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Discriminating parametric and non parametric methods for stability and adaptability analysis

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ABSTRACT

In the present study, fifteen dwarf field pea genotypes were evaluated in six locations under three agro climatic zones of India viz., Central zone, North West Plain zone and North East Plain zones for the purpose of identifying stable and adaptable genotypes. Two parametric models, viz. Shukla's stability variance σ_i^2(1972) and Wricke's ecovalence (W_i^2) (Wricke 1962) as well as one non-parametric model, Huehn's measure of stability parameters were considered for genotype evaluation. Shukla's stability variance (σ_i^2) revealed FP-16-15, FP-16-5 and FP-16-13 as consistent performer across the six tested environments whereas Wricke's ecovalence (W_i) identified FP-16-13, FP-16-15 and FP-16-5 as ideal genotype with high stability. The non-parametric stability parameter of Huehn (1979) depicted FP-16- 8, FP-16-10 and FP-16-13 as stable genotype. Both the models expressed equivalent potential of genotype ranking depending upon the data set.

Keywords: Adaptability, genotype × environment interaction, parametric methods, non-parametric methods, stability

1. INTRODUCTION

In agricultural experimentation, large numbers of genotypes are normally evaluated over a wide range of environments for validation of performance regarding quantitative characters. The performance of a genotype is determined by three factors: genotypic main effect (G), environmental main effect (E) and their interaction (GE) (Yan *et al.*, 2007). Therefore, the occurrence of the genotype (G) by environment (E) interaction (GEI) effect further complicates the selection of superior genotypes for a target environment. In the absence of GEI, the superior genotype in one environment may be regarded as universally superior irrespective of environmental factors. Unfortunately, the presence of the GEI confounds genotype superiority in relation with environmental parameters thus complicate selection process of the breeder. The performance of a genotype is determined by three factors: genotypic main effect (G), environmental main effect (E) and their interaction (GE) (Yan *et al.*, 2007). In the crop improvement programme development of varieties with broad adaptation in wide range of environments is the ultimate goal of plant breeders. Low level of interaction with unpredictable variables such as adverse weather conditions would result more uniform and stable yields, whereas a high level of interaction with a controllable variable such as fertilizer application, is always desirable (Mohebodini *et al*., 2006). High yield stability usually refers to a genotype's ability to perform consistently, whether at high or low yield levels, across a wide range of environments (Annicchiarico, 2002). Generally, stability of genotypes refers to its performance with respect to changing environmental factors overtime within a given location. This implies that a stable variety is less sensitive to the temporal environmental variations generally prevailing in nature. Unlike stability, adaptability is a spatial concept and refers to the stability in performance of genotypes with respect to changes across locations. Lacks of comprehensive studies regarding clear cut distinction between these two types of stability seek immediate attention. When GE interaction is important the parameters of stability and adaptability together with information on crop yield will help to identify varieties suited for general as well as specific adaption in a set of environments. Several parametric and non-parametric methods have been deployed in many crops for enumeration of genotype adaptability and stability (Awoke and Sharma, 2016; Yaghotipoor *et al*., 2017). Dearth of information regarding comparative evaluation of different parametric and non-parametric methods for discerning stability and adaptability analysis do not provide proper justification of selecting any of the method for analysing stability and adaptability of crop varieties under diverse locations. Keeping these in the backdrop the present study has been carried out through deploying two parametric models *viz*. Shukla's variance σ_i^2 (Shukla, 1972) and Wricke's ecovalence (Wricke, 1962) and one non-parametric model *viz*. Huehn's measure of stability for identification of stable genotypes across six environments. The current study addresses the main challenge of estimating the nature of genotype x environment interaction and their putative control for specifying varietal adaptability and stability.

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2. MATERIALS AND METHODS

Material for the study

The datasheet of the present study comprised of 15 dwarf field pea genotypes evaluated under the aegis of All India Coordinated Research Project on Mungbean, Urdbean, Lentil, Lathyrus, Rajmash and Pea (AICRP on MULLaRP). These 15 field pea genotypes were evaluated across six locations under three different agro-climatic zones during the winter season of 2016-17. Among the various testing environments, locations 1 and 2 constituted of North Western Plane Zone, locations 3 and 4 represented North Eastern Plane Zone and rest two locations depicted Central Zone.

Experimental design

The original experimental set up included 15 genotypes of field pea evaluated in 6 locations across three different agro-climatic zones under the Co-ordinated scheme. At each location genotypes were sown during middle to last week of November in randomized block design with 6 rows each of 4 m length with 45 cm spacing between rows and having a plot size of 10.8 m^2. Standard package of practices was followed across all locations to raise the crop. Data were recorded regarding yield performance of the genotype at physiological maturity from the whole plot and were expressed in kg ha^{-1} using the plot size as factor.

Statistical Models

Parametric methods

Shukla's stability variance parameter $\left(\sigma_i^2\right)$

Shukla (1972) defined the stability variance of genotype i as its variance across environments after the main effects of environmental means have been removed. Since the genotype main effect is constant, the stability variance is thus based on the residual (GE_{ij}+ e_{ij}) matrix in a two-way classification. The stability statistic is termed as "stability variance" $\left(S_i^2\right)$ and is estimated as follows :

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

Where *Yij* is the mean yield of the genotype in the environment, Y_i is the mean of the genotype *i* in all environments, Y_j is the mean of all genotypes in *jth* environments and is the mean of all genotypes in all environments. A genotype is called stable if its stability variance (σ_i^2) is equal to the environmental variance (σ_i^2) which means that (σ_i^2) = 0. A relatively large value of (σ_i^2) will thus indicate greater instability of genotype *i*. As the stability variance is the difference between two sums of squares, it can be negative, but negative estimates of variances are not uncommon in variance component problems. Negative estimates (σ_i^2) may be taken as equal to zero as usual (Shukla, 1972). Homogeneity of estimates can be tested using Shukla's (1972) approximate test. The stability variance is a linear combination of the ecovalence, and therefore both W_i and S_i^2 are equivalent for ranking purposes.

Wricke's ecovalence (W_i)

Wricke (1962, 1964) defined the concept of ecovalence as the contribution of each genotype to the GEI sum of squares. The ecovalence (W_i) or stability of the genotype is its interaction with the environments, squared and summed across environments, and expressed as:

$$W_i=\left[\bar{Y}_{ij}-\bar{Y}_i-\bar{Y}_j-\bar{Y}\right]^2$$

Where $\bar{Y}_{ij}$ is the mean performance of genotype *i* in the j^{th} environment and $\bar{Y}_i$ and $\bar{Y}_j$ are the genotype and environment mean deviations, respectively, and $\bar{Y}$ is the overall mean. For this reason, genotypes with a low W_i value have smaller deviations from the mean across environments and are thus more stable.

Non parametric stability model

Several nonparametric methods have been developed to describe and interpret the responses of genotypes to environmental variation. In the current study, Huehn's measure of stability have been considered for evaluation of genotypic stability**.**

Huehn's measure of stability parameters

Huehn (1990) proposed 4 non parametric measures of phenotypic stability based on a classification of the genotype in each environment, and defined stable genotype as those whose position in relation to the other remained unaltered in the set of environments assessed. The 4 stability parameters are defined as ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$). Out of these four parameters, two have been considered for this study *viz.* ($S_i^{(1)}$, $S_i^{(2)}$).

$$S_i^{(1)} = 2\sum_{j}^{n-2} \frac{\sum_{j'=j+1}^{n} \left| r_{ij} - r_{ij'} \right|}{\left[N(N-1) \right]}$$

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

$$S_i^{(2)} = \frac{\sum_{j=1}^{n} (r_{ij} - \bar{r}_{i.})^2}{N-1}$$

2) The parameter $S_i^{(2)}$ gives the variance among the ranks over environments.

Test of significance for the parameters $S_i^{(1)}$ and $S_i^{(2)}$

The stability statistics $S_i^{(1)}$ and $S_i^{(2)}$ are based on ranks of genotypes across environments. This statistic gives equal weight to each environment unlike $S_i^{(3)}$ and $S_i^{(6)}$ which combine yield and stability based on yield performance of genotypes in each environment as a relative measure of genotypic potential. Hence, tests of significance for stability of a single genotype and stability comparisons between certain genotypes under the parameters $S_i^{(1)}$ and $S_i^{(2)}$ was proposed by Nassar and Huehn (1987) and given as follows :

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

Where $Z_i^{(m)}$ have an appropriate chi-squared distribution with one degree of freedom.

The mean $E\left(S_i^{m}\right)$ and variance $V\left(S_i^{(m)}\right)$ may be computed from the discrete uniform distribution (1,2………,k) under the assumption of null hypothesis that all genotypes are equally stable. The formulas are given by,

$$E(S_i^{(1)}) = (K^2 - 1)/3\,KV(S_i^{(1)}) = \frac{(K^2 - 1)[(K^2 - 4)(N + 3) + 30]}{45K^2N(N - 1)}$$

$$E(S_i^{(2)}) = (K^2 - 1)/12\,V(S_i^{(2)}) = \frac{(K^2 - 1)[2(K^2 - 4)(N - 1) + 5(K^2 - 1)]}{360N(N - 1)}$$

Similarly, the statistic

$$S^{(m)} = \sum_{i=1}^{k} Z_i^{(m)}, m = 1,2$$

May be approximated by a chi-squared distribution with (k-1) degrees of freedom.

3. RESULTS AND DISCUSSION

3.1. Stability analysis using parametric methods:

Parametric stability analysis of the field pea genotypes were carried out by considering Shukla's stability variance parameter (1972) and Wricke's ecovalence (1962) stability model.

Shukla's stability variance parameter (σ_i^2): The environmental variance (σ_i^2) is one of the major stability measures for the static stability concept, *i.e.*, the variance of genotype yields recorded across test environments. The smaller the, S_i^2 the more stable the i^{th} genotype. The mean performance of genotype, genotype's variance across environments and coefficient of variation were presented in Table1. From the result it can be depicted that the most stable genotype was genotype FP-16-12 followed by genotype FP-16-05. Parametric stability analysis like Shukla's stability variance parameter provides a general summary of the response patterns of genotypes to environmental change. In the present study these two genotypes considered as consistent performer across the six environments as these genotypes were revealing lowest S_i^2 value. FP-16-09 and FP-16-02 with the S_i^2 largest value, was considered as highly sensitive (less stable) genotype across the six regions.

Wricke's ecovalence (W_i)

The result of the analysis as per ecovalence method of Wricke (1962) was presented in table 2. Wricke (1962) suggested the use of ecovalance (W_i^2) as a stability parameter. According to this stability parameter, genotypes with the smallest ecovalance (W_i^2) values are considered as stable. It was revealed that in affirmation with Shukla's Stability Variance Parameter model in this analysis the most stable genotypes were genotype FP-16-12 followed by genotype FP-16-5 and genotype FP-16-15. The most unstable genotypes with higher values of ecovalance (W_i^2) were FP-16-9, FP-16-5 and FP-16-15.

Several parametric methods for enumerating stability of the genotype are routinely used in comprehensive plant breeding programme. Usually, parametric methods are based on variance components and related statistics. These stability measures provide good estimates under certain statistical assumptions, based on the normal distribution of error and GEI effects, but may not perform well if these assumptions are violated by factors such as the presence of outliers (Sood *et al*., 2016). The stability component in YSi is based on Shukla's (1972) stability-variance statistic (σ_i^2). Shukla (1972) partitioned genotype x environment interaction into components, one corresponding to each genotype, and referred to it as stability variance (Kang, 2002). Previous reports deploying parametric methods *viz*. Shukla's stability variance parameter and Wricks ecovalence parameter confirmed the result of similar trend during discriminating stable genotype (Awoke and Sharma, 2016; Sood *et al*., 2016; Yaghotipoor *et al*., 2017).

3.2. Stability analysis using non parametric methods

Among the various non parametric stability analysis approaches, Huehn (1979) stability model have been considered for evaluation of the field pea genotypes

Mean of the absolute rank differences ($S_i^{(1)}$) of a genotype and variance among the ranks ($S_i^{(2)}$) over the environments

The result (Table 3) clearly reflected that the genotypes FP-16-10, FP-16-8, FP-16-13 and FP-16-5 had the lowest value of $S_i^{(1)}$. On contrary, genotype FP-16-3, FP-16-1 and FP-16-11 had the higher $S_i^{(1)}$. According to this method genotypes with less change in ranks are expected to be more stable. The mean absolute rank difference $S_i^{(1)}$ estimates all possible pair wise rank difference across environments for each genotype. The $S_i^{(2)}$ estimates are simply the variance of ranks for each genotype over environments. For the variance of ranks $S_i^{(2)}$, smaller estimates may indicate relative stability. Often, $S_i^{(2)}$ has less power for detecting stability than $S_i^{(1)}$. Hence, genotype FP-16-10, FP-16-8, FP-16-13 and FP-16-5 were stable where as genotypes FP-16-3, FP-16-1 and FP-16-11 were unstable. Since $S_i^{(1)}$ =22.51 lesser than critical value $\chi^2_{.05,14=23.68}$, there were not significant differences in rank stability for yield performance among 15 genotype grown in 6 diverse locations. Additionally, same kind of trend was obtained in case of $S_i^{(2)}$.

Nonparametric stability measures based on ranks provide a viable alternative to present parametric measures based on absolute data (Nassar and Huehn, 1987). In any comprehensive breeding programme plant breeders are more focused on superiority of the genotype based on their rank or order. Previous studies reported that the parametric methods are more informative and useful than non-parametric approaches. But when large number of genotypes is tested in a set of environments, the risk of selecting inferior genotypes from use of nonparametric measures is minimal (Rao and Prabhakaran, 2000). Previous reports corroborated the importance of rank correlation as stability measure. Significant positive rank correlation between $S_i(^1)$ and $S_i(^2)$ was reported earlier in bread wheat, durum wheat and barley by Mohammadi *et al*., 2009.

Table 1: Mean grain yield, environmental variance (S_i^2), and coefficient of variation (CVi) of the 15 field pea genotype

Genotype	S_i^2	CVi	RANK
FP-16-01	154112.70	25.06	12
FP-16-02	162381.15	29.40	14
FP-16-03	272584.30	23.55	10
FP-16-04	96866.82	18.22	6
FP-16-05	83037.10	15.39	2
FP-16-06	154840.29	20.62	7
FP-16-07	281177.19	27.75	13
FP-16-08	136843.37	16.12	4
FP-16-09	386635.19	33.44	15
FP-16-10	89834.01	20.63	8
FP-16-11	266182.67	24.42	11
FP-16-12	82844.66	16.21	5
FP-16-13	90966.82	16.07	3
FP-16-14	205299.81	21.81	9
FP-16-15	89654.24	13.91	1

Table 2: Wricke's ecovalence value for 15 field pea genotypes at 6 environments

Genotype	Wricke's Ecovalence (Wi)	Rank
FP-16-01	724560.81	8
FP-16-02	760390.77	10
FP-16-03	1237937.74	13
FP-16-04	476495.34	6
FP-16-05	416566.54	2
FP-16-06	727713.71	9
FP-16-07	1275173.61	14
FP-16-08	649727.04	7
FP-16-09	1732158.27	15
FP-16-10	446019.84	4
FP-16-11	1210197.34	12
FP-16-12	415732.64	1
FP-16-13	450928.67	5
FP-16-14	946371.61	11
FP-16-15	445240.81	3

3.3. Relationship among parametric and non-parametric methods

The Spearman's rank correlation between different parametric and non-parametric stability measures (Awoke and Sharma, 2016) for evaluating stability of 15 field pea genotypes was presented in table 3. It was observed that Shukla's Stability Variance Parameter (Si) correlated with Wi, $Si^{(1)}$ and $Si^{(2)}$. The parameter Wi was significantly correlated with Si, $Si^{(1)}$ and $Si^{(2)}$. Grippingly, the parameter $Si^{(1)}$ was also significantly correlated with Wi, Si, and $Si^{(2)}$. On the other hand $Si^{(2)}$ was significantly correlated with Wi, Si, and $Si^{(1)}$.

The differential response of genotype to the varied environmental condition is known as genotype by environment interaction. This interaction misleads the selection process thus reduce genetic gain in plant breeding programme. Genotypic stability is the deviation of a specific genotype's performance from the performance of the best cultivar in a trial (Lin and Binns, 1988). Therefore, stable cultivars have genetic homeostasis with having least genotype by environment interaction effect. Comparative assessment was carried out among the parametric and non-parametric

Table 3: Mean absolute rank difference ($S_i^{(1)}$) and variance of ranks ($S_i^{(2)}$) for yield of 15field pea genotypes.

Genotype	$S_i^{(1)}$	Rank	$Z_i^{(1)}$	$S_i^{(2)}$	Rank	$Z_i^{(2)}$
FP-16-01	2.07	13.00	0.56	26.80	13.00	0.96
FP-16-02	1.80	10.50	0.94	15.80	9.00	0.12
FP-16-03	2.13	14.00	0.49	24.40	12.00	0.48
FP-16-04	1.20	5.00	2.14	10.25	6.00	1.02
FP-16-05	1.13	3.00	2.31	6.40	2.00	2.18
FP-16-06	1.67	9.00	1.16	14.45	8.00	0.26
FP-16-07	1.47	7.00	1.54	28.05	14.00	1.28
FP-16-08	1.13	3.00	2.31	8.25	3.00	1.57
FP-16-09	2.33	15.00	0.29	28.60	15.00	1.43
FP-16-10	0.67	1.00	3.61	4.40	1.00	2.94
FP-16-11	1.87	12.00	0.83	22.65	11.00	0.23
FP-16-12	1.47	7.00	1.54	10.60	7.00	0.94
FP-16-13	1.13	3.00	2.31	9.45	5.00	1.23
FP-16-14	1.80	10.50	0.94	19.45	10.00	0.01
FP-16-15	1.47	7.00	1.54	8.65	4.00	1.45
$E(S_i^1)$	2.98		$S^{(1)}$	$E(S_i^2)$	18.66	$S^{(2)}$
$Var(S_i^1)$	1.48		22.51243	$V(S_i^2)$	69.06	16.09282
χ^2	23.68					

Table 4: Spearman's rank correlation coefficients between different parametric and non-parametric stability parameters for yield of 15 field pea genotypes

	Yield	Wi	S_i	$S_i^{(1)}$	$S_i^{(2)}$
Yield	1.000				
Wi	-0.239	1.000			
Si	0.286	.821**	1.000		
$Si^{(1)}$	-0.086	.715**	.704**	1.000	
$Si^{(2)}$	-0.043	.836**	.821**	.870**	1.000

***** Correlation is significant at the 0.05 level (2-tailed).
******Correlation is significant at the 0.01 level (2-tailed).

approaches of stability analysis. It was observed that the parametric stability measure like Shukla (ói^2) and Wricke (Wi^2) model had a total correspondence (r =1.00) which indicated the potential of these approaches regarding genotype ranking like non-parametric models. Therefore, these parametric stability measures along with s^2 were also in total correspondence with nonparametric stability measures $S_i(^1)$ and $S_i(^2)$ (Sood *et al.*, 2016). In both the cases, lower values reflecting less GI effect and high stability. Analogy of both parametric and non parametric approaches implied the equivalent significance regarding selection of stable genotypes in plant breeding programme.

4. CONCLUSION

In the present study the stable genotypes according to the parametric methods were FP-16-12, FP-16-6, FP-16-14, FP-16-15 and FP-16-4 while FP-16-6, FP-16-14, FP-16-15 and FP-16-8 were stable according to the non-parametric methods. Shukla's Stability Variance Parameter (σ_i^2) revealed that genotype FP-16-15, FP-16-5 and FP-16-13 were consistent performer across the six environments while Wricke's ecovalence (W_i) identified that genotype FP-16-12, FP-16-05 and FP-16-15 were good performer. The stability parameter of Huehn (1979) revealed that genotypes FP-16-8, FP-16-10 and FP-16-13 were stable performer. Therefore, both the parametric and non-parametric methods corroborated same finding regarding selection of stable genotypes. However, depending on data set the result of both the methods may vary.

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