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G × E evaluation for feed barley genotypes evaluated in country by AMMI analysis

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Abstract: AMMI analysis of feed barley genotypes exhibited highly significant effects of environments, genotypes and interactions for both the years. The major portion of the total variance was described by the environmental effects up to 45.6% and 42.3% in respective years. The genotypes effects contributed marginally as of only 8.6% and 6.9% of total variation. The significant interaction effects were partitioned into IPCA1, IPCA2 , IPCA3 and IPCA4; which explained upto 42.4, 18.3, 9.7 and 8.1% of the first year and 32.2, 20.3, 15.6 and 10.5% for second year. The cumulative effect of first two interaction principal components comes out to 60.7% and 52.3% respectively. Maximum genotype yield during study period varied from 49.8 to 48 whereas the lowest yield ranged from 37 to 36.4 q/ha. AMMI stability index identified genotypes G9(BH 972), G15(JB 274) for former and G23(DWRB 109) & G2(KB 1205) for latter year. AMMI distance marked G15(JB 274) & G7(NDB 1561) for first and genotypes G26(UPB 1034) & G23(DWRB 109) for the second year. Desirable genotypes for selection would be G11(PL 871), G27(PL 872) and G23(DWRB 109), G20(BH 946) for respective years a per the GSI score. Genotypes with IPCA-1 scores close to zero identified G1(PL 751), G9(BH 972) and G27(PL 872) for first year and G5(RD 2786), G4(NDB 1554) and G24 (UPB 1036) for second year would have wider adaptation to the tested environments as per AMMI graphical plots.

Keywords: ASV, Biplots, D, GSI, GxE interaction, IPCA, MET

INTRODUCTION

Barley crop is suitable for diverse production conditions of the India owing to its tolerance to biotic and abiotic stresses. This cereal crop is popularly grown as feed in many parts of the world including Indian subcontinent. The Barley Network under All India Coordinated Wheat and Barley Improvement Programme (AICW&BIP) develops new genotypes to sustain barley production in the country through multi-location trials. Higher yield is one of the prime objectives of the barley improvement programme.

Genotype by environment interaction (GxE) refers to the differential responses of genotypes across environments (Abdipur & Vaezi , 2014). The popular ANOVA procedure describe the genotypic main effects under the assumption of an additive model, while, PCA based on multiplicative model, does not describe the additive main effects. Although the linear regression models combine both additive and multiplicative components however, the interaction affects gets confounded with the main effects (Alake & Ariyo, 2012). The additive main effects and multiplicative interaction (AMMI) model, describes interaction effects more effectively. The use of graphical biplot methodology explains the complex interaction in a much simpler manner (Bavandpori *et al*., 2015). AMMI biplot analysis is considered to be an effective tool to diagnose interaction patterns graphically. The biplot display based on PCA scores of genotypes and environments provides visual inspection and interpretation of interaction (Dehghani *et al*., 2006). Hence, this study was conducted to quantify the magnitude of genotype x environment interaction and stability performance of barley genotypes evaluation under multi-location trials. The objectives of this study were to (i) interpret genotype-environment interaction of yield performances by AMMI analysis (ii) differentiate barley genotypes as per the various statistics defined on AMMI models estimates.

MATERIALS AND METHODS

The AMMI model is usually referred to as biplot analysis and model for main effects and GE interaction effects defined as (Zobel *et al*., 1988):

$$Y_{ij} = \mu + g_{i.} + e_{.j} + \sum_{k=1}^{n} \lambda_k \gamma_{ik} \delta_{jk} + \rho_{ij} \quad \text{(i)}$$

where Y_{ij} is the yield of the i-th genotype in the j-th environment; μ is the grand mean; gi. and e.j are the genotype and environment deviations from the grand mean, respectively ; l_k is the eigen value of the Principal Component analysis axis k; g_{ik} and d_{jk} are the genotype and environment principal component scores (eigenvectors) for axis k; n is the number of principal components retained in the model and r_{ij} is the error term.

Twenty seven and twenty eight barley genotypes were evaluated under national varietal trials carried out by All India coordinated wheat and barley improve-

ment programme centers. The experiments were conducted during cropping seasons 2012-13 and 2013-14 across 12 environments. The details of considered environments along with pedigrees of investigated genotypes are presented in tables 1 & 4 respectively. The field layout of trials considered randomized complete block design with four replications. All the cultural practices were carried out as per zone recommendations to harvest good yield. AMMI analysis was conducted using computer software Genstat version 17.1. (VSN International, 2014). In addition various AMMI estimates statistics were also calculated as follows:

AMMI Stability Value (ASV) is the distance from the coordinate point to the origin in a two-dimensional scatter graph of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase *et al*., 2000). The score of IPCA1 contributes more to the GxE interaction sum of squares, a weighted value is calculated for each genotype and environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS as follows:

AMMI Stability Value (ASV) =

$$\sqrt{\left[\frac{SSIPCA1}{SSIPCA2} * \text{IPCA1 score}\right]^2 + \text{IPCA2 score}^2} \quad \text{(ii)}$$

where SSIPCA1 and SSIPCA2 are sum of squares by the IPCA1, IPCA2 respectively and the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. The larger absolute value the IPCA score confirms the more specific adaptation genotypes to certain environments. Smaller IPCA scores indicate a more stable genotype across environments. Similarly, IPCA2 score near zero revealed more stable, while large values indicated more responsive and less stable genotypes.

The AMMI distance statistic coefficient (D) (Zang *et al*., 1998) was calculated as the distance of the interaction principal component (IPC) from the origin

AMMI Distance (D_i)= $\sqrt{\sum_{i=1}^{n} \gamma_{is}^2}$ (i= 1,2,3,.. n) (iii)

Genotypic stability index (GSI) defined by Farshadfar (2008) considering the rank of yield of genotypes across environments and rank of AMMI stability value. This index incorporate mean and stability index in a single criteria and calculated as:

GSI = RASV+RY (iv) where, RASV is the rank of AMMI stability value and RY is the rank of mean yield of genotypes (RY) across environments.

RESULTS AND DISCUSSION

AMMI analysis of variance: The main effects of interactions, environments and genotypes were observed as highly significant at $P < 0.01$ (table 2). The GxE interaction effect explained 34.8% of the total variance. The multiplicative variance of the treatment sum of squares due to interaction was partitioned into the significant IPCA1, IPCA2, IPCA3 and IPCA4; which explained 42.4, 18.3, 9.7 and 8.1% of the interaction sum of squares, respectively (Ntawuruhunga *et al*.,2001). The cumulative effects of first two interaction principal components was up to 60.7% of the interaction sum of squares.

The second year of trial exhibited highly significant effects of interactions ,environments and genotypes The interaction effect explained to the tune of 42.3% of the total variance (table 5). The interaction effects was partitioned into significant IPCA1, IPCA2, IPCA3 and IPCA4; which explained 32.2, 20.3, 15.6 and 10.5% of the interaction sum of squares, respectively. The joined effects of first two components explained 52.5% of the interaction sum of squares.

Average yield: The mean yield of genotype during first year ranged from 49.8 to 37.1 q/ha with genotype PL871 recorded highest grain yield followed by RD2552 and PL872.Genotypes with lower yield were observed as DWRB109, UPB1035 and RD2853 (table3).

Second year of study observed the variation in yield from 48 to 36.4 q/ha among the tested genotypes. BH946 observed as highest yielder closely followed by RD2552 and HUB113 (table 6). Lower yielder genotypes were observed as RD2876, RD2877 and UPB1042.

IPCAs (crossover and non-crossover interactions): IPCA 1 scores of 18 and 9 genotypes showed positive and negative values during the year 2012-13. Genotype G14(RD 2855) had large negative IPCA1 score and showed positive IPCA3 value (table 3). This disproportionate genotype response referred to as crossover GE interaction response. (Yan & Hunt, 2001). The genotypes with lower IPCA-1 scores would produce a lower absolute G×E interaction effect than those with higher absolute IPCA-1 scores and had less variable yields (more stable) across genotypes (Mohammadhi *et al*., 2007). Genotypes G5(RD 2786) and G7(NDB 1561) with yields greater than the overall mean and low IPCA-1 scores had a combination of high yield and stability performances. Genotypes G16(RD 2854) and G12 (KB 1204) showed positive and negative IPCA1 values for second year (table 6). Genotype G22(JB 278) has large negative IPCA1 score and positive IPCA3 value. Genotypes G6(BH 971) and G22(JB 278) with yields greater than the overall mean and low IPCA-1 scores had a desirable combination of high yield and stabile performance.

AMMI stability index (D): The index 'D' incorporates the scores of significant IPCA towards the interaction SS and the lower D values indicate high stability across the tested environments and vice versa (Zang *et al*., 1988). The ranking of genotypes for the year 2012-13 in ascending order of D values were as G9 (1.18) = G15 (1.18) < G12 (1.36) < G11 (1.39) (table 3). Genotypes G22(DWRB 109) and G8(UPB 1035) with lowest yield also exhibited D values 2.51 and 3.62 respectively. Genotype G14(RD 2855) showed lower yield with and smallest negative IPCA-1 score (-3.65). Therefore, genotype RD2855 was recognized with stable yield of lowest magnitude.

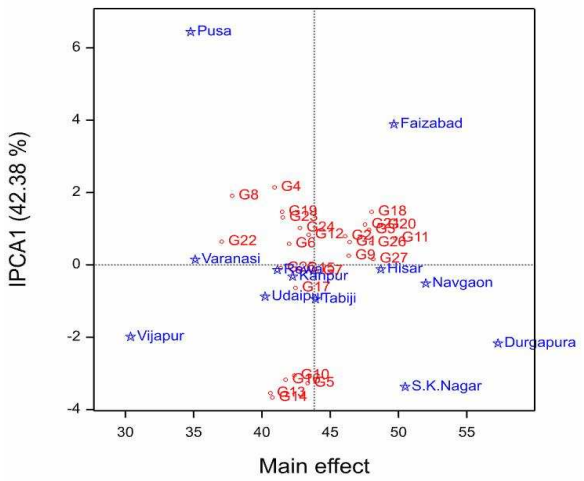

Fig. 1. *First principal axis of interaction (PCA1) versus mean yield of genotypes Legends for figure (Genotypes depicted by red colour circles and environments by blue colour stars) (2012-13)*

G1	G2	G3	G4	G5	G6	G7	G8	G9
PL	KB	BH	NDB	RD	BH	NDB	UPB	BH
751	1205	970	1554	2786	971	1561	1035	972
G10	G11	G12	G13	G14	G15	G16	G17	G18
RD	PL	KB	RD	RD	JB	RD	JB	JYO
2852	871	1204	2853	2855	274	2854	277	TI
G19	G20	G21	G22	G23	G24	G25	G26	G27
PL	RD	JB	DWR	UPB	DW	UPB	BH	PL
873	2552	278	B 109	1036	RB	1034	902	872

110

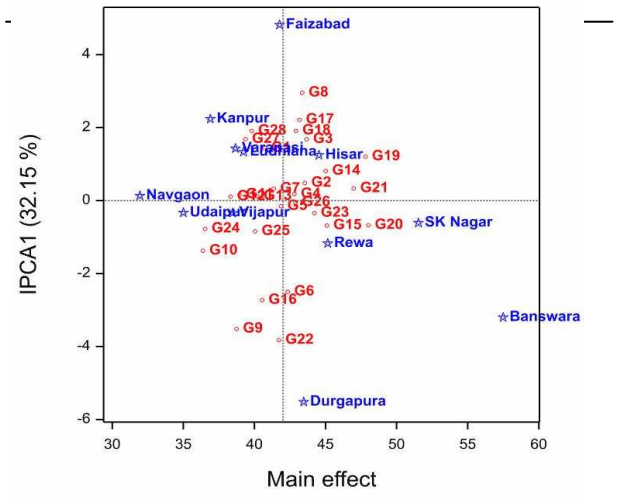

Fig. 3. *First principal axis of interaction (PCA1) versus mean yield of genotypes Legends for figure (Genotypes depicted by red colour circles and environments by blue colour stars) (2013-14)*

G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
PL	KB	BH	NDB	RD	BH	NDB	UPB	BH	RD
751	1205	970	1554	2786	971	1561	1035	972	2852
G11	G12	G13	G14	G15	G16	G17	G18	G19	G20
PL	KB	RD	RD	JB	RD	JB	JYO	PL	BH
871	1204	2853	2855	274	2854	277	TI	873	946
G21	G22	G23	G24	G25	G26	G27	G28		
RD	JB	DWR	UPB	DWR	UPB	BH	PL		
2552	278	B 109	1036	B 110	1034	902	872		

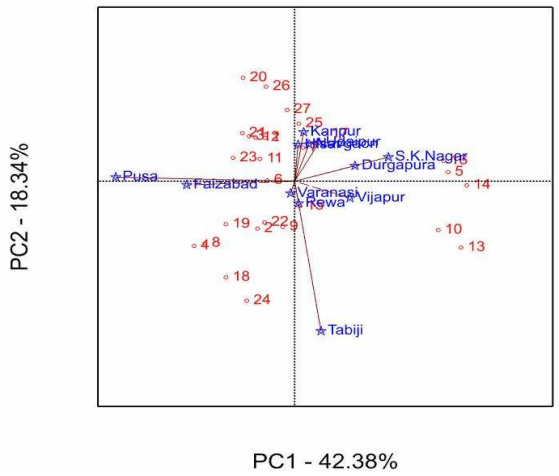

Fig. 2. *AMMI biplot for PCA1 versus PCA2 Legends for figure (Genotypes depicted by red colour circles and environments by blue colour stars) (2012-13)*

G1	G2	G3	G4	G5	G6	G7	G8	G9
PL	KB	BH	NDB	RD	BH	NDB	UPB	BH
751	1205	970	1554	2786	971	1561	1035	972
G10	G11	G12	G13	G14	G15	G16	G17	G18
RD	PL	KB	RD	RD	JB 274	RD	JB	JY
2852	871	1204	2853	2855		2854	277	OTI
G19	G20	G21	G22	G23	G24	G25	G26	G27
PL	RD	JB	DWR	UPB	DWR	UPB	BH	PL
873	2552	278	B 109	1036	B 110	1034	902	872

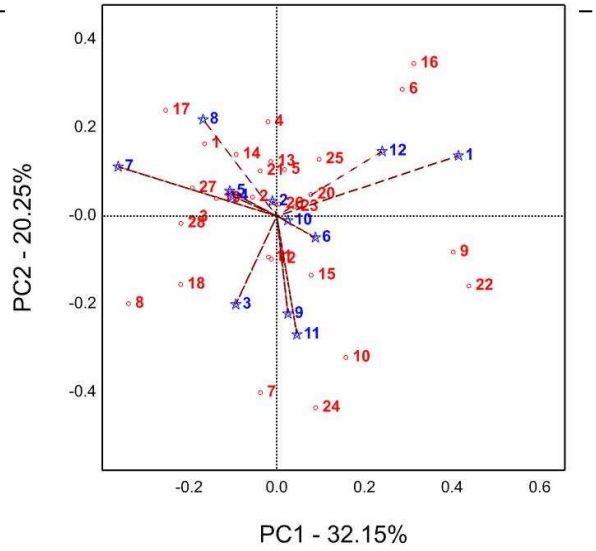

Fig. 4. *IPCA1 versus IPCA2) Legends for figure (Genotypes depicted by red colour circles and environments by blue colour stars) (2013-14)*

G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
PL	KB	BH	NDB	RD	BH	NDB	UPB	BH	RD
751	1205	970	1554	2786	971	1561	1035	972	2852
G11	G12	G13	G14	G15	G16	G17	G18	G19	G20
PL	KB	RD	RD	JB 274	RD	JB	JYOT	PL	BH
871	1204	2853	2855		2854	277	I	873	946
G21	G22	G23	G24	G25	G26	G27	G28		
RD	JB	DWR	UPB	DWR	UPB	BH	PL		
2552	278	B 109	1036	B 110	1034	902	872		

Table1 . Details of feed barley genotypes, parentage and environments (2012-13)

Code	Genotype	Parentage	Code	Locations	Latitude	Longitude	Mean Sea Level (m)
G1	PL 751	K 226/PL226	E1	Hisar	29◦10'N	75 ◦46 ' E	215.2
G2	KB 1205	K508/K745	E2	Tabiji	26◦35'N	74◦61' E	456.1
G3	BH 970	HBL 276/RD2683	E3	Durgapura	26◦51 'N	75 ◦47 ' E	390
G4	NDB 1554	NB-3/HUB 114	E4	Navgaon	18◦70 'N	72◦86' E	8.5
G5	RD 2786	RD2634/NDB1020//K425	E5	Pusa	25◦98 'N	85◦67' E	52.12
G6	BH 971	HBL 405/RD2683	E6	Varanasi	25 ◦20 ' N	83 ◦03 ' E	75.5
G7	NDB 1561	30th IBYT 929 (2008-09)	E7	Kanpur	26◦29 ' N	80 ◦18 ' E	125.9
G8	UPB 1035	LAKHAN/ (GIORIA-BAR/4/ SOTOL//2762/BC-B/3/11012.2/…)	E8	Faizabad	26◦47'N	82◦12 'E	113
G9	BH 972	29th EIBGN-22/BH 646	E9	Rewa	24 ◦31 ' N	81 ◦15 ' E	365.7
G10	RD 2852	RD2035/BH550//GLORIA-BAR	E10	Vijapur	23°35 'N	72◦55 'E	41.1
G11	PL 871	DWR47/K711	E11	Udaipur	24◦34 ' N	70 ◦42 ' E	582
G12	KB 1204	K409/RD2712	E12	SK Nagar	24◦19 ' N	72 ◦19 ' E	154.5
G13	RD 2853	RD2618/NDB1173//PETUNIA-1					
G14	RD 2855	RD2552/PL770//RD2685					
G15	JB 274	BH331/RD2501					
G16	RD 2854	RD2025/DL-88/RD2552//DL472					
G17	JB 277	PL419/ RD2501					
G18	JYOTI	K 12/C 251					
G19	PL 873	IBYT-LRA-M 08-09-7					
G20	RD 2552	RD2035/DL472					
G21	JB 278	RD2503/K478					
G22	DWRB 109	IBYT-HI-8 (10-11)					
G23	UPB 1036	JYOTI/(CABUYA/JAZMIN// PETUNIA. 1)					
G24	DWRB 110	IBYT-HI-14 (10-11)					
G25	UPB 1034	RD2624/DWR46					
G26	BH 902	BH495/RD2552					
G27	PL 872	DWR47/K711					

Table 2. AMMI analysis of barley genotypes over locations (2012-13).

Source of variation	Degree of freedom	Mean Sum of squares	Variance ratio	% TSS	% GxE
Treatments	323	463.9	26.73***	89.05	
Genotypes	26	558.2	32.16***	8.63	
Environments	11	6980.4	115.44***	45.64	
Block	36	60.5	3.48		
Interactions	286	204.6	11.79***	34.79	
IPCA 1	36	689.1	39.70		42.38
IPCA 2	34	315.7	18.19		18.34
IPCA 3	32	177.8	10.25		9.72
IPCA 4	30	157.3	9.06		8.06
Residuals	154	81.7	4.71		
Error	936	17.4			
Total	1295	129.9			

The second year of study ordered genotypes in ascending order of D values as G23 (1.32) < G2 (1.42) < G20 (1.47)<G21(1.63) (table 6). Genotypes G10(RD 2852) and G24(UPB 1036) with lowest yield also exhibited D values of 3.19 and 3.49 respectively. Genotype G22(JB 278) showed moderate high yield with and smallest negative IPCA-1 score (-3.65) along with 1.63 D value. RD2786 may be recommended with stable moderate yield.

AMMI Stability Value (ASV): Genotype with least ASV score judged as the stable one (Purchase *et al.*, 2000) accordingly G15(JB 274), followed by G7 (NDB 1561), G9 (BH 972), G6(BH 971) and G25 (UPB 1034) were the stable genotypes, while G14(RD 2855), G13(RD 2853) and G5(RD 2786) were unstable genotypes for first year of study (table 3).

Genotype G26(UPB 1034), followed by G23(DWRB 109), G11(PL 871) and G12(KB 1204) were observed as the stable genotypes during the year 2013-14 , while genotypes G22(JB 278), G9(BH 972) and G16(RD 2854) were unstable (table 6).

Genotype Selection Index (GSI): Based on the least value of GSI, the desirable genotype satisfying the stability and high grain yield would be G11(PL 871), G27(PL 872) followed by G9(BH 972), G7(NDB 1561) (table 3) for first year.

During the year 2013-14, the least GSI value satisfied by G23(DWRB 109), G20(BH 946), G21(RD 2552)

Table 3: Recent AMMI estimates and ranking of genotypes(2012-13).

Code	Genotype	Gm	R_{Gm}	IPCA1	IPCA2	IPCA3	IPCA4	D	R_D	ASV	R_{ASV}	GSI
G1	PL 751	46.42	8	0.631	1.053	0.735	1.219	1.88	8	1.80	9	17
G2	KB 1205	46.09	10	0.791	-1.151	0.116	1.282	1.90	9	2.16	11	21
G3	BH 970	47.83	6	0.971	1.090	0.787	-0.040	1.66	7	2.49	13	19
G4	NDB 1554	40.93	23	2.142	-1.570	1.279	0.562	3.00	16	5.19	22	45
G5	RD 2786	43.35	13	-3.271	0.221	-1.304	1.294	3.76	24	7.56	25	38
G6	BH 971	41.99	18	0.582	0.021	1.544	-1.260	2.08	10	1.35	4	22
G7	NDB 1561	43.99	11	-0.177	0.815	-1.203	-0.724	1.63	6	0.91	2	13
G8	UPB 1035	37.82	26	1.908	-1.506	-2.686	-0.092	3.62	22	4.66	21	47
G9	BH 972	46.36	9	0.251	-1.108	-0.191	0.257	1.18	1	1.25	3	12
G10	RD 2852	42.37	17	-3.058	-1.186	1.575	0.812	3.73	23	7.17	23	40
G11	PL 871	49.77	1	0.739	0.542	0.915	0.498	1.39	4	1.79	8	9
G12	KB 1204	43.42	12	0.830	1.062	-0.158	0.129	1.36	3	2.19	12	24
G13	RD 2853	40.62	25	-3.545	-1.611	0.156	0.582	3.94	27	8.35	26	51
G14	RD 2855	40.76	24	-3.667	-0.100	0.832	-0.630	3.81	26	8.48	27	51
G15	JB 274	42.77	15	-0.111	-0.603	-0.515	-0.871	1.18	2	0.66	1	16
G16	RD 2854	41.74	19	-3.175	0.495	-0.921	0.527	3.38	21	7.36	24	43
G17	JB 277	42.46	16	-0.639	1.145	-0.617	-2.897	3.24	19	1.87	10	26
G18	JYOTI	48.03	4	1.464	-2.333	1.903	-0.149	3.35	20	4.11	20	24
G19	PL 873	41.48	21	1.466	-1.044	-2.085	1.416	3.10	17	3.54	17	38
G20	RD 2552	48.72	2	1.100	2.509	-0.902	2.469	3.80	25	3.57	18	20
G21	JB 278	47.55	7	1.115	1.165	1.862	0.617	2.54	15	2.83	15	22
G22	DWRB 109	37.06	27	0.642	-0.999	-1.226	-1.839	2.51	13	1.79	7	34
G23	UPB 1036	41.53	20	1.311	0.566	0.161	0.055	1.44	5	3.08	16	36
G24	DWRB 110	42.78	14	1.020	-2.900	-0.230	-0.634	3.15	18	3.74	19	33
G25	UPB 1034	41.37	22	-0.089	1.397	-1.026	-1.385	2.22	11	1.41	5	27
G26	BH 902	48.00	5	0.609	2.298	-0.099	0.120	2.38	12	2.69	14	19
G27	PL 872	48.14	3	0.160	1.734	1.297	-1.314	2.54	14	1.77	6	9

Table 4 . Details of feed barley genotypes, parentage and environments (2013-14).

Code	Varieties	Parentage		Locations	Latitude	Longitude	Mean Sea Level (m)
G1	HUB 236	DL88/22nd lBYT15	E1	Durgapura	26°51 'N	75 °47 ' E	390
G2	KB 1353	K508/RD2676	E2	Navgaon	18°70'N	72°86' E	8.5
G3	NDB 1580	NB3/HUB114	E3	Hisar	29°10'N	75 °46 ' E	215.2
G4	BH 981	RD2660/RD2683	E4	Ludhiana	30°56 ' N	75 °52 ' E	247
G5	KB 1369	Jaqriti/K169	E5	Varanasi	25 °20 ' N	83 °03 ' E	75.5
G6	HUB 237	EIBGNOT-18/RD250B	E6	Rewa	24 °31 ' N	81 °15 ' E	365.7
G7	BH 982	'13" EMBSN-14/RD2683	E7	Faizabad	26°47 °N	82°12 'E	113
G8	BH 980	NBD1276/8H393	E8	Kanpur	26°29 ' N	80 °18 ' E	125.9
G9	RD 2875	RD2552/PL419//RD2508	E9	Vijapur	23°35 °N	72°55 'E	41.1
G10	RD 2876	RD266O/PENCO/CHEVRON-BAR	E10	Udaipur	24°34 ' N	70 °42 ' E	582
G11	UPB 1040	IBON-LRA-M-31 (EIBGN 2010-11-30)	E11	SK Nagar	24°19 ' N	72 °19 ' E	154.52
G12	UPB 1042	INBYT-LRA-M-17 (EIBGN 2010-11)	E12	Banswara	23°55' N	74°45' E	216.4
G13	JB 291	DL88/K633					
G14	PL 880	PL426/BC473					
G15	BH 902	BH495/RD2552					
G16	PL 881	PL426/K537					
G17	JYOTI	K 12/C 251					
G18	PL 751	K226/PL226					
G19	RD 2552	RD2035/DL472					
G20	BH 946	BHMS22A/BH549 //RD2552					
G21	HUB 113	KARAN2BO/C138					
G22	RD 2786	RD2634/NDB1020//K425					
G23	JB 290	JB58/RD25OB					
G24	RD 2877	RD2052/DWR64//RD2660					
G25	UPB 1041	IBON-Hl-33 (EIBGN 2012-13-45)					
G26	RD 2874	NDB 1173 /BH902// RD27I5					
G27	NDB 1578	BCB128/NDB940					
G28	KB 1367	PFCBO23/MSEL					

Table 5. AMMI analysis of barley genotypes over locations (2013-14).

Source of variation	Degree of freedom	Mean Sum of squares	Variance ratio	% TSS	% GxE
Treatments	335	437.4	18.17	85.63	
Genotypes	27	439.4	18.26	6.93	
Environments	11	5669.1	169.23	36.44	
Block	36	33.5	1.39		
Interactions	297	243.4	10.12	42.25	
IPCA 1	37	628.2	26.10		32.15
IPCA 2	35	418.3	17.38		20.25
IPCA 3	33	341.6	14.20		15.59
IPCA 4	31	245.0	10.18		10.51
Residuals	161	96.5	4.01		
Error	972	24.1			
Total	1343	127.4			

%TSS, percentage of total sum of squares, % GxE, percentage of GxE total sum of squares
*** denotes significant at 0.001 level of significance

Table 6: Recent AMMI estimates and ranking of genotypes (2013-14).

Code	Genotype	Gm	R_{Gm}	IPCA1	IPCA2	IPCA3	IPCA4	D	R_D	ASV	R_{ASV}	GSI
G1	HUB 236	40.72	18	1.436	1.275	-1.048	0.394	2.22	12	2.61	15	33
G2	KB 1353	43.55	8	0.481	0.334	-1.021	-0.797	1.42	2	0.83	5	13
G3	NDB 1580	43.67	7	1.678	-0.023	0.724	0.443	1.88	7	2.66	16	23
G4	BH 981	42.81	13	0.174	1.663	1.441	-2.567	3.39	21	1.69	13	26
G5	KB 1369	41.87	15	-0.156	0.819	1.095	2.380	2.75	15	0.86	6	21
G6	HUB 237	42.35	14	-2.501	2.234	-1.194	0.926	3.68	25	4.56	24	38
G7	BH 982	41.36	17	0.324	-3.114	0.134	-0.384	3.16	17	3.16	19	36
G8	BH 980	43.36	9	2.952	-1.544	-0.543	1.131	3.56	24	4.93	25	34
G9	RD 2875	38.74	25	-3.516	-0.635	-2.327	1.786	4.62	27	5.62	27	52
G10	RD 2876	36.38	28	-1.378	-2.493	-1.027	1.018	3.19	18	3.32	21	49
G11	UPB 1040	38.95	24	0.163	-0.723	0.453	-1.545	1.77	5	0.77	3	27
G12	UPB 1042	38.32	26	0.105	-0.759	-0.895	-1.377	1.81	6	0.78	4	30
G13	JB 291	40.19	20	0.118	0.961	0.575	1.678	2.02	9	0.98	8	28
G14	PL 880	45.02	5	0.809	1.087	-1.799	-1.674	2.81	16	1.68	12	17
G15	BH 902	45.1	4	-0.685	-1.044	3.098	-0.741	3.42	22	1.51	10	14
G16	PL 881	40.54	19	-2.731	2.691	2.766	-0.361	4.74	28	5.10	26	45
G17	JYOTI	43.17	10	2.212	1.866	-0.467	1.578	3.33	20	3.98	23	33
G18	PL 751	42.92	11	1.912	-1.208	1.421	-0.635	2.75	14	3.27	20	31
G19	RD 2552	47.81	2	1.203	0.312	0.822	1.379	2.03	10	1.93	14	16
G20	BH 946	48.02	1	-0.677	0.381	-0.277	-1.217	1.47	3	1.14	9	10
G21	HUB 113	46.99	3	0.330	0.797	-1.259	-0.570	1.63	4	0.95	7	10
G22	RD 2786	41.73	16	-3.826	-1.232	1.451	-0.470	4.30	26	6.20	28	44
G23	JB 290	44.22	6	-0.344	0.162	-1.100	-0.630	1.32	1	0.57	2	8
G24	RD 2877	36.54	27	-0.776	-3.381	-0.291	0.269	3.49	23	3.60	22	49
G25	UPB 1041	40.05	21	-0.845	1.000	-2.667	-1.241	3.22	19	1.67	11	32
G26	RD 2874	42.88	12	-0.049	0.210	1.309	1.433	1.95	8	0.22	1	13
G27	NDB 1578	39.38	23	1.680	0.494	0.560	0.979	2.08	11	2.71	17	40
G28	KB 1367	39.81	22	1.907	-0.129	0.068	-1.185	2.25	13	3.03	18	40

Gm-Genotype mean yield, ASV-AMMI stability value, D- AMMI Distance; GSI -Genotypic Stability Index

followed by G2(KB 1205), G26(UPB 1034) (table 6).

AMMI analysis plots the mean effects of genotypes and locations on the abscissa and IPCA-1 scores of both effects, simultaneously on the ordinate (Figure 1). The differences in main effects reflected by displacement along the abscissa, whereas the positions along the ordinate differentiates the interaction effects. During the first year of study genotypes G1(PL 751), G9(BH 972) and G27(PL 872) with IPCA-1 scores close to zero had small interactions and had wider adaptation to the tested environments (Carbonell *et al*., 2004). The environments showed variability in both main effects and interactions as scattered in all quadrants (Figure 1). The high yielder environments Durgapura and SK nagar can be seen in quadrant-II, with minimum interaction effects, high negative IPCA-1 scores. The low potential environment Vijapur was in quadrant- I, with low negative IPCA-1 and yield. Faizabad environment showed higher yield potential with positive IPCA-1.

The discriminating ability of the environments can be judged by calculating the distance of each environment from the biplot origin. In this regard, the environments

E-1, E-2 and E-3 are most discriminating as indicated by long distance from the biplot origin. (Samonte *et al*., 2005).IPCA1 was plotted in the x-axis versus IPCA2 in the y-axis (Figure 3). the genotypes closer to the center would be stable and vice versa for unstable genotypes (Purchase *et al*., 2000). The G13 (RD 2552) located near to the origin implied its stable behavior as compared to the genotypes G3 (BH 970), G17 (JB 277), G9(BH 972), G12(KB 1204), G18(JYOTI) located distant from the origin. The cosine of angle involving a pair of environment or genotype vectors approximated correlation (Mortazavian *et al.*, 2014). An acute angle (less than 90^o) indicates a strong positive correlation between environments (SK Nagar, Durgapura), (Pusa, Faizabad); an angle close to 90^o indicates the environments are not correlated(Tabiji, Faizabad), (SK Nagar, Tabiji) ; whereas, an obtuse angle close to 180^o represents a strong negative relationship (Faizabad, Durgapura) and (SK Nagar, Faizabad). Vectors corresponding to (Pusa, Tabiji) showed angles more than 90^o angle suggesting that these environments tend to discriminate among genotypes in a similar manner. During the year 2013-14, G5(RD 2786), G4(NDB 1554) and G26(UPB 1034) with IPCA-1 scores close to zero had small interactions as well as wider adaptation to the tested environments (Figure 4). Banswara was spotted as high yielder environment in quadrant-II, with minimum interaction effects, high negative IPCA-1 scores. Udaipur showed the low yielder environment in quadrant- I, with low negative IPCA-1 and yield. Locations Faizabad and Hisar showed higher yield with positive IPCA-1.

G26 (UPB 1034), G23(DWRB 109) located near to the origin implied stable behavior as compared to the genotypes distant from the origin G8 (UPB 1035), G24 (UPB 1036), G22(JB 278), G16(RD 2854), G17 (JB 277) for second year of study. Strong positive correlation exhibited between environments (Vijapur, SK Nagar),(Durgapura, Banswara),(Faizabad, Kanpur) as observed acute angle,; an angle close to 90^o indicated the environments were not correlated(Hias, Kanpur), (Kanpur, Durgapura) ; whereas, an obtuse angle close to 180^o represented a strong negative relationship (Varanasi,Rewa) ..

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