

Stability Index Based on Weighted Average of Absolute Scores of AMMI and Yield of Wheat Genotypes Evaluated Under Restricted Irrigated Conditions for Peninsular Zone

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ABSTRACT

Highly significant effects of environment (E), G×E 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 Peninsular zone of the country. WAASB measure observed suitability of HI 1605, HI 8805 & HI 8802 genotypes. Superiority index while weighting 0.65 and 0.35 for yield & stability found MACS 6695, HI 1605 & NIAW 3170 as of stable performance with high yield. PRVG and MHPRVG measures observed suitability of NIAW 3170, MACS 6695 & MACS 6696 wheat genotypes. Moreover, the average yield of genotypes ranked NIAW 3170, MACS 6695 & MACS 6696 as of order of choice. SI expressed only negative values of correlations most of other stability measures except of MHPRVG, PRVG, yield. WAASB measure exhibited direct relationships with other measures analogous of negative values with MASV, SI, MHPRVG, PRVG, yield. Analytic measures MHPRVG & PRVG had only positive values with SI, and yield remaining stability measures maintained negative values. MP1358, NIDW1149 & NIAW3170 would be suitable genotypes as per WAASB measure during second year of study. Superiority index found MP1358, NIAW3170 & MACS4087 as of stable performance with high yield. PRVG and MHPRVG measures observed suitability of MP1358, HI1605 & MACS4087 wheat genotypes. More over the average yield of genotypes ranked MP1358, MACS4087 & HI1605 as of order of choice. SI expressed mostly negative values other measures except of weak direct relation with MASV1, MASV along with strong with yield, MHPRVG & PRVG measures. WAASB measure exhibited direct relationships with other measures and indirect with only MASV1& SI.

Highlights

- ① Stability measure WAASB based on all significant interaction principal components observed suitability of wheat genotypes associated with lower values of measure.
- ② Superiority index provided variable weighting mechanism between stability and yield of genotypes under multi environment trials. Assigning 0.65 and 0.35 weights to yield & stability respectively selected wheat genotypes of stable performance with high yield.
- ③ Recent analytic measures of stability PRVG and MHPRVG measures expressed strong association with superiority index.

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

Additive main effects and multiplicative interaction (AMMI) model had been most widely used analytic tool to analyse and estimate G×E interaction in multi environmental trials (Zhang *et al.* 1998; Gauch 2013; Veenstra *et al.* 2019). Cross over genotype-by-environment interactions hinder the selection

process of breeders (Bocianowski *et al.* 2019). Biased

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interpretation of stability of genotypes observed for instances where low proportion of the variance explained by first interaction principal component IPCA1 (Zali *et al.* 2012; Ajay *et al.* 2019; Olivoto *et al.* 2019). Stability measure (WAASB) considered the weighted average of all the significant IPCA scores based on the sum of absolute values of the IPCA scores (Olivoto 2018). 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; Farshadfar *et al.* 2011). WAASBY i.e. superiority index 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 Peninsular Zone of the country under restricted irrigated timely sown trials in recent past.

MATERIALS AND METHODS

Mainly Maharashtra and Karnataka states represents the Peninsular zone of our country. All three species of wheat viz *T. aestivum*, *T. durum*, and *T. dicoccum* are cultivated in this zone. Bread wheat cultivation is concentrated under irrigated environments, whereas, the cultivation of durum and dicoccum wheat is generally confined to rainfed/ restricted irrigation situation. Twelve advanced promising wheat genotypes eight major locations and ten genotypes at eight 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 1 & 2 for ready reference. Stability measure Weighted Average of Absolute Scores has been calculated as

$$WAASB = \sum_{k=1}^p |IPCA_{ik} \times EP_k| / \sum_{k=1}^p EP_k$$

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,

$$SI = \frac{(rG_i \times \theta_y) + (rW_i \times \theta_s)}{(\theta_y + \theta_s)},$$

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 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,

Averages of the squared eigenvector values	$EV = \sum_{n=1}^N \lambda_n^2 / n$	Zobel
Sums of the absolute value of the IPC scores	$SIPC = \sum_{n=1}^N \lambda_n^{0.5} \gamma_{in}$	Sneller <i>et al.</i>
AMMI stability Value	$ASV = \left[\left(\frac{SSIPC1}{SSIPC2} PCI \right)^2 + (PC2)^2 \right]^{1/2}$	Purchase <i>et al.</i>
AMMI based stability parameter	$ASTAB = \sum_{n=1}^n \lambda_n \gamma_{ni}^2$	Rao and Prabha-karan
ASV1	$ASV1 = \left[\frac{SSIPC1}{SSIPC2} (PCI)^2 + (PC2)^2 \right]^{1/2}$	Zali <i>et al.</i>
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 <i>et al.</i>
Absolute value of the relative contribution of IPCs to the interaction	$Z_a = \sum_{n=1}^N \lambda_n \gamma_{in} $	Zali <i>et al.</i>



MASV1	$MASV1 = \sqrt{\sum_{n=1}^{N-1} \left(\frac{SSIPC_n}{SSIPC_{n+1}} PC_n \right)^2 + (PC_{n+1})^2}$	Ajay <i>et al.</i>
Relative performance of genotypic values across environments	$PRVG_{ij} = VG_{ij} / VG_i$	Resende and Durate
Harmonic mean of Relative performance of genotypic values	$MHPRVG_i = \text{Number of environments} / \sum_{j=1}^k \frac{1}{PRVG_{ij}}$	Resende and Durate
Superiority Index	$SI = \frac{(rG_i \times \theta_Y) + (rW_i \times \theta_S)}{(\theta_Y + \theta_S)}$	Olivato <i>et al.</i>

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

First year of study (2018-19)

AMMI analysis of genotypes

The AMMI model is comprised of additive main effects of genotype and environment, and the multiplicative effect of G×E interaction, and thus can explain more information compared to other methods (Gauch 2013). AMMI analysis as such does not make provision for a quantitative stability measure that is deemed useful to quantify the ranking of studied genotypes according to their yield stability. AMMI stability parameters permit to evaluate yield stability after reduction of the noise from the G×E interaction effects (Zhang *et al.* 1998). Highly significant effects of environment (E), G×E interaction and genotypes (G) had been

observed by AMMI analysis (Table 3). Environment explained about significantly 21.6% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 3). Significant proportion of G×E interaction deserves the stability estimation of genotypes over environments (Veenstra *et al.* 2019). Genotypes explained only 18% of total sum of squares, whereas G×E interaction accounted for 21.5% of treatment variations in yield. More of G×E interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex G×E interaction for wheat yield. Further partitioning of G×E interaction revealed that the first six multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5 and IPCA6) explained 47.1%, 17.9%, 14.7%, 9.4%, 8.2% and 1.9% of interaction sum of squares, respectively. Total of significant components were 99.3% and remaining 0.7% is the residual or noise, which is not interpretable and thus discarded (Adjebeng *et al.* 2017).

Stability analysis

Low absolute value of IPCA1 expressed by G7, G5, G9 and higher value achieved by G3 (Table 5). Minimum values of (EV) associated with stable genotype accordingly, the genotype G9 followed by G5 G4 and G12 had the maximum value of EV measure. SIPC measure identified G9 followed by G5, G4 possessed lower value, whereas G2 would be of least stable behaviour. Za measure considered absolute value of the relative contribution of IPCs to the interaction revealed G8, G12 and G5 genotypes as most stable in descending order of stability, whereas G2 genotype with the least stability. ASTAB measure observed genotypes G9 G5 and G12 as most stable and genotype G2 was least stable in this study (Rao and Prabhakaran 2005). ASV measure showed that genotypes G9, G7, G5 possessed lower values would express stable performance and G3 be of least stable type. Values of ASV1 selected G7 G5 G9 for their stable behaviour whereas G3 would express unstable performance. Measures MASV and MASV1 consider all significant IPCAs. Values of MASV showed that the genotypes, G9, G5 and G8 were most stable and G12 G8 & G9 would be stable by MASV1 measure respectively (Ajay *et al.* 2019). The lower values of WAASB associated with stable

**Table 1:** Parentage details of genotypes and environmental conditions (2018-19)

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G 1	NIAW 3170	(SKOLL/ROLF07)	Niphad	20° 4 ' N	74° 6' E	551
G 2	GW 1346	(GW1236/AR06-3)	Pune	18° 31 ' N	73° 51' E	562
G 3	MACS 4058	(MACS3125/AKDW2997-16//MACS3125)	Parbhani	19° 15 ' N	76° 46' E	413
G 4	DBW 93	(WHEAR/TUKURU//WHEAR)	Savalivihir	19°48' N	74°27' E	519.42
G 5	HI 8805	(IWP5070/HI8638//HI8663)	Dharwad	15° 27' N	75° 0' E	724
G 6	AKDW 2997-16	(CPAN6140/RAJ1555)	Bailahongal	15°48' N	74°51' E	696.61
G 7	MACS 6695	(NI5439*2/HD2934)	Nippani	16° 23 ' N	74° 22' E	606
G 8	UAS 446	(DWR185/DWR2006//UAS419)	Bagalkot	16°10' N	75°42' E	524
G 9	HI 1605	(BOW/VEE/5/ND/VG9144//KAL//BB/3/ YACO/4/CHIL/6/CASKOR/3/CROC_ 1/A.SQUARROSA(224)//OPATA/7/ PASTOR//MILAN/KAUZ/3/BAV92				
G 10	MACS 6696	(NI5439/HD2934)				
G 11	NIDW 1149	(NIDW295 /NIDW15)				
G 12	HI 8802	(HI8627/HI8653)				

Table 2: Parentage details of genotypes and environmental conditions (2019-20)

Code	Genotype	Parentage	Environments	Latitude	Longitude	Altitude
G 1	NIDW1149	(NIDW295/NIDW15)	Niphad	20° 4 ' N	74° 6' E	551
G 2	UAS446	(DWR185/DWR2006//UAS419)	Pune	18° 31 ' N	73° 51' E	562
G 3	HI1605	(BOW/VEE/5/ND/VG9144//KAL//BB/3/ YACO/4/CHIL/6/CASKOR/3/CROC_1/ AE.SQ(224)//OPATA/7/PASTOR//MILAN/ KAUZ/3/BAV92	Parbhani	19° 15 ' N	76° 46' E	413
G 4	MACS4087	(MACS3125/NG-87(DHTON-23/ BIJAGAYELLOW)//DWR1005	Nashik	19° 59 ' N	73° 47' E	583
G 5	MP1358	(KACHU*2/MUNAL#1/K1215)	Savalivihir	19°48' N	74°27' E	519.42
G 6	AKDW2997-16	(CPAN6140/RAJ1555)	Dharwad	15° 27' N	75° 0' E	724
G 7	HI8805	(IWP5070/HI8638//HI8663)	Bailahongal	15°48' N	74°51' E	696.61
G 8	UAS472	(BIJAGAYELLOW/(YAZI_1/AKAKI_4// SOMAT_3/3/AUK/GUIL//GREEN/5)	Bagalkot	16°10' N	75°42' E	524
G 9	MPO1357	(PDW02/TERTER//GW1133)				
G 10	NIAW3170	(SKOLL/ROLF07)				

Table 3: AMMI analysis of wheat genotypes evaluated under MET (2018-19)

Source	Degree of freedom	Mean Sum of Squares	Proportional contribution of factors	G×E interaction Sum of Squares (%)	Cumulative Sum of Squares (%) by IPCA's
Treatments	95	100.38	61.07		
Genotype (G)	11	255.71	18.01		
Environment (E)	7	481.69	21.60		
G×E interaction	77	43.52	21.46		
IPC1	17	92.90		47.12	47.12
IPC2	15	39.97		17.89	65.01
IPC3	13	38.14		14.79	79.81
IPC4	11	28.75		9.44	89.24
IPC5	9	30.66		8.23	97.48
IPC6	7	8.94		1.87	99.34
Residual	5	4.40			
Error	288	21.10			
Total	383	40.77			

**Table 4:** AMMI analysis of wheat genotypes evaluated under MET (2019-20)

Source	Degree of freedom	Mean Sum of Squares	Proportional contribution of factors	G×E interaction Sum of Squares (%)	Cumulative Sum of Squares (%) by IPCA's
Treatments	79	59.24	64.91		
Genotype (G)	9	86.15	10.76		
Environment (E)	7	347.19	33.71		
G×E interaction	63	23.40	20.45		
IPC1	15	37.18		37.84	37.84
IPC2	13	28.76		25.36	63.20
IPC3	11	21.72		16.21	79.41
IPC4	9	13.84		8.45	87.86
IPC5	7	16.65		7.90	95.76
IPC6	5	10.31		3.50	99.26
Residual	3	3.64			
Error	240	10.54			
Total	319	22.60			

Table 5: Measures of stability of wheat genotypes as per AMMI analysis (2018-19)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
G 1	1.66	7.26	4.77	4.57	3.02	23.60	0.053	5.89	41.63	1.257	68.37	1.122	1.137	35.01
G 2	2.05	7.69	4.81	5.57	3.58	24.90	0.050	6.02	43.80	1.348	3.56	0.861	0.880	27.35
G 3	2.21	6.87	4.30	5.91	3.73	21.59	0.039	4.95	39.85	1.211	21.72	0.924	0.941	28.98
G 4	0.41	5.28	3.23	1.73	1.51	11.40	0.026	3.28	14.87	0.559	58.30	0.975	0.981	30.53
G 5	0.19	3.84	2.62	1.05	0.97	10.15	0.022	3.19	11.03	0.471	64.86	0.999	1.003	30.94
G 6	1.23	8.77	4.88	3.33	2.15	20.42	0.053	5.53	29.49	1.034	25.09	0.917	0.927	28.59
G 7	0.09	5.55	4.72	0.86	0.84	14.67	0.065	4.37	41.13	0.696	88.90	1.121	1.132	34.97
G 8	0.74	3.74	3.07	2.55	2.03	14.03	0.031	3.92	20.57	0.719	23.29	0.847	0.861	26.91
G 9	0.35	3.76	2.12	1.09	0.83	8.32	0.013	2.50	5.75	0.403	84.26	1.064	1.065	33.05
G 10	2.04	5.98	3.95	5.37	3.32	19.07	0.037	4.33	34.75	1.069	67.01	1.084	1.096	33.97
G 11	0.87	4.34	3.48	2.37	1.53	15.01	0.046	4.27	23.98	0.753	61.21	1.021	1.028	31.79
G 12	0.85	2.94	332.83	2.27	1.42	10.10	0.066	3.39	14.00	0.513	51.61	0.943	0.949	29.48

nature of genotypes as G9, G5, G12 for considered locations of the zone at the same time maximum value obtained by G2, that is, the one that deviates maximum from the average performance across environments. Lower value of Superiority index had observed for G2 G3 and G8 whereas large value by G7. Genotypes G8 G2 and G6 were identified for their more stable yield performance by MHPRVG as well as by PRVG measures and G1 with least stable yield. Maximum yield expressed by G1 G7 followed by G2 and G10 as good variation had been observed from 26.9 to 35 q/ha among genotypes.

Ranking of wheat genotypes as per AMMI based measures and yield

Stability alone is not a desirable selection criterion as stable genotypes may not be a high yielders, simultaneous use of yield and stability in a single measure is essential (Kang 1993; Farshadfar *et al.*

2008). Simultaneous Selection Index also referred to as genotype stability index (GSI) or yield stability index (YSI) (Farshadfar *et al.* 2011) was computed by adding the ranks of stability measure and average yield of genotypes. Ranks for IPCA1 measure selected MACS 6695, HI 1605 & HI 8805 for stable high yield performance, whereas high values suggested as least stable yield for GW 1346 (Table 7). EV measure identified HI 1605, HI 8805 & MACS 6696 whereas by SPIC favoured genotypes were HI 1605, HI 8805 & DBW 93. Genotypes HI 1605, MACS 6695 & HI 8805 possessed lower value of Za measure. WAASB measure observed suitability of HI 1605, HI 8805 & HI 8802 genotypes. Superiority index while weighting 0.65 and 0.35 for yield & stability found MACS 6695, HI 1605 & NIAW 3170 as of stable performance with high yield. Analytic measures MASV and MASV1 consider all significant principal components of interactions. MASV HI

**Table 6:** Measures of stability of wheat genotypes as per AMMI analysis (2019-20)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
G 1	0.12	3.92	3.78	2.53	2.53	44.77	0.071	4.16	30.40	0.770	58.12	1.032	1.044	26.01
G 2	1.45	3.26	2.61	2.93	2.22	41.44	0.040	3.86	16.81	0.788	26.56	0.938	0.946	23.43
G 3	2.20	4.42	3.27	4.26	3.10	30.97	0.048	4.11	26.99	0.922	46.06	1.038	1.051	26.02
G 4	1.53	4.83	3.35	2.93	2.12	22.34	0.040	3.76	19.04	0.761	60.39	1.037	1.048	26.15
G 5	0.06	6.40	3.63	0.25	0.24	28.44	0.056	4.04	13.65	0.549	94.88	1.107	1.111	27.64
G 6	0.42	5.59	2.95	0.86	0.65	26.13	0.033	3.26	7.86	0.485	55.61	0.954	0.958	23.84
G 7	0.35	6.59	3.72	0.71	0.53	46.53	0.065	4.59	14.78	0.643	47.22	0.968	0.973	24.21
G 8	0.94	3.24	2.30	1.87	1.39	48.31	0.032	3.42	9.68	0.617	24.39	0.881	0.887	22.08
G 9	1.14	6.85	4.31	2.18	1.58	35.27	0.075	5.29	24.37	0.888	24.56	0.960	0.968	23.95
G 10	0.09	2.86	2.48	1.33	1.32	31.14	0.039	3.66	12.71	0.606	61.46	1.007	1.013	25.18

Table 7: Simultaneous ranks of genotypes as per yield and AMMI based measures (2018-19)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
NIAW 3170	10	11	10	10	10	12	11	12	12	11	3	1	1	1
GW 1346	22	22	21	22	22	23	19	23	23	12	12	11	11	11
MACS 4058	21	18	16	21	21	19	15	18	18	10	11	9	9	9
DBW 93	11	13	11	11	12	11	10	10	11	4	7	7	7	7
HI 8805	8	10	8	8	9	9	8	8	8	2	5	6	6	6
AKDW 2997-16	18	22	21	18	18	19	19	20	17	8	9	10	10	10
MACS 6695	3	9	10	3	4	8	13	10	12	5	1	2	2	2
UAS 446	17	14	15	19	19	17	16	17	17	6	10	12	12	12
HI 1605	7	7	5	7	5	5	5	5	5	1	2	4	4	4
MACS 6696	13	11	9	13	13	11	8	10	11	9	4	3	3	3
NIDW 1149	12	10	10	11	11	12	12	11	11	7	6	5	5	5
HI 8802	14	9	20	13	12	10	20	12	11	3	8	8	8	8

Table 8: Simultaneous ranks of genotypes as per yield and AMMI based measures (2019-20)

Genotype	IPCA1	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
NIDW1149	7	8	13	11	13	12	13	12	14	7	4	4	4	4
UAS446	17	12	12	18	17	16	14	14	15	17	8	9	9	9
HI1605	13	8	8	13	13	7	9	10	12	13	7	2	2	3
MACS4087	11	8	8	10	9	3	6	6	9	11	3	3	3	2
MP1358	2	9	8	2	2	4	8	7	5	2	1	1	1	1
AKDW2997-16	13	15	12	11	11	10	10	9	9	13	5	8	8	8
HI8805	10	15	14	8	8	15	14	15	11	10	6	6	6	6
UAS472	16	12	11	15	15	20	11	12	12	16	10	10	10	10
MPO1357	14	17	17	13	13	13	17	17	15	14	9	7	7	7
NIAW3170	7	6	7	9	9	10	8	8	8	7	2	5	5	5

1605, HI 8805, MACS 6696 genotypes of choice for these locations of the zone as and MASV1 settled for HI 1605, HI 8802. MACS 6695. Least magnitude of ASV and ASV1 pointed towards MACS 6695, HI 1605 and HI 8805 wheat genotypes (Oyekunle *et al.* 2017). PRVG and MHPRVG measures observed suitability of NIAW 3170, MACS 6695 & MACS 6696 wheat genotypes. Moreover, the average yield of genotypes ranked NIAW 3170, MACS 6695 & MACS 6696 as of order of choice. In the present study, all

measures identified genotypes HI 1605, MACS 6696 and HI 8805 as stable and high yielders.

Biplot graphical analysis

Loadings of stability measures as per first two significant principal components for evaluated wheat genotypes were reflected in table 9. Biplot graphical analysis based on two significant principal component analysis (PCA) as these PCAs accounted for 91.4% of variation of the original variables



(Balestre *et al.* 2019). The stability measures of wheat genotypes grouped into three major groups (Fig. 1). SI clubbed with MASV and EV. Yield clubbed with PRVG & MHPRVG measures. Large group consisted of ASTAB, ASV, IPCA1, ASV1, SIPC, Za, MASV1. Measure WAASB maintained distance from stability measures and observed as outlier in graphical analysis.

except of MHPRVG, PRVG, yield. Only indirect relations were observed with stability measures (EV, SIPC) by SI measure otherwise positive values of correlation were seen. WAASB measure exhibited direct relationships with other measures analogous of negative values with MASV, SI, MHPRVG, PRVG, yield.

Table 9: Loadings of stability measures as per first two PC's (2018-19)

Measure	PC1	PC2
IPCA1	-0.284	-0.049
MASV1	-0.269	-0.164
MASV	-0.263	0.050
ASV1	-0.285	-0.034
ASV	-0.288	-0.058
Za	-0.287	-0.190
EV	-0.239	0.044
SIPC	-0.287	-0.169
ASTAB	-0.275	-0.226
WAASB	-0.172	-0.637
SI	-0.285	0.152
MHPRVG	-0.261	0.373
PRVG	-0.261	0.373
Yield	-0.261	0.373
% variance	79.98	11.46

Table 10: Loadings of stability measures as per first two PC's (2019-20)

Measure	PC1	PC2
IPCA1	-0.281	-0.044
MASV1	-0.238	0.179
MASV	-0.258	-0.008
ASV1	-0.278	-0.142
ASV	-0.280	-0.162
Za	-0.285	0.174
EV	-0.272	-0.082
SIPC	-0.282	-0.112
ASTAB	-0.288	-0.301
WAASB	-0.117	-0.662
SI	-0.292	-0.144
MHPRVG	-0.284	0.313
PRVG	-0.284	0.313
Yield	-0.254	0.353
% variance	67.98	13.87

Association analysis

Average yield expressed only significant positive correlations with SI, ASTAB, MHPRVG, PRVG & EV (Table 11). SI expressed only negative values of correlations most of other stability measures

Analytic measures MHPRVG & PRVG had only positive values with SI, and yield remaining stability measures maintained negative values. AMMI based measures Za, SIPC, SV, ASV1, MASV1 and ASTAB achieved only positive correlation values among themselves and with others (Ajay *et al.* 2019). More over MASV had maintained only

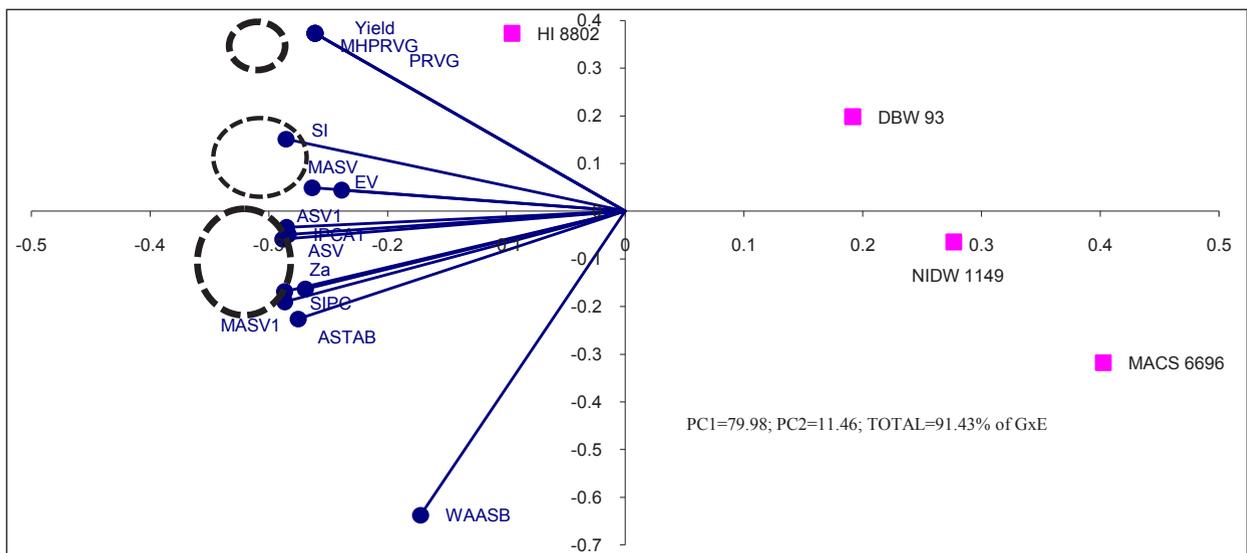


Fig. 1: Biplot analysis of stability measures for wheat genotypes evaluated under MET (2018-19)

Table 11: Association analysis of SI with other stability measures for wheat genotypes (2018-19)

Measure	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	0.637	-0.080	0.995	0.974	0.847	0.226	0.717	0.675	0.897	-0.569	-0.216	-0.175	-0.189
MASV1		-0.429	0.655	0.663	0.871	0.318	0.863	0.756	0.841	-0.430	-0.068	-0.031	-0.055
MASV			-0.127	-0.186	-0.326	0.464	-0.247	-0.289	-0.298	-0.002	-0.155	-0.172	-0.165
ASV1				0.992	0.866	0.209	0.734	0.704	0.915	-0.592	-0.236	-0.193	-0.207
ASV					0.874	0.169	0.741	0.714	0.920	-0.619	-0.268	-0.223	-0.236
Za						0.413	0.965	0.897	0.994	-0.536	-0.126	-0.076	-0.097
EV							0.567	0.583	0.374	-0.119	0.048	0.073	0.061
SIPC								0.884	0.934	-0.524	-0.140	-0.093	-0.116
ASTAB									0.882	-0.300	0.086	0.139	0.122
WAASB										-0.547	-0.138	-0.088	-0.107
SI											0.903	0.881	0.891
MHPRVG												0.998	0.998
PRVG													0.999

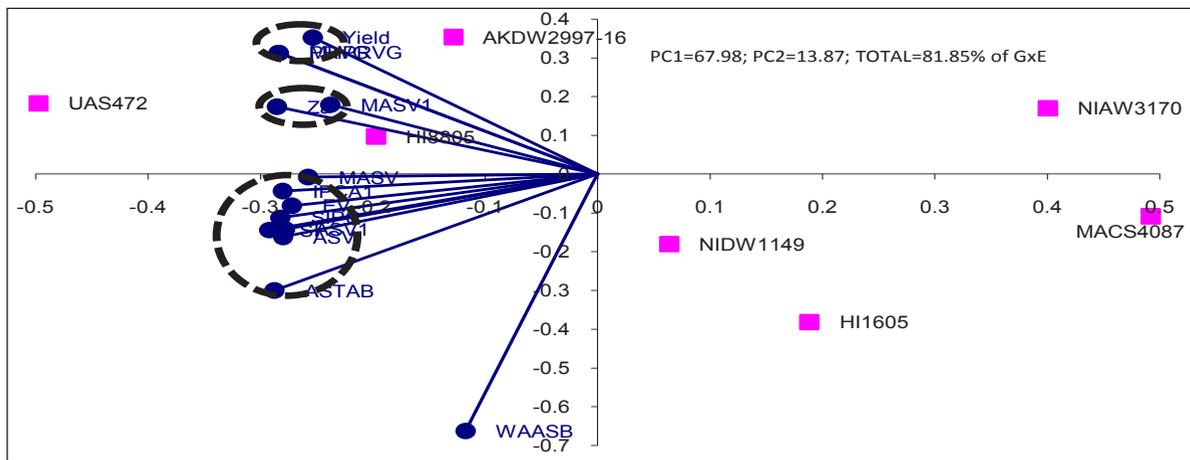


Fig. 2: Biplot analysis of stability measures for wheat genotypes evaluated under MET (2019-20)

negative relationships with all measures. Negative correlations of SIPC with SI, PRVG, MHPRVG and yield were of low magnitude. Indirect relations of Za observed with PRVG, MHPRVG and yield of moderate negative values. Same behaviour of negative correlations had displayed by IPCA1, ASV1, MASV1, ASV, MASV also.

Second year of study (2019-20)

AMMI analysis of genotypes

Highly significant effects of environment (E), G×E interaction and genotypes (G) had been observed by AMMI analysis. Environment explained about significantly 33.7% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield (Table 4). Significant proportion of G×E interaction deserves the stability estimation of genotypes over

environments (Veenstra *et al.* 2019). Genotypes explained only 10.7% of total sum of squares, whereas G×E interaction accounted for 20.5% of treatment variations in yield. Partitioning of G×E interaction revealed that the first six multiplicative terms (IPCA1, IPCA2, IPCA3, IPCA4, IPCA5 and IPCA6) explained 37.8%, 25.4% , 16.2%, 8.5%, 7.9% and 3.5 % of interaction sum of squares, respectively. Total of significant components were 99.3 % and remaining 0.7% is the residual or noise, which is not interpretable and thus discarded (Adjebeng *et al.* 2017).

Stability analysis

Wheat genotypes G5, G10, G1 expressed least value of IPCA1 and higher value achieved by G3 (Table 6). The genotype G8, G6 followed by G10 had expressed lower and G9 showed the maximum value of EV measure. The lower value SIPC measure

Table 12: Association analysis of SI with other stability measures for wheat genotypes (2019-20)

Measure	MASV1	MASV	ASV1	ASV	Za	EV	SIPC	ASTAB	WAASB	SI	MHPRVG	PRVG	Yield
IPCA1	-0.136	-0.064	0.846	0.692	-0.160	-0.207	0.092	0.352	0.730	-0.508	-0.145	-0.112	-0.133
MASV1		0.790	-0.415	-0.507	-0.218	0.568	0.602	0.031	-0.049	0.232	0.255	0.237	0.232
MASV			-0.039	-0.031	-0.075	0.898	0.829	0.599	0.382	0.181	0.439	0.444	0.435
ASV1				0.970	-0.020	-0.047	0.081	0.672	0.852	-0.446	-0.016	0.030	0.012
ASV					0.051	0.026	0.064	0.746	0.822	-0.376	0.039	0.087	0.072
Za						0.282	0.210	0.095	0.093	-0.534	-0.554	-0.548	-0.547
EV							0.892	0.662	0.419	0.045	0.309	0.316	0.304
SIPC								0.584	0.586	-0.210	0.131	0.139	0.117
ASTAB									0.843	-0.102	0.373	0.411	0.395
WAASB										-0.470	0.059	0.100	0.074
SI											0.852	0.831	0.845
MHPRVG												0.999	0.998
PRVG													0.999

identified G6 followed by G8, G10 as the most stable genotypes, whereas G9 would be of least stable behaviour. Za measure revealed G4 G6 and G5 would be stable genotypes in descending order of stability, whereas G8 genotype with the least stability. ASTAB measure observed genotypes G7 G8 and G10 as most stable and genotype G1 was least stable in this study (Rao and Prabhakaran 2005). ASV and ASV1 measures showed that genotypes G5, G7, G6 possessed lower values would express stable performance as compared to G3. Analytic measures MASV and MASV1 consider all the significant IPCAs. Values of MASV showed that the genotypes G8 G10 and G2 were most stable while MASV1 measure suggested the stable behaviour of G10, G8 & G2 genotype (Ajay *et al* 2019). Stable nature of genotypes as G6, G5, G10 confirmed with the lower values of WAASB measure for considered locations of the zone at the same time G3 deviated maximum from the average performance across environments. Lower value of Superiority index had observed for G8 G9 and G2 whereas unstable performance of G5 by large value. Genotypes G8 G2 and G6 were identified by MHPRVG and PRVG measure along with least stable yield of G5. Maximum yield expressed by G5 followed by G4 and G3 as good variation had been observed from 22 to 27.5 q/ha among genotypes.

Ranking of wheat genotypes as per AMMI based measures and yield

Least ranks of IPCA1 measure considered MP1358, NIAW3170 & NIDW1149 were as stable with high yield, whereas high values suggested as least stable

yield for UAS446 (Table 8). EV measure identified MACS4087, MP1358 & NIAW3170 whereas SPIC favoured MACS4087, MP1358 & NIAW3170 genotypes. MACS4087, MP1358 & HI1605 possessed lower value of Za measure. WAASB measure observed suitability of MP1358, NIDW1149 & NIAW3170 genotypes. Superiority index while weighting 0.65 and 0.35 for yield & stability found MP1358, NIAW3170 & MACS4087 as of stable performance with high yield. Composite measures MASV as well as MASV1 selected NIAW3170, HI1605, MACS4087 genotypes of choice for these locations of the zone. Values of least magnitude of ASV and ASV1 pointed towards MP1358, HI8805 and NIAW3170 wheat genotypes (Oyekunle *et al.* 2017). PRVG and MHPRVG measures observed suitability of MP1358, HI1605 & MACS4087 wheat genotypes. More over the average yield of genotypes ranked MP1358, MACS4087 & HI1605 as of order of choice. In the present study, all measures identified genotypes MACS4087, MP1358 & NIAW3170 as stable and high yielders.

Biplot graphical analysis

Loadings of stability measures as per first two significant principal components for evaluated wheat genotypes were reflected in table 10. Biplot graphical analysis based on two significant principal component analysis (PCA) the simultaneous ranks (Fig. 2). These two PCAs accounted for 81.8% of variation of the original variables (Balestre *et al.* 2019). The stability measures of wheat genotypes grouped into three major groups. MASV1 clubbed with Za and yield grouped with PRVG & MHPRVG



measures. Larger group comprises of ASTAB , MASV, ASV, IPCA1, ASV1, SIPC. Measure WAASB maintained distance from stability measures and observed as outlier in analysis.

Association analysis

Mean yield showed mostly positive correlations and only negative values expressed towards Za and IPCA1. Similar behaviour of MHPRVG & PRVG measures seen with other stability measures (Table 12). SI expressed mostly negative values other measures except of weak direct relation with MASV1, MASV along with strong with yield, MHPRVG & PRVG measures. WAASB measure exhibited direct relationships with other measures and indirect with only MASV1 & SI. AMMI based measures SIPC, SV, MASV1, MASV and ASTAB achieved only positive correlation values among themselves and with others (Ajay *et al.* 2019). More over Za and EV had maintained positive relationships with other non AMMI based measures. ASTAB, ASV, ASV1, SIPC, Za had indirect relation with SI measure.

CONCLUSION

AMMI model is an effective tool to study G×E interaction in multi-environment yield trials. Stability measures by simultaneous use of AMMI model and yield would be more meaning full and useful as compared to measures consider either the AMMI or yield of genotypes only. The stability measures found to be correlated well with each other. Measures MASV, MASV1, WAAB and SI could be used to identify stable high-yielding genotypes. Stability measures by simultaneous use of AMMI model and yield would be more meaning full and useful as compared to measures consider either the AMMI or yield of genotypes only.

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