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Augmentation of parametric with rank based measures for stable performance of Faba bean (*Vicia faba*) genotypes

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Abstract

Faba bean genotypes were evaluated under for long term experiments by parametric and rank based measures of stability at CCSHAU, Hisar during 2015-16 to 2019-20. Higher yielder HB14.32, HB14-18, HB14-14 genotypes were also selected by Geometric as well as by Harmonic means. Squared deviations from regression selected HB14-15, HB14-18, and HB14-31 genotypes. Shukla's measure pointed for HB14-40, HB14-15, and HB14-16. Dynamic stability of Wricke ecovalence observed suitability of HB14-15, HB14-40, and HB14-07. Superiority measure P_i favoured the HB14.32, HB14-18 HB 14-14. Moreover higher R^2_i values expressed by HB14-18, HB14-22, HB14-31 genotypes. Rank based S_i^s selected HB14-18, HB 14-15, HB14-40 genotypes, while genotypes HB14-15, HB14-40, HB14-36 HB 14-43 pointed by corrected rank based measures CS_i^s. Composite measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ pointed for HB14-15, HB14-40, HB14-07 as genotypes for wide area cultivation. Biplot analysis found 68.3 % of the total variation accounted by First two PCA. Clustering pattern observed bigger group joined Z_2 , W^2_i ,SDR, S^2_{di}, and S_i^1, S_i^2, S_i^3, S_i^4, S_i^5, S_i^6, S_i^7 other of S^2_{xi}. Highly significant positive correlation with GAI, HM, bi, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and negative notably with P_i, AvgR values. CS_i^s measures expressed strong positive with S_i^s and with σ^2_i S^2_{xi} W^2_i R^2_i parametric measures. Composite measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ also expressed strong positive with parametric measures σ^2_i ,S^2_{xi} W^2_i , R^2_i. Parametric and rank based measures would be augmented to make selection of genotypes.

Keywords biplot, faba bean, genotypes, parametric

Introduction

Legume crops had been cultivated throughout the world as a plant based protein source [1]. This multiuse cultivated crop provides food for human population, fodder to animals and fixation of atmospheric nitrogen in the soils [2]. The selection of high-yielding genotypes with a stable performance had been emphasized in crop improvement programs [3]. The grain yield may be affected by the genotype-by-environment (GxE) interaction. Cross over GxE hinders the selection of promising genotypes with wide or specific adaptations [4]. The stability or adaptability measures had been computed by breeders to assess the performance of genotypes over the locations or across the years [5]. Good numbers of parametric and rank based non parametric measures have been advocated in the literature [6]. Commonly used parametric measures based on the variance of genotypes, linear regression coefficient, deviations from regression, variance, coefficient of determination, Ecovalence and superiority index etc [7]. The rank based nonparametric measures for the stability considered the ranks of genotypes and provides an important alternative to the parametric strategies including univariate and multivariate measures [8]. The lack of information noticed regarding the joint behavior or inter-relationships among recent analytic measures. The objectives of the present study were (1) to examine the stability of faba bean genotypes using modern analytical techniques (2) to distinguish among genotypes performance as per parametric and rank based non parametric measures (3) estimate the degree of association among BLUP, parametric and rank based non parametric measures.

Methodology

At the MAP Section of the Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, twenty promising Faba bean genotypes were assessed during of five years from 2015–16 to 2019–20.

Field evaluation of genotypes carried out at research stations by following randomized complete block designs with three replications. To get a good yield, recommended agronomic procedures were used. Data were collected on branches per plant, pod length (cm), plant height, Pods per plant and yield (q/ha). Let X_{ij} de¬notes the yield of ith genotype in jth environment where i=1,2, k, ,j =, 1, 2 , n and rank of the ith genotype in the jth environment reflected by r_{ij} and $\overline{r_1}$ as the mean of ith genotype. Following measures generally used for stability based on the ranks of the genotypes as per corresponding yield and corrected yield as follows:

$S^2{}_{xi} = \frac{\Sigma(X_{ij}-\bar{X}_{i.})^2}{E-1}$	i.
$\sigma^2{}_i = \frac{1}{(G-1)(G-2)(E-1)}\left[G(G-1)\Sigma_j\left(X_{ij}-\bar{X}_{i.}-\bar{X}_{.j}+\overline{X..}\right)^2 - \Sigma_i\Sigma_j\left(X_{ij}-\bar{X}_i-\bar{X}_{.j}+\overline{X..}\right)^2\right]$	ii.
$S^2{}_{di} = \frac{1}{E-2}\left[\sum_{j=1}^{n}\left(X_{ij}-\bar{X}_{i.}-\bar{X}_{.j}+\overline{X..}\right)^2 - (b_i-1)^2\sum_{j=1}^{n}(\bar{X}_{j.}-\overline{X..})^2\right]$	iii.
$P_i = \frac{\sum_{j=1}^{n}\left(X_{ij}-M_j\right)^2}{2E}$	iv.
$R_i^2 = 1-\frac{S_{di}^2}{S_{xi}^2}$	v.
$Wi^2 = \sum\left(X_{ij}-\bar{X}_{i.}-\bar{X}_{.j}+\overline{X..}\right)^2$	vi.
$b_i = 1+\frac{\sum_{j=1}^{n}\left(X_{ij}-\bar{X}_{i.}-\bar{X}_{.j}+\bar{X}..\right)(\bar{X}_{.j}-\overline{X..})}{\sum_{j=1}^{n}\left(\bar{X}_{.j}-\overline{X..}\right)^2}$	vii.
$S_i^{(1)} = \frac{2\Sigma_j^{n-1}\Sigma_{j'=j+1}^{n}\lvert r_{ij}-r_{ij'}\rvert}{[n(n-1)]}$	viii.

$S_i^{(2)} = \frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_{i'})^2}{(n-1)}$	ix.
$S_i^{(3)} = \frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{\bar{r}_{i.}}$	x.
$S_i^{(4)} = \sqrt{\frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{n}}$	xi.
$S_i^{(5)} = \frac{\sum_{j=1}^{n}\lvert r_{ij} - \bar{r}_i\rvert}{n}$	xii.
$S_i^{(6)} = \frac{\sum_{j=1}^{n}\lvert r_{ij} - \bar{r}_i\rvert}{\bar{r}_{i.}}$	xiii.
$S_i^{(7)} = \frac{\sum_{j=1}^{n}(r_{ij} - \bar{r}_i)^2}{\sum_{j=1}^{n}\lvert r_{ij} - \bar{r}_i\rvert}$	xiv.
$Z_i^{(v)} = \frac{[S_i^{(v)} - E\{S_i^{(v)}\}]^2}{Var\{S_i^{(v)}\}}, v = 1,2$	xv.

Non parametric composite stability measures proposed by as NPi(1), NPi(2), NPi(3) and NPi(4) centered on the ranks of genotypes as per yield and corrected yield of genotypes [9-10]. Additionally, the median and average rankings of genotypes as indicated by the corrected yield X*ij are denoted by r*ij. by $\bar{r}_i$ and M*di.

$NP_i^{(1)} = \frac{1}{n}\sum_{j=1}^{n}\lvert r_{ij}^* - M_{di}^*\rvert$	xvi.
$NP_i^{(2)} = \frac{1}{n}\left(\frac{\sum_{j=1}^{n}\lvert r_{ij}^* - M_{di}^*\rvert}{M_{di}}\right)$	xvii.
$NP_i^{(3)} = \frac{\sqrt{\sum(r_{ij}^* - \bar{r}_{i.}^*)^2/n}}{\bar{r}_{i.}}$	xviii.
$NP_i^{(4)} = \frac{2}{n(n-1)}\left[\sum_{j=1}^{n-1}\sum_{j'=j+1}^{m}\frac{\lvert r_{ij}^* - r_{ij'}^*\rvert}{\bar{r}_{i.}}\right]$	xiv.

The tests to find out the significance of $S_i^{(1)}$ and $S_i^{(2)}$ measures proposed by Mahtabi et al., [11].

Results and Discussion

Parametric measures

Since average yield of genotypes expressed significant differences over the years and high values of mean yield, Geometric Adaptability Index and Harmonic means observed for HB14.32, HB14-18, and HB14-14 genotypes over the years (Table 1). The biological/static stability measure implied a stable genotype would be having small variance across the tested locations of the present study [11]. HB14-15, HB14-40 & HB14-36 genotypes expressed lower values of variance. Genotypes HB14-15, HB14-18, HB14-31 exhibited the least deviation from regression mean squares (S^2_{di}). Least values of Shukla [12] variance (σ^2_i) by HB14-40, HB14-15, and HB14-16 showed their variance very near to the environmental variance for the stable performance. The contribution of the dynamic concept of stability represented by the ratio of the interaction sum of squares by each genotype to the interaction sum of squares in analysis and the low values of Wricke's ecovalence (W^2_i) observed for HB14-15, HB14-40, HB14-07 for consistent performance. Vikrant, HB14-31, and HB14-22 genotypes pointed by Finlay & Wilkinson regression coefficient (b_i) as the regression of the mean of i^{th} genotype in j^{th} environment on the mean performance of all genotypes in that environment. HB14.32, HB14-18 HB 14-14 genotypes expressed their less distance from high yielder genotypes as assured by Pi the superiority index of Lin and Binns. The breeder's goal is supported by this explanation of superiority, as superior genotype should be located in the most productive surroundings. The index R^2_i nature of is robust as compared to CV and S^2_{di} measures since its value ranges between zero and one. Stable nature of HB14-18, HB14-22, HB14-31 faba bean expressed by R^2_i values.

Rank based measures

Higher Average values of ranks (AvgR) observed for Vikrant, HB14-07, HB14-05 while least values of standard deviation of ranks (SDR) maintained by HB14-20, HB14-15, HB14-40 gentypes. Median of ranks (MedR) highlighted large values for HB14.32, HB14-18, and HB14-20 genotypes. Descriptive measures would be utilized for the comparative performance of faba bean genotypes [13]. Proposed two approaches for ranking data based on the mean and standard deviation of ranks [14], and demonstrated benefits of these non-parametric techniques for stability investigations. Smaller values of S_i^1 measure showed by HB14-18, HB14-15, and HB14-40 as opposed to S_i^2 values by HB14-18, HB14-15, and HB14-40. Whereas least values of S_i^3 considered HB14-18, HB14-15, and HB14-40 while S_i^4 measure pointed for HB14-18, HB14-15, HB14-40 faba bean genotypes. Next two S_i^5 and S_i^6 showed least values for HB14-18, HB14-15, and HB14-40 while minimum values of S_i^7 expressed by HB14-20, HB14-15, and HB14-40 genotypes. More of less same set of genotypes pointed out by rank based measures.

Rank based measures as per corrected yield

Higher values of average ranks of genotypes as per corrected yield (CMR) expressed by HB14-36, HB14-07, and HB14-15 while least values for standard deviation (CSD) observed HB14-15, HB14-40, and HB14-36 (Table 2). The biological idea of stability was connected with the corrected nonparametric measurements of phenotypic stability [6]. Large median values (CMed) showed by HB14-25, HB14-18, and HB14-07. CS_i^1 measure observed least values for HB14-15, HB14-40, HB14-36, HB14-15, HB14-40, and HB14-43 exhibited for CS_i^2 while CS_i^3 observed for HB 14-15, HB14-40, HB 14-43. Lower values CS_i^4 and CS_i^5 measures maintained by HB14-15, HB14-40, HB14-43 while least CS_i^6 observed for HB14-15, HB14-40, HB14-36 and lastly CS_i^7 values identified HB14-15, HB14-40 , HB14-43. The phenotypic stability corrected nonparametric metrics were connected to the biological idea of stability [15]. Descriptive measures pointed out moreover less same set of genotypes, more over few of genotypes were also pointed out by rank based measures as per corrected yield of genotypes over the years.

Rank based composite measures

No parametric measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ consider simultaneously the ranks of genotypes as per yield and corrected yield values. These would be more desirable as compared to base on ranks either as per original or the corrected yield of genotypes. Lower values $NP_i^{(1)}$ measure observed for HB14-15, HB14-40, HB14-43 and least values of $NP_i^{(2)}$ and $NP_i^{(3)}$ expressed by HB14-15, HB14-40, HB14-07 [15]. Last measure $NP_i^{(4)}$ pointed towards HB14-15, HB14-40, and HB14-07 genotypes.

Table 1. Non parametric measures as per ranks of genotypes for original yield values

Genotypes	Mean	GAI	HM	S2x	Pi	bi	W2i	σ2i	S2di	Ri2	Si1	Si2	Si3	Si4	Si5	Si6	Si7	AvgR	SDR
HB 14-05	34.81	34.16	33.55	4.90	14.52	1.15	17.23	4.42	4.51	0.079	5.00	3.98	1.76	4.28	3.68	1.77	18.30	10.40	4.28
HB 14-07	34.03	33.60	33.19	5.05	19.86	0.92	9.43	2.19	2.82	0.442	3.60	3.22	0.78	2.95	2.16	0.96	8.70	11.20	2.95
HB 14-14	38.18	37.23	36.35	19.41	1.74	1.49	41.67	11.40	0.72	0.963	6.00	4.86	4.25	4.88	3.92	3.50	23.80	5.60	4.88
HB 14-15	35.24	34.71	34.21	0.40	10.80	1.07	1.27	-0.14	0.12	0.697	2.00	1.75	0.27	1.67	1.28	0.62	2.80	10.40	1.67
HB 14-16	34.58	34.21	33.84	3.10	16.88	0.87	8.21	1.84	1.81	0.415	5.20	5.77	2.58	4.98	3.44	1.79	24.80	9.60	4.98
HB 14-18	38.55	37.76	37.03	17.43	0.75	1.36	23.20	6.13	0.37	0.979	0.40	0.50	0.06	0.45	0.32	0.50	0.20	3.20	0.45
HB 14-20	37.61	36.91	36.22	11.13	2.79	1.22	22.24	5.85	4.77	0.571	5.00	5.35	3.54	4.45	2.96	2.64	19.80	5.60	4.45
HB 14-22	33.98	33.82	33.66	10.96	24.95	0.57	32.26	8.71	0.28	0.975	5.20	4.33	1.86	4.27	3.36	1.71	18.20	9.80	4.27
HB 14-25	33.63	33.28	32.92	13.63	25.21	0.72	37.08	10.09	7.99	0.414	7.00	5.51	3.54	5.89	5.04	2.57	34.70	9.80	5.89
HB 14-31	34.26	34.12	33.99	11.60	24.45	0.53	38.69	10.55	0.35	0.970	7.20	5.84	4.64	6.02	4.96	3.18	36.20	7.80	6.02
HB 14.32	38.91	38.08	37.29	22.02	0.43	1.39	30.01	8.07	1.54	0.930	4.20	3.43	3.34	3.56	2.96	3.89	12.70	3.80	3.56
HB 14-36	35.65	35.12	34.60	2.69	10.15	1.05	10.66	2.54	3.42	-0.268	6.20	5.98	3.06	5.13	3.52	2.05	26.30	8.60	5.13
HB 14-40	35.03	34.55	34.09	0.67	12.13	1.01	1.56	-0.06	0.52	0.223	3.00	3.00	0.61	2.51	1.68	0.81	6.30	10.40	2.51
HB 14-42	36.76	36.00	35.29	7.85	6.03	1.30	23.49	6.21	2.95	0.624	4.00	4.31	2.09	3.71	2.56	1.94	13.80	6.60	3.71
HB 14-43	35.87	35.27	34.71	3.35	9.49	1.12	12.72	3.13	3.40	-0.014	5.20	4.33	2.33	4.27	3.36	2.15	18.20	7.80	4.27
Vikrant	30.90	30.81	30.73	54.41	57.02	0.24	111.79	31.44	5.13	0.906	5.00	4.44	1.54	4.47	3.60	1.38	20.00	13.00	4.47

Table 2. Composite measures based on the ranks of genotypes as per corrected yield values

Genotypes	MedR	CSi1	CSi2	CSi3	CSi4	CSi5	CSi6	CSi7	CAvgR	CSDR	CMedR	NPi(1)	NPi(2)	NPi(3)	NPi(4)	Z1	Z2
HB 14-05	8.00	4.80	5.08	2.30	4.39	3.04	1.81	19.30	8.40	4.39	7.00	2.600	0.325	0.378	0.462	0.0248	0.0326
HB 14-07	12.00	4.60	3.63	1.61	3.81	3.20	1.78	14.50	9.00	3.81	11.00	2.800	0.233	0.304	0.411	0.0479	0.3909
HB 14-14	5.00	8.40	6.73	5.93	7.06	5.92	3.52	49.80	8.40	7.06	10.00	5.600	1.120	1.127	1.500	0.8994	6.9932
HB 14-15	10.00	1.00	0.88	0.08	0.84	0.64	0.36	0.70	8.80	0.84	9.00	0.600	0.060	0.072	0.096	1.7548	3.6232
HB 14-16	11.00	5.20	5.21	2.42	4.51	3.12	1.86	20.30	8.40	4.51	9.00	3.000	0.273	0.420	0.542	0.0012	0.0077
HB 14-18	3.00	6.20	4.88	3.17	5.22	4.48	2.60	27.30	8.60	5.22	11.00	4.000	1.333	1.460	1.938	0.0743	0.3140
HB 14-20	5.00	6.60	5.23	3.49	5.41	4.48	2.67	29.30	8.40	5.41	6.00	4.000	0.800	0.865	1.179	0.1564	0.5560
HB 14-22	9.00	6.20	4.95	3.50	5.36	4.64	2.83	28.70	8.20	5.36	5.00	4.000	0.444	0.489	0.633	0.0743	0.4762
HB 14-25	13.00	6.60	5.50	4.22	6.02	5.28	3.07	36.30	8.60	6.02	13.00	4.400	0.338	0.550	0.673	0.1564	1.9433
HB 14-31	7.00	7.60	6.07	5.60	6.61	5.76	3.69	43.70	7.80	6.61	4.00	5.000	0.714	0.758	0.974	0.4937	4.3241
HB 14.32	2.00	8.00	6.35	5.27	6.57	5.44	3.32	43.20	8.20	6.57	7.00	5.200	2.600	1.547	2.105	0.6815	4.1336
HB 14-36	8.00	4.20	3.97	1.31	3.51	2.48	1.32	12.30	9.40	3.51	9.00	2.400	0.300	0.365	0.488	0.1168	0.6872
HB 14-40	10.00	2.60	2.04	0.53	2.17	1.84	1.05	4.70	8.80	2.17	10.00	1.600	0.160	0.186	0.250	0.6942	2.3500
HB 14-42	6.00	5.80	4.85	2.65	4.72	3.68	2.19	22.30	8.40	4.72	8.00	3.600	0.600	0.640	0.879	0.0224	0.0095
HB 14-43	6.00	4.20	3.62	1.43	3.51	2.72	1.58	12.30	8.60	3.51	7.00	2.400	0.400	0.402	0.538	0.1168	0.6872
Vikrant	16.00	9.00	7.19	7.19	7.58	6.40	4.00	57.50	8.00	7.58	6.00	6.000	0.375	0.522	0.692	1.2830	11.2741

The Z_1 sum and Z_2 sum measure were distributed as χ^2 and were less & more than the critical value of χ^2. More over the four individual Z values more than the critical value of χ^2 (0.05, 1) = 3.84 were observed for HB14-14, HB14-31, HB14.32.

Biplot graphical analysis

Among the 36 non-parametric measures, the first two PCA explained 68.3% of the overall variation (Table 3). A total variation of 39.6% was explained by the first principal component (PC) in figure 1. It showed maximum of the variations accounted in CSDR, $W^2{}_i$, $\sigma^2{}_i$, $CS_i{}^4$, $CS_i{}^7$, and CSDR measures etc. Principal component two was responsible for 28.6% of the overall variation in figure 1.

Table 3. Loading of parametric and rank based stability measures

Measures	PC1	PC2	Measures	PC1	PC2
Mean	-0.0534	0.2785	Si6	0.1586	0.1173
GAI	-0.0501	0.2803	Si7	0.1622	-0.0828
HM	-0.0461	0.2811	CAvgR	-0.1777	-0.0289
S2xi	0.1916	-0.0098	CSDR	0.2356	0.0681
Pi	0.1221	-0.2322	CMedR	-0.0928	0.0127
bi	-0.1038	0.2322	CSi1	0.2324	0.0817
W2i	0.2091	-0.0615	CSi2	0.2289	0.0643
σ2i	0.2091	-0.0615	CSi3	0.2395	0.0488
S2di	0.0765	-0.1082	CSi4	0.2356	0.0681
R2i	0.1228	0.1065	CSi5	0.2338	0.0676
AvgR	-0.0154	-0.2820	CSi6	0.2363	0.0613
SDR	0.1578	-0.0953	CSi7	0.2388	0.0545
MedR	0.0245	-0.2698	NPi(1)	0.2331	0.0791
Si1	0.1538	-0.0922	NPi(2)	0.0879	0.2451
Si2	0.1297	-0.0911	NPi(3)	0.1101	0.2507
Si3	0.1627	0.0569	NPi(4)	0.1066	0.2536
Si4	0.1578	-0.0953	Z1	0.0166	-0.0377
Si5	0.1723	-0.0928	Z2	0.1547	-0.0449
68.31	39.65	28.66			

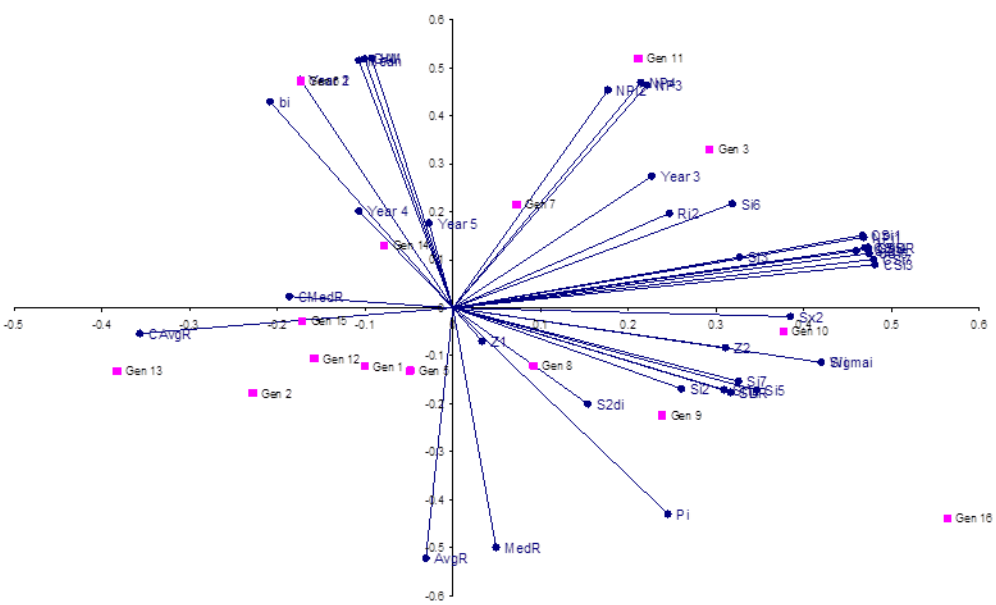

Figure 1. Biplot analysis of parametric and rank based measures

Six measures, Mean, HM, GAI, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ including CMedR, AvgR, were to contribute more to second PC. Graphical representation under the biplot analysis would be more appropriate to analyse interaction between genotypes and measures of stability as allow narrowing down the number of measures to the ones contributing a major portion to the variability. According to Verma [5], the vector length of the genotype, which is a measurement of how distinct the genotype is from other genotypes, is the distance between the biplot origin and genotype position in the biplot. Rank based S_i^1, S_i^2, S_i^4, S_i^5, S_i^7 expressed strong positive association with parametric W^2_i, σ^2_i, S^2_{di}, SDR and Pi measures in biplot. Mean yield has expressed strong relationship with HM, GAI whereas no relation with rank based non parametric measures S_i^s. Median based on the corrected ranks of genotypes CMedR exhibited strong bondage with Cmean. Three of non-parametric composite measures $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ formed tight group while $NP_i^{(1)}$ had maintained close relationship with CS_i^3, CS_i^6, CCVR, CSDR, CS_i^5, CS_i^2.

Clustering pattern

There are six total clusters of different measures, which include larger and smaller sizes, as shown in figure 2. Mean clustered with HM and GAI measures to show the agreement among these measures regarding the performance of Faba bean genotypes. Rank based measures based on the corrected yield of genotypes grouped with rank based measures as per yield of genotypes S_i^3, S_i^6 and parametric R_i^2 measure. This affinity expressed the overall agreement among measures for the genotypes behavior. Non parametric composite measures $NP_i^{(2)}$, $NP_i^{(3)}$ and $NP_i^{(4)}$ grouped in small cluster that was adjacent to cluster of other non-parametric measures. Descriptive measures as per rank of genotypes AvgR, MedR, CAvgR, CMedR clustered as apart. Last bigger group formed by parametric S^2_{xi}. W^2_i, SDR, σ^2_i, S^2_{di}, and rank based non parametric measures S_i^1, S_i^2, S_i^4, S_i^5, and Si7 Z_2. This clustering pattern among the considered analytic measures confirmed the association among them.

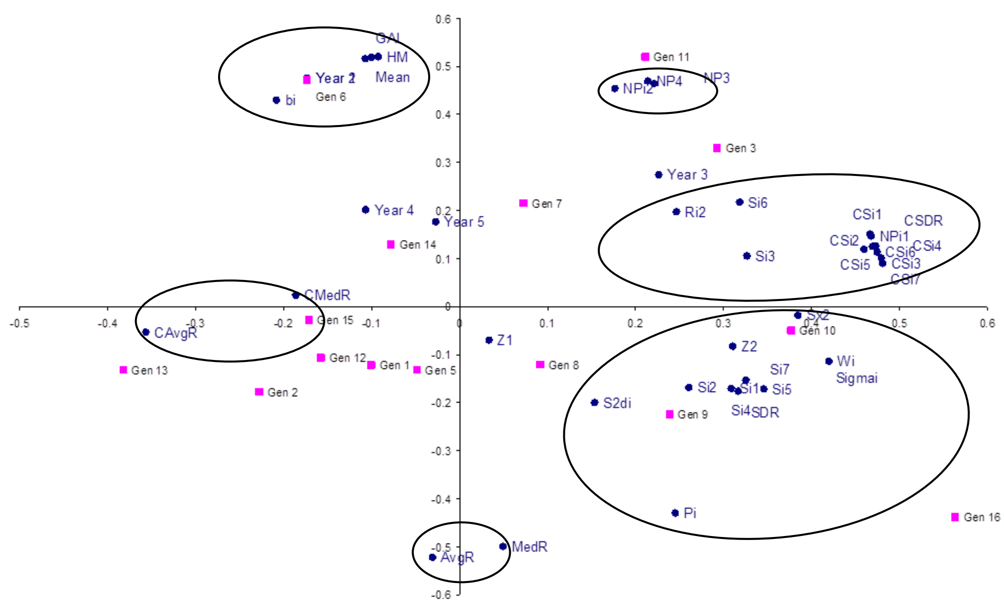

Figure 2. Clustering patterns of stability measures

Association analysis

Highly noteworthy positive association of average yield observed with GAI, HM, bi, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ and negative relation with Pi, AvgR measures as well as no relation with rank based CS_i^4, CS_i^5 values (Table 4).

Table 4. Correlation analysis among parametric and rank based measures of Faba bean genotypes

	GAI	HM	S^2_{xi}	P_i	b_i	W^2_i	σ^2_i	S^2_{di}	R^2_i	AvgR	S_i^1	S_i^2	S_i^3	S_i^4	S_i^5	S_i^6	S_i^7	CAvgR	CS_i^1	CS_i^2	CS_i^3	CS_i^4	CS_i^5	CS_i^6	CS_i^7	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$	$NP_i^{(4)}$	Z1	Z2
Mean	0.998	0.991	-0.254	-0.928	0.916	-0.420	-0.420	-0.346	0.134	-0.925	-0.326	-0.285	0.159	-0.341	-0.366	0.339	-0.319	0.123	0.048	0.009	-0.073	0.000	-0.012	-0.040	-0.049	0.032	0.692	0.688	0.702	-0.146	-0.292
GAI		0.997	-0.254	-0.922	0.892	-0.419	-0.419	-0.370	0.158	-0.937	-0.318	-0.277	0.173	-0.333	-0.360	0.348	-0.305	0.101	0.060	0.016	-0.061	0.012	0.003	-0.022	-0.039	0.045	0.704	0.701	0.714	-0.152	-0.297
HM			-0.253	-0.911	0.860	-0.415	-0.415	-0.401	0.187	-0.946	-0.309	-0.269	0.187	-0.325	-0.353	0.356	-0.291	0.074	0.072	0.023	-0.047	0.024	0.020	-0.003	-0.027	0.059	0.715	0.713	0.726	-0.158	-0.299
S2xi				0.587	-0.377	0.959	0.959	0.244	0.546	0.044	0.091	0.020	0.104	0.113	0.185	0.174	0.121	-0.538	0.761	0.701	0.833	0.748	0.759	0.768	0.829	0.787	0.331	0.407	0.405	0.374	0.805
Pi					-0.931	0.715	0.715	0.348	0.126	0.766	0.320	0.259	-0.071	0.341	0.389	-0.199	0.332	-0.342	0.269	0.274	0.394	0.304	0.321	0.350	0.371	0.292	-0.433	-0.399	-0.412	0.241	0.536
bi						-0.535	-0.535	-0.222	-0.111	-0.725	-0.387	-0.339	-0.008	-0.401	-0.427	0.173	-0.420	0.336	-0.169	-0.164	-0.286	-0.212	-0.247	-0.282	-0.257	-0.195	0.475	0.448	0.463	-0.133	-0.354
W2i							1.000	0.317	0.488	0.185	0.292	0.204	0.212	0.311	0.382	0.211	0.317	-0.597	0.764	0.722	0.850	0.766	0.776	0.792	0.842	0.788	0.151	0.250	0.242	0.329	0.802
σ2i								0.317	0.488	0.185	0.292	0.204	0.212	0.311	0.382	0.211	0.317	-0.597	0.764	0.722	0.850	0.766	0.776	0.792	0.842	0.788	0.151	0.250	0.242	0.329	0.802
S2di									-0.404	0.282	0.436	0.433	0.230	0.465	0.472	0.145	0.438	0.078	0.212	0.284	0.167	0.245	0.208	0.177	0.188	0.176	-0.218	-0.165	-0.175	-0.260	0.006
R2i										-0.311	-0.182	-0.267	0.073	-0.174	-0.088	0.183	-0.109	-0.683	0.576	0.447	0.653	0.559	0.627	0.651	0.642	0.633	0.497	0.578	0.575	0.369	0.476
AvgR											0.198	0.180	-0.307	0.203	0.210	-0.452	0.130	0.115	-0.318	-0.262	-0.192	-0.276	-0.275	-0.253	-0.211	-0.305	-0.791	-0.854	-0.860	0.221	0.198
Si1												0.937	0.847	0.990	0.977	0.691	0.959	-0.267	0.427	0.503	0.426	0.466	0.427	0.430	0.426	0.400	-0.122	-0.120	-0.135	-0.199	0.172
Si2													0.807	0.963	0.873	0.608	0.911	-0.184	0.356	0.449	0.315	0.379	0.316	0.317	0.315	0.311	-0.188	-0.172	-0.180	-0.286	0.056
Si3														0.842	0.823	0.927	0.848	-0.369	0.584	0.616	0.554	0.596	0.562	0.562	0.559	0.560	0.312	0.329	0.319	-0.153	0.176
Si4															0.972	0.676	0.966	-0.305	0.446	0.536	0.439	0.485	0.433	0.438	0.438	0.412	-0.130	-0.119	-0.134	-0.222	0.161
Si5																0.694	0.957	-0.391	0.497	0.579	0.518	0.546	0.508	0.515	0.516	0.474	-0.072	-0.064	-0.085	-0.156	0.238
Si6																	0.644	-0.427	0.629	0.639	0.594	0.625	0.593	0.593	0.601	0.608	0.582	0.511	0.508	-0.074	0.222
Si7																		-0.312	0.469	0.551	0.473	0.518	0.480	0.484	0.473	0.445	-0.114	-0.041	-0.063	-0.227	0.156
CAvgR																			-0.674	-0.657	-0.742	-0.686	-0.687	-0.738	-0.714	-0.676	-0.344	-0.382	-0.371	-0.141	-0.436
CSi1																				0.971	0.961	0.995	0.982	0.978	0.969	0.993	0.559	0.680	0.670	-0.073	0.503
CSi2																					0.920	0.977	0.930	0.926	0.928	0.944	0.496	0.616	0.602	-0.166	0.426
CSi3																						0.964	0.968	0.978	0.998	0.976	0.496	0.596	0.584	0.171	0.687
CSi4																							0.987	0.983	0.971	0.988	0.519	0.650	0.636	-0.091	0.491
CSi5																								0.996	0.974	0.991	0.517	0.653	0.638	-0.033	0.524
CSi6																									0.979	0.988	0.509	0.634	0.620	0.006	0.551
CSi7																										0.982	0.507	0.614	0.601	0.148	0.671
NPi(1)																											0.558	0.680	0.669	0.006	0.561
NPi(2)																												0.922	0.930	0.020	0.170
NPi(3)																													0.999	-0.089	0.161
NPi(4)																														-0.080	0.161
Z1																															0.765

HM and GAI measures expressed similar association with other measures. S^2_{xi} showed only direct relationships W^2_i, σ^2_i, CS_i^1, CS_i^2, CS_i^3, CS_i^4, CS_i^5, CS_i^6, CS_i^7, Z_2 measures. Superiority index P_i maintained significant relation with bi, W_I, σ^2_i, Z_2 measures. Regression coefficient bi expressed negative values with other measures. Wricke's ecovalence W^2_i showed perfect positive with σ^2_i. Moderate to weak type of associations expressed by S^2_{di} with other measures. R^2_i measure expressed moderate positive correlation values with rank based non parametric measures. Composite non parametric measures $NP_i^{(1)}$, $NP_i^{(2)}$, $NP_i^{(3)}$, $NP_i^{(4)}$ expressed strong positive association with commonly used parametric measures σ2i ,S2xi ,W2i , R^2_i measures. Direct or indirect type of relationships of non-parametric measures with other considered univariate and multivariate measures highlighted the appropriateness of rank based non parametric measures.

Conclusion

Recent analytic measures for the stability analysis had considered the parametric univariate, parametric multivariate and rank based non parametric measures. Non parametric have been observed as computationally easy and robust to the presence of outliers in data sets. The use of non-parametric metrics in the stability and adaptability analysis of genotypes is encouraged by the moderate to a strong relationship of these measures with other research studies.

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