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Association of Different Parametric and Non parametric Stability Models in Durum Wheat (*Triticum turgidum* Desf.) Genotypes

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Authors' contributions

This work was carried out in collaboration between all authors. Author FA Designed the study, wrote the first draft of the proposal and managed the literature searches, wrote the protocol and conducted the experiment, performed the statistical analysis and wrote this manuscript. Author FM serve as Major Adviser, edit the first draft of the proposal, participate on supervision of the experiment at field condition and edit the first draft of this manuscript. Author YD serve as Co- Adviser, edit the first draft of both the proposal and this manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Thirteen durum wheat genotypes were evaluated in a randomized complete block design with three replications across four locations of north western Ethiopia for two consecutive years (2010 and 2011). The objective of this experiment was to investigate the association of different parametric and non parametric stability models that can be used for stability analysis of multi location trials. Spearman rank correlation showed that a significant positive perfect correlation between Shukla's stability variance (σ_i^2) and Wricke's ecovalence (W_i) stability models. This indicated that instead of

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using the two stability models, only one of these stability models can be used for identifying stable genotypes in multi location wheat trials. However, Coefficients of determination (r_i^2) and deviation from regression (S_{di}^2) showed a highly significant negative rank correlation (r = - 0.8581), which implies neither of these stability model alone could be sufficient for identification of stable genotypes that had consistence grain yield performance across different locations.

Keywords: Wheat; yield; correlation; parametric and non-parametric stability models.

1. INTRODUCTION

Wheat (tetraploid and hexaploid) is an important cereal crop which grown in different parts of world and ranked third next to maize and rice in terms of total amount of production [1]. From the total wheat cultivated areas of world, durum wheat (*Triticum turgidum* spp. *durum*) had covered 20 million hectares of land [2], with annual production of 651 million metric tons [3]. In Ethiopia, particularly in the high lands of Central, South Eastern and North Western part of the country, durum wheat has been widely grown by small scale farmers on heavy black clay soils (vertisols) under rainfed conditions. In Amhara region, particularly in north western part of the country where crop requirements and disease development vary to a high degree; genotype environment interaction became a common phenomena and complicates the selection of high yielding genotypes that showed consistence grain yield performance across different environments. Therefore, plant breeders usually use both parametric and non parametric stability models so as to interpret the existing genotype environment interaction (GEI) and identify stable genotypes in multi location trials [4]. But these two groups of stability models are different in their properties, for example parametric stability models have the following properties: they are dependent on the statistical assumptions (normal distribution of errors and GE interaction effects). i.e they may not perform properly if these assumptions are violated by other factors such as outliers [5]; addition or deletion of a single genotype causes great variation in the estimated values of stability models [6] and they have three different stability

Concepts: Type 1 (a static, or a biological concept of stability) which states that genotypes with a minimal variance across different environments are considered stable [7], while this concept of stability is not acceptable by many breeders and agronomists, who are interested on genotypes with high mean yield and the potential to respond to agronomic inputs or better environmental conditions [8]. Another stability concept is Type 2 (dynamic or agronomic concept of stability), in this stability concept a genotype is considered to be stable if its response to environments is parallel to the mean response of all genotypes in the trial [7]. The third stability concept is Type 3, in this concept of stability, genotype which has small residual mean square (MS) from the regression model on the environmental index is considered as stable genotype.

Unlike parametric stability models, non parametric stability models have the following properties: (i) They are based on the ranks of genotypes in each environment but did not need any assumptions (ii) They reduce biases caused by outliers, and easy to interpret and use in plant breeding program where the ranking order of the tested genotype is very crucial. (iii) Addition or deletion of one or few genotypes does not cause much variation in estimating value of the stability models [9]. Due to the existence of the above mentioned difference among the two groups of stability models (parametric and non parametric models), researchers may have got different results from the same source raw data, which confuse them to reach on the correct conclusions. Hence, in this research work different seven parametric stability models (P_i = cultivar performance measure; σ_i^2= Shukla's stability variance; W_i = Wricke's ecovalence; b_i = regression coefficient; S_{di}^2 = Eberhart and Russell's' deviation from regression; ASV=AMMI stability value and r_i^2 = Coefficient of determination) and two non parametric stability models(S_i^1 = mean absolute rank difference and S_i^2 = variance of ranks) were evaluated with the objective of identifying the level of association among these stability models.

2. MATERIALS AND METHODS

2.1 Experimental Design and Methods

Thirteen durum wheat genotypes were used as experimental material and evaluated across four durum wheat growing areas of north western Ethiopia (as shown Table 2) in 2010 and 2011 main cropping seasons. The layout of the experiment was randomized block design with three replications. Each Experimental material (shown Table 1) was sowed on a plot size of 3 m^2 (1.2 m x 2.5 m) with spacing of 20cm between rows and 1m between the two adjacent replications. Fertilizer was applied on the rate of 92 kg/ha N and 46 kg/ha P_2O_5 in the form of urea and DAP (Di ammonium phosphate) respectively. The whole amount of DAP was applied at planting while Urea was split in to half at planting and the remaining half at tillering stage. All agronomic managements were done as per the recommendation.

2.2. Statistical Analysis

The analysis of variance for each location and the combined analysis of variance over locations were computed using the SAS statistical program [10]. Both Bartlett's homogeneity and normality tests were also conducted to determine the validity of the combined analysis of variance and homogeneity of error variance between environments.

A total of nine parametric and non parametric stability models: Lin and Binns cultivar superiority measure (P_i), Shukla's stability variance (σ_i^2), Wricke's ecovalenc (W_i), Regression coefficient (bi), Eberhart and Russell's joint Regression and Deviation from Regression (S_{di}^2), AMMI Stability Value (ASV) , Coefficient of determination (r_i^2) , Nassar and Huehn's mean Absolute rank difference (S_i^1) and variance of ranks (S_i^2) were computed using AGROBASE20 computer program to identify stable genotypes which had consistence yielding performance across the testing environments. Spearsman's rank correction coefficients [11] was also computed between all possible pairs of stability models including grain yield using SAS Statistical software computer program [10].

3. RESULTS AND DISCUSSION

3.1 Cultivar Superiority Measure (P_i)

According to this stability parameter, a genotype with lowest P_i value would be considered as the most stable genotype which shows a consistence performance across environments. Therefore, genotypes Selam, Megenagna, Mosobo, Metaya and Bakalcha had showed lowest cultivar superiority value with high mean grain yield performance (Table 3). i.e. these genotypes had least contribution to the total variation due to genotype by environment interaction. While genotypes Yegibir sinde (Local), Flakit, Obsa and Leliso had highest cultivar superiority value with lower mean grain yield were considered as unstable genotype. i.e their contribution to the total variation due to GEI is high. Different authors such as [15,16] used this stability parameter to identify high yielding and stable Bread wheat and Barley genotypes respectively.

3. 2 Eberhart and Russell's Stability Model

The pooled analysis of variance (Table 4) revealed that the presence of a significant mean square of GEI (linear), which indicated that the presence of difference among the regression coefficient (b_i) of tested genotypes as shown in the Table 3. This result confirms the previous findings of different researchers who work on bread and durum wheat genotypes [17,18,15,19,20]. In the Eberhart and Russell's stability model mean grain yield performance, regression coefficient (b_i) and deviation from regression (S_{di}^2) of a tested genotype play a crucial role on the identification of a stable genotype. A high yielding genotype with a unit regression coefficient and deviation from regression nearly equal to zero is identified as stable genotype [21,22]. Hence, genotype Metaya had high grain yield performance, regression coefficient closer to unity and deviation from regression very closer to zero could be considered as stable, while genotype Megenagna had high grain yield performance and deviation from regression very closer to zero but it's coefficient of regression is not approaches to one; that made it unstable. Similarly by using grain yield, deviation from regression and coefficient of regression as a selection criteria, [23] identified unstable high yielding genotype which have deviation from regression very closer to zero but it's coefficient of regression is far less than from unity. However, [24] found that all high yielder wheat genotypes were associated with coefficient of regression close to unity.

3.3 Coefficient of Determination (r_i^2)

Coefficient of determination (r_i^2) represents the predictability of estimated response of the genotypes for grain yield was varied (Table 3). The values ranged from 0.75 to 1.00 which indicated that 75% to 100% of the variation in the mean grain yield was explained by genotypes response across the testing environments. Among high yielding genotypes Megenagna, Metaya and Bakalcha are the most stable genotypes which associated with high coefficient of determination. This confirmed that the previous findings of different authors, who reported high value of coefficient determination associated with stable durum wheat genotypes [17,15,19] as well as [24] on bread wheat genotypes.

3.4 Wricke's Ecovalence (W_i)

By using Wricke's ecovalence, thirteen durum wheat genotypes were evaluated and Metaya, Oda and Flakit had showed lowest ecovalence value with ranking positions of 4th, 8th and 12 th in grain yield performance respectively and considered as stable genotype (Table 3). Whereas genotypes Obsa, Yegibirsinde (Local) and Leliso had highest ecovalence value, hence these genotypes contribute highest amount of variation to the total GEI variance and considered as unstable. Among high yielding genotypes, Mosobo, Selam and Bakalcha were identified as unstable genotypes due to their highest ecovalence value. In a similarly fashion, this stability model had used by different researchers to evaluate the stability of bread and durum wheat genotypes [25,24,19]. Among these researchers no one had reported the association of high value ecovalence with high yielding genotypes.

3.5 Shukla's Stability Variance (σi^2)

As compared to other tested genotypes, genotype Metaya and Megenagna were identified as the most desirable and stable genotypes because of their high grain yield performance and low value of Shukla's stability variance (as shown Table 3). Even though, genotypes Mosobo and Selam showed high grain yield performance, their high Shukla's stability variance value made them undesirable for wider adaptation rather recommend for specific adaptation. Worldwide many researchers have been used this stability parameter to identify high yielding stable genotypes on different crop. For example, [19] was used it on wheat genotypes where as [26] on barely genotypes.

3.6 Nassar and Huehn's Mean Absolute Rank Difference (S_i^1) and Variance of Ranks (S_i^2)

According to this non-parametric stability models, genotypes Metaya, Megenagna and Ejersa showed very low estimates of S_i^1 with higher grain yield performance. Hence they were considered as the most desirable and stable genotypes .The homogeneity of S_i^1 values of all genotypes were measured by using the two overall chi-square calculated stability values (Z_1= 11.71 and Z_2= 9.22) with tabulated chi-square values at ($X^2_{0.05,}$ 13df) = 22.36 and ($X^2_{0.01,}$ 13df)= 27.69. This result indicated that as there were no any significant differences among the genotypes. In the previous time, different authors reported similar results on wheat genotypes [27,5, 18,15,28].

3.7 AMMI Stability Value

In this model, genotypes with least ASV or have smallest distance from the origin are considered as the most stable genotypes where as those which have highest ASV are considered as unstable. Accordingly genotypes Bakalcha, Metaya and Ejersa could be considered as the most stable genotypes. whereas genotypes Leliso, Obsa and *Yegibir sinde* (Local) were considered as unstable genotypes (Table 3). Previously, different researchers used AMMI stability value as stability parameter to study the stability of grain yield and quality of different wheat genotypes across various environments [29,18,30,28].

3.8 Comparison of Stability Models

Different Parametric and non parametric stability models as well as grain yield were compared for stability ranking of the genotypes (Table 3). Even though there was change in ranking order of genotypes from one stability model to another stability model, genotype Metaya had been found the most stable genotype by most of stability models, namely Wricke Ecovalence, Cultivar superiority performance, regression coefficient (bi), Shukla Stability variance , AMMI stability value (ASV), mean absolute rank difference (S_i^1) and variance of ranks (S_i^2). Hence, this genotype has better buffering capacity to environmental changes such as occurrence of disease and frost. Besides to the above, among high yielding Genotypes Megenagna and Ejersa were relatively stable genotypes by the stability models of mean absolute rank difference (Si^1) and variance of ranks (Si^2).

Spearman's rank correlation coefficient [11] was also determined for each of the possible pair wise comparisons of the ranks of the different stability models. The result of spearman's rank correlation coefficient (Table 5) showed a negative highly significant rank correlation (r= -0.95**) between grain yield and cultivar superiority measure. Similarly [19] were reported that the presence of negative highly significant correlation among yield and cultivar superiority performance (P_i) stability model on wheat genotypes. While grain yield had negative non significant rank correlations with the remaining stability models. Similarly previous findings of [31] on durum wheat genotypes also showed that a negative non significant rank correlation of grain yield with mean absolute rank difference (S_i^1) and variance of ranks (S_i^2).

Eberhart and Russell's deviation from regression model showed highly significant negative rank correlation with coefficient of determination (r_i^2), which indicated that the genotypes that were highly responsive to high yielding environments were less responsive to low yielding environments and vice versa. This finding support the previous finding of [15], which also found that highly significant negative correlation between S^2_{di} and r_i^2 on durum wheat genotypes. It had also negative non significant rank correlation with mean grain yield, cultivar superiority measure (P_i) and AMMI stability value (ASV).

Shukla's stability variance had a positive perfect rank correlation (r=1.00) with Wricke's ecovalence and highly significant positive rank correlation with S_i^1(r=0.912) and S_i^2(r=0.909). The occurrence of perfect significant correlation between Shukla's stability variance and Wricke's ecovalence indicates that these two parameters were equivalent for genotype ranking purposes. In line with this result [19] reported the ranking equivalency of these two stability models in the evaluation of wheat genotypes. Conversely, Shukla's stability variance had non-significant negative rank correlation with grain yield and coefficient of determination (r_i^2).

Cultivar superiority (P_i) method showed a highly significant negative rank correlation (r = - 0.965) with mean yield. This indicates that high yielding and responsive genotypes like Megenagna, Selam and Mosobo tended to have lower P_i value, which is in harmony with the [19] in wheat genotypes. Besides, the presence of this significant negative rank correlation between mean yield and cultivar superiority measure (P_i) indicates that neither of these stability model alone could be sufficient for durum wheat genotype stability assessment and recommendation. This result seems to have similar idea with the definition of [32], they define cultivar superiority measure as the deviation of a specific genotype's performance from the performance of the best genotype in a trial (a stable genotype is the one that performs in tandem with the environment). i.e. this procedure appears to be considerably more of a genotype performance measure, rather than a stability model over sites.

The Wricke's ecovalence shows a highly significant positive rank correlation with ASV (r= 0.776), S_i^1 (r=0.912) and S_i^2 (r=0.909) and perfect rank correlation (r =1.00) with Shukla's stability variance model. It had also positive non significant rank correlation with Eberhart and Russell's deviation from regression (S_{di}^2) and cultivar superiority measure (P_i) as shown in (Table 5). The presence of positive but non significant rank correlation between W_i and S_{di}^2 indicates that the regression coefficient (b_i) was significantly different from unity, as the result the sum of environmental effects $\left[\sum_j(\bar{X}.\text{j}-\bar{X}..)^2\right]$ is not constant for all genotypes. In other words the ecovalence value was contributed by both the deviation from regression and coefficient of regression (b_i). i.e. from the covariance between GEI effects and environmental effects $\left[(b_i-1)^2\sum_j(\bar{X}.\text{j}-\bar{X}..)^2\right]$. Conversely, ecovalence had negative rank correlation with coefficient of determination (ri^2) and coefficient of regression (bi). Nassar and Huehn's mean absolute rank difference (Si^1) and variance of ranks (Si^2) showed a highly significant positive rank correlation (r=0.997**) with each other. In line with this finding, highly significant positive rank correlation among the above two non parametric stability model was reported on wheat genotypes by different authors [31,5,15,28]. These two non parametric models also had highly significant positive rank correlation with Shukla's stability variance, Wricke's ecovalence and AMMI stability value (ASV). i.e. Both mean absolute rank difference (Si^1) and variance of ranks (Si^2) showed similar correlation trends with different stability models. This confirms that the similarity of mean absolute rank difference (Si^1) and variance of ranks (Si^2). Consequently, only one of these stability models would be enough to identify stable genotypes in a wheat breeding program.

Table 1. Code, genotypes, pedigree, origin, altitude and mean yield of genotypes

Code	Genotypes	Pedigree	Origin	Altitude (masl)	Yield potential in research field(t/ha)
G1	Mosobo	DZ-2178	ADARC/ARARI	1900-2800	2.0 – 4.0
G2	Megenagna	DZ-2023	ADARC/ARARI	1900-2800	2.0 – 4.0
G3	Selam	DZ-1666-2	ADARC/ARARI	1900-2800	2.2 - 3.6
G4	Metaya	DZ-2212	ADARC/ARARI	2000-2800	2.1 - 3.5
G5	Bakalcha	98-OFN-Gedilfa/Guerou/15patho	SARC/ORARI	2300-2600	6.70
G6	Ude	CHEN/ALTAR84//JO69	DZARC/EARO	1800-2700	30 – 5.0
G7	Ejersa	LABUD/NIGRIS-3//Gan-CD98206	SARC/ORARI	2300-2600	6.20
G8	Oda	DZ046881/imlo/cit71/3/RCHI/LD357//imlo/4/Yemen/cit'5'/plc'5'/3/Taganroy	SARC/ORARI	2300-2600	3.8 - 5.3
G9	Leliso	Cit-71/3/Gerado//61130/G//"S''/4/Boohai// Hora//Gerado/3/Bohai	SARC/ORARI	2300-2800	3.2 - 7.8
G10	Obsa	ALTAR84//ALTAR84/SERI/3/6*ALTAR84	SARC/ORARI	2300-2600	6.80
G11	Yerer	CHEN/TEZ/GVIL//C11	DZARC/EARO	1800-2700	3.0 – 5.0
G12	Flakit	EN-25	SARC/ARARI	2400-3000	2.15
G13	Yegibrsinde	–	FARMERS	-	-

Note that: ADARC = Adet Agricultural Research Center, DZARC = DebreZeit Agricultural Research Center, SRARC = Sirinka; Agricultural Research Center, SARC = Sinana Agricultural Research Center, ARARI=Amhara Region Agricultural Research Institute, EARO= Ethiopian Agricultural Research Organization, ORARI= Oromiya Region Agricultural Research Institute, masl = meter above sea level

Table 2. Environmental code, locations, cropping season, altitude, soil type latitude and longitude of the experimental sites

Environmental code	Locations	Cropping season	Altitude (meter)	Soil type	Global position	
					Latitude	Longitude
E1	Adet	2010	2216	Nitosol	$11^0$16'N	$37^0$29'E
E2	Debretabor	2010	2706	Luvisol	$11^0$51'N	$38^0$01'E
E3	Gaint	2010	3120	Luvisol	$11^0$44'N	$38^0$28'E
E4	Simada	2010	2460	Luvisol	$11^0$03'N	$37^0$03'E
E5	Adet	2011	2216	Nitosol	$11^0$16'N	$37^0$29'E
E6	Debretabor	2011	2706	Luvisol	$11^0$51'N	$38^0$01'E
E7	Gaint	2011	3120	Luvisol	$11^0$44'N	$38^0$28'E
E8	Simada	2011	2460	Luvisol	$11^0$03'N	$37^0$03'E

Sources: [12,13,14]

Table 3. Grain yield, estimated values and ranks of various stability models using thirteen durum wheat genotypes

Gen	GY	Parametric stability models														Non-parametric stability models			
		P_i	R	b_i	R	Sdi^2	R	r_i^2	R	W_i	R	$σi^2$	R	ASV	R	$Si^1(Z_1)$	R	$Si^2(Z_2)$	R
G1	3.63	0.242	3	0.652	9	0.115	10	0.810	12	1.889	10	0.886	9.5	1.395	10	5.036(0.728)	9	15.484(0.084)	9
G2	3.60	0.229	2	0.722	7	0.050	3	0.920	7	1.175	5	0.526	5	1.103	8	3.214(1.643)	2	6.688(2.037)	2
G3	3.57	0.168	1	1.129	3	0.243	12	0.870	11	1.887	9	0.886	9.5	0.839	6	5.071(0.801)	10	15.938(0.143)	10
G4	3.50	0.260	4	0.922	2	0.087	7	0.910	8.5	0.871	1	0.371	1	0.524	2	3.036(2.223)	1	6.359(2.224)	1
G5	3.49	0.262	5	1.132	4	0.151	11	0.910	8.5	1.341	6	0.610	6	0.517	1	4.821(0.363)	7.5	14.109(0.000)	7
G6	3.45	0.316	7	1.380	10	0.018	2	0.990	2	1.476	8	0.678	8	0.974	7	4.821(0.363)	7.5	14.859(0.028)	8
G7	3.44	0.294	6	1.248	6	0.056	5	0.970	4	1.092	4	0.484	4	0.593	3	3.893(0.236)	3	8.984(0.958)	3
G8	3.32	0.483	8	0.991	1	0.095	8	0.930	6	0.877	2	0.374	2	0.648	4	4.107(0.055)	4	10.609(0.468)	4
G9	3.30	0.605	10	0.445	13	-0.001	1	1.000	1	2.568	11	1.231	11	1.754	13	5.321(1.412)	11.5	19.234(1.044)	12
G10	3.23	0.649	11	1.382	11	0.283	13	0.880	10	3.077	13	1.489	13	1.736	12	5.321(1.412)	11.5	17.109(0.368)	11
G11	3.14	0.540	9	1.319	8	0.052	4	0.980	3	1.366	7	0.622	7	1.180	9	4.429(0.020)	6	12.188(0.125)	6
G12	2.61	1.256	12	1.186	5	0.075	6	0.960	5	1.008	3	0.441	3	0.800	5	4.286(0.001)	5	11.75(0.193)	5
G13	2.55	1.533	13	0.492	12	0.105	9	0.750	13	2.842	12	1.370	12	1.543	11	5.643(2.449)	13	20.438(1.579)	13
						Overall Chi-square for stability				(Z_1) =11.71				(Z_2) = 9.22		13 df			

Note that: Gen = Genotypes, R= Rank, G1= Mosobo, G2= Megenagna, G3= Selam, G4= Metaya, G5= Bakalcha, G6= Ude, G7= Ejersa, G8= Oda,G9=Leliso, G10=Obsa, G11=Yerer, G12= Flakit, G13= Yegibir sinde, GY = Mean grain yield, P_i = Lin and Binns's cultivar performance measure; b_i = regression coefficients; S_{di}^2 = Eberhart and Russell's' deviation from regression, r_i^2= Coefficients of determination, W_i = Wricke's ecovalence; $σ_i^2$= Shukla's stability variance; ASV=AMMI stability value ,S_i^1 = mean absolute rank difference and S_i^2 = variance of ranks

Table 4. Pooled analysis of variance for grain yield of thirteen durum wheat genotypes

Source	DF	SS	MS	F-value	Pr> F
Total	311	128.970			
Genotypes	12	11.743	0.979**	6.39	0.0000
Env.+ in Gen.x Env.	91	117.227	1.288		
Env. in linear	1	95.760			
Gen. x Env. (linear)	12	9.525	0.794**	5.18	0.0000
Pooled deviation	78	11.942	0.153		
Residual	208	10.600	0.051		
Grand mean = 3.294		R-squared = 0.8981		C.V. = 11.87	

**, ** -Significant at P<0.05 and p<0.01 respectively*

Table 5. Spearman's rank correlations between stability models for durum wheat genotypes

	GY	P_i	b_i	S_{di}^2	W_i	r_i^2	σ_i^2	S_i^1	S_i^2
P_i	-0.965**								
b_i	-0.140	0.839							
S_{di}^2	-0.035	-0.070	0.168						
W_i	-0.308	0.364	0.084	0.175					
r_i^2	-0.109	0.116	0.165	-0.858**	-0.199				
σ_i^2	-0.308	0.364	0.839	0.175	1.000**	-0.199			
S_i^1	-0.470	0.516	-0.004	0.284	0.912**	-0.223	0.912**		
S_i^2	-0.469	0.518	-0.028	0.217	0.909**	-0.168	0.909**	0.997**	
ASV	-0.448	0.525	-0.098	-0.224	0.776**	0.107	0.776*	0.635*	0.657*

**, ** significant P<0.05 and P<0.01 respectively, ns= non significant, GY=Mean grain yield, P_i = Lin and Binns's Cultivar performance measure; bi= regression coefficients, σ_i^2 = Shukla's stability variance; W_i = Wricke's ecovalence; S_{di}^2 = Eberhart and Russell's' deviation from regression, S_i^1 = mean absolute rank difference, S_i^2 = variance of ranks, ASV=AMMI stability value, r_i^2 = Coefficient of determination*

4. CONCLUSION

Among the tested Parametric and non parametric stability models, Wricke' ecovalence and Shukla's stability variance had a perfect correlation (r = 1.00), indicating these two stability models were equivalent for stability evaluation of different genotypes across multi environment trials. Therefore, instead of using these two stability models simultaneously, only one of them is enough for selecting stable genotypes. Moreover this, the two non parametric models: Nassar and Huehn's mean Absolute rank difference (S_i^1) and variance of ranks (S_i^2) had also showed positive significant correlation with AMMI stability value, Shukla's stability variance and Wricke' ecovalence stability models. Hence it is possible to use either of the two non parametric models instead of using the two non parametric stability models.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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