Research Article

Comparison Among Different Stability Models for Yield in Bread Wheat

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Abstract | A critical comparison of stability models is essential to give an insight to breeders for developing relatively stable wheat cultivars. A multi-environment trial (MET) was conducted to assess the pattern of genotype by environment interaction (GEI) effects on yield using multiple stability models *viz.* Additive Main effect and Multiplicative Interaction (AMMI), GGE biplot analysis and stability parameters. Eighty-one wheat genotypes were evaluated during three consecutive years (2013/14, 2014/15 and 2015/16) across nine environments (sites × year combination) in Khyber Pakhtunkhwa, Pakistan. Graphical stability approaches such as AMMI and GGE provided almost similar results for identifying the high-yielding and stable wheat genotypes. The AMMI analysis identified G-58 and G-79, whereas GGE biplot identidified G-79 as the most stable and high yielding genotype. Numerical stability parameters like Eberhart and Russell's model and Francis coefficient of variation (CV) declared G-79 as top-ranked genotype while Shukla stability value (σ_i^2) and Wrick's ecovalence (W_i) identified G-80 (check cultivar Janbaz), G-52 and G-79 as leading wheat genotypes based on grain yield. Spearman's rank correlation revealed significant positive correlations of AMMI stability value (ASV) with CV, σ_i^2 with W_i, and W_i with CV indicating that these parameters could invariably be used for identifying stable wheat genotypes depending upon the nature of the experiment, breeding material, and the complexity of data. Different stability models identified G-79 as high yielding and stable genotype and thus could be recommended for commercialization in the province of Khyber Pakhtunkhwa, Pakistan. Furthermore, stability parameters can supplement the use of AMMI and GGE biplot analysis to get more credible and reliable scrutiny of wheat genotypes in METs.

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Introduction

Wheat (*Triticum aestivum* L.) is a leading food grain which occupies more area than any other crop in Pakistan. Wheat contributes about 10.0 percent to the value-added in agriculture and 2.1 percent to GDP. In Pakistan, the main wheat-growing areas fall in the Indus plains. About 70% of the wheat is grown on irrigated land and 30% is grown under rain-fed conditions (Ain et al., 2015). The development of high yielding stable genotypes is a primary objective of all wheat breeding programs.

Increasing the yield without sacrificing stability in performance is a great challenge for wheat breeders. The performance of cultivars largely depends on their genetic makeup, environment and the interaction between genotypes and environment. The response of genotypes varies across years and locations as a result of interaction between genotypes and the environment. Therefore, testing of wheat genotypes across years and location is essential (Abraha et al., 2019). Several stability methods including both univariate and multivariate have been proposed to analyze and interpret the performance of genotypes across environments. However, no single method can adequately explain cultivar performance across environments (Dia et al., 2018). The AMMI model can efficiently interpret GEI as it splits main and interaction effects (Gauch, 2006). It has proved to be a powerful tool to determine the magnitude of GEI for identifying stable and adaptable genotypes (Crossa, 1990). Therefore, Neisse et al. (2018) suggested that the AMMI model was efficient to analyze MET data. However, the AMMI1 biplot is ineffective to identify the discriminating ability and representativeness of environments in METs. Therefore, Yan et al. (2000) endorsed the proposal of Gabriel (1971), who used the biplot technique to display the genotype main effect plus GEI (G+GE) using METs data and called it the GGE biplot. GGE biplot is a graphical tool that displays, interprets and explores two important sources of variation, namely genotype main effect and GE interaction of MET data (Fan et al., 2007; Dyulgerova and Dyulgerov, 2019).

Several univariate parameters have been developed since the 1960s which are still in practice to explain complex patterns of GEI. Among them, the most widely used stability parameters are a deviation from regression (S_2d_i) proposed by Eberhart and Russel (1966), coefficient of determination (R_i^2) Pinthus (1973), Wricke'secovalence (W_i) (1962), Perkins and Jinks (1968) proposed B_i and D_{Ji} values. Similarly, Lin and Binns (1988) developed a new stability parameter (P_i) based on unpredictable environment variance (year) of genotypic means averaged across a predictable environment (location). The reliability of a model in selecting suitable genotypes has always been a concern of researchers. The AMMI stability value (ASV) is one of the recently developed techniques to measure the stability of genotypes across environments. The ASV developed by Purchase et al. (2000) is the measure of distance from the origin in AMMI2 biplot using scores of PC1 and PC2 of AMMI analysis. The objectives of this study were to; i) assess and compare fitness of different stability models, and ii) identify high yielding and stable wheat lines based on various stability models.

Materials and Methods

Description of experimental sites

Eighty-one wheat genotypes including 79 $F_{5:8}$ recombinant inbred lines (RILs) and two check cultivars "Janbaz" and "Atta-Habib" were evaluated in nine environments during 2013-16. During 2013-14, the experimental material was planted at single location i.e. The University of Agriculture Peshawar (E-01) for evaluation and seed multiplication, whereas, during 2014-16 at the University of Agriculture Peshawar (E-02 and E-03, respectively), Cereal Crops Research Institute, Pirsabak Nowshehra (E-04 and E-05, respectively), Agricultural Research Station, Swabi (E-06 and E-07, respectively) Agricultural Research Station, Charsadda (E-08 and E-09, respectively). Hereafter, these will be referred to as E-01, E-02, E-03, E-04, E-05, E-06, E-07, E-08, and E-09. Agro-metrological features of test sites/environments including temperature, rainfall, and altitude, etc. are given in Table 1.

Experimental design and procedure

Experimental material was planted in a 9×9 alpha lattice design with two replicates at each environment. Each plot had 6 rows of 5-meter length and a row-to-row space of 30 cm. The standard dose of nitrogen (120 kg ha^{-1}) and phosphorous (80 kg ha^{-1}) was applied using broadcast method. Uniform cultural practices i.e. weeding, roughing etc. required for wheat crops were followed throughout the growing season.

Statistical analysis

Data on grain yield were subjected to Analysis of variance (ANOVA) technique using SAS (SAS, 2009) computer software. Upon significant genotype by environment interaction, grain yield data were further subjected to various stability models i.e. AMMI model, GGE biplot and stability parameters using GEA-R version 4.0 computer software (Pacheco et al., 2018).

Results and Discussion

First two principal components of AMMI model for grain yield captured 54.8% of GEI sum of squares, while the first two principal components of GGE biplot analysis cumulatively explained 54.8% of variation caused by GE interaction (Figure 1, 2). The cumulative PCA scores of both models were the same, providing a uniform condition for selecting appropriate genotype with respect to stability. Eberhart and Russell's model identified G-79 as a widely stable genotype, whereas genotypes G-17 and G-21 were identified as the stable than other genotypes (Figure 3). Coefficient of variation (CV) declared G-79, G-08, and G-56 as highly productive stable genotypes (Figure 4). Although the cumulative PC scores of both AMMI and GGE model were similar, none of the genotypes was unanimously declared as stable by both models. However, Eberhart and Russell's model and Francis coefficient of variation identified G-79 as a widely adapted stable genotype.

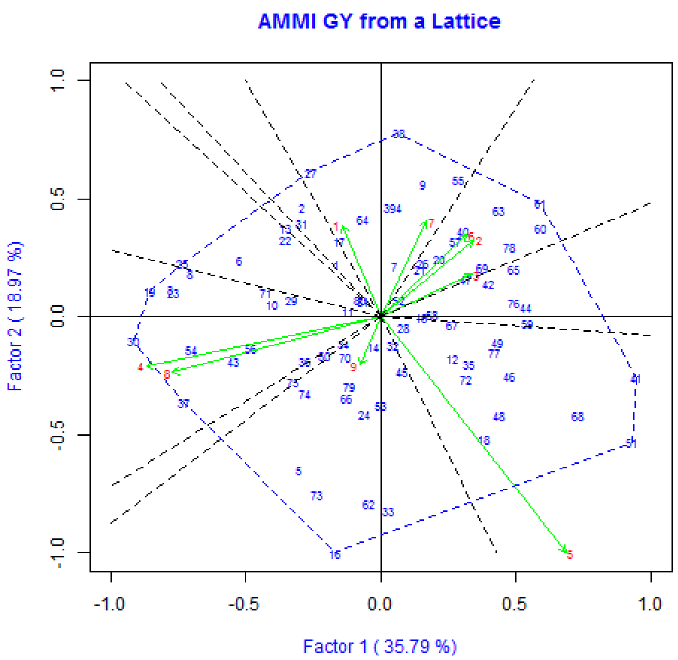

Figure 1: *AMMI biplot for grain yield.*

Based on mean grain yield, G-79 was identified as a top-ranked wheatgenotype, followed by G-08, G-56, G-37, and G-19. The AMMI stability value (ASV) found G-14, G-81, G-52, G-32, and G-28 as more stable wheat genotypes, whereas, coefficient of determination (R^2_i) revealed G-04, G-38, G-57, G-60 and G-63 as top-ranked genotypes for grain yield. Similarly, Francis coefficient of variation (CV) and cultivar superiority measure (P_i) declared G-79 as top-ranked genotype while Shukla stability value (σ_i^2) and Wrick's ecovalence (W_i) confirmed G-80 (check cultivar Janbaz), G-52 and G-79 as leading wheat genotypes based on grain yield performance (Table 3).

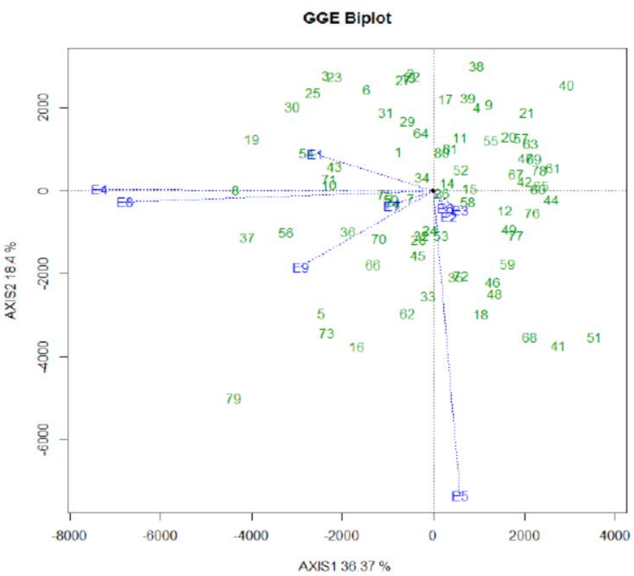

Figure 2: *GGE biplot for grain yield.*

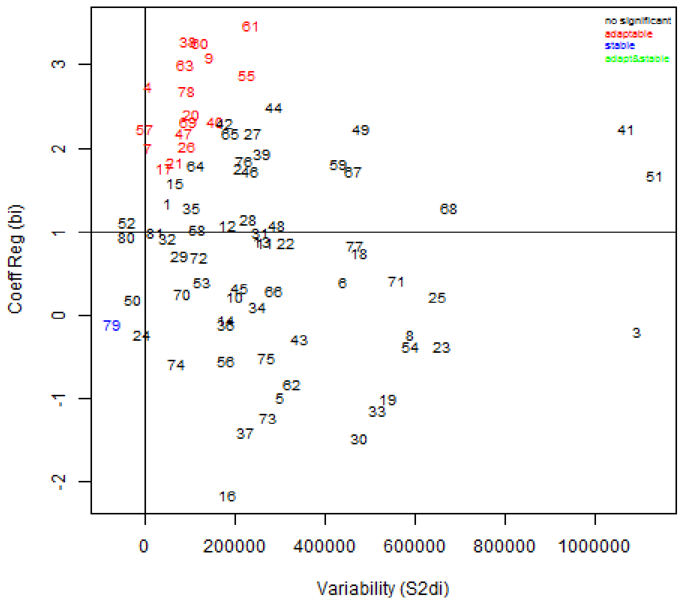

Figure 3: *Eberhart and Russel (b_i, S_2d_i) biplot for grain yield.*

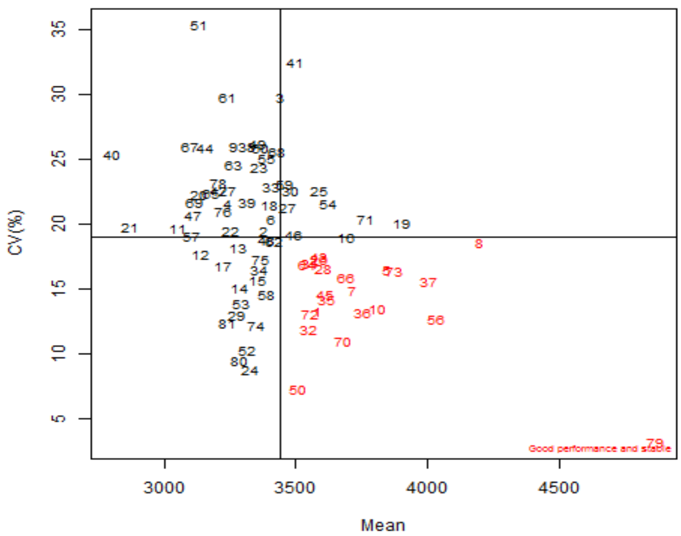

Figure 4: *Francis (CV) vs. Mean biplot for grain yield.*

Table 1: *Description of nine environments used for evaluation of 81 wheat during 2014-2016 cropping season.*

Environments	Growing season	Geographical positon		Altitude (m.a.s.l)	Average rainfall (mm)	Temperature (⁰c)	
		Latitude	Longitude			Min.	Max.
E1	2014 (AUP)	34.0150° N	71.5805° E	359	238	20.1	34.8
E2	2015 (AUP)	--do--	--do--	--do--	415	19.5	35.4
E3	2016 (AUP)	--do--	--do--	--do--	189	17.8	38.2
E4	2015 (CCRI)	34.0159° N	71.9755° E	288	220	10.1	28.6
E5	2016 (CCRI)	--do--	--do--	--do--	112	16.3	35.9
E6	2015 (ARSS)	34.1442° N	72.3785° E	321	263	18.0	36.7
E7	2016 (ARSS)	--do--	--do--	--do--	312	14.5	32.1
E8	2015 (ARSC)	34.1494° N	71.7428° E	381	460	10.4	28.5
E9	2016 (ARSC)	--do--	--do--	--do--	392	17.4	36.2

Table 2: *List of wheat RILs with pedigree.*

Code	Pedigree	Code	Pedigree
G-01	Takbir × Khatakwal-3-1	G-42	Tatara × Inqilab-26-7
G-02	Takbir × Khatakwal-3-5	G-43	Tatara × Inqilab-26-11
G-03	Takbir × Khatakwal-3-7	G-44	Tatara × Inqilab-26-15
G-04	Takbir × Khatakwal-3-8	G-45	Tatara × Inqilab-26-20
G-05	Takbir × Khatakwal-3-9	G-46	Tatara × Ghaznavi 98-31-1
G-06	Takbir × Khatakwal-3-16	G-47	Tatara × Ghaznavi 98-31-2
G-07	Takbir × Khatakwal-3-18	G-48	Tatara × Ghaznavi 98-31-4
G-08	Tatara × Inqilab-4-3	G-49	Tatara × Ghaznavi 98-31-7
G-09	Tatara × Inqilab-4-6	G-50	Ghaznavi 98 × Khatakwal -33-5
G-10	Tatara × Inqilab-4-9	G-51	Ghaznavi 98 × Khatakwal -33-7
G-11	Tatara × Inqilab-4-10	G-52	Ghaznavi 98 × Khatakwal -33-10
G-12	Tatara × Inqilab-4-11	G-53	Ghaznavi 98 × Khatakwal -33-15
G-13	Tatara × Inqilab-4-13	G-54	Tatara × Ghaznavi 98-37-15
G-14	Tatara × Inqilab-4-16	G-55	Tatara × Margala-43-2
G-15	Wafaq × Ghaznavi 98	G-56	Tatara × Margala-43-4
G-16	Wafaq × Ghaznavi 98	G-57	Tatara × Margala-43-11
G-17	Wafaq × Ghaznavi 98	G-58	Tatara × Margala-43-12
G-18	Tatara × Takbir-9-8	G-59	Tatara × Inqilab -45-10
G-19	Tatara × Takbir-9-10	G-60	Takbir × Inqilab -45-12
G-20	Tatara × Takbir-9-12	G-61	Tatara × Ghaznavi 98-48-2
G-21	Tatara × Takbir-9-813	G-62	Tatara × Ghaznavi 98-48-3
G-22	Tatara × Inqilab-18-15	G-63	Tatara × Ghaznavi 98-48-13
G-23	Tatara × Inqilab-18-19	G-64	Tatara × Ghaznavi 98-48-15
G-24	Tatara × Inqilab-18-20	G-65	Tatara × Ghaznavi 98-48-19
G-25	Tatara × Takbir-19-3	G-66	Wafaq × Ghaznavi 98-49-2
G-26	Tatara × Takbir-19-4	G-67	Wafaq × Ghaznavi 98-49-4
G-27	Tatara × Takbir-19-8	G-68	Wafaq × Ghaznavi 98-49-5
G-28	Tatara × Takbir-19-11	G-69	Wafaq × Ghaznavi 98-49-6
G-29	Tatara × Takbir-19-16	G-70	Wafaq × Ghaznavi 98-49-9
G-30	Tatara × Takbir-19-18	G-71	Wafaq × Ghaznavi 98-49-10
G-31	Tatara × Ghaznavi 98-22-1	G-72	Wafaq × Ghaznavi 98-49-12
G-32	Tatara × Ghaznavi 98-22-2	G-73	Wafaq × Ghaznavi 98-49-13
G-33	Tatara × Ghaznavi 98-22-6	G-74	Wafaq × Ghaznavi 98-49-15
G-34	Tatara × Ghaznavi 98-22-8	G-75	Wafaq × Ghaznavi 98-49-16
G-35	Tatara × Ghaznavi 98-22-9	G-76	Wafaq × Ghaznavi 98-49-19
G-36	Tatara × Ghaznavi 98-22-12	G-77	Wafaq × Ghaznavi 98-49-20
G-37	Tatara × Ghaznavi 98-22-13	G-78	Tatara × Takbir-19-17
G-38	Tatara × Ghaznavi 98-22-19	G-79	Tatara × Takbir-19-18

G-39	Tatara × Ghaznavi 98-22-20	Check	Janbaz
G-40	Tatara × Inqilab-26-4	Check	Atta-Habib
G-41	Tatara × Inqilab-26-6		

Table 3: *Mean ranking of genotypes for grain yield using various stability parameters.*

Genotype	Mean	Mean rank	ASV	R^2_i	CV	σ_i^2	W_i	P_i	Genotype	Mean	Mean rank	ASV	R^2i	CV	σi^2	W_i	P_i
G-01	3581	22	18	27	14	07	07	15	G-42	3207	68	43	19	60	42	42	65
G-02	3378	42	40	30	43	31	31	36	G-43	3588	21	68	74	34	57	57	23
G-03	3441	33	77	79	78	81	81	60	G-44	3156	71	64	22	72	54	54	74
G-04	3239	65	26	01	55	24	24	61	G-45	3612	17	09	68	18	29	29	17
G-05	3844	07	54	48	26	64	64	07	G-46	3490	29	59	31	42	39	39	28
G-06	3405	37	65	69	49	58	58	32	G-47	3111	76	31	13	50	22	22	76
G-07	3715	11	08	08	20	08	08	10	G-48	3391	40	58	45	39	43	43	35
G-08	4195	02	72	76	37	70	70	02	G-49	3356	47	52	32	77	66	66	55
G-09	3264	59	33	06	75	52	52	66	G-50	3506	27	22	66	02	04	04	21
G-10	3812	08	44	75	15	30	30	06	G-51	3134	73	81	49	81	79	79	79
G-11	3054	79	07	54	45	40	40	78	G-52	3315	51	03	15	05	02	02	38
G-12	3138	72	28	41	35	23	23	69	G-53	3296	54	17	62	16	19	19	46
G-13	3281	57	45	51	36	36	36	56	G-54	3623	15	71	72	54	73	73	26
G-14	3284	56	01	81	21	32	32	50	G-55	3389	41	49	12	69	56	56	47
G-15	3354	48	11	23	23	12	12	39	G-56	4030	03	57	60	10	49	49	03
G-16	3692	13	67	21	40	75	75	20	G-57	3105	77	30	03	41	13	13	75
G-17	3222	67	21	14	29	09	09	59	G-58	3392	39	14	39	19	17	17	30
G-18	3400	38	56	61	53	61	61	43	G-59	3459	32	66	35	65	60	60	31
G-19	3901	05	78	57	47	76	76	09	G-60	3366	44	69	04	73	55	55	53
G-20	3131	74	25	10	58	27	27	71	G-61	3241	62	70	09	79	69	69	72
G-21	2873	80	13	18	46	15	15	80	G-62	3419	35	48	58	38	63	63	37
G-22	3251	61	42	56	44	46	46	62	G-63	3264	60	61	05	68	50	50	63
G-23	3362	45	76	73	67	74	74	52	G-64	3544	26	23	25	30	20	20	24
G-24	3325	50	20	64	03	11	11	40	G-65	3179	70	62	20	59	41	41	70
G-25	3589	20	73	77	63	72	72	27	G-66	3693	12	19	71	24	47	47	13
G-26	3590	19	16	16	33	21	21	18	G-67	3101	78	27	38	76	62	62	77
G-27	3467	31	46	26	52	48	48	29	G-68	3429	34	75	52	71	71	71	44
G-28	3608	18	05	43	28	28	28	16	G-69	3116	75	41	11	57	25	25	73
G-29	3274	58	34	46	11	10	10	48	G-70	3678	14	12	67	06	16	16	11
G-30	3481	30	79	44	62	78	78	34	G-71	3767	09	51	70	48	68	68	12
G-31	3556	23	37	47	31	34	34	25	G-72	3554	24	36	50	12	18	18	22
G-32	3548	25	04	37	07	06	06	19	G-73	3873	06	55	42	25	65	65	05
G-33	3409	36	53	53	64	77	77	49	G-74	3349	49	32	55	08	26	26	33
G-34	3358	46	10	80	27	44	44	41	G-75	3366	43	38	63	32	51	51	45
G-35	3615	16	35	33	17	14	14	14	G-76	3225	66	60	28	51	37	37	64
G-36	3756	10	29	78	13	33	33	08	G-77	3240	63	50	59	61	59	59	67
G-37	4003	04	74	36	22	67	67	04	G-78	3206	69	63	07	66	38	38	68
G-38	3314	53	47	02	74	53	53	58	G-79	4862	01	06	65	01	03	03	01
G-39	3315	52	24	29	56	45	45	51	G-80	3287	55	15	24	04	01	01	42
G-40	2804	81	39	17	70	35	35	81	G-81	3240	64	02	34	09	05	05	57
G-41	3497	28	80	40	80	80	80	54									

AMMI stability value (ASV); Coefficient of determination (Ri2); Francis coefficient of variation (CV); Shukla variance (σi2); Wricke's ecovalence value (Wi) and Lin and Binns model (Pi).

Spearman's rank correlation coefficient analysis indicated that R_i^2 had significantly positive correlations with mean grain yield and significantly negative with yield ranking (0.47 *vs* -0.47). The relationship of R_i^2 with mean performance and yield ranking of wheat genotypes for grain yield indicated that the ranking of genotypes was not similar as calculated by R_i^2 and mean performance. Furthermore, P_i exhibited significantly positive correlations with yield ranking and significantly negative with mean grain yield (0.96 *vs* -0.96). The relationship of P_i with mean performance and yield ranking of wheat genotypes for grain yield indicated that the ranking of genotypes was almost similar as calculated by P_i and mean performance. Moreover, the rest of the stability parameters displayed non-significant correlations with both mean and ranking of the genotypes for grain yield. The ASV showed significantly positive associations with CV (0.62), σ_i^2 (0.82) and W_i (0.82), inferring that these parameters were same in their abilities to identify stable genotypes (Table 4). The CV exhibited significantly positive correlations with σ_i^2 (0.69), W_i (0.69) and P_i (61). Shukla stability parameter (σ_i^2) expressed a perfect relationship with W_i (1.00), indicating that both parameters had similar results. Positive correlations of ASV with CV, σ_i^2 with W_i, and W_i with CV revealed that these parameters could invariably be used for identifying stable wheat genotypes (Table 4).

Table 4: *Spearman ranks correlation coefficient among stability parameter for grain yield in wheat.*

	Mean	Mean rank	ASV	R^2_i	CV	σ_i^2	W_i
Mean rank	-1.00**						
ASV	0.15 ns	-0.15 ns					
R^2_i	0.47**	-0.47**	0.09 ns				
CV	-0.30 ns	0.30 ns	0.62**	-0.31 ns			
σ_i^2	0.18 ns	-0.18 ns	0.82**	0.25 ns	0.69**		
W_i	0.18 ns	-0.18 ns	0.82**	0.25 ns	0.69**	1.00**	
Pi	-0.95**	0.95**	0.04 ns	-0.45**	0.60**	0.04 ns	0.04 ns

AMMI stability value (ASV); Coefficient of determination (Ri2); Francis coefficient of variation (CV); Shukla variance (σi2); Wricke's ecovalence value (Wi) and Lin and Binns model (Pi).

The main purpose of this study was to check the adequacy of various stability models with respect to the findings of the current study. Serious limitations for the analysis of genotype by environment interaction have been identified while using simple ANOVA (Gauch and Zobel, 1988). Moreover, regression and other stability analysis provide less information regarding the performance and classification of steady genotypes in METs (Manrique and Hermann, 2002). Among several statistical methods, AMMI and GGE biplot analyses had been reported to be efficient in explaining the complexity of GE interactions (Malik et al., 2019). Various studies have been carried out to examine the efficiency of AMMI and GGE biplot methods in which different researchers presented different logics to support their viewpoints (Gauch, 2006; Yan et al., 2007; Gauch et al., 2008). They also claimed that AMMI2 was more efficient than GGE, thus summarizing their statement as AMMI2>GGE>AMMI1. This statement has been further validated by the conclusions of this study. Hagos and Abay (2013) suggested that both GGE and AMMI biplots were important for evaluating stable and adaptable genotypes in METs. Similar results were reported by Stojakovic et al. (2010), Mitrovic et al. (2012), Rad et al. (2013) and Tiwari (2019), indicating that AMMI biplot performed equally well as the GGE biplot. Numerical stability parameters had also been identified as a good tool to rank genotypes based on their stability in METs (Sayyed and Mohammadi, 2008; Tamene et al., 2015). Spearman's rank correlation exhibited that most of the stability parameters had a significantly positive correlation with each other, indicating that these parameters were equally applicable for identifying stable genotypes.

Before jumping into conclusions, this study supports the idea of Yang et al. (2009) that complementary statistical tests should be followed in addition to biplot analysis to ascertain genotypic stability. However, despite some flaws, the usefulness and suitable visualization of GE interaction of these models cannot be surpassed. More critical analyses would open the horizons for further improvement of the weakspots that exist in these models. Soon, it is generally accepted among the scientists that AMMI and GGE biplot analyses would be the ultimate choice to obtain conclusive information from METs. Based on current results, it is recommended that AMMI and GGE biplot analysis should be complemented by the critical review of genotypes stability with multiple stability models to scrutinize wheat genotypesfor wider adaptation.

Conclusions and Recommendations

Graphical stability approaches provided more or less similar results in terms of identifying stable wheat genotypes for grain yield. Different stability models viz. AMMI, GGE biplot, Eberhart and Russell's model, Francis coefficient of variation (CV) declared the genotype G-79 as top-ranked while Shukla stability value (σi^2) and Wrick's ecovalence (Wi) identified G-80 (check cultivar Janbaz), G-52 and G-79 as leading wheat genotypes based on grain yield. Spearman's rank correlation revealed significant positive correlations of AMMI stability value (ASV) with CV, σi^2 with Wi, and Wi with CV indicating that these parameters could invariably be used for identifying stable wheat genotypes. Different stability models identified G-79 as high yielding and stable genotype and thus could be recommended for commercialization in the province of Khyber Pakhtunkhwa, Pakistan.

Novelty Statement

A high yielding stable wheat genotypes was identified using multiple stability models out of 81 wheat recombinant inbred lines (RIL's) tested across nine environments during three years.

Author's Contribution

Malak Atiq Ullah Khan: Conducted the experiments and collected the data.
Fida Mohammad: Designed the experiment.
Fahim Ullah Khan: Wrote the paper.
Sheraz Ahmad: Analyzed the data.
Mian Ahmad Raza: Collected data
Tariq Kamal: Reviewed the paper

Conflict of interest
The authors have declared no conflict of interst.

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