Journal of Experimental Biology and Agricultural Sciences

<http://www.jebas.org>

ISSN No. 2320 – 8694

GXE INTERACTION ANALYSIS OF WHEAT GENOTYPES UNDER RESTRICTED IRRIGATED TIMELY SOWN CONDITIONS FOR NORTH WESTERN PLAINS ZONE OF THE COUNTRY BY AMMI MODEL

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Received – April 11, 2020; Revision – May 14, 2020; Accepted – June 21, 2020

Available Online – June 25, 2020

DOI: [http://dx.doi.org/10.18006/2020.8\(3\).287.295](http://dx.doi.org/10.18006/2020.8(3).287.295)

KEYWORDS

AMMI model

ASV

ASV1

ASTAB

EV

D

MASV

Association analysis

ABSTRACT

Highly significant effects of genotypes, environments and their interactions were observed by AMMI analysis of wheat genotypes. . Smaller values of EV1 observed for G4, G6, G8, corresponding to D1 were (G4, G6, G8) while as per ASTAB1 (G4, G6, G8) and SIPC1 values for (G2, G3, G10). Genotypes selected by Least values EV2 settled for G7, G4 and G3 genotypes whereas as D2 , G7, G4, G3 would be desirable & SIPC2 suitable wheat genotypes were (G6, G2, G3). Same set of genotypes (G4, G6, G7) identified by ASV & ASV1 measures. Composite measures MASV and MASV1 identified G2, G5, G6 & G9. GAI found G5, G10 and G2 as of stable adaptations whereas HM and PRVG identified G5, G10, G3 and G7. MHPRVG found G7, G4, G6 genotypes for broad adaptations. Biplot analysis exhibited that largest cluster consisted of D1, D2, EV1, EV2, ASV, ASV1, ASTAB1, ASTAB2 and SIPC3 measures.. Second year of study as per smaller values of EV1 observed for (G3, G5, G6) & D1 for (G3, G5, G6), absolute values of SIPC1 for (G4, G8, G10) and ASTAB1 were (G3, G5, G6). D7 expressed minimum values for G7, G10, G1 genotypes; SIPC7 observed G8, G5, G4 for stable & EV7 pointed towards G7, G1, G6 & ASTAB7 identified G7, G10, G1 as desirable. Wheat genotypes G7, G10, G1 marked by MASV & MASV1 measures for stable behavior. Analytic measure MHPRVG found G1, G3, G8 as suitable genotypes. Largely four clusters were seen by biplot analysis of AMMI and other measures. Large cluster consisted of EV7, D7, Ev3, ASTAB7, ASTAB3, ASTAB5, MASV, EV5, D5, EV2 & ASTAB2 measures.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher India [HPI]
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1 Introduction

Multi Environment trials (MET) of cereal crops consider efficient estimation of main and interaction effects (Agahi et al., 2020). Yield potential of genotypes and their adaptation demands an efficient estimation of GXE interactions in crop improvement program (Bocianowski et al., 2019). Numbers of statistical methods are available for analysis of MET, aimed to partition the information contained in a complex GXE interactions into simpler and more meaningful interpretations (Haider et al., 2017). Methods varied from univariate parametric models, such as regression slope; environmental variance, to multivariate models such as the additive main effect and multiplicative interaction (AMMI) analysis (Shahriari et al., 2018). Mostly practiced linear regression analysis failed to explain confounding of main effects (Tekdal & Kendal, 2018) as well as unable to highlight non linear response genotypic effects (Yau, 1995).

AMMI model is a hybrid model involving both additive and multiplicative components of two-way data structure (Kamila et al., 2016). The model separates the additive variance from the multiplicative variance and then applies principal component analysis (PCA) to the interaction portion (Hongyu et al., 2014). The AMMI analysis has been shown to be effective because it captures a large portion of the GXE sum of squares, clearly separating main and interaction effects to present different kinds of opportunities for agricultural researchers (Gauch, 2013). The study was carried out with prime objectives as (i) assess the various AMMI based measures (ii) explore the association analysis among different AMMI and adaptability measures.

2 Materials and Methods

North Western Plain Zone of India comprises of the 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). Ten advanced wheat genotypes were evaluated at thirteen locations and ten genotypes at fourteen major locations of the mega zone of country to interpret complex genotype by environment (GE) interactions by AMMI model during 2017-18 and 2018-19 cropping seasons. Genotypes were evaluated at research centers with recommended agronomic practices to harvest good yield. Tables 1 & 2 reflected the details of parentage and environmental conditions. Hybrid mechanism of AMMI calculates the additive effects by ANOVA afterwards use PCA for residual analysis. Purchase, 1997 proposed AMMI stability value (ASV) by utilizing relative weights of $IPCA_1$ and $IPCA_2$ scores. In certain cases where more than two IPCAs were significant, ASV failed to encompass all the variability explained by GEI. In order to overcome this difficulty, Zali et al. (2012) attempted to present a modified version ASV i.e., Modified ASV which would cover all available IPCAs. But in doing so, Zali et al. (2012) interpreted the formula of ASV incorrectly compared to the original formula of Purchase (1997). In the present study the original MASV formula of Zali et al. (2012) and a revised version of MASV (Ajay et al 2019) were compared with other AMMI based measures of interaction effects. AMMI based measures were mentioned as follows.

Table 1 Parentage of wheat genotypes and environmental conditions (2017-18)

Code	Genotype	Parentage	Code	Environments	Latitude	Longitude	Mean sea level
G1	BRW3806	(NI5439/MACS2496)	E1	Bulandshahr	28° 24 'N	77° 50 'E	204
G2	HD 3237	(HD3016/HD2967)	E2	Delhi	28° 38'N	77° 13 'E	222
G3	HI1620	(NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU)	E3	Diggi	26°22'N	75°26 'E	329
G4	DBW252	(PFAU/MILAN/5/CHEN/AE.SQ(TAUS)//BCN/3/VEE#7/BO W/4/PASTOR)	E4	Bhartpur	27° 13'N	77° 29 'E	182
G5	HI1628	(FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/PFA U/WEAVER//BRAMBLING)	E5	Sriganganagar	29° 54'N	73° 52 'E	175
G6	NIAW 3170	(SKOLL/ROLF07)	E6	Hisar	29° 19'N	75° 43 'E	215
G7	WH1142	(OEN/Ae.Sq.(TAUS)/FCT/3/2*WEAVER)	E7	Uchani	29°73'N	76.98 'E	253
G8	WH1080	(PRL/*2PASTOR)	E8	Pantnagar	29°05'N	79°29 'E	236
G9	PBW644	(PBW175/HD2643)	E9	Jammu	32° 43'N	74° 51 'E	351
G10	HD 3043	(PJM/BOW//OPATA*2/3CROC_1/A.SUARROSA(224)//O PATA)	E10	Kapurthala	31° 22'N	75° 22 'E	229
			E11	Ludhiana	30° 54'N	75° 51 'E	252
			E12	Gurdaspur	32° 2 'N	75° 24 'E	265
			E13	Balachaur	31° 3 'N	76° 18 'E	272

$$\text{Zobel, 1994 EV1 EVF } EV = \sum_{n=1}^N \lambda_{in}^2 / n$$

$$\text{Sneller et al., 1997 SIPC1 SPCF SIPC} = \sum_{n=1}^N \lambda_n^{0.5} \gamma_{in}$$

$$\text{Purchase, 1997 ASV } ASV = [(\frac{SSIPC}{SSIPC} \frac{1}{2} PCI)^2 + (PC2)^2]^{1/2}$$

$$\text{Annicchiarico, 1997 D } D = \sqrt{\sum_{n=1}^N (\lambda_n \gamma_{in})^2}$$

$$\text{Rao \& Prabhakaran, 2005 ASTAB } ASTAB = \sum_{n=1}^n \lambda_n \gamma_{ni}^2$$

$$\text{Zali et al., 2012 ASV1 } ASV = [(\frac{SSIPC}{SSIPC} \frac{1}{2} PCI)^2 + (PC2)^2]^{1/2}$$

$$\text{Zali et al., 2012 MASV } MASV = \sqrt{\sum_{n=1}^{N-1} \frac{SSIPC_n}{SSIPC_{n+1}} (PC_n)^2 + (PC_{n+1})^2}$$

$$\text{Ajay et al., 2019 MASV1 } MASV1 = \sqrt{\sum_{n=1}^{N-1} (\frac{SSIPC_n}{SSIPC_{n+1}} PC_n)^2 + (PC_{n+1})^2}$$

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. AMMI based measures were compared with recent analytic measures of adaptability calculated as the relative performance of genetic values (PRVG) and MHVG (Harmonic mean of Genetic Values), based on the harmonic mean of the genotypic values across different environments. MHPRVG (harmonic mean based measure based on relative performance of the genotypes) devised by Resende & Durate, 2007 for stability, adaptability along with yield of genotypes.

$$PRVG_{ij} = VG_{ij} / VG_i$$

$$MHVG_i = \text{Number of environments} / \sum_{i=1}^k \frac{1}{X_i}$$

$$MHPRVG_i = \text{Number of environments} / \sum_{j=1}^k \frac{1}{PRVG_{ij}}$$

VG_{ij} is the genotypic value of the i genotype, in the j environment, expressed as a proportion of the average in this environment. Geometric adaptability index (GAI) (Mohammadi & Amri, 2008) was calculated as $\sqrt[n]{\prod_{k=1}^n \bar{X}_k}$; in which $\bar{X}_1, \bar{X}_2, \bar{X}_3, \dots, \bar{X}_m$ are the mean yields of the first, second and m th genotype across environments and n is number of environments. Genotypes with higher values of GAI are desirable

3 Results and Discussion

AMMI analysis provided a better understanding of the GXE interaction through analysis of variance, facilitated identification of genotypes possessing stable yields as well as discriminating environments and adaptability of the genotypes to specific environments. Additive Main effect and Multiplicative Interaction (AMMI) is a statistical tool which leads to identification of stable genotypes with their adaptation behavior in an easy manner. Actually AMMI fits a family of models with retaining 0, 1, 2, or more significant interaction principal components (IPCs).

3.1 First year of study (2017-18)

Estimated sums of squares for GXE signal and GXE noise were 85.47% and 14.53% respectively

Note that the SS for GXE signal is 3.53 times that for genotypes main effects. Hence, narrow adaptations are important for this dataset. Even just IPC1 alone is 1.56 times the genotypes main effects. Also note that GXE noise is 0.60 times the genotypes main effects. Discarding noise improves accuracy, increases repeatability, simplifies conclusions, and accelerates progress (Gauch, 2013). Moreover, FR-tests at the 0.01 level diagnose AMMI6. Model diagnosis determined AMMI7 model is best for a given dataset, satisfying statistical and practical considerations.

Highly significant environments, GxE interaction and genotypes were observed by ANOVA analysis. These significant values had justified the selection of diverse environments (Akbarpour et al., 2014). The percentage contribution of significant IPCA's had exploited to devise measures, as type-1 used up to 33.6 %, 58.6% by type-2 measures while type 3 accounted up to 74.1%, type 5 measures benefited up to 91% and lastly 98% of variation utilized by type 7 measures (Table 3). Use of most of the significant IPCAs had been advocated by Kendal & Tekdal (2016).

Wheat genotypes (G4, G6, G8) and (G9, G2) pointed out by smaller & large values of EV1 while (G4, G6, G8) and (G9, G2) by corresponding values of D1; SIPC1 favoured (G2, G3, G10) and (G9, G5) and for ASTAB1 values (G4, G6, G8) & (G9, G2) genotypes of choice. EV2 observed (G7, G4, G3) as desirable

Table 2 Parentage details of genotypes along with environmental conditions (2018-19)

Code	Genotype	Parentage	Code	Environments	Latitude	Longitude	Mean sea level
G1	HI 1620	(NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KACHU/6/KACHU)	E1	Delhi	28° 36'N	77° 13'E	216
G2	PBW 796	(W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1*2/5/WHEAR/SOKOLL)	E2	Hisar	29° 9' N	75° 43'E	215
G3	HI 1628	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/PFAU/ WEAVER//BRAMBLING	E3	Bawal	28° 5' N	76° 35' E	266
G4	WH 1142	(OEN/Ae.Sq.(TAUS)/FCT/3/2*WEAVER)	E4	IIWBR	29° 43'N	77° 0'E	240
G5	HD 3043	(PJN/BOW//OPATA*2/3CROC_1/A.SQUARROSA(224)//OPATA)	E5	Jammu	32° 43'N	74° 51'E	327
G6	PBW 644	(PBW175/HD2643)	E6	Ludhiana	30° 54'N	75° 51' E	262
G7	HD 3237	(HD3016/HD2967)	E7	Gurdaspur	32° 2' N	75° 24' E	241
G8	BRW 3806	(NI5439/MAC52496)	E8	Kapurthala	31° 22'N	75° 22'E	225
G9	NIAW 3170	(SKOLL/ROLF07)	E9	Balachaur	31° 3' N	76° 18' E	271
G10	WH 1080	(PRL/*2PASTOR)	E10	Bulandshahr	28° 24' N	77° 50'E	195
			E11	Pantnagar	29°1' N	79°29' E	244
			E12	Diggi	26°22' N	75°26' E	332
			E13	Sriganganagar	29° 54' N	73° 52' E	178
			E14	Bharatpur	27° 13' N	77° 29' E	183

Table 3 AMMI analysis of genotypes (2017-18)

Source	df	MS	Level of significance	% of Total SS	% of GxE SS	Cumulative % SS by PCA's
Treatments	129	197.62	***	83.27		
Genotypes	9	296.11	***	8.71		
Environments	12	1285.19	***	50.38		
GxE interactions	108	68.57	***	24.19		
IPC1	20	124.35	***		33.58	33.58
IPC2	18	102.77	***		24.98	58.56
IPC3	16	72.10	***		15.58	74.14
IPC4	14	49.53	***		9.36	83.50
IPC5	12	46.46	***		7.53	91.03
IPC6	10	32.19	**		4.35	95.38
IPC7	8	24.45			2.64	98.02
Residual	10	14.68				
Error	390	13.13				
Total	519	58.99				

wheat genotypes; (G7, G4, G3) selected by D2 & SIPC2 favoured (G6, G2, G3) & ASTAB2 marked (G7, G4, G3) wheat genotypes (Tables 4 and 5). Same set of suitable genotypes (G4, G6, G7) recommended by ASV & ASV1 (Table 5). Two IPCAs in ASV & ASV1 measures exploited 58.6% of GXE interaction sum of squares though these two IPCAs have different values and meanings (Purchase, 1997).

Total of 74 % of GXE interaction utilized by Type 3 measures and values of EV3 preferred G4, G7, G2 and unstable performance of G3, G9 whereas D3 pointed towards G4, G7, G5 and G3, G9 whereas SIPC3 pointed towards G6, G2, G8 & G9, G5; ASTAB3 measure considered G4, G7, G5 & G3, G9 (Table 5 & 6). Genotypes G1, G7, G6 expressed least values of EV5; SIPC5 found G2, G8, G10 as suitable and G7, G4, G5 considered by D5

Table 4 AMMI analysis of genotypes (2018-19)

Source	df	MS	Level of significance	% of Total SS	% of GxE SS	Cumulative % SS by PCA's
Treatments	139	300.8173	***	87.46		
Genotypes	9	321.4462	***	6.05		
Environments	13	2320.575	***	63.10		
GxE interactions	117	74.8129	***	18.31		
IPC1	21	96.4066	***		23.13	23.13
IPC2	19	91.61295	***		19.89	43.02
IPC3	17	83.56214	***		16.23	59.24
IPC4	15	91.24467	***		15.64	74.88
IPC5	13	84.71625	***		12.58	87.46
IPC6	11	45.92164	***		5.77	93.23
IPC7	9	40.51416	**		4.17	97.40
Residual	12	18.96842				
Error	420	14.27202				
Total	559	85.52389				

Table 5 Principal components analysis of genotypes (2017-18)

	EV1	EV2	EV3	EV5	EV7	D1	D2	D3	D5	D7	SIPC1	SIPC2	SIPC3	SIPC5	SIPC7
G1	0.0438	0.0625	0.0447	0.0333	0.0584	3.93	6.19	6.33	6.66	7.66	1.4786	-0.3905	-0.9407	0.2447	0.7242
G2	0.0803	0.0414	0.0278	0.0559	0.0403	5.32	5.39	5.39	7.32	7.33	-2.0008	-2.3371	-2.4477	-5.5763	-5.7412
G3	0.0772	0.0389	0.1241	0.0795	0.0582	5.21	5.23	9.26	9.44	9.46	-1.9623	-2.1104	1.0535	1.7353	2.1326
G4	0.0001	0.0250	0.0174	0.0562	0.0542	0.22	3.76	3.82	6.51	7.06	0.0844	1.5495	1.8245	2.2959	0.9741
G5	0.0665	0.0424	0.0284	0.0436	0.0376	4.84	5.35	5.35	6.63	6.84	1.8214	2.7073	2.5984	1.0309	2.2159
G6	0.0088	0.0489	0.0372	0.0424	0.0547	1.76	5.31	5.56	6.67	7.32	-0.6628	-2.6195	-3.3006	-1.4784	-3.3728
G7	0.0127	0.0212	0.0197	0.0341	0.0578	2.11	3.58	4.02	5.43	6.84	-0.7956	0.3346	-0.4207	1.8262	4.3110
G8	0.0091	0.0630	0.0430	0.0547	0.0499	1.79	6.01	6.06	7.49	7.86	0.6723	-1.5702	-1.8865	-3.3810	-2.5821
G9	0.1591	0.0998	0.0790	0.0481	0.0480	7.49	8.21	8.65	8.68	8.96	2.8172	4.1368	5.2622	5.2213	4.0562
G10	0.0423	0.0568	0.0788	0.0522	0.0408	3.86	5.92	7.70	7.89	8.01	-1.4525	0.2993	-1.7424	-1.9188	-2.7179

EV = Eigenvector, SIPC = Sum of the value of the IPC Scores, D = Parameter of Annicchiarico; SIPC1 = SIPC for first IPCA, SIPC 2 = SIPC for first two IPCAs, IPCA, principal component of interaction, ASV = AMMI stability value; MASV = Modified AMMI stability value; ASTAB = Ammi stability

values as & ASTAB5 selected G7, G4, G5 wheat genotypes. As per type 7 measures accounted more than 97% of GXE interaction sum of squares, D7 expressed minimum values for G5, G7, G4 genotypes for stable yield performance for considered locations while G3, G9 would be of undesirable performance; SIPC7 observed G2, G6, G10 for stable & G7, G9 of unstable yield (Table 5). EV7 pointed towards G5, G2, G10. Wheat genotypes G5, G7, G1 identified by ASTAB7 over the studied environments.

Composite measures Set of genotypes G2, G5, G6, G9 selected by MASV and MASV1 selected G2, G5, for stable performance.

Highly significant variations had observed among genotypes yield and mean yield exhibited G5, G2 and G10 genotypes would be suitable for general and G7 along with G6 for specific cultivations. GAI pointed towards G5, G10 and G2 as of stable adaptations whereas G7 & G6 would be of unstable nature. HM and PRVG

Table 6 AMMI based estimates of genotypes (2017-18)

	ASTAB1	ASTAB2	ASTAB3	ASTAB5	ASTAB7	MASV1	MASV	ASV1	ASV	MEAN	GAI	PRVG	MHPRVG	HM
G1	15.44	38.35	40.12	44.40	58.67	5.38	4.52	2.73	2.54	45.45	44.90	0.9744	0.0427	44.34
G2	28.27	29.01	29.08	53.59	53.77	3.76	4.24	2.71	2.34	48.46	47.95	1.0403	0.0436	47.37
G3	27.19	27.34	85.68	89.06	89.58	6.75	5.79	2.64	2.28	44.84	44.26	0.9635	0.0303	43.68
G4	0.05	14.13	14.57	42.36	49.87	5.24	4.98	1.47	1.47	47.85	47.52	1.0305	0.0562	47.20
G5	23.43	28.57	28.64	43.93	46.72	4.02	4.04	2.60	2.29	49.73	49.45	1.0728	0.0453	49.17
G6	3.10	28.21	30.92	44.48	53.59	4.71	4.52	2.15	2.10	44.74	44.02	0.9558	0.0500	43.26
G7	4.47	12.85	16.17	29.49	46.81	6.14	4.82	1.56	1.46	41.67	41.21	0.8940	0.0614	40.73
G8	3.19	36.17	36.76	56.14	61.76	5.61	5.09	2.42	2.37	46.80	46.11	1.0018	0.0432	45.26
G9	56.05	67.47	74.85	75.28	80.27	5.18	4.49	4.01	3.52	47.51	47.10	1.0243	0.0276	46.72
G10	14.90	35.03	59.32	62.32	64.14	5.84	4.96	2.62	2.43	48.45	48.02	1.0424	0.0375	47.59

Figure 1 Biplot analysis of genotypes and AMMI based estimates (2017-18)

measures identified G5, G10, G3 and G7 & G6 for general and specific adaptations. Adaptability measure MHPRVG found G7, G4, G6 as genotypes for broad adaptations for studied environmental conditions and G9, G3 for specific conditions.

Biplot analysis, help to visualize the relationships among AMMI measures along with yield based. Second PCA scores of measures and genotypes are plotted against their respective first PCA scores

in biplot analysis. Graphically, the relationship among these estimates is displayed in a plot of PC1 versus PC2 as 70% total variation accounted first two axes (Figure 1). Largest cluster consisted of D1, D2, EV1, EV2, ASV, ASV1, ASTAB1, ASTAB2 and SIPC3 measures. Nearby second cluster had yield based measures i.e. Mean, HM, GAI, PRVG with SIPC1 & SIPC2. Third cluster i.e. second largest group kept D3, D5, D7, ASTAB3, ASTAB5, ASTAB7 & EV3 measures together. Fourth cluster had

Table 7 Principal components analysis of genotypes (2018-19)

	EV1	EV2	EV3	EV5	EV7	D1	D2	D3	D5	D7	SIPC1	SIPC2	SIPC3	SIPC5	SIPC7
G1	0.0507	0.0348	0.0240	0.0378	0.0398	10.14	11.64	11.79	17.12	18.35	1.5110	0.6256	0.3159	-0.7298	1.0676
G2	0.1243	0.0733	0.0553	0.0550	0.0485	15.86	17.05	17.83	20.93	21.67	2.3649	3.3313	2.4821	0.5564	1.3309
G3	0.0002	0.0293	0.0209	0.0568	0.0424	0.68	10.11	10.38	18.78	18.90	0.1012	-1.4597	-1.8480	1.2141	1.8254
G4	0.1750	0.1530	0.1026	0.0738	0.0552	18.82	24.13	24.18	25.83	25.98	-2.8058	-0.4685	-0.2086	-1.2290	-1.0129
G5	0.0018	0.0011	0.0638	0.0389	0.0607	1.93	2.10	16.53	16.64	19.56	0.2879	0.4142	-2.2567	-1.7916	-4.8544
G6	0.0024	0.0060	0.0124	0.0555	0.0406	2.19	4.64	7.57	19.60	19.68	-0.3260	-0.9604	0.0125	2.4483	2.9810
G7	0.0106	0.0083	0.0069	0.0154	0.0307	4.63	5.64	6.13	10.64	13.08	-0.6909	-0.1940	0.1964	2.0183	1.8522
G8	0.0372	0.1161	0.0883	0.0820	0.0630	8.68	20.36	21.47	25.20	25.46	-1.2941	-4.1459	-3.0350	-6.1818	-7.3095
G9	0.0758	0.0637	0.1044	0.0653	0.0637	12.38	15.60	22.52	22.88	24.15	1.8463	3.3150	5.9600	6.0181	4.5750
G10	0.0220	0.0144	0.0215	0.0195	0.0555	6.67	7.52	10.36	12.01	15.86	-0.9944	-0.4575	-1.6185	-2.3230	-0.4553

Table 8 AMMI based estimates of genotypes (2018-19)

	ASTAB1	ASTAB2	ASTAB3	ASTAB5	ASTAB7	ASV	ASV1	MASV1	MASV	MEAN	GAI	HM	PRVG	MHPRVG
G1	15.31	20.38	20.97	46.52	55.79	1.8546	1.9679	4.8582	4.3761	52.28	51.86	51.46	1.0810	1.0751
G2	37.51	43.55	47.97	68.83	75.56	2.7274	2.9154	6.0123	4.9794	49.20	48.33	47.47	1.0087	1.0008
G3	0.07	15.81	16.73	59.17	60.23	1.5647	1.5654	6.9701	5.4110	50.46	50.06	49.68	1.0440	1.0377
G4	52.81	88.09	88.51	102.09	103.82	3.8235	4.0141	5.6233	5.2342	47.90	46.82	45.83	0.9787	0.9680
G5	0.56	0.66	44.45	45.10	67.87	0.3352	0.3579	5.2020	4.9718	45.03	44.45	43.81	0.9274	0.9208
G6	0.71	3.31	9.12	62.96	63.60	0.7253	0.7390	5.1712	4.8266	45.90	45.16	44.49	0.9421	0.9357
G7	3.20	4.80	5.73	18.25	31.01	0.8955	0.9447	3.5584	3.2786	49.99	49.26	48.57	1.0256	1.0227
G8	11.23	63.76	71.34	100.87	103.76	3.1750	3.2246	7.0027	6.1440	49.80	49.38	48.97	1.0321	1.0213
G9	22.87	36.80	79.75	82.50	95.15	2.4743	2.6017	5.8565	5.5352	50.06	49.18	48.34	1.0267	1.0183
G10	6.63	8.50	16.77	23.16	47.64	1.1993	1.2751	4.1101	3.7189	45.66	44.80	43.95	0.9338	0.9289

kept MASV, MASV1, EV5, SIPC5 & SIPC7 measures. Two measures MHPRVG & EV7 were observed as outliers as placed far from studied measures.

3.2 Second year of study (2018-19)

Model diagnosis based on statistical and practical considerations observed AMMI7 is significant at the 0.01 level by FR-tests. Estimated sums of squares for GXE signal and GXE noise were 80.92% and 19.08% respectively of total GXE sums of squares. More over earlier IPCs capture signal while latter ones noise. Sum of Squares from GXE interaction for signal is 2.45 times that for genotypes main effects. The narrow adaptations are important for this dataset. First IPC1 is about 0.70 times the genotypes main effects. Also note that GE-noise is 0.58 times the genotypes main effects. Discarding noise improves accuracy, increases repeatability, simplifies conclusions, and accelerates progress.

AMMI derived measures based on the use of significant IPCA's were calculated as EV1, ASTAB1, SIPC1, D1 measures (only first significant IPCA), while ASV, EV2, ASV1, ASTAB2, SIPC2, D2 utilized first two significant IPCA's, measures EV3, ASTAB3, SIPC3 and D3 considered first three significant IPCAs, while EV5, ASTAB5, SIPC5 & D5 (exploited total variability accounted by first five significant IPCAs), whereas measures MASV1, EV7, ASTAB7, MASV, SIPC7 and D7 utilized 91.7% variability explained by seven significant IPCAs. G3, G5, G6 genotypes were marked as desirable genotypes by EV1, D1, ASTAB1 measures while (G4, G8, G10) by SIPC1 values

Type -2 measure pointed towards (G5, G6, G7) by EV2 and values of D2 genotypes for (G5, G6, G7) whereas SIPC2 settled for (G8, G3, G6) & (G9, G2) and ASTAB2 observed suitability of (G5, G6, G7). Wheat genotypes (G5, G6, G7) recommended ASV and ASV1 measures (Table 7). Considering first two IPCAs in ASV & ASV1 measures utilized 43.2% of GXE interaction sum of squares. Genotypes G7, G6, G3, G10 would be of stable performance by D3, EV3, ASTAB3 whereas SIPC3 favored G8, G5, G3 wheat genotypes (Table 8).

Wheat genotypes G7, G10, G5 considered by EV5, D5 & ASTAB5 measures and SIPC5 identified G9, G11, G10 as suitable genotypes. According to type 7 measures accounted more than 97% of GXE interaction sum of squares, D7 expressed minimum values for G7, G10, G1 genotypes for stable yield performance for considered locations while G8, G4 would be of undesirable performance; SIPC7 observed G8, G5, G4 for stable & G9, G6 of unstable yield (Tables 7 and 8). EV7 pointed towards G7, G1, G6 & G9, G8. Promising genotypes G7, G10, G1 selected by ASTAB7 over the studied environments. G7, G10, G1 genotypes would be recommended for cultivation by Composite measures MASV as well as MASV1.

Average yield considered G1, G3 and G9 genotypes would be suitable for general and G5 along with G10 for specific cultivations. Values of GAI pointed towards G1, G3 and G8 as of stable adaptations whereas G5 & G10 would be unsuitable. Measures HM and PRVG identified G1, G3, G8 and G5 & G10 for general and specific adaptations. Analytic measure of adaptability MHPRVG found G1, G3, G8 genotypes for broad adaptations for studied environmental conditions.

Figure 2 Biplot analysis of genotypes and AMMI based estimates (2018-19)

To understand the relationship if any among the AMMI measures, Principal component analysis (PCA) was performed. The relationship among these estimates is graphically displayed in a plot of PC1 versus PC2 as 71% total variation accounted first two axes. By large four clusters observed among the AMMI & yield based measures (Figure 2). Twelve measures as EV7, D7, EV3, ASTAB7, ASTAB3, ASTAB5, MASV, EV5, D5, EV2, ASTAB2 clubbed in largest group and EV1, MASV1, ASTAB1, D1, D2, ASV, ASV1 measures placed in second cluster. Separate group consisting of SPIC1, SPIC2, SPIC5 and SPIC7 measures. Fourth group contains average yield, harmonic mean, GAI, PRVG, HMPRVG with SIPC3. No measures were observed as outliers in graphical representation based on biplot analysis.

Conclusions

Plant breeders use number of measures to highlight yield stability of genotypes for various environmental conditions. For this AMMI analysis would be of most suited one. based measures explains the different concept of stability and these measure would be of use to plant breeders always attempt to select genotypes with high, stable and predictable yield across environments. AMMI analysis has been observed as useful for exploring complex GXE interaction to increase experimental efficiency. The scientific information explained could be of help in developing location specific breeding strategies to sustain wheat productivity of the country.

Acknowledgements

The wheat genotypes were evaluated at coordinated centers of AICW&BIP across the country. Authors sincerely acknowledge the hard work of all the staff for field evaluation and data recording.

Conflict of interest

No conflict of interest

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