5}, CS_i^{2}. SDR showed a strong association with S_i^{5}, S_i^{2}, S_i^{1}, $NP^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$, CVR, S_i^{3}, S_i^{6} and AvgR measures. Spearman rank correlation showed a highly significant positive correlation with GAI, Har, S_i^{3}, S_i^{6}, Coefficient of variation based on ranks (CVR), Median value based on ranks of genotypes (MedR), Average of ranks (AvgR) measures and significant positive correlation with $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ while very weak relationships expressed with Geometric Adaptability Index based on corrected yield values (CGAI), Harmonic mean as per corrected yield values (Char), CSdr, Z_1, Z_2, CS_i^{1} ,CS_i^{2},CS_i^{3},CS_i^{4},CS_i^{5},CS_i^{6},CS_i^{7}, $NP_i^{(1)}$,CSdr measures. Highly significant positive correlation expressed by GAI with Har, MedR AvgR and CAvgR only and weak with S_i^{3}, S_i^{6}, more over weak negative correlations with remaining measures. Nonparametric measures would be quite useful to the breeders to put forward stable high yielder genotypes in changing climatic fluctuations.

Keywords: Faba bean, Rank based measures, $S_i^{(s)}$, $CS_i^{(s)}$, $NP_i^{(s)}$, Biplot analysis

INTRODUCTION

Faba bean (*Vicia faba* L.) is cultivated in almost seventy countries for its beneficial nutritious properties for human food and feed worldwide (Sarah *et al*., 2009; Khazaei *et al*., 2021; Sharan *et al*., 2021). Development of high yield and stable genotypes by breeders for large scale cultivation across the diverse environmental conditions for their adoption by farmers needs not to be elaborated (Tekalign *et al.*, 2019; Papastylianou *et al.*, 2021; Abuellail *et al.,* 2021). Long term evaluation trials are to be conducted before the release of genotypes for specific and general adaptations of the promising genotypes as climate change sets new challenges to major crop species especially to faba bean for their successful adaptation to stressful environments (Tadele *et al*., 2017; Raiger *et al*., 2021). Recent breeding experiments utilized the non parametric approaches for stability assessment as the performance of genotypes had been judged by their corresponding ranks (Pour *et al*., 2019; Narasimhulu *et al.,* 2022). Additionally these methods reduce the bias factor due to outliers and simple to use and interpret (Vaezi *et al*., 2018). A large number of nonparametric procedures have been compared to interpret the stability analysis for the number of crops (Nassar and Huehn, 1987; Tamene *et al*., 2015; Mohammadi*et al*., 2016; Vaezi *et al*., 2018; Khamassi *et al*., 2021). The pivotal role of the faba bean in farming systems as cultivation provides ecological advantages for the sustainable agriculture of the country with soil enrichment by nitrogen fixation and feeding habitat provision with nectar and pollen for pollinators (Nair *et al.,* 2021). The present study was carried out with the objectives (1) to analyze the stability of genotypes by nonparametric methods (2) to differentiate genotypes performance possessing high yield along with general and specific adaptations of genotypes, (3) to find out the association among the nonparametric stability measures.

MATERIALS AND METHODS

Twenty promising faba bean genotypes were evaluated over a period of six years at MAP Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar during the period of 2013-14 to 2018-19. Field trials were conducted in randomized complete block design with three replications with a plot size of 1.8 x 6.0 m. Row to row spacing was kept 30 cm and plant to plant spacing was 10 cm. Recommended agronomic practices were followed to harvest good yield.

Huehn (1990 a &b) proposed seven non parametric methods for assessing GxE interaction and stability analysis. X_{ij} denotes the yield of i^{th} genotype in j^{th} environment where *i*=1,2, ...*k, ,j* =, 1, 2 ,...,*n* and rank of the i^{th} genotype in the j^{th} environment by r_{ij}, and $\bar{r}_i$ as the mean of i^{th} genotype. Hameed *et al.*(2020) proposed the correction for a yield of i^{th} genotype in j^{th} environment as (X^*_{ij} = X_{ij}–$\bar{x}_{i.}$+ $\bar{x}_{..}$) as X^*_{ij}, was the corrected phenotypic value; $\bar{X}_i$.was the mean of i^{th} genotype in all environments and $\bar{X}_{..}$ was the grand mean.

Generally used seven statistics based on ranks of genotypes yield and corrected yiewasere expressed as follows:

$$S_i^{(1)} = \frac{2\Sigma_j^{n-1}\Sigma_{j'=j+1}^{n}\left|r_{ij} - r_{ij'}\right|}{[n(n-1)]} \quad S_i^{(2)} = \frac{\Sigma_{j=1}^{n}(r_{ij} - \bar{r}_{i'})^{2}}{(n-1)}$$

$$S_i^{(3)} = \frac{\Sigma_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{\bar{r}_{i.}} \quad S_i^{(4)} = \sqrt{\frac{\Sigma_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{n}}$$

$$S_i^{(5)} = \frac{\Sigma_{j=1}^{n}|r_{ij} - \bar{r}_i|}{n} \quad S_i^{(6)} = \frac{\Sigma_{j=1}^{n}|r_{ij} - \bar{r}_i|}{\bar{r}_{i.}}$$

$$S_i^{(2)} = \frac{\Sigma_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{\Sigma_{j=1}^{n}|r_{ij} - \bar{r}_i|} \quad \bar{r}_i = \frac{1}{n}\Sigma_{j=1}^{n} r_{ij.}$$

$$Z_i^{(v)} = \frac{\left[S_i^{(v)} - E\{S_i^{(v)}\}\right]^2}{Var\{S_i^{(v)}\}}, v = 1,2$$

Non parametric measures for stability analysis proposed by Thennarasu (1995) as $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ based on ranks of corrected means of genotypes. Ranks of genotypes as per corrected yield $X^*_{..}$ denoted by r^*_{ij} with an average of ranks and median by $\bar{r}_i^*$ and M^*_{di}.

$$NP_i^{(1)} = \frac{1}{n}\Sigma_{j=1}^{n}\left| r^*_{ij} - M^*_{di}\right.$$

$$NP_i^{(2)} = \frac{1}{n}\left(\frac{\Sigma_{j=1}^{n}\left|r^*_{ij} - M^*_{di}\right|}{M_{di}}\right)$$

$$NP_i^{(3)} = \frac{\sqrt{\Sigma(r^*_{ij} - \bar{r}^*_{i.})^2/n}}{\bar{r}_{i\cdot}}$$

$$NP_i^{(4)} = \frac{2}{n(n-1)}\left[\Sigma_{j=1}^{n-1}\Sigma_{j'=j+1}^{m}\frac{\left|r^*_{ij} - r^*_{ij'}\right|}{\bar{r}_{i\cdot}}\right]$$

Nassar and Huehn (1987) proposed a test to judge the significance of $Si^{(1)}$ and $Si^{(2)}$ measures. The degree of similarity among measures was assessed by correlation among genotypes ranking. Spearman's rank correlation values among pairs (Piepho and Lotito, 1992) estimated as follows :

$$\bar{r}_s = 1 - \frac{6\,\Sigma_{i=1}^{n} d_i^2}{n(n^2-1)}$$

where, d_i denotes the difference between ranks for i^{th} genotype and sum over the number of pairs.

https://doi.org/10.37992/2022.1302.055

RESULTS AND DISCUSSION

Among tested genotypes higher yielder were HB13-48, HB13-10, HB13-46 whereas, Geometric Adaptability Index (GAI) selected HB13-48, HB13-10, HB13-11genotypes (Golkar *et al*., 2020). HB13-48, HB13-10, HB13-11 genotypes were identified by larger values of Harmonic means of genotypes. Consistent yield performance of HB13-2, HB13-16 and HB13-18 genotypes was observed by least values of standard deviation. Average of ranks (AvgR), standard deviation of ranks (SDR) and coefficient of variation of ranks (CVR) were calculated as per the ranks for the yield of genotypes. AvgR was identified for HB13-48, HB13-38, HB13-46, while the consistent yield of HB13-15, Vikrant, HB13-9 was expressed by values of SDR (**Table 1**). Genotypes HB13-15, Vikrant and HB13-9 are pointed by values of CVR also. These descriptive statistics based on ranks can be used for genotype comparative evaluation. Farshadfar *et al*. (2014) proposed two ranking methods according to mean and standard deviation of ranks, while Ahmadi *et al*.(2015) reported advantages of these non - parametric procedures in stability studies. Median of ranks (MedR) pointed towards HB13-48, HB13-46, HB13-41 genotypes. Measure S_i^1 selected HB13-11, Vikrant, HB13-48 as opposed to HB13-15, HB13-6, HB13-9 by S_i^2 values. Vikrant, HB13-9, HB13-6 genotypes considered by S_i^3 and S_i^4 measure selected HB13-15, Vikrant, HB13-9 faba bean genotypes. S_i^5 and S_i^6 pointed towards HB13-15, Vikrant, HB13-49 genotypes, while S_i^7 favoured HB13-15, Vikrant and HB13-9 genotypes (Mohammadi *et al.,* 2016).

Mean of corrected yield values pointed towards as high yielders Vikrant, HB13-49 & HB13-48 over the years. More over the values of corrected GAI favoured HB13-2, HB13-16, HB13-18, while corrected Harmonic values identified HB13-2, HB13-16, HB13-18 genotypes. The least values of standard deviation as per corrected yield values observed the consistent yield of HB13-2, HB13-16, HB13-18 over the studied years (Ahmadi *et al*., 2015). Average ranks as per corrected yield values (CMR) selected HB13-49, HB13-20, HB13-40 and corrected standard deviation (CSD) observed suitability of HB13-15, HB13-9, and HB13-38 genotypes (**Table 2**). Coefficient of variation as per corrected yield (CCV) values exhibited HB13-15, HB13-9, HB13-6, while median values (CMed) for HB13-46, HB13-20, HB13-41. Measure based on ranks as per corrected yield CS^1 selected HB13-15, HB13-9, HB13-38, whileCS_i^2 favoured HB13-15, HB13-9, HB13-6 as per values of CS_i^3 HB13-15 HB13-9, HB13-6 as desirable genotypes. Values of measure CS_i^4 identified HB13-15, HB13-9, HB13-6 and measure CS_i^5 pointed towardsHB13-15, HB13-38, HB13-43, while CS_i^6 observed HB13-15, HB13-9, HB13-26 as suitable genotypes and lastly CS_i^7valuesidentified HB13-15, HB13-9 , HB13-38 faba bean genotypes The mentioned strategy determines the stability of genotype over environment if its rank is similar over other environments (biological concept). Many authors have used the corrected Huehn's (1990b) nonparametric measures of phenotypic stability and demonstrated that these statistics were associated with the biological concept of stability (Farshadfar *et al*., 2014; Ahmadi *et al.,* 2015).

Non parametric measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ consider the ranks of genotypes as per yield and corrected yield simultaneously, values of $NP^{(1)}$ measure observed suitability of, HB13-11, HB13-38, HB13-43 whereas, as per $NP_i^{(2)}$, HB13-15, HB13-9, HB13-18 would be genotypes of choice, while $NP_i^{(3)}$ identified HB13-15, HB13-9, HB13-6. The last composite measure $NP_i^{(4)}$ found HB13-9, HB13-6, Vikrant as suitable genotypes, while values of Z_1 favoured HB13-16, HB13-2, Vikrant and Z_2 settled for HB13-2, Vikrant, HB13-18. Kendall's coefficient of concordance, W was used as an additional tool to evaluate the degree of agreement among non-parametric measures and mean yield. A value of W = 1 indicates a perfect agreement among rankings of the measures across the environments and while, W = 0 indicates total disagreement (Vaezi *et al*., 2018). Calculated values of W = 0.29 and for its significance values of χ^2 statistic = 199.78 (**Table 2**). The calculated value was more than the table value of χ^2 (0.05, 665) = 140.2 (149.6), which resulted an overall similarity among non parametric measures. Z_1 and Z_2 values were calculated for each genotype, as per the ranks of adjusted yield and then summed: Z_1 sum = 5.17 and Z_2 sum = 58 (**Table 2**). Both these statistics were distributed as χ^2 and were less and more than the critical value of χ^2 (0.05, 19) = 30.14. This indicated the non-significant differences among genotypes as per ranks of CS^1 and significant differences among genotypes as per CS_i^2 measures (Farshadfar *et al*., 2014). More over the four individual Z values are more than the critical value of χ^2 (0.05, 1) = 3.84 as observed by Hameed *et al*. (2020).

First two PCA accounted for 68.3 % of the total variation among the 36 non parametric measures (**Table 3**). The first principal component (PC) accounted for 47.8 per cent of the total variation. It illustrated most of the variations accounted in NP_i^4, NP_i^3, CS_i^4, CS_i^7, CSDR measures etc. Principal component two contributed 20.5% to the total variation. Six measures, including AvgR, Har, GAI, CVR, Mean, CMedR were to contribute more to the second PC. Out of the 36 measures evaluated, 11 contributed most to the first two principal components (**Table 3**) and these are considered most desirable to summarize variation among the accessions through hierarchical cluster analysis (**Fig. 1**). Vectors of traits in biplot showing acute angles are positively correlated whereas those showing obtuse or straight angles are negatively correlated and those with right angles have no correlation (Pour *et al*., 2019). Mean has expressed a strong

Table 1. Simple non parametric measures of stability as per original yield values

Code	Genotypes	Pedigree	Mean	GAI	Har	Sdrr	S_i^7	S_i^2	S_i^3	S_i^4	S_i^5	S_i^6	S_i^1	AvgR	SDR	CVR	MedR
G 1	HB13-2	HB 85/ Vikrant	34.50	34.35	34.20	1.598	38.40	6.86	2.95	6.20	4.67	2.15	7.20	13.00	6.20	0.4767	15
G 2	HB13-6	HB 603/ Vikrant	34.76	33.90	32.91	3.511	17.20	4.30	1.43	4.15	3.33	1.67	5.07	12.00	4.15	0.3456	11.5
G 3	HB13-9	EC-243770/ Vikrant	33.62	33.15	32.67	2.673	16.97	4.39	1.32	4.12	3.22	1.51	4.87	12.83	4.12	0.3210	14
G 4	HB13 -10	HB(M)-1/ Vikrant	39.33	38.43	37.51	4.119	43.77	6.63	4.95	6.62	5.50	3.74	8.20	8.83	6.62	0.7489	8.5
G 5	HB13-11	HB 73/ Vikrant	37.37	36.73	35.96	3.070	29.87	5.89	3.58	5.47	4.22	3.04	6.67	8.33	5.47	0.6558	9
G 6	HB13-15	IC-329424/ Vikrant	35.86	35.48	35.10	2.521	3.07	1.92	0.30	1.75	1.33	0.77	2.13	10.33	1.75	0.1695	10.5
G 7	HB13-16	HB 40/ Vikrant	35.00	34.78	34.57	1.916	33.07	5.90	3.10	5.75	4.67	2.63	6.93	10.67	5.75	0.5391	9
G 8	HB13-18	HB 70/ Vikrant	35.62	35.28	34.93	2.338	36.17	7.75	3.06	6.01	3.89	1.97	6.87	11.83	6.01	0.5082	12.5
G 9	HB13-20	HB 617/ Vikrant	31.98	31.36	30.76	3.103	25.07	5.53	1.98	5.01	3.78	1.79	6.00	12.67	5.01	0.3953	13.5
G 10	HB13-26	EC-117792/ Vikrant	36.54	36.05	35.55	2.921	24.27	6.28	2.60	4.93	3.22	2.07	5.07	9.33	4.93	0.5278	8
G 11	HB13-28	EC-248710/ HB 123	35.33	34.11	32.89	4.445	29.07	5.45	3.11	5.39	4.44	2.86	6.13	9.33	5.39	0.5776	7
G 12	HB13-38	EC-248710/ HB 180	37.28	36.22	35.06	4.068	26.27	5.18	3.94	5.13	4.22	3.80	5.73	6.67	5.13	0.7688	4
G 13	HB13-40	EC-248710/ HB 182	32.52	31.46	30.29	3.853	27.90	5.37	2.23	5.28	4.33	2.08	6.20	12.50	5.28	0.4226	10.5
G 14	HB13-41	EC-248710/ HB 502	37.06	35.52	33.70	4.748	49.20	6.83	6.15	7.01	6.00	4.50	7.60	8.00	7.01	0.8768	4
G 15	HB13-43	Vikrant/ EC-117799	35.85	34.89	33.85	3.829	22.40	6.22	2.80	4.73	3.00	2.25	5.07	8.00	4.73	0.5916	7
G 16	HB13-45	Vikrant/ Mumant-II	32.75	31.68	30.47	3.829	38.57	7.05	2.79	6.21	4.56	1.98	7.27	13.83	6.21	0.4489	15
G 17	HB13-46	EC-248710/Munant-I	38.00	35.69	32.83	5.666	78.67	8.68	10.26	8.87	7.56	5.91	9.87	7.67	8.87	1.1569	3
G 18	HB13-48	Vikrant/ HB 204	40.91	39.67	38.22	4.479	24.17	6.14	5.80	4.92	3.28	4.72	4.73	4.17	4.92	1.1798	2
G 19	HB13-49	Vikrant/ EC-329675	32.67	30.50	27.84	5.139	20.97	6.17	1.77	4.58	2.83	1.44	5.13	11.83	4.58	0.3870	11.5
G 20	Vikrant	National check	29.87	28.69	27.42	3.847	12.97	4.52	0.76	3.60	2.39	0.83	3.53	17.17	3.60	0.2098	18

Table 2. Composite non parametric measures of stability based on corrected and original yield values

Corrected	CMean	CGAI	CHar	CSdrr	CAvgR	CSDR	CCVR	CMedR	CS_i^7	CS_i^2	CS_i^3
HB13-2	34.50	35.19	35.05	1.598	11.67	5.75	0.4929	12	33.07	5.90	2.83
HB13-6	35.50	34.50	33.53	3.511	11.17	4.07	0.3645	11.5	16.57	4.36	1.48
HB13-9	36.50	34.90	34.44	2.673	11.00	3.95	0.3591	12	15.60	4.33	1.42
HB13 -10	37.50	34.33	33.30	4.119	13.67	6.80	0.4977	15	46.27	8.26	3.39
HB13-11	38.50	34.65	33.81	3.070	12.00	7.04	0.5869	13.5	49.60	7.29	4.13
HB13-15	39.50	34.96	34.57	2.521	12.33	2.94	0.2387	11	8.67	2.95	0.70
HB13-16	40.50	35.13	34.92	1.916	11.00	5.44	0.4946	9.5	29.60	5.69	2.69
HB13-18	41.50	35.00	34.65	2.338	12.83	5.98	0.4660	14.5	35.77	7.56	2.79
HB13-20	42.50	34.78	34.23	3.103	8.33	7.31	0.8775	6	53.47	7.71	6.42
HB13-26	43.50	34.83	34.31	2.921	11.50	4.28	0.3720	10.5	18.30	4.82	1.59
HB13-28	44.50	34.12	32.90	4.445	8.83	6.40	0.7246	8	40.97	6.21	4.64
HB13-38	45.50	34.22	32.97	4.068	10.17	4.07	0.4003	9.5	16.57	4.78	1.63
HB13-40	46.50	34.38	33.33	3.853	8.67	7.76	0.8957	7	60.27	7.53	6.95
HB13-41	47.50	33.69	31.74	4.748	9.67	7.00	0.7246	6.5	49.07	6.94	5.08
HB13-43	48.50	34.37	33.30	3.829	9.50	4.59	0.4835	9	21.10	5.86	2.22
HB13-45	49.50	34.36	33.26	3.829	10.50	6.38	0.6076	10	40.70	6.56	3.88
HB13-46	50.50	32.77	29.52	5.666	8.67	8.85	1.0208	4	78.27	8.63	9.03
HB13-48	51.50	33.85	32.04	4.479	11.33	6.74	0.5950	13	45.47	6.69	4.01
HB13-49	52.50	33.39	31.06	5.139	7.67	6.68	0.8717	6.5	44.67	8.17	5.83
Vikrant	53.50	34.37	33.33	3.847	9.50	5.82	0.6129	9.5	33.90	5.84	3.57

Table 2. Continued

Corrected	CS_i^4	CS_i^5	CS_i^6	CS_i^1	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Z_1	Z_2
HB13-2	5.75	4.67	2.40	7.07	4.67	0.311	0.404	0.544	0.015	0.000
HB13-6	4.07	3.17	1.70	5.00	3.17	0.275	0.310	0.417	0.239	2.643
HB13-9	3.95	3.00	1.64	4.80	3.00	0.214	0.281	0.374	0.300	2.959
HB13 -10	6.80	4.67	2.05	7.60	4.67	0.549	0.703	0.860	0.079	1.609
HB13-11	7.04	5.67	2.83	8.40	5.33	0.593	0.771	1.008	0.268	2.539
HB13-15	2.94	2.44	1.19	3.33	2.00	0.190	0.260	0.323	0.964	**5.740**
HB13-16	5.44	4.33	2.36	6.40	4.33	0.481	0.466	0.600	0.005	0.127
HB13-18	5.98	3.94	1.84	5.93	3.17	0.253	0.461	0.501	0.045	0.060
HB13-20	7.31	5.78	4.16	8.67	5.67	0.420	0.527	0.684	0.356	**3.882**
HB13-26	4.28	3.17	1.65	5.00	3.17	0.396	0.418	0.536	0.239	2.123
HB13-28	6.40	5.50	3.74	7.80	5.50	0.786	0.626	0.836	0.116	0.566
HB13-38	4.07	2.89	1.70	4.87	2.83	0.708	0.557	0.730	0.279	2.643
HB13-40	7.76	6.67	4.62	9.33	6.67	0.635	0.567	0.747	0.631	**6.932**
HB13-41	7.00	5.89	3.66	8.00	5.33	1.333	0.799	1.000	0.160	2.376
HB13-43	4.59	3.00	1.89	5.13	2.83	0.405	0.524	0.642	0.202	1.402
HB13-45	6.38	5.17	2.95	7.93	5.17	0.344	0.421	0.573	0.144	0.527
HB13-46	8.85	7.56	5.23	9.73	6.00	2.000	1.053	1.270	0.833	**19.247**
HB13-48	6.74	5.67	3.00	8.13	5.67	2.833	1.477	1.952	0.193	1.417
HB13-49	6.68	4.56	3.57	7.60	4.33	0.377	0.516	0.642	0.079	1.238
Vikrant	5.82	4.83	3.05	7.13	4.83	0.269	0.310	0.416	0.020	0.004
								Sum=	5.167	58.033

relationship with GAI and MedR in one quadrant while Cmean exhibited strong bondage with CMedR in other quadrant. NP_i^1 had a close relationship with CS_i^3, CS_i^6, CCVR, CSDR, CS_i^5, CS_i^2 and CHM whereas, weak nature of association with CAvgR, Har as observed altogether in the first quadrant. SDR showed a strong association with S_i^5, S_i^2, S_i^1, NP_i^2, NP_i^3, NP_i^4, CVR, S_i^6, S_i^3 and AvgR as observed in the last quadrant. MedR expressed no relationship with AvgR as observed by obtuse angle. Similar behavior for CS_i^6, CCVR with CMean, CMedR. The negative relationship of Har with SDR, S_i^5,S_i^2 also of CAvgR with CVR, S_i^3, S_i^6 , measures CCVR, CS_i^6 with CVR, S_i^3, S_i^6.

Rank based measures as per original and corrected yield of genotypes had been studied for any clustering pattern among them by highly advocated Biplot analysis technique. Principal component analysis was carried out for genotypes with ranks as per the number of measures. The loadings of the considered measures based on the first two principal components axes (PCA) were shown in **Table 3** (Khalili and Pour, 2016). Measures had been scattered in all quadrants of the biplot graph. In total five clusters of measures comprises of larger and smaller sixes depicted in **Fig. 2**. A larger cluster grouped of measures based on corrected yield, NP_i^1 and standard deviation. Another two smaller clusters of Z_1, Z_2 and other of Har and CAvgR also seen in same quadrant. Measures Mean, GAI and MedR formed a cluster in a separate quadrant. Two clusters adjacent to each other are observed in one quadrant. One comprises of measures $NP_i^{(2)}$, $NP_i^{(3)}$ & $NP_i^{(4)}$, S_i^1, S_i^2, S_i^4, S_i^5 with SDR, more over an adjacent cluster of CVR, AvgR coupled with S_i^3, S_i^6. CMean measure along with CMedR expressed a distance from other measures and placed in a separate quadrant.

Spearman Rank correlation was computed among the non parametric measures to have an idea of linear relationship among them. Mean yield had expressed both positive and negative correlations with measures (**Table 4**). Highly significant positive correlation with GAI, Har, S_i^3, S_i^6 , CVR, MedR, AvgR measures and significant positive correlation with $NP_i^{(2)}$ $NP_i^{(3)}$ and $NP_i^{(4)}$ whilem very weak relationships expressed with CGAI, Char, CSdr, Z_1, Z_2, CS_i^1,CS_i^2,CS_i^3,CS_i^4,CS_i^5,CS_i^6,CS_i^7 ,$NP_i^{(1)}$) ,CSdr measures (Khalili and Pour, 2016) . Highly significant positive correlation expressed by GAI with Har, MedR, AvgR & CAvgR only and weak with S_i^3, S_i^6 , more over weak negative correlations with remaining measures. Har measure maintained CS_i^6 MedR, CCVR and negative with CMedR, AvgR, S_i^6 ranks. Positive association or MR observed with CV, Med, CCV, CS_i^6, $NP_i^{(3)}$and $NP_i^{(4)}$ measures. SD expressed positive with CSdrr, Char, CGAI, CCVR, $NP_i^{(2)}$,$NP_i^{(3)}$,$NP_i^{(4)}$,AvgR ,CS_i^3,CS_i^6 while, indirect with MedR CMedR & S_i^7 expressed very strong positive with S_i^4, S_i^5, S_i^1, SDR, S_i^3, S_i^2 positive with S_i^6,CS_i^4, CS_i^5, CS_i^1, $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$,$NP_i^{(4)}$ along with weak negative withZ_1, Z_2, MedR, CMedR measures. S_i^2 had very strong direct with S_i^4, S_i^1, SDR strong with CS_i^2,S_i^3 negative with Z_1,CMean measures. S_i^3 exhibited very strong to strong direct relationship with CVR, S_i^6, $NP_i^{(2)}$,$NP_i^{(3)}$,$NP_i^{(4)}$, AvgR significant indirect association with MedR values. $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ measures had maintained positive relationship most of the measures with MedR and CMedR as exceptions. Values ofZ_1& Z_2 expressed only indirect

Table 3. Loading of rank based measures

Measures	PC1	PC2
Mean	0.089	-0.310
GAI	0.068	-0.332
Har	-0.006	-0.337
Sdrr	-0.171	-0.077
S_i^7	-0.170	0.122
S_i^2	-0.130	0.093
S_i^3	-0.188	0.215
S_i^4	-0.170	0.122
S_i^5	-0.158	0.113
S_i^6	-0.185	0.207
S_i^1	-0.156	0.082
CMean	0.107	0.159
CGAI	-0.166	-0.061
CHar	-0.166	-0.061
CSdrr	-0.171	-0.077
CS_i^7	-0.215	-0.097
CS_i^2	-0.191	-0.069
CS_i^3	-0.206	-0.173
CS_i^4	-0.215	-0.097
CS_i^5	-0.201	-0.117
CS^6	-0.194	-0.200
CS_i^1	-0.209	-0.122
NP_i^1	-0.193	-0.124
NP_i^2	-0.209	0.077
NP_i^3	-0.222	0.081
NP_i^4	-0.223	0.069
Z_1	-0.004	-0.020
Z_2	-0.031	-0.010
AvgR	-0.116	0.235
SDR	-0.170	0.122
CVR	-0.177	0.225
MedR	0.133	-0.197
CAvgR	-0.091	-0.274
CSDR	-0.215	-0.097
CCVR	-0.196	-0.205
CMedR	0.100	0.217
% variation	47.78	20.49

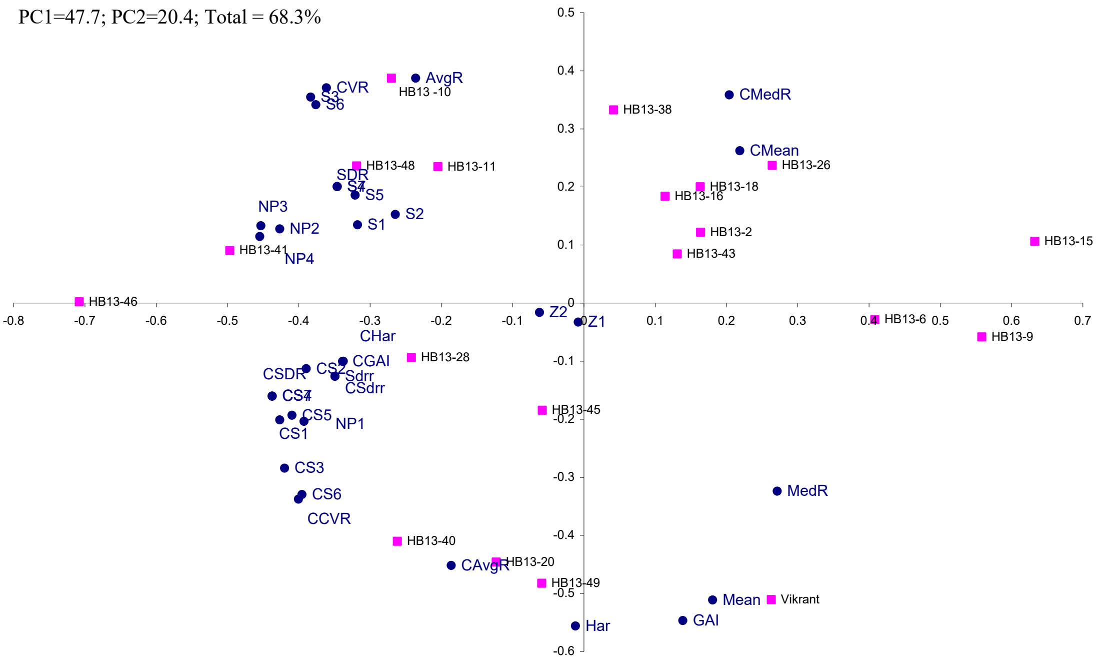

Fig. 1. Clustering pattern of non parametric stability measures

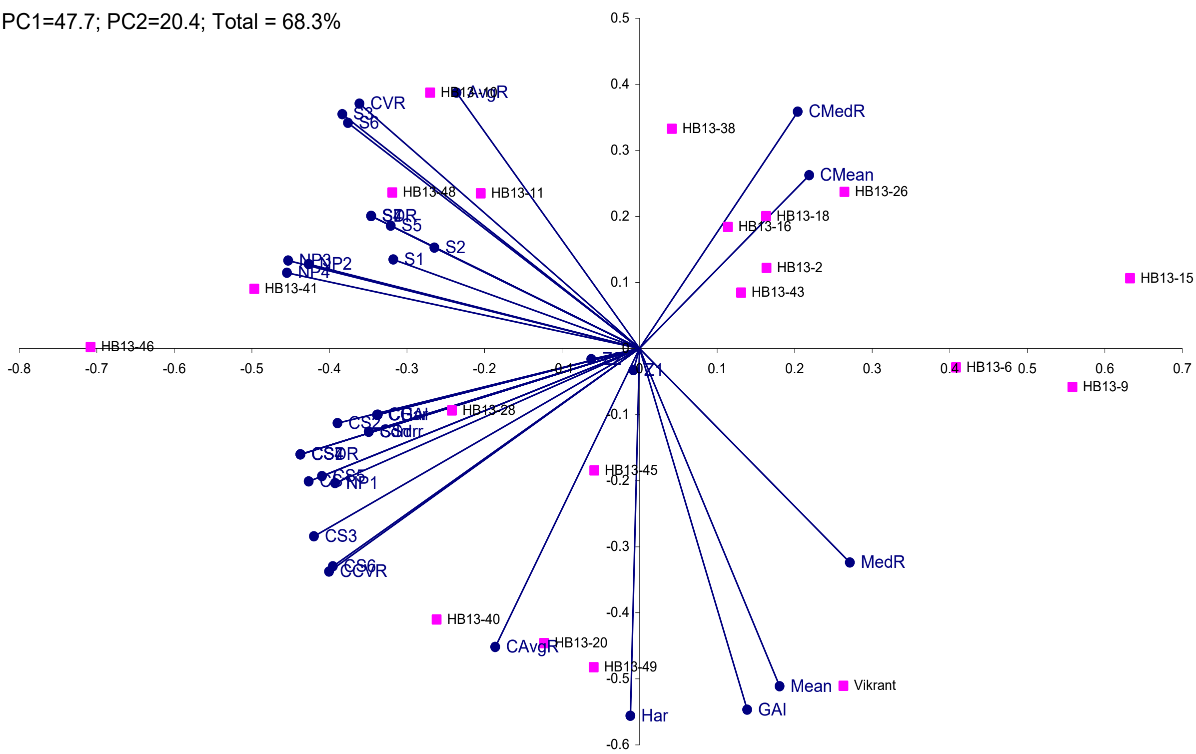

Fig. 2. Degree of association among stability measures as per Biplot analysis

Table 4. Association analysis among non parametric measures of stability of Faba bean genotypes

	GAI	Har	Sdrr	S_i^7	S_i^2	S_i^3	S_i^4	S_i^5	S_i^6	S_i^1	CMean	CGAI	CHar	CSdrr	CS_i^7	CS_i^2	CS_i^3	CS_i^4	CS_i^5
Mean	0.974	0.823	-0.262	-0.347	-0.295	-0.744	-0.347	-0.292	-0.737	-0.192	-0.065	-0.289	-0.284	-0.262	-0.079	-0.111	0.096	-0.079	0.006
GAI	1	0.905	-0.053	-0.099	-0.087	-0.465	-0.099	-0.038	-0.462	0.068	0.108	-0.077	-0.058	-0.053	0.065	0.076	0.235	0.065	0.101
Har	1	1	0.272	0.092	0.066	-0.229	0.092	0.147	-0.215	0.240	-0.126	0.254	0.274	0.272	0.283	0.258	0.464	0.283	0.314
Sdrr	1	1	1	0.242	0.192	0.504	0.242	0.244	0.528	0.234	-0.593	0.983	0.975	1.000	0.553	0.510	0.611	0.553	0.480
S_i^7	1	1	1	1	0.776	0.770	1.000	0.931	0.676	0.966	0.040	0.262	0.253	0.241	0.615	0.611	0.531	0.615	0.619
S_i^2	1	1	1	1	1	0.589	0.775	0.551	0.455	0.735	-0.201	0.233	0.240	0.192	0.455	0.620	0.404	0.455	0.412
S_i^3	1	1	1	1	1	1	0.770	0.729	0.962	0.655	-0.134	0.450	0.450	0.429	0.503	0.471	0.385	0.503	0.451
S_i^4	1	1	1	1	1	1	1	0.930	0.676	0.966	0.040	0.263	0.253	0.242	0.615	0.611	0.531	0.615	0.619
S_i^5	1	1	1	1	1	1	1	1	0.696	0.919	0.159	0.247	0.231	0.244	0.532	0.444	0.468	0.532	0.601
S_i^6	1	1	1	1	1	1	1	1	1	0.564	-0.136	0.534	0.523	0.528	0.510	0.381	0.422	0.510	0.532
S_i^1	1	1	1	1	1	1	1	1	1	1	0.126	0.246	0.236	0.234	0.610	0.634	0.537	0.610	0.587
CMean	1	1	1	1	1	1	1	1	1	1	1	-0.613	-0.639	-0.593	-0.294	-0.289	-0.439	-0.294	-0.240
CGAI	1	1	1	1	1	1	1	1	1	1	1	1	1.000	0.983	0.499	0.465	0.566	0.499	0.438
CHar	1	1	1	1	1	1	1	1	1	1	1	1	1	0.974	0.485	0.448	0.561	0.485	0.429
CSdrr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.553	0.510	0.611	0.553	0.480
CS_i^7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.902	0.945	1.000	0.929
CS_i^2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.833	0.902	0.719
CS_i^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.945	0.908
CS_i^4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.929
CS_i^5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CS^6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CS_i^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NP_i^1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NP_i^2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NP_i^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NP_i^4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Z_1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Z_2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AvgR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SDR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CVR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MedR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CAvgR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CSDR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CCVR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 4. Continued

	CS_i^6	CS_i^1	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Z_1	Z_2	AvgR	SDR	CVR	MedR	CAvgR	CSDR	CCVR	CMedR
Mean	0.194	-0.014	0.047	-0.526	-0.570	-0.540	-0.159	-0.213	-0.876	-0.347	-0.795	0.812	0.479	-0.079	0.189	-0.302
GAI	0.307	0.116	0.131	-0.275	-0.285	-0.258	0.083	0.070	-0.545	-0.099	-0.519	0.738	0.616	0.065	0.304	-0.335
Har	0.526	0.326	0.307	-0.014	-0.026	-0.004	0.225	0.238	-0.349	0.092	-0.284	0.514	0.803	0.283	0.535	-0.544
Sdrr	0.601	0.529	0.463	0.714	0.735	0.735	0.198	0.294	0.568	0.242	0.535	-0.501	0.567	0.553	0.637	-0.481
S_i^7	0.520	0.577	0.561	0.508	0.566	0.561	-0.238	-0.139	0.234	1.000	0.634	-0.011	0.044	0.615	0.526	-0.004
S_i^2	0.359	0.416	0.343	0.257	0.381	0.361	-0.357	-0.365	0.188	0.775	0.534	0.020	0.011	0.455	0.397	0.007
S_i^3	0.331	0.454	0.420	0.814	0.842	0.821	-0.134	-0.043	0.736	0.770	0.967	-0.728	-0.077	0.503	0.314	0.011
S_i^4	0.520	0.577	0.561	0.508	0.566	0.561	-0.238	-0.139	0.234	1.000	0.634	-0.011	0.044	0.615	0.526	-0.004
S_i^5	0.510	0.523	0.568	0.555	0.527	0.542	-0.180	-0.025	0.203	0.930	0.583	-0.024	0.103	0.532	0.489	-0.047
S_i^6	0.442	0.502	0.514	0.888	0.855	0.850	-0.001	0.082	0.773	0.676	0.970	-0.549	0.100	0.510	0.413	-0.001
S_i^1	0.524	0.563	0.522	0.418	0.487	0.491	-0.209	-0.081	0.136	0.966	0.510	0.131	0.131	0.610	0.545	-0.039
CMean	-0.428	-0.335	-0.217	-0.362	-0.342	-0.325	0.048	0.104	-0.177	0.039	-0.210	0.535	-0.475	-0.294	-0.470	0.627
CGAI	0.555	0.492	0.415	0.687	0.706	0.712	0.162	0.232	0.573	0.263	0.555	-0.484	0.534	0.499	0.592	-0.445
CHar	0.554	0.486	0.405	0.676	0.691	0.697	0.164	0.220	0.561	0.253	0.546	-0.476	0.553	0.485	0.590	-0.465
CSdrr	0.601	0.529	0.463	0.714	0.734	0.734	0.198	0.294	0.568	0.242	0.535	-0.501	0.567	0.553	0.637	-0.481
CS_i^7	0.871	0.971	0.9	0.650	0.777	0.784	0.073	0.162	0.189	0.578	0.434	-0.214	0.397	1.000	0.892	-0.346
CS_i^2	0.713	0.811	0.68	0.460	0.672	0.660	-0.087	0.001	0.156	0.592	0.389	-0.150	0.282	0.902	0.768	-0.241
CS_i^3	0.968	0.949	0.89	0.615	0.690	0.713	0.018	0.079	0.080	0.471	0.314	-0.158	0.616	0.945	0.977	-0.557
CS_i^4	0.871	0.971	0.90	0.650	0.777	0.784	0.073	0.162	0.189	0.578	0.434	-0.214	0.397	1.000	0.892	-0.346
CS_i^5	0.898	0.968	0.98	0.632	0.678	0.704	0.044	0.111	0.073	0.544	0.373	-0.146	0.402	0.929	0.878	-0.350
CS^6	1	0.910	0.89	0.603	0.618	0.644	-0.036	0.019	0.014	0.412	0.262	-0.128	0.698	0.871	0.985	-0.637
CS_i^1	1	1	0.95	0.654	0.734	0.762	0.069	0.126	0.126	0.529	0.394	-0.177	0.446	0.971	0.913	-0.383
NP_i^1	1	1	1	0.644	0.663	0.693	0.048	0.106	0.056	0.486	0.349	-0.131	0.411	0.900	0.862	-0.314
NP_i^2	1	1	1	1	0.937	0.943	0.129	0.223	0.712	0.505	0.842	-0.794	0.335	0.650	0.583	-0.353
NP_i^3	1	1	1	1	1	0.986	0.104	0.199	0.712	0.565	0.850	-0.735	0.246	0.777	0.620	-0.243
NP_i^4	1	1	1	1	1	1	0.104	0.196	0.674	0.561	0.826	-0.696	0.264	0.784	0.644	-0.247
Z_1	1	1	1	1	1	1	1	0.945	0.268	-0.239	-0.050	-0.253	0.193	0.073	-0.030	-0.249
Z_2	1	1	1	1	1	1	1	1	0.305	-0.139	0.007	-0.329	0.197	0.162	0.037	-0.289
AvgR	1	1	1	1	1	1	1	1	1	0.361	0.861	-0.744	-0.062	0.208	0.035	0.105
SDR	1	1	1	1	1	1	1	1	1	1	0.635	-0.254	-0.064	0.578	0.418	-0.052
CVR	1	1	1	1	1	1	1	1	1	1	1	-0.827	-0.049	0.434	0.251	-0.010
MedR	1	1	1	1	1	1	1	1	1	1	1	1	-0.032	-0.214	-0.12	0.201
CAvgR	1	1	1	1	1	1	1	1	1	1	1	1	1	0.397	0.70	-0.868
CSDR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.89	-0.346
CCVR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-0.631

https://doi.org/10.37992/2022.1302.055

relationship with SDR and CMedR measures. CS_i^1 ,CS_i^2 , CS_i^3 ,CS_i^4 ,CS_i^5 ,CS_i^6,CS_i^7 had displayed highly significant to significant direct association with other measures except of MedR and CMedR (Hameed *et al.*, 2020). Med expressed only positive correlations with measures. Indirect relationships of AvgR, SDR, CVR, MedR with MedR and CAvgR measures were also observed.

Stability measures $NP_i^{(2)}$,$NP_i^{(3)}$& $NP_i^{(4)}$, S_i^1, S_i^2, S_i^4, S_i^5 with SDR, more over adjacent cluster of CVR, AvgR coupled with S_i^3, S_i^6 in biplot analysis. Non parametric measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ had expressed direct relationship most of the measures. Values of CS_i^1 ,CS_i^2 ,CS_i^3 ,CS_i^4 ,CS_i^5 ,CS_i^6,CS_i^7 had displayed highly significant to significant direct association with other measures. Non parametric measures had been exploited in analysis for their ease of calculation along with meaningful interpretations.

ACKNOWLEDGEMENT

The authors acknowledge the financial support to the Network Coordinator, AICRN project (Research on potential crops) ICAR-NBPGR, New Delhi. The authors would also like to thank Dr. J. S. Hooda Ex. Head, MAP Section and all the persons who contributed directly and indirectly for any kind of help during the study.

REFERENCES

Abuellail, F.FB, El–Taib, A.B.A. and Hefny, Y. A.M. 2021. Stability analysis and performance of promising sugarcane varieties for yield and quality traits. *Electronic Journal of Plant Breeding,* **12(3):** 623-636. [Cross Ref]

Ahmadi, J., Vaezi, B., Shaabani, A., Khademi, K., Ourang, S. and Pour-Aboughadareh, A. 2015. Non-parametric measures for yield stability in grass pea (*Lathyrus sativus* L.) advanced lines in semi warm regions. *Journal of Agricultural Science and Technology,* **17**:1825-1838.

Farshadfar, E., Mahmudi, N. and Sheibanirad, A .2014. Nonparametric methods for interpreting genotype×environment interaction in bread wheat genotypes. *Journal of Biodiversity & Environmental Sciences,* **4**: 55-62.

Golkar, P., Rahmatabadi, N., Mohammad, S. A. and Maibody, M. M .2020. Improvement of yield and yield stability in safflower using multivariate, parametric and non-parametric methods under different irrigation treatments and planting date. *Acta Agriculturae Slovenica,* **115(2):** 315–327. [Cross Ref]

Hameed, M., Shah, S. H. and Khan, H. H .2020. A nonparametric analysis for stability of wheat genotypes tested in Southern Punjab Pakistan. *European Online Journal of Natural and Social Sciences,* **9(1):**153-163.

Huehn, M .1990a. Non-parametric measures of phenotypic stability. Part 1. Theory. *Euphytica,* **4 7**:189-194. [Cross Ref]

Huehn, M .1990b. Non-parametric measures of phenotypic stability: Part 2. Application. *Euphytica,* **47**:195-201. [Cross Ref]

Khalili, M. and Pour-Aboughadareh, A. 2016. Parametric and non- parametric measures for evaluating yield stability and adaptability in barley doubled haploid lines. *Journal of Agricultural Science and Technology,* **18**: 789–803.

Khamassi, K., Elyes, B., Rouissi, M., Dakhlaoui, A., Ayed, R. B. and Hanana, M. 2021. Genetic variability of tunisian faba beans (*Vicia faba* L.) based on seeds' morphophysical properties as assessed by statistical analysis. *Journal of Food Quality,* **2021**:1-10. [Cross Ref]

Khazaei, H., Sullivan, D. M. O' and Stoddard, F. L. 2021. Recent advances in faba bean genetic and genomic tools for crop improvement. *Legume Science,* **3(3):** e75. [Cross Ref]

Mohammadi, R., Farshadfarar, E. and Amri, A .2016. Comparison of rank-based stability statistics for grain yield in rainfed durum wheat. *New Zealand Journal of Crop & Horticulture Science,* **44**: 25–40. [Cross Ref]

Nair, S., Veerasamy, S., Vijayaraghavan, A., Suresh, G., Anees A. and Yuvaraj, T. 2021. Selection of clones of Eucalyptus camaldulensis (Dehnh.) based on stability for tree volume. *Electronic Journal of Plant Breeding*, **12(3):** 732-740. [Cross Ref]

Narasimhulu, R. Satyavathi, C. T., Reddy, B. S. and Ajay, B.C. 2022. Principal components of genetic diversity and association studies for yield related traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Electronic Journal of Plant Breeding*, **13(1):** 175-181. [Cross Ref]

Nassar, R. and Huehn, M.1987. Studies on estimation of phenotypic stability: tests of significance for non-parametric measures of phenotypic stability. *Biometric,* **43**: 45- 53. [Cross Ref]

Papastylianou, P., Vlachostergios, D.N., Dordas, C., Tigka, E., Papakaloudis, P., Kargiotidou, A., Pratsinakis, E., Koskosidis, A., Pankou, C., Kousta, A., et al. 2021. Genotype X environment interaction analysis of faba bean (*Vicia faba* L.) for biomass and seed yield across different environments. *Sustainability,* **13**: 2586. [Cross Ref]

Piepho, H.P. and Lotito, S. 1992. Rank correlation among parametric and nonparametric measures of phenotypic stability. *Euphytica,* **64**: 221–225. [Cross Ref]

Pour-Aboughadareh, A., Yousefian, M., Moradkhani, H., Poczai, P. and Siddique, K. H. M. 2019. STABILITYSOFT: A new online program to calculate parametric and non- parametric stability statistics for crop traits. *Applications in Plant Sciences,* **7(1):** e1211. [Cross Ref]

Raiger, H.L., Yadav, S.K., Arya, R. K. and Phogat, B. S. 2021. Studies on variability and character association for yield and yield related traits in faba bean (*Vicia faba*). *Ekin J.* **7(2):**125-130.

Sarah, A.E., Hassan, A.B. and Babiker, E.E. 2009. Nutritional evaluation of cooked faba bean (*Vicia faba* L.) and white bean (*Phaseolus vulgaris* L.) cultivars. *Australian Journal of Basic and Applied Sciences,* **3**:2484-2490.

Sharan, S., Zanghelini, G. and Zotzel, J. 2021. Fava bean (*Vicia faba* L.) for food applications: from seed to ingredient processing and its effect on functional properties, anti nutritional factors, flavor, and color. *Comprehensive Reviews in Food Science and Food Safety,* **20(1)**: 401–428. [Cross Ref]

Tadele Tadesse, Behailu Mulugeta, Gashaw Sefera and Amanuel Tekalign. 2017. Genotypes by environment interaction of faba bean (*Vicia faba* L.) grain yield in the highland of bale Zone, Southeastern Ethiopia. *plant,*.**5(1):** 13-17. [Cross Ref]

Tamene, T., Gemechu, K., Tadese, S. and Mussa J. 2015. Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. *The crop Journal,* **3**: 258 - 268. [Cross Ref]

Tekalign, A., Bulti, T. and Dagnachew, L .2019. Interaction effects of genotype by environment and AMMI stability analysis of seed yield and agronomic performance of faba bean genotypes in the highlands of Oromia Region, Ethiopia". *International Journal of Research in Agriculture and Forestry*, **6(10):**22-31.

Thennarasu, K. 1995. On certain non-parametric procedures for studying genotype-environment interactions and yield stability. Unpublished Ph.D. Thesis. P.G. School, IARI, New Delhi

Vaezi, B., Pour-Aboughadareh, A., Mehraban, A., Hossein-Pour, T., Mohammadi, R., Armion, M. and Dorri, M .2018. The use of parametric and non- parametric measures for selecting stable and adapted barley lines. *Archives of Agronomy and Soil Science,* **64**: 597–611. [Cross Ref]