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RESEARCH PAPER

Superiority index based on AMMI and yield of wheat genotypes evaluated in North Western Plains Zone under restricted irrigated timely sown conditions

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Abstract : Highly significant effects of environment (E), GxE interaction and genotypes (G) were observed by AMMI analysis during 2018-19 and 2019-20 study years for wheat genotypes evaluated at major locations of mega zone of the country. WAASB measure observed suitability of HD3237, WH1080 and PBW644 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found HI1620, HD3237 and HI1628 as of stable performance with high yield. PRVG measure observed suitability of HI1620, HI1628 and BRW3806 while MHPRVG measure identified HI1620, HI1628 and HD3237 wheat genotypes. More over the average yield of genotypes ranked HI1620, HI1628 and NIAW3170 as of order of choice. SI had expressed all direct relations of moderate to high degree of correlations except with WAASB and weak relations with yield, PRVG and MHPRVG values. Only negative correlations had expressed by WAASB measure while positively correlated with yield, PRVG and MHPRVG. Second year of study observed suitability of NIAW3170, DBW296 and PBW644 genotypes as far as WAASB values were concerned. Superiority index found DBW296, HUW838 and NIAW3170 as of stable performance with high yield. More over the average yield of genotypes ranked DBW296, HUW838 and JAUW672 as of order of choice. Mean yield showed a highly significant positive correlation with SI, MHPRVG, PRVG and negative values of correlation with AMMI based measures. SI had expressed all inverse relations with measures WAASB, EV, ASV, MASV as only negative values were seen. Positive correlations were maintained by WAASB measure with Za, SIPC, ASTAB, ASV1.

Key Words : AMMI analysis, ASV, SIPC, Za, EV, SI, SSI, Biplot graphs

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INTRODUCTION

Worldwide crop breeding programmes select genotypes based on yield and stability over the variable environmental conditions (Veenstra *et al.,* 2019). The cross over genotype-by-environment interactions limits the selection process (Bocianowski *et al.,* 2019). Additive main effects and multiplicative interaction (AMMI) model had been most widely used analytic tool to analyse and estimate GxE interaction in multi environmental trials (Zhang *et al.,* 1998 and Gauch, 2013). The genotype

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(G) and environment (E) effects interpreted as additive effects, using two-way ANOVA, by least square principle and genotype × environment interaction (G×E) considered as multiplicative effect by applying singular value decomposition (SVD) on the residuals from ANOVA (Balestre *et al.,* 2009 and Adjebeng-Danquah *et al.,* 2017). Instances of biased interpretation for stability of the genotypes observed when low proportion of the variance explained by first interaction principal component IPCA1 (Zali *et al.,* 2012; Ajay *et al.,* 2019 and Olivoto *et al.,* 2019). The quantitative stability measure (WAASB) considered the weighted average of all the significant IPCA scores based on the sum of absolute values of the IPCA scores. The stable genotype judged the lower value of WAASB measure. Ranking of genotypes based on yield as well as stability in multi-environment-trials is essential as it can assist breeders in choosing best genotype for a location. The simultaneous consideration of yield and stability in a single measure by adding the corresponding ranks had been advocated (Kang, 1993; Farshadfar, 2008 and Farshadfar *et al.,* 2011). The superiority index WAASBY allowed variable weighting between yield and stability (WAASB) (Olivato, 2019). The present study was planned to validate the relationships between SI and other AMMI based stability measures for wheat genotypes evaluated under multi environmental trials in the North Western Plains Zone of the country under restricted irrigated timely sown trials in recent past.

Material and Methods

Parts of sub-humid Sutlej-Ganga Alluvial Plains and arid western plains, which comprises Punjab, Haryana, Delhi, Rajasthan (except Kota and Udaipur divisions), Western Uttar Pradesh (except Jhansi division and hilly areas), parts of Jammu and Kashmir (Jammu and Kathua districts) and parts of Himachal Pradesh (Paonta Valley and Una districts) categorised as the North Western Plain

Zobel *et al.* (1988)	Averages of the squared eigenvector values	$\mathrm{EV} = \sum_{n=1}^{N} \lambda_{in}^{2} / n$
Sneller *et al.* (1997)	Sums of the absolute value of the IPC scores	$\mathrm{SIPC} = \sum_{n=1}^{N} \lambda_{n}^{0.5} \gamma_{in}$
Purchase *et al.* (2000)	AMMI stability value	ASV = $[(\frac{SSIPC\,1}{SSIPC\,2} PCI)^2 + (PC2)^2]^{1/2}$
Rao and Prabhakaran (2005)	AMMI based stability parameter	$ASTAB = \sum_{n=1}^{n} \lambda_n \gamma_{ni}^2$
Zali *et al.* (2012)	ASV1	ASV1 = $[\frac{SSIPC\,1}{SSIPC\,2}(PCI)^2 + (PC2)^2]^{1/2}$
Zali *et al.* (2012)	Modified AMMI stability value	$MASV = \sqrt{\sum_{n=1}^{N-1} \frac{SSIPC_n}{SSIPC_{n+1}} (PC_n)^2 + (PC_{n+1})^2}$
Zali *et al.* (2012)	Absolute value of the relative contribution of IPCs to the interaction	$Z_a = \sum_{n=1}^{N} \lvert \lambda_n \gamma_{in} \rvert$
Ajay *et al.* (2019)	MASV1	$\mathrm{MASV1} = \sqrt{\sum_{n=1}^{N-1} (\frac{SSIPC_n}{SSIPC_{n+1}} PC_n)^2 + (PC_{n+1})^2}$
Resende and Durate (2007)	Relative performance of genotypic values across environments	$PRVG_{ij} = VG_{ij} / VG_i$
Resende and Durate (2007)	Harmonic mean of relative performance of genotypic values	$MHPRVG_{i.}$ = Number of environments / $\sum_{j=1}^{k} \frac{1}{PRVG_{ij}}$
Olivoto (2018)	Superiority index	SI = $\frac{(rG_i \times \theta_Y) + (rW_i \times \theta_S)}{(\theta_Y + \theta_S)}$

Zone of India. Higher productivity of wheat genotypes had been reported by the states from this mega zone of the country. Ten advanced promising wheat genotypes fourteen locations and nine genotypes at thirteen locations were evaluated under field trials during 2018-19 and 2019-20 cropping seasons, respectively. Field trials were conducted at research centers in Randomized Complete Block Designs with three replications. Recommended agronomic practices were followed to harvest good yield. Details of genotype parentage along with environmental conditions were reflected in Tables A and B for ready reference. Stability measure weighted average of absolute scores has been calculated as:

$$\mathbf{WAASB} = \sum_{k=1}^{p} \left| \mathbf{IPCA_{ik}} \ \mathbf{x} \ \mathbf{EP_k} \right| / \sum_{k=1}^{p} \mathbf{EP_k}$$

where, $WAASB_i$ is the weighted average of absolute scores of the i^{th} genotype (or environment); $IPCA_{ik}$ is the score of the i^{th} genotype (or environment) in the k^{th} IPCA and EP_k is the amount of the variance explained by the k^{th} IPCA. Superiority index allowed variable weights to yield and stability measure (WAASB) to select genotypes that combine high performance and stability as $\mathbf{SI} = \frac{(\mathbf{rG_i} \ \mathbf{x} \ \theta_Y) + (\mathbf{rW_i} \ \mathbf{x} \ \theta_s)}{(\theta y + \theta s)}$ where rG_i and rW_i are the rescaled values for yield and WAASB, respectively, for the i^{th} genotype; G_i and W_i are the yield and the WAASB

Table A : Details of parentage and environmental conditions (2018-19)

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G1	HI 1620	(NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU)	Delhi	28 °4'N	77 °13 'E	228
G2	PBW 796	(W15.92/4/PASTOR//HXL7573/2*BAU/3/ WBLL1*2/5/WHEAR/SOKOLL)	Hisar	29 ° 10' N	75 ° 46'E	229
G3	HI 1628	(FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/PFAU/WEAVER//B RAMBLING)	Bawal	28 ° 10'N	76 ° 50'E	266
G4	WH 1142	(OEN/Ae.Sq.(TAUS)/FCT/3/2*WEAVER)	Karnal	29 ° 43' N	70 ° 58'E	245
G5	HD 3043	(PJN/BOW//OPATA*2/3CROC_1/A.SQUARROSA(224)//OPATA)	Jammu	32 ° 40' N	74 ° 54'E	356
G6	PBW 644	(PBW175/HD2643)	Ludhiana	30 ° 54' N	75 ° 48 'E	247
G7	HD 3237	(HD3016/HD2967)	Gurdaspur	30° 02' N	75 ° 24 'E	265
G8	BRW 3806	(NI5439/MACS2496)	Kapurthala	31° 22' N	75° 22 'E	229
G9	NIAW3170	(SKOLL/ROLF07)	Balachaur			
G10	WH 1080	(PRL/*2PASTOR)	Bulandshahr	28 ° 40'N	77 ° 84'E	195
			Pantnagar	29 ° 02'N	79 ° 48'E	243.8
			Diggi	26°22'N	75°26 'E	329.24
			Sriganganagar	29 ° 66'N	75 ° 53'E	175.6
			Bharatpur	27° 13'N	77° 29 'E	182

Table B : Details of parentage and environmental conditions (2019-20)

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G1	HUW838	(WBLL1*2/BRAMBLING/4/BABAX/LR42//BABAX*2/3/SHAMA*2/5/PBW343 *2/KUKUNA*2//FRTL/PIFED)	Delhi	28 °4'N	77 °13 'E	228
G2	HD3043	(PJN/BOW//OPATA*2/3CROC_1/A.SQUARROSA(224)//OPATA)	Jammu	32 ° 40' N	74 ° 54'E	356
G3	PBW644	(PBW175/HD2643)	Hisar	29 ° 10' N	75 ° 46'E	229
G4	DBW296	(DBW16/BH1146)	Karnal	29 ° 43' N	70 ° 58'E	245
G5	HI1628	(FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/PFAU/WEAVER//BRAM BLING)	Ludhiana	30 ° 54' N	75° 48 'E	247
G6	WH1080	(PRL/*2PASTOR)	Gurdaspur	30° 02' N	75° 24 'E	265
G7	JAUW672	(SERI.18*2/3/KAUZ*2/BOW//KAUZ/4/CROC)	Kapurthala	31° 22' N	75° 22 'E	229
G8	WH1142	(OEN/Ae.Sq.(TAUS)/FCT/3/2*WEAVER)	Balachaur	31° 3 'N	76° 18 'E	272
G9	NIAW3170	(SKOLL/ROLF07)	Bulandshahr	28 ° 40'N	77 ° 84'E	195
			Nagina	29 ° 28' N	78 ° 32'E	245
			Modipuram			
			Pantnagar	29 ° 02'N	79 ° 48'E	243.8
			Sriganganagar	29 ° 66'N	75 ° 53'E	175.6

values for i^{th} genotype. SI superiority index for the i^{th} genotype that weights between yield and stability and θ_Y and θ_S are the weights for yield and stability assumed to be of order 65 and 35, respectively in this study.

AMMI analysis was performed using AMMISOFT version 1.0, available at *https://scs.cals.cornell.edu/people/ hugh-gauch/* and SAS software version 9.3. Stability measures had been compared with recent analytic measures of adaptability calculated as the relative performance of genetic values (PRVG) and harmonic mean based measure of the relative performance of the genotypic values (MHPRVG) for the simultaneous analysis of stability, adaptability and yield (Resende and Durate, 2007).

Results and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

First year (2018-19):

AMMI analysis:

Highly significant effects of environment (E), GxE interaction and genotypes (G) were observed by AMMI analysis of variance. About 63 per cent of the total sum of squares due to treatments explained by environmental variations. This implied diverse environmental conditions induced more variations in genotypes yield performance. Genotypes explained 6.1 per cent of total sum of squares, whereas GxE interaction accounted for 18.4 per cent of treatment variation in yield. Higher values of GxE interaction (sum of squares) as compared to genotypes indicated complex GxE interaction as far as yield of genotypes were concerned. Similar nature of more GxE interaction effects over genotype are reported in several studies (Bornhofen *et al.,* 2017 and Ajay *et al.,* 2019), thus, making selection of stable genotype difficult. Further division of GxE interaction sum of squares into significant seven multiplicative terms (IPCA1, IPCA2 and. IPCA7) explained 23.1 per cent, 19.8 per cent, 16.4 per cent, 15.4 per cent, 12.6 per cent, 5.7 per cent and 4.4 per cent, respectively. Total of significant components were 97.4 per cent and remaining 2.6 per cent is the residual or noise, which is not interpretable and thus, discarded (Oyekunle *et al.,* 2017).

Stability measures:

According to averages of the squared eigenvector values (EV) stability statistic, a genotype is considered to be more stable if EV is low. Accordingly, the genotype G7 followed by G6 and G1 had high stability and genotype G9 had the least stability. Least value of absolute IPCA1 expressed by G3, G6, G7 and higher value achieved by G2.The sums of the absolute value of the IPC scores (SIPC) identified G6 followed by G7 and G3 as the most stable genotypes, whereas G8 as the least stable one. Absolute value of the relative contribution of IPCs to the interaction (Za) revealed G7, G6 and G3 genotypes as most stable in descending order of stability, whereas G8 genotype with the least stability. AMMI-based stability parameter (ASTAB) identified genotypes G7,

Table 1: AMMI analysis of wheat genotypes under MET (2018-19)

Source	Degree of freedom	Mean sum of squares	Level of significance	% contribution of factors	GxE interaction sum of squares (%)	Cumulative sum of squares (%) by IPCA's
Treatments	139	301.60	***	87.44		
Genotype (G)	9	324.07	***	6.08		
Environment (E)	13	2323.64	***	63.00		
GxE interaction	117	75.21	***	18.35		
IPC1	21	96.87	***		23.12	23.12
IPC2	19	91.48	***		19.75	42.87
IPC3	17	84.99	***		16.42	59.29
IPC4	15	90.41	***		15.41	74.70
IPC5	13	85.63	***		12.65	87.36
IPC6	11	45.76	***		5.72	93.08
IPC7	9	42.59	**		4.36	97.43
Residual	12	18.82	0.20			
Error	420	14.34				
Total	559	85.77				

G10 and G1 as most stable and genotype G4 was least stable in this study (Rao and Prabhakaran, 2005). Results of ASV showed that genotype, G5, G6, G7 were the stable and G4 the least stable. Values of ASV1 selected G5, G6, G7 for their stable behaviour whereas G4 would express unstable performance. The values of MASV and MASV1 which consider all significant IPCAs also showed that the genotypes G7, G10 and G1 were most stable and G3 and G8 would be least stable by measures, respectively. The genotype with the lowest WAASB value is considered the most stable, that is, the one that deviates least from the average performance across environments. G7, G10 and G6 pointed by measure WAASB as desirable genotypes for considered locations of the zone. Lower value of superiority index had been observed for G5, G4 and G10 whereas large value by G1. Genotypes G5, G10 and G6 were identified for their more stable yield performance by PRVG and MHPRVG measures along with least stable yield of G1. Maximum yield expressed by G1 followed by G3 and G9 as good variation observed from 52 to 45q/ha among genotypes.

Ranking of genotypes as per simultaneous use of AMMI model and yield:

HI1620, HD3237 and HI1628 identified by EV measure whereas SPIC favoured HI1628, HD 3237 and HI1620 genotypes.The least values of simultaneous index as per IPCA1 measure HI1628, HI1620 and HD3237 were considered as stable with high yield, whereas high values suggested as least stable with low yield for WH1142 genotype. HI1628, HD3237 and HI1620 genotypes possessed lower value of Za measure. Values of least magnitude of ASV and ASV1 pointed towards HI1620, HI1628 and HD3237 wheat genotypes.

Table 2: AMMI analysis of wheat genotypes under MET (2019-20)

Source	Degree of freedom	Mean sum of squares	Level of significance	% contribution of factors	GxE interaction sum of squares (%)	Cumulative sum of squares (%) by IPCA's
Treatments	116	369.04	***	91.31		
Genotype (G)	8	589.01	***	10.05		
Environment (E)	12	1696.76	***	43.43		
GxE interaction	96	184.74	***	37.83		
IPC1	19	351.09	***		37.61	37.61
IPC2	17	290.10	***		27.81	65.42
IPC3	15	193.39	***		16.36	81.78
IPC4	13	102.86	***		7.54	89.32
IPC5	11	98.15	***		6.09	95.41
IPC6	9	62.35	***		3.16	98.57
IPC7	7	27.71	*		1.09	99.66
Residual	5	11.94	0.39			
Error	351	11.60				
Total	467	100.39				

Table 3: Measures of stability as per AMMI analysis for wheat genotypes (2018-19)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	SI	WAASB	MHPRVG	PRVG	Yield
G1	1.61	4.88	4.39	2.13	2.01	18.65	0.040	7.49	57.35	82.37	1.12	1.0751	1.0810	52.28
G2	2.42	5.93	4.92	2.96	2.75	19.88	0.048	7.89	75.49	50.67	1.21	1.0008	1.0087	49.20
G3	0.00	7.10	5.49	1.58	1.58	15.20	0.043	5.83	61.98	76.29	0.90	1.0377	1.0440	50.46
G4	2.73	5.63	5.25	3.95	3.76	22.03	0.055	8.52	103.18	30.70	1.38	0.9680	0.9787	47.90
G5	0.29	5.25	5.02	0.34	0.31	15.99	0.061	7.05	68.85	27.68	0.90	0.9208	0.9274	45.03
G6	0.47	5.20	4.80	0.77	0.75	14.35	0.040	5.41	62.23	37.04	0.87	0.9357	0.9421	45.90
G7	0.75	3.44	3.22	1.06	1.00	13.00	0.029	5.57	30.82	79.46	0.74	1.0227	1.0256	49.99
G8	1.28	6.88	6.07	3.13	3.08	24.39	0.062	9.53	102.65	42.74	1.49	1.0213	1.0321	49.80
G9	1.83	5.91	5.58	2.70	2.57	22.35	0.064	9.03	96.65	51.04	1.36	1.0183	1.0267	50.06
G10	0.92	4.12	3.73	1.19	1.11	15.30	0.057	6.67	48.62	34.99	0.86	0.9289	0.9338	45.66

Composite measures MASV selected HI1620, HD3237, HI1628 and MASV1 as HI1620, HD 3237, NIAW3170 genotypes of choice for these locations of the zone. In the present study, all measures identified genotypes HI1620, HD3237 and HI1628 as stable and high yielders. WAASB measure observed suitability of HD3237, WH1080 and PBW644 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found HI1620, HD3237 and HI1628 as of stable performance with high yield (Olivoto *et al.,* 2019). PRVG measure observed suitability of HI1620, HI1628 and BRW3806 while MHPRVG measure identified HI1620, HI1628 and HD3237 wheat genotypes (Resende and Durate, 2007). More over the average yield of genotypes ranked HI1620, HI1628 and NIAW3170 as of order of choice.

Biplot graphical analysis:

Biplot graphical analysis carried out to better understand the relationships among measures, principal component analysis (PCA) based on the ranks matrix

Table 4: Measures of stability as per AMMI analysis for wheat genotypes (2019-20)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
G1	2.61	6.18	5.30	3.72	3.25	152.74	0.574	8.88	29.92	1.527	87.72	1.0834	1.0968	58.56
G2	2.33	6.80	5.61	3.19	2.75	139.84	0.566	8.52	29.27	1.398	32.05	0.9229	0.9363	50.23
G3	0.09	10.44	7.85	3.61	3.61	139.65	0.773	8.04	39.83	1.396	27.66	0.9220	0.9361	49.62
G4	1.69	7.39	5.48	2.71	2.44	137.56	0.424	7.61	21.88	1.376	93.44	1.0895	1.0988	58.57
G5	2.56	9.89	7.68	4.65	4.30	213.99	0.858	11.04	46.87	2.140	11.05	0.9506	0.9672	51.14
G6	2.80	8.62	6.72	3.78	3.25	156.10	0.703	8.37	38.05	1.561	38.92	0.9564	0.9750	52.01
G7	0.90	9.15	7.25	1.89	1.78	152.44	0.740	10.08	36.92	1.524	58.51	1.0067	1.0184	54.52
G8	3.19	6.41	5.43	4.35	3.75	151.07	0.671	9.08	34.55	1.511	37.04	0.9446	0.9597	51.50
G9	0.64	7.85	6.32	2.66	2.63	119.93	0.612	7.96	28.76	1.199	69.92	1.0019	1.0118	54.43

Table 5 : Simultaneous ranking of genotypes as per AMMI based measures and yield (2018-19)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
HI 1620	8	4	4	7	7	7	4	7	4	6	1	1	1	1
PBW 796	15	14	11	14	14	13	11	13	13	7	5	6	6	6
HI 1628	3	12	10	7	7	5	6	5	6	5	3	2	2	2
WH 1142	17	13	14	17	17	15	13	15	17	9	9	7	7	7
HD 3043	12	15	16	11	11	15	18	15	16	4	10	10	10	10
PBW 644	11	12	12	10	10	10	10	9	13	3	7	8	8	8
HD 3237	8	5	5	7	7	5	5	6	5	1	2	3	5	4
BRW 3806	11	14	15	14	14	15	14	15	14	10	6	4	3	5
NIAW 3170	11	10	12	10	10	12	13	12	11	8	4	5	4	3
WH 1080	14	11	11	13	13	13	16	13	11	2	8	9	9	9

Table 6 : Simultaneous ranking of genotypes as per AMMI based measures and yield (2019-20)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
HUW838	9	3	3	8	7	9	5	8	6	7	2	2	2	2
HD3043	13	11	12	12	12	12	10	13	11	4	7	8	8	8
PBW644	10	18	18	14	16	12	17	12	17	3	8	9	9	9
DBW296	5	5	4	4	3	3	2	2	2	2	1	1	1	1
HI1628	13	15	15	16	16	16	16	16	16	9	9	6	6	7
WH1080	13	11	11	12	11	13	11	9	12	8	5	5	5	5
JAUW672	6	10	10	4	4	9	10	11	9	6	4	3	3	3
WH1142	15	8	8	14	14	11	11	13	11	5	6	7	7	6
NIAW3170	6	9	9	6	7	5	8	6	6	1	3	4	4	4

(Fig. 1) was used. The first two PCAs explained 88.7 per cent of variation (Balestre *et al.,* 2009). The relationships among the different measures displayed graphically by plotting the first two PCs scores (Fig. 1). The PC1 and PC2 axes distinguish measures into three groups. SI clubbed with EV and yield joined with PRVG and MHPRVG measures. Mostly AMMI based measures clustered in separate cluster of ASV, ASV1, IPCA1, MASV, MASV1, SPIC, Za. Stability measure WAASB observed as outlier in biplot analysis.

Association analysis among stability measures:

Correlation was computed for each pair of measures to have an idea of association among stability measures. Mean yield showed only significant positive correlations

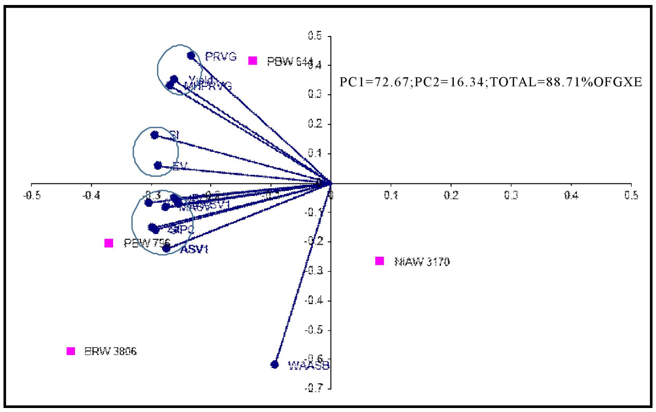

Fig. 1: Biplot graphical analysis of stability measures for wheat genotypes evaluated under MET (2018-19)

Table 7 : Loadings of stability measures as per first two PC's (2018-19)

Measure	PC1	PC2
IPCA1	-0.261	-0.051
MASV1	-0.255	-0.071
MASV	-0.275	-0.082
ASV1	-0.275	-0.223
ASV	-0.275	-0.223
Za	-0.297	-0.151
EV	-0.289	0.058
SIPC	-0.293	-0.159
ASTAB	-0.304	-0.066
WAASB	-0.094	-0.620
SI	-0.294	0.163
MHPRVG	-0.268	0.331
PRVG	-0.233	0.432
Yield	-0.262	0.351
% variance	72.37	16.34

with WAASB MHPRVG, PRVG, ASV, ASV1 and indirect relations of low magnitude with EV only. SI had expressed all direct relations with moderate to high degree of correlations except with WAASB and weak relations with yield, PRVG and MHPRVG values. Only negative correlations had expressed by WAASB measure while positively correlated with yield, PRVG and MHPRVG. All AMMI based measures Za, SIPC, EV , ASV, ASV1, MASV1, MASV achieved only positive correlation values. EV expressed negative correlations with WAASB, Yield, PRVG and MHPRVG.

Second year (2019-20):

AMMI analysis:

Effects of environment (E), GE interaction and genotypes (G) were highly significant by the AMMI analysis of variance. About 43.3 per cent of the total sum of squares due to treatments explained by environmental effects justified the diversity of environments. Genotypes explained 10.1 per cent of total sum of squares, whereas GxE interaction explained 37.8 per cent of treatment variation in yield. The larger magnitude of GxE interaction (sum of squares) than genotypes indicated the presence of genotypic differences across environments and complex GxE interaction for wheat yield. Further partitioning of GxE interaction revealed that the first six multiplicative terms (IPCA1, IPCA2 and IPCA6) of AMMI were highly significant and explained 37.6 per cent, 27.8 per cent 16.4 per cent, 7.5 per cent, 6.1 per cent, 3.2 per cent and 1.1 per cent of GEI sum of squares, respectively. Approximately 98.6 of sum of squares accounted by six PC's very little left the residual or noise, which is not interpretable and thus, discarded (27).

Stability measures:

Least value of absolute IPCA1 expressed by G3, G9, G7 and higher value achieved by G8. According to averages of the squared eigenvector values (EV) stability statistic, a genotype is considered to be more stable if EV is low. Accordingly, the genotype G4 followed by G2 and G1 had high stability and genotype G5 had the least stability. Since EV does not provide any advantage in favourable environments, genotypes screened by this measure can be recommended for less favourable environments. SIPC measure considered sums of the absolute value of the IPC scores identified G4 followed by G9 and G3 as the most stable genotypes, whereas G5 as the least stable one. Absolute value of the relative contribution of IPCs to the interaction (Za) revealed G9, G4 and G3 genotypes as most stable in descending order of stability, whereas G5 genotype with the least stability.

Results of ASV showed that genotype, G7, G4, G9 were the stable and G5 the least stable. Values of ASV1 selected G7, G9, G4 for their stable behaviour whereas G5 would express unstable performance. Measures ASV and ASV1 are useful when the proportion of variation explained by the first two IPCAs is high, but when three or more IPCAs are significant total variation explained by these parameters is low. The values of MASV and MASV1 which consider all significant IPCAs also showed that the genotypes G1, G8 and G4 by MASV and G1, G8 and G2 by values of MASV1 were most stable and G3 would be least stable by both measures. AMMI-based stability parameter (ASTAB) identified genotypes G4, G9 and G2 as most stable and genotype G5 was least stable in this study. The lowest WAASB value deviates least from the average performance across environments, therefore, G9, G4 and G3 genotypes would be of stable performance whereas G5 would be undesirable genotype for considered locations of the zone. Lower value of Superiority index had been observed for G5, G3 and G2 whereas large value by G4. Genotypes G2, G3 and G8 were identified for their more stable yield performance by PRVG and G3, G2, G8 by values of MHPRVG measure along with least stable yield of G4. Maximum yield expressed by G4 followed by G1 and G7 as good variation observed from 49.6 to 58.7q/ha among genotypes.

Ranking of genotypes as per simultaneous use of AMMI model and yield:

Wheat genotypes DBW296, HUW838 and NIAW3170 identified by EV measure whereas SPIC favoured DBW296, NIAW3170 and HUW838 genotypes. The least values of simultaneous index as per IPCA1 measure DBW296, JAUW672 were considered as stable with high yield, whereas high values suggested as least stable with low yield for WH1142 genotype. DBW296, NIAW3170 genotypes possessed lower value of Za measure. Values of least magnitude of ASV and ASV1 pointed towards DBW296, JAUW672 and NIAW3170 wheat genotypes. MASV and MASV1 selected HUW838, DBW296, WH1142 as wheat genotypes of choice for these locations of the zone. WAASB measure observed suitability of NIAW3170, DBW296 and PBW644 genotypes. Superiority index while weighting 0.65 and 0.35 for yield and stability found DBW296, HUW838 and NIAW3170 as of stable performance with high yield. Surprisingly PRVG and MHPRVG measures identified DBW296, HUW838 and JAUW672 wheat genotypes. More over the average yield of genotypes ranked DBW296, HUW838 and JAUW672 as of order of choice. Composite measures. In the present study, all measures identified genotypes DBW296, HUW838 and NIAW3170 as stable and high yielders.

Biplot graphical analysis:

Loadings of stability measures as per first two significant principal components were depicted in Table 8. Biplot graphical analysis based on the simultaneous ranks of stability measures (Fig. 2) was used. About 90.2 per cent of variation of the measures accounted by first two PCAs explained. Superiority index clubbed with EV, ASV, ASTAB and yield grouped with PRVG, MASV, MASV1 and MHPRVG measures. AMMI based measures clustered in separate cluster of ASV1, IPCA1, SIPC, Za. WAASB measure maintained distance from other measures and observed as outlier in biplot analysis.

Table 8 : Loadings of stability measures as per first two PC's (2019-20)

Measure	PC1	PC2
IPCA1	-0.233	0.332
MASV1	-0.256	-0.282
MASV	-0.264	-0.268
ASV1	-0.277	0.159
ASV	-0.287	0.031
Za	-0.271	0.317
EV	-0.285	-0.078
SIPC	-0.268	0.193
ASTAB	-0.295	0.009
WAASB	-0.111	0.663
SI	-0.298	-0.019
MHPRVG	-0.277	-0.212
PRVG	-0.277	-0.212
Yield	-0.287	-0.196
% variance	77.87	12.29

Association analysis among stability measures:

Correlation was computed for each pair of measures to have an idea of association among measures. Mean yield showed a highly significant positive correlation with SI, MHPRVG, PRVG and negative values of correlation

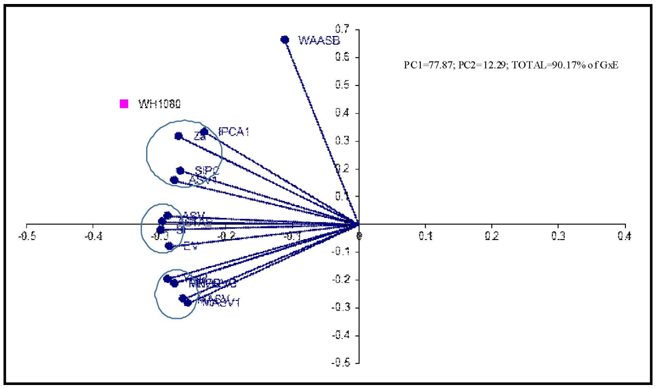

Fig. 2: Biplot graphical analysis of stability measures for wheat genotypes evaluated under MET (2019-20)

with EV, ASTAB, MASV, ASV, *i.e.* AMMI based measures. SI had expressed all inverse relations with measures WAASB, EV, ASV, MASV as only negative values were seen. Positive correlations were maintained by WAASB measure with Za, SIPC, ASTAB, ASV1 etc. Measure ASTAB expressed direct relations of larger magnitude except with IPCA1. SIPC measure achieved only positive values of correlation coefficient with Za and EV. Measures Za, ASV and ASV1 revealed only positive correlation with other measures and comparisons based on these methods will be equivalent to comparisons based on first two PCA axes. Negative values of correlation expressed by IPCA1 with MASV and MASV1 measures.

Conclusion:

AMMI model proved to be an effective tool to study GxE interaction in multi-environment trials. The stability measures found to be correlated well with each other, and measures also exhibited a significant positive correlation with yield. Stability measures considering stability and yield simultaneously would be used to identify stable high-yielding wheat genotypes.

Table 9: Association analysis of SI with other stability measures (2018-19)

Measure	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	0.075	0.173	0.860	0.838	0.712	0.251	0.693	0.566	-0.156	0.734	0.191	0.218	0.272
MASV1		0.937	0.467	0.490	0.573	0.428	0.460	0.701	-0.092	0.587	0.251	0.284	0.247
MASV			0.504	0.526	0.711	0.610	0.623	0.865	-0.296	0.719	0.119	0.159	0.125
ASV1				0.999	0.867	0.330	0.791	0.759	-0.062	0.895	0.389	0.426	0.456
ASV					0.872	0.335	0.792	0.768	-0.058	0.900	0.398	0.435	0.462
Za						0.652	0.974	0.909	-0.255	0.995	0.280	0.322	0.325
EV							0.735	0.730	-0.692	0.600	-0.343	-0.311	-0.323
SIPC								0.855	-0.299	0.950	0.215	0.253	0.258
ASTAB									-0.485	0.917	0.013	0.059	0.058
WAASB										-0.239	0.854	0.830	0.830
SI											0.295	0.337	0.344
MHPRVG												0.999	0.996
PRVG													0.996

Table 10 : Association analysis of SI with other stability measures (2019-20)

	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	-0.544	-0.501	0.622	0.426	0.459	-0.082	0.292	0.056	0.459	-0.144	-0.014	0.013	0.015
MASV1		0.981	0.006	0.179	0.373	0.737	0.307	0.713	0.372	-0.523	-0.406	-0.405	-0.458
MASV			0.047	0.214	0.422	0.837	0.420	0.800	0.421	-0.589	-0.470	-0.468	-0.515
ASV1				0.972	0.614	0.406	0.304	0.520	0.614	-0.564	-0.398	-0.373	-0.410
ASV					0.606	0.505	0.300	0.597	0.606	-0.609	-0.441	-0.420	-0.465
Za						0.635	0.851	0.742	1.000	-0.542	-0.199	-0.175	-0.232
EV							0.689	0.980	0.634	-0.781	-0.631	-0.618	-0.653
SIPC								0.712	0.851	-0.477	-0.203	-0.189	-0.216
ASTAB									0.741	-0.811	-0.619	-0.601	-0.645
WAASB										-0.542	-0.198	-0.174	-0.232
SI											0.929	0.920	0.943
MHPRVG												0.999	0.997
PRVG													0.996

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References

Adjebeng-Danquah, J., Manu-Aduening, J., Gracen, V.E., Asante, I.K. and Offei, S.K. (2017). AMMI stability analysis and estimation of genetic parameters for growth and yield components in cassava in the forest and guinea savannah ecologies of Ghana. *Int. J. Agron.,* **2017**:1–10.

Ajay, B. C., Aravind, J., Fiyaz, R. Abdul, Kumar Narendra, Lal Chuni, Gangadhar, K., Kona Praveen, Dagla, M. C. and Bera, S.K. (2019). Rectification of modified AMMI stability value (MASV) *Indian J. Genet.,* **79**(4) :726-731.

Balestre, M., Von Pinho, R.G., Souza, J.C. and Oliveira, R.L. (2009). Genotypic stability and adaptability in tropical maize based on AMMI and GGE biplot analysis. *Genet. Mol. Res.,* **8** : 1311–1322.

Bocianowski, J., Niemann, J. and Nowosad, K. (2019). Genotype-by environment interaction for seed quality traits in interspecific cross-derived *Brassica* lines using additive main effects and multiplicative interaction model. *Euphytica.,* **215** (7):1–13.

Bornhofen, E., Benin, G., Storck, L., Woyann, L.G., Duarte, T., Stoco, M.G. and Marchioro, S.V. (2017). Statistical methods to study adaptability and stability of wheat genotypes. *Bragantia,* **76**:1–10.

Farshadfar, E. (2008). Incorporation of AMMI stability value and grain yield in a single non-parametric index (GSI) in bread wheat. *Pak. J. Biol. Sci.,* **11**:1791–1796.

Farshadfar, E., Mahmodi, N. and Yaghotipoor, A. (2011). AMMI stability value and simultaneous estimation of yield and yield stability in bread wheat (*Triticum aestivum* L.). *Aust. J. Crop Sci.,* **5** : 1837–1844.

Gauch, H.G. (2013). A simple protocol for AMMI analysis of yield trials. *Crop Sci.,* **53**:1860–1869.

Kang, M.S. (1993). Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. *Agronomy J.,* **85** :754-757.

Olivoto, T. (2018). *WAASB data, Mendeley Data*, v2. doi. org/ 10.17632/2sjz32k3s3.2

Olivoto, T., Lucio, A. Dal'Col, Gonzalez, Silva, J.A. da and Marchioro, V.S. (2019). Mean performance and stability in multi-environment trials I: Combining features of AMMI and BLUP techniques. *Agron. J.,* **111**:1–12.

Oyekunle, M., Menkir, A., Mani, H., Olaoye, G., Usman, I.S., Ado, S.G. (2017). Stability analysis of maize cultivars adapted to tropical environments using AMMI analysis. *Cereal Res. Commun.,* **45** : 336–345.

Purchase, J.L., Hatting, H. and Deventer, C.S. van. (2000). Genotype × environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: II. Stability analysis of yield performance. *S. Afr. J. Plant Soil,* **17**:101–107.

Rao, A.R. and Prabhakaran, V.T. (2005). Use of AMMI in simultaneous selection of genotypes for yield and stability. *J. Indian Society of Agric. Statist.,* **59**:76-82.

Resende, M.D.V. and Duarte, J.B. (2007). Precision and quality control in variety trials. *Pesquisa Agropecuaria Tropical,* **37**: 182-194.

Sneller, C.H., Norquest, L. Kilgore and Dombek, D. (1997). Repeatability of yield stability statistics in soybean. *Crop Sci.,* **37** : 383–390.

Veenstra, L.D., Santantonio, N., Jannink, J.L. and Sorrells, M.E. (2019). Influence of genotype and environment on wheat grain fructan content. *Crop Sci.*, **59**:190–198.

Zali, H., Farshadfar, E., Sabaghpour, S.H. and Karimizadeh, R. (2012). Evaluation of genotype × environment interaction in chickpea using measures of stability from AMMI model. *Ann. Biol. Res.,* **3** : 3126–3136.

Zhang, Z., Lu, C. and Xiang, Z.H. (1998). Analysis of variety stability based on AMMI model. *Acta Agronomica Sinica,* **24** : 304-309.

Zobel, R.W., Wright, M.J. and Gauch, H.G. Jr. (1988). Statistical analysis of yield trial. *Agron. J.,* **80** : 388-393.

Webliography

Olivoto, T. (2019). Metan: multi environment trials analysis. R package version1.1.0.*https://github.com/TiagoOlivoto/metan.*