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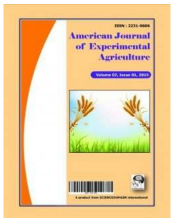

Association of Stability Models in Measuring Stability of Common Bean Varieties

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Authors' contributions

This work was carried out in collaboration among all authors. Author NK designed the study, wrote the protocol, performed the analysis and wrote the first draft of the manuscript. Authors NK and FM identified the varieties. Authors FM and YD reviewed the experimental design and all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Plant breeders have been challenged with genotype by environment (G x E) interaction to develop high yielder and stable varieties. They have been using different univariate stability models to simplify the challenge. The major ones are coefficient of variation (CV_i), absolute rank difference (S_i^1), variance of rank (S_i^2), σ_i^2, W_i, b_i, S_i^2d, P_i, ASV and r^2. This study was designed in order to increase information on the associations and reliability that might exist among stability models. The study was carried out on 15 common bean varieties replicated three times at Kobo, Sirinka, Jari, Chefa, Shewarobit and Kogo in 2011-2012 and 2012-2013 in Ethiopia. A combined analysis of variance, stability statistics and rank correlations among stability parameters and yield were determined. The varieties differed significantly for seed yield at P = 0.001. The different stability parameters were categorized into three types. Based on the correlation analysis SY, CV_i (type I), P_i, (type II), b_i and r^2 (type III) were strongly correlated. Moreover, S_i^1, S_i^2 (type I), W_i^2, σ_i^2(type II), S_i^2d and ASV (type III) were correlated at P = 0.01. On the other hand, SY with CV_i and P_i; CV_i with b_i and r^2; b_i with P_i; P_i with r^2 were correlated negatively at P = 0.01 while r^2 with S_i^1, S_i^2, W_i^2 and σ_i^2 were moderate and negatively correlated. Coefficient of determination (r^2) had strong association

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with eight of the stability parameters. AMMI Stability Value (ASV) and deviation from regression (S_i^2d) had also strong association with five of the models. Consequently, they can explain stability of varieties better following coefficient of determination. Thus, bean breeders can use those three stability models for better explanation and interpretation of G x E interaction of varieties/genotypes.

Keywords: Common bean; varieties; stability model; correlation and association.

1. INTRODUCTION

Stability is a central keyword for plant breeders analyzing genotype by environment (G x E) data because it enhances the progress from selection in any environment [1]. There are two concepts of stability: static and dynamic. The static (biological) concept means that a genotype has a stable performance across environments and there is no different response among environmental variance [2]. This would mean that a genotype would not respond to high levels of inputs, such as fertilizer. This type of stability would not be beneficial for the farmer. The dynamic (agronomic) concepts mean that a genotype has a stable performance, but, for each environment, its performance corresponds to the estimated level or predicted level and the level of actual performance [3]. A variety of methods and statistics are currently available for estimation of stability in crop improvement. However, the stability estimate provided by a given procedure may be interpretatively different from stability that the breeder is actually seeking. Choosing for the use of a particular method or parameter has been difficult even for those who are experts in the field of G x E interaction. To interpret G x E interaction, agricultural scientists have used parametric and non-parametric stability models.

Nassar and Huehn [4] described a non-parametric stability measure by using the mean absolute rank difference (S_i^1) which estimates all possible pair wise rank differences across environments for each genotype and the variances of ranks (S_i^2) that estimates the variance of each genotype over environments. Similar methods have been suggested by [5] who used the phenotypic coefficient of variation (CV_i). On the other hand parametric models such as σ_i^2 [6] and W_i^2 [7] determined based on the partitioning of G x E interaction into variance components that are attributed to each variety or genotype. More widely used methods, however, are those based on Regression. Regression coefficient was determined for each genotype by regressing individual genotype yield performance against the environmental means. [8] proposed the use of variance of deviation from regression (S_i^2d) to measure varietal stability, and regression coefficient (b_i) to evaluate varietal adaptation. [9,10] favored the coefficient of determination (r_i^2) over variance of deviations from regression as measure of the predictability of the estimated response. AMMI stability value (ASV) was proposed by [11] to quantify the degree of stability; genotypes which have low ASV have low contribution for the interaction and considered stable.

The different stability concepts that prompted the development of these various methods were categorized by [12]. According to [12] there are three types of stability. In Type 1, CV_i [5], S_i^1 and S_i^2 [4], a genotype is considered to be stable provided that the environmental variance is small in the other way it is called biological or static stability; in Type 2, P_i [13], σ_i^2 [6] and W_i^2 [7], a genotype is considered to be stable if its response to environment is parallel to the mean response of all genotypes in the trial and in Type 3, ASV, b_i and S_i^2d [8] and r_i^2 [9] are highly confiablity of estimated response and a genotype is considered to be stable if the residual mean squares from the regressions model on the environment index is small. [3] and [14] have commented on the similarities among these stability parameters as well as on the consequences of the utilization of different parameters for ordering of genotypes.

This work was designed in order to increase information on the associations and reliability that might exist among stability models derivable from ten different models [4-9,11,13] in measuring stability of common bean varieties.

2. MATERIALS AND METHODS

The trial was conducted at six locations namely Kobo, Sirinka, Jari, Chefa, Shewarobit and Koga; experimental locations of Amhara Agricultural Research Institute, Ethiopia as indicated in Table 1 during 2011- 2012 and 2012-2013 cropping years and provided a total of 12 environments.

Fifteen common bean varieties released from national and regional agricultural research centers of Ethiopia were used in this experiment. The experiment was conducted using randomized complete block design with three replications at six locations. The size of the experimental plot was 6.4 m^2 (1.6 m x 4 m). The spacing was 0.4 m and 0.1 m between rows and plants, respectively. The spacing between replications was 1 m. Planting was carried out from the first week of July up to mid-July. Sowing was done by hand drilling and covered with soil. Fertilizer was not applied and weeding and other agronomic practices were done as required.

Yield data were subjected to analysis of variance using Genstat statistical program ver. 13^{th}. Stability parameters were calculated for each of the methods reported by [4-9,11,13]. To statistically compare between the above stability models, Spearman's coefficient of rank correlation (r_s) was determined [15] and it was analyzed using Agrobase [16]. Parameter definitions are presented in the following section, with Y_{ij} representing the yield of the i^{th} genotype in the j^{th} environment, n is the number of genotypes, and m the number of environments. The grand mean yield of each genotype was estimated by

$$Yi = \frac{Yi.}{m}$$

2.1 Nassar and Huehn (1987) Method of Nonparametric Measure

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

$S_i^2 = \frac{\sum_{j=1}^{q}(r_{ij} - \overline{r_{i.}})^2}{(q-1)}$ Where $\overline{r_{i.}}$ =mean of ranks over environments; r_{ij} =rank of genotypes in each environment; rank assigned from lowest to highest; q= number of environments

2.2 Francis and Kannenberg (1978)

Phenotypic coefficient of variation was estimated using the formula

$$\text{CVi} = (\sqrt{\frac{ev_i}{(n-1)}}x100)/\overline{y_i}$$

Where ev_i, sum of squares of interaction effects and $\overline{y_i}$ the mean of i^{th} genotype

2.3 Shukla's Variance Stability Model (δ_i^2)

It was estimated as follow

$$\delta^2 = \frac{1}{(G-1)(G-1)(E-1)}\big(G(G-1)\big)\textstyle\sum_j\big(Y_{ij} - Y_{i.} -$$
$$Y.j{-}Y..2{-}\textstyle\sum i \sum j Yij{-}Yi.{-}Y.j{-}Y..2$$

Where Y_{ij} is the mean yield of the i^{th} genotype in the j^{th} environment, $Y_{\,j.}$ is the mean of the genotype *i* in all environments, $Y_{.j}$ is the mean of all genotypes in j^{th} environments and *Y* is the mean of all genotypes in all environments. G and E represent genotype and environment respectively.

2.4 Method of Wricke (W_i)

Ecovalence (E_i) was estimated for each genotype as:

$$\text{E}_\text{i} = \sum_\text{j}\left(\text{Y}_\text{ij} - \text{Y}_\text{i.} - \text{Y}_\text{.j} + \text{Y}_{..}\right)^2$$

Table 1. Rain fall, soil type, altitude, latitude and longitude of the testing sites

Locations	Altitude (m.a.s.l.)	Temp./min and max	Rain fall average (mm)	Soil type	Global position	
					Latitude	Longitude
Sirinka	1850	13.6-27.3℃	876	Eutric vertisol	11°08'	3 9°28'
Kobo	1470	15.8-29.1℃	637	Eutric fluvisol	12°8'21''	3 9°18'21''
Jari	1680	NA	NA	Vertisol	11°21'	39°38'
Chefa	1400	11.6-30.4℃	850	Vertisol	10°57'	39°47'
Shewarobit	1300	13.1-32.5℃	928	NA	10°06'	39°53'
Koga	1900	16-20℃	1589	Nitisol	11°25'	37°17'

Source: Sirinka and Debre Birhan Agricultural Research Centers for altitude, rain fall and soil type; Wikipedia for global position, NA= Non-available

2.5 Eberhart and Russell's Model

Here parameters bi and S_i^2d were estimated for each genotype by linear regression of Y_{ij} over the environmental index I_j as follow:

$$I_j = Y_{.j} - Y_{..}$$

$$b_i = \sum_j Y_{ij} I_i / \sum I_j^2$$

and

$$s^2 d_i = \left\{\left(\sum_j Y_{ji}^2 - Y_{i.}^2 / m\right) - \left[\left(\sum_j Y_{ij} I_j\right)^2 / \right.\right.$$
$$jIj2 / m-2$$

Coefficient of determination (r_i^2) can be calculated

$$r_i^2 = b_i^2 S_{Ij}^2 / S_i^2$$

Where $S_{Ij}^2 = \sum_j I_j^2 / (m-1)$

2.6 Cultivar Superiority Measure (P_i) of Lin and Binns Model

The underlying estimate of parameter P_i, measures the deviation from the yield of a given genotype in relation to the maximum in each one of the environments. The ideal genotype is the one with the lowest P_i value and the lowest contribution to the genotype by environment interaction.

$$P_i = \frac{n(x_{i.} - m)^2 + \sum_j \left(x_{ij} - x_{i.} - m_{.j} + m\right)^2}{2n}$$

Where x_{ij} is the response of the i^{th} genotype in the j^{th} environment, $x_{i.}$ is the mean of genotype i in the overall environments, m_j is the genotype with maximum response among all genotypes in the j^{th} environment, m is the mean of the genotypes with maximum response over all environments and n is the number of environments.

2.7 AMMI's Stability Value (ASV)

Following testing of the significance of the GEI mean square over three replications for yield of varieties i at location j, Y_{ij} was subjected to AMMI stability analysis. AMMI's stability value (ASV) was calculated using the following formula.

$$ASV = \sqrt{\left[\frac{SSIPCA1score}{SSIPCA2score} \times IPCA1score\right]^2 + (IPCA2score)^2}$$

Where ASV = AMMI's stability value, SS = sum of squares, IPCA1 = interaction of principal component analysis one, IPCA2 = interaction of principal component analysis two.

To statistically compare between the above stability models, Spearman's coefficient of rank correlation (r_s) was calculated [15] using the formula.

$$r_s = \frac{6\sum d_i^2}{n(n^2-1)}$$

The significance of r_s was tested by means of Student's t test [15]

$$t = \frac{r_s\sqrt{n-2}}{\sqrt{1-r_s^2}}$$

Where: n-2, degree of freedom; n, number of genotypes arranged in the same following order to two stability parameters; X_i, indicates the ranking order of the i^{th} genotype for the first parameter; Y_i, indicates the ranking order of the i^{th} genotype of the second parameter, then $d_i = X_i - Y_i$ (i = 1, 2, 3 …n)

3. RESULTS AND DISCUSSION

Analysis of variance model for grain yield revealed significant difference (p<0.001) for the main effects of variety (V), location (L), and year(Y) as well as interaction effects of VL, VY, LY and VLY (Table 2). The significance of the VLY interaction and its linear and nonlinear components demonstrated that genotypes differed in their responses to these environmental variations. This result indicated that this data base would be suitable for estimating the various stability statistics, and to deal with the inter-relationship among the various stability Models. Determining the extent of the association among stability statistics would help bean breeders in choosing stability parameters for discriminating among varieties/genotypes in a manner that best fits their concept of stability.

Different stability models were used to compare the stability of various varieties of common bean which were released at national and regional levels. Even though there was change in ranking order of varieties from one stability parameter to another parameter, varieties Tabor and Roba-1 with average yield greater than the mean yield, Red Wolayita with yield below the average, Chercher yield on average deemed to be stable among the others as they have low stability value in most stability models. Wodo and Bobe Red with mean seed yield of 2.09 and 2.02 tons/ha, respectively were identified as non-stable varieties (Table 3). Varieties with low and high stability value said to be stable and non-stable respectively. As indicated in Table 4 varieties with lower rank have low interaction with the environments while varieties with highest rank are highly interactive with the environments. However, the stability analysis of common bean using ten different stability models showed that there is no observable trend between stability and yield.

As indicated in Table 4, the models rank the yielding potential of the varieties differently. In such situation, it is difficult for breeders to choose the best varieties/genotypes using all the stability models. Different scholars reported about the interpretation of diversity using different stability statistics [3,12]. Most agricultural scientists used only some of the existing statistics and did not include all groups that are characteristics of stability parameters. However, the efficiency of the stability model in measuring the stability of varieties/genotypes varies and inconsistent. Inconsistency in ranking using a univariate approach was previously suggested to be difficult to reconcile into a unified conclusion by [12]. A series of univariate analysis alone cannot give accurate picture of complete response pattern [17]. As mentioned earlier; Tabor, Roba-1, Red Wolayita and Chercher were recognized as stable varieties and sensibly explained by Coefficient of determination (r^2), deviation from regression (Si^2d), AMMI stability value (ASV), wricks (W_i) and Shukla (δ^2_i) than the other stability models (see both Table 3 and 4).

Table 2. Combined ANOVA of yield for fifteen bean varieties at Kobo, Sirinka, Jari, Chefa, Shewarobit and Koga for the year 2011-2012 and 2012-2013

Source of variation	d.f.	S.S.	M.S.	V.R.	F pr.
Location	5	34.38099	6.87620	27.85	<.001
Year	1	7.93264	7.93264	149.00	<.0.007
Loc x year	5	77.90154	15.58031	39.70	<.001
Variety	14	58.81482	4.20106	70.17	<.001
Loc x Variety	70	39.55449	0.56506	9.44	<.001
Year x Variety	14	11.11104	0.79365	13.26	<.001
Year x loc x variety	70	26.56078	0.37944	6.34	<.001
Residual (error)	336	20.11598	0.05987		

d.f=degree of freedom, S.S=sum of squares, M.S=mean squares, V.R=variance ratio, Fpr=fussier probability

Table 3. Values of different stability models for fifteen common bean varieties

Variety name	SY	Cvi	Bi	Si^2d	Pi	S_i^1	S_i^2	Wi	δ^2_i	ASV	r^2
Tabor	1.94	15.20	1.18	0.04	0.16	4.55	13.42	0.52	0.13	0.07	0.98
Hawassa Dume	1.88	15.91	1.08	0.16	0.25	5.11	17.19	1.63	0.47	0.61	0.90
Dimutu	1.43	14.88	1.28	0.11	0.62	4.11	10.91	1.24	0.35	0.78	0.95
Nasir	1.53	15.84	1.11	0.20	0.57	5.03	17.08	2.00	0.59	0.96	0.89
Deme	0.71	29.13	0.20	0.15	1.62	6.38	27.74	3.32	1.01	1.10	0.25
Awash Melka	1.80	14.89	1.09	0.15	0.35	5.03	17.06	1.57	0.46	0.63	0.91
Roba-1	1.72	16.13	0.99	0.12	0.40	5.05	17.24	1.22	0.35	0.46	0.91
Zebra	1.44	16.18	0.70	0.13	0.65	5.09	16.97	1.45	0.42	0.27	0.83
Awash-1	1.37	22.37	0.81	0.19	0.62	4.86	15.91	1.91	0.56	0.94	0.81
Red wolayita	1.38	21.76	1.03	0.02	0.58	3.36	8.56	0.23	0.03	0.11	0.99
Bobe red	2.02	12.10	1.35	0.39	0.20	6.58	29.72	4.22	1.29	1.51	0.86
Wodo	2.09	15.19	1.13	0.30	0.16	5.97	24.25	3.06	0.92	1.24	0.84
Lehode	1.50	17.47	0.90	0.10	0.51	4.96	18.41	1.00	0.27	0.27	0.91
Chercher	1.59	14.32	1.04	0.09	0.44	5.14	17.41	0.86	0.23	0.62	0.94
Haramaya	1.53	16.53	1.15	0.14	0.54	5.32	19.74	1.47	0.42	0.57	0.92

SY = seed yield, Cv_i = coefficient of variation, bi = Regression Coefficient, S_i^2d = Deviation from Regression, P_i = Cultivar Superiority Value, S_i^1= absolute rank difference, S_i^2= variance of rank, W_i= Variance of Equivalence, δ^2_i = Shukla's Stability Variance, ASV = AMMI stability value, r^2 = Coefficient of Determination

Table 4. Ranks of common bean varieties based on the various stability parameters

Variety name	Entry	SY	Cvi	bi	Si^2d	Pi	S_i^1	S_i^2	Wi	δ^2_i	ASV	r^2	CR
Tabor	1	3	6	13	2	1	3	3	2	2	1	2	3
Hawassa Dume	2	4	8	8	11	4	10	8	10	10	7	9	8
Dimutu	3	12	3	14	5	12	2	2	6	6	10	3	7
Nasir	4	8	7	10	13	10	7	7	12	12	12	10	10
Deme	5	15	15	1	9	15	14	14	14	14	13	15	13
Awash Melka	6	5	4	9	10	5	6	6	9	9	9	8	7
Roba-1	7	6	9	5	6	6	8	9	5	5	5	6	6
Zebra	8	11	10	2	7	14	9	5	7	7	4	13	8
Awash-1	9	14	14	3	12	13	4	4	11	11	11	14	10
Red wolayita	10	13	13	6	1	11	1	1	1	1	2	1	5
Bobe red	11	2	1	15	15	3	15	15	15	15	15	11	11
Wodo	12	1	5	11	14	2	13	13	13	13	14	12	10
Lehode	13	10	12	4	4	8	5	11	4	4	3	7	7
Chercher	14	7	2	7	3	7	11	10	3	3	8	4	6
Haramaya	15	9	11	12	8	9	12	12	8	8	6	5	9

CR = Cumulative rank

Mean seed yield was highly correlated with CV_i (r=-0.8364), b_i (r=0.7932), P_i (=-0.9586) and r^2 (r=0.6659) as depicted in Table (5). The negative correlation of seed yield with P_i and CV_i indicate that high yielding and responsive varieties like Wodo, Tabor, Hawasa dume, Bobe red and Awash melka leaned to have lower P_i and CV_i value. However, [18] showed that CV_i was not correlated with seed yield while he approved that P_i was negatively correlated with seed yield. The strong positive association between seed yield and b_i and r^2 indicates that they measure similar aspect of stability of varieties and can be used one in the absence of the other. The none-correlation of mean seed yield and the other six stability parameters (Table 5) showed that those parameters and mean seed yield can be simultaneously used in the selection of high-yielding, stable varieties. Similar result was obtained by [19].

Association of stability parameters in type I which are mainly explains in terms of main effect of genotypes is assumed to be a constant phenotypic expression (biological or homeostasis). This group includes, Nassar and Huehn's mean absolute rank difference (S_i^1), variance of ranks (S_i^2) and Francis and Kannenberg (CV_i). The correlation of CV_i with S_i^1 and S_i^2 is almost zero (r=0.0822 and 0.04073 respectively). However, Nassar and Huehn's mean absolute rank difference (S_i^1) and variance of ranks (S_i^2) showed a highly significant positive rank correlation with each other. Consequently, only one of these stability measures would be enough to identify stable genotypes in common bean breeding program. In Type 2, σ_i^2 [6] and W_i^2 [7] and P_i [13] are found and P_i has no correlation with both σ_i^2 and W_i^2. However, W_i and δ_i^2 had perfect and positive rank correlation (r=1.0) and ranked varieties in exactly the same manner Table 5. Ecovalence value of Wricke (W_i) and stability variance parameter of Shukla (δ_i^2) showed similar values and trends [18,20]. The low value of ecovalence of Wricke (W_i) and stability variance of Shukla (δ_i^2) is a good indication of stability in varietal evaluation across environment.

Type 3 stability parameters include, ASV, bi Sdi^2 and ri^2. There are strong association between ASV and S_i^2d. Moreover, r^2 highly associated with b_i in this group. The dependence relationship between coefficients of regression and coefficient of determination can be easily noticed in the mathematical expression:

$$r_i^2 = b_i^2 s^2 I_j / s_i^2$$

Noticeably, r_i^2 is very sensitive to any variation in b_i because it is directly proportional to the square of the regression coefficient [21]. Such association shows that high responses tend to result in high coefficients of determination and vice versa. The independent association of regression coefficients and variance of deviation from regression (S_i^2d) indicates that they can be jointly used in a stability study.

Table 5. The spearman's rank correlation coefficients for all stability measures including seed yield

	SY	**CV_i**	**b_i**	**S_i^2d**	**P_i**	**S_i^1**	**S_i^2**	**W_i**	**δ^2_i**	**ASV**	**r^2**
SY	1										
CV_i	-0.83642**	1									
b_i	0.79322**	-0.84407**	1								
S_i^2d	0.3771	-0.26466	0.20545	1							
P_i	-0.95857**	0.84806**	-0.84848**	-0.20127	1						
S_i^1	0.0822	0.00428	-0.23613	0.7639**	0.15277	1					
S_i^2	0.04073	0.06802	-0.24312	0.76914**	0.18954	0.98242**	1				
W_i	0.04778	0.0736	-0.13499	0.90518**	0.17865	0.87597**	0.89709**	1			
δ^2_i	0.04704	0.07406	-0.13744	0.90333**	0.18044	0.87693**	0.89734**	0.99994**	1		
ASV	0.06486	-0.00004	0.02908	0.88662**	0.11509	0.73451**	0.74065**	0.91501**	0.91344**	1	
r^2	0.66594**	-0.75281**	0.83554**	-0.19752	-0.83811**	-0.58767*	-0.6055*	-0.57567*	-0.57823*	-0.43305	1

Stability parameters from different groups were also compared. CV_i is a type I stability parameter was correlated with P_i in type II and with b_i and r^2 from type III. S_i^1 and S_i^2 from type I have similar trend in their association with type II and III. They have correlation with wricks and shuklas from type II and S_i^2d, ASV and r^2 from type III. This indicates that type I stability models can evaluated stability aspect that are similar to those measured by type II and III stability models. It can be concluded that parameters in type II and III, besides characterizing the degree of agronomic stability of the genotype, also evaluate biological stability which is measured by the parameters of type I. Thus, the joint utilization of all these parameters is not justifiable. Association among parameters of S_i^1 and S_i^2 in type I and coefficient of determination (r^2) in type III were generally low to moderate, but significant, suggesting that the stability aspect in each type measures is somewhat different, but also somewhat overlapping. Simultaneous utilization of these measures could, in some cases, be justified. Wricks and shuklas from type II were significantly correlated with ASV, r^2 and Si^2d, but not with b_i that are categorized in type III. Moreover, P_i which are categorized in type II, correlated with b_i and r^2 but not with ASV and S_i^2d. Duarte and Zimmermann (1995) showed that type II and type III were generally independent from each other. However, with this study they are not independent with the exception of regression coefficient (b_i) with Shuklas and Wricks, P_i with S_i^2d and ASV. The non-correlation of among these parameters indicated that they could be jointly used without the risk of measuring the same aspects of yield stability.

4. CONCLUSION

Various stability statistics have been employed in this study to quantify stability of common bean varieties with respect to yield. The study indicates that both stability parameter and yield should be considered simultaneously to exploit the useful effect of G x E interaction and to make selection of the stable varieties/genotypes more precise and refined. Indeed, the different stability models do not provide information for reaching definitive conclusions. However, coefficient of determination (r^2) had strong association with eight of the stability parameters so that it can explain similar aspects of stability of the varieties with the eight of these models. AMMI Stability Value (ASV) and deviation from regression (S_i^2d) had also strong association with five of the models consequently they can explain stability of varieties better following to coefficient of determination. Thus, bean breeders can use those three stability models for better explanation and interpretation of G x E interaction of varieties/genotypes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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