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Assessment of Genotype-by-Environment Interaction Using Additive Main Effects and Multiplicative Interaction Model (AMMI) in Maize (*Zea mays* L.) Hybrids

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Abstract: The present study was performed to analyze the genotype-by-environment (G×E) interaction for commonly cultivated 20 commercial maize hybrids over 4 locations and 3 years in Bangladesh. Objectives of this study were to evaluate the magnitude of stability and adaptability of the genotypes in different regions of the country in different environmental status. Multivariate technique was used for grain yield and plant height where two genotypes used as local check. The AMMI model (Additive Main effects and Multiplicative Interaction) was used to assess the interaction and to select better performing ones having higher yield and other potential attributes. Considering the mean, bi and S^2di, it was evident that all the genotypes showed different responses of adaptability under different environmental conditions. Analysis of variance showed high significant effects of environments, genotypes and G×E for grain yield and plant height. Among the hybrids Nath Samrat, King-999, Y-367, NK-46, Laxmi-999 and Pacific-60 found highly stable across the environments. Genotypes Nath Samrat, Y-367, NK-46, BHM-5 and Pacific-60 are highly stable as well as high yielder. NK-40 is the highest yielder but responsive to environments. King-999 is the most stable but not good yielder. Burirhat of Rangpur (Northern part of Bangladesh) was found highly suitable region for hybrid maize cultivation followed by Jessore (Western part).

Key words: Maize · Adaptability · Hybrid · Stability · Selection · AMMI · G×E interaction

INTRODUCTION

Maize (*Zea mays* L.) plays a significant role in human and livestock nutrition worldwide. In Bangladesh it is an important cereal crop ranks third and first position in terms of acreage and production, respectively. Due to high yield potentiality, versatile uses, almost year round growth ability and higher per hectare yield compare to other cereals, area and production of maize is increasing day by day in our country. Its production also has increased significantly in the country because of the fast growing poultry and poultry feed industry and price hike of food materials.

In Bangladesh, human consumption of corn is mainly limited within roasted green cobs. One of the greatest challenges to maize breeders is to select a hybrid with high mean yield and the widest possible adaptation across various environments so that the maize hybrids can be produced on large scale. The most used methods to interpret genotype stability are based on regression analyses [1-4]. Agronomic zoning is used to stratify environments in sub-regions within which the interactions are not significant [5]. These methods are dependent on the genotypes and environments under study and may not be much informative if linearity fails [6]. The additive nature of the common analysis of variance (ANOVA) allows for an adequate description of the main effects (genotypic and environmental effects). The multi-locational testing however, usually results in genotype-by-environment (G×E) interactions that often complicate the interpretation of results obtained and reduce efficiency in selecting the best genotypes [7]. This interaction is a result of changes in a cultivar's relative performance across environments, due to differential responses of the genotypes to various edaphic, climatic and biotic factors [8]. The analysis of G×E, therefore,

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becomes an important tool employed by breeders for evaluating varietal adaptation and also for selecting parents for base populations. The Additive Main effects and Multiplicative Interaction model (AMMI) was found suitable to handle both the main effects and G×E interactions in multilocational yield trials more effectively and efficiently than other statistical packages [9].

The AMMI model combines regular analysis of variance for additive effects with principal component analysis (PCA) for multiplicative structure within the interaction. AMMI also provides a visual representation of patterns in the data through a biplot that makes use of the first interaction principal component axis (IPCA1) and the mean yields of both the genotypes and environments [10].

The need therefore to exploit the possibility of identifying genotypes that a re less influenced by G×E interaction to help in the selection procedure. So, the main objectives of the present investigation are to determine the GEI effects on grain yield of maize hybrids for diverse agro-ecological regions in Bangladesh, to identify areas where hybrid maize is well adapted to give economic returns and to select hybrids that are broadly adapted across the maize growing areas in Bangladesh.

MATERIALS AND METHODS

The experiments were conducted under Plant Breeding Division of Bangladesh Agricultural Research Institute (BARI) at four different agro ecological zones in the country for three planting seasons (2007-08, 2008-09 and 2009-10). Twenty commercial field corn hybrid varieties including two checks BARI Hybrid Maize3 (BHM3) and BARI Hybrid Maize5 (BHM5) were evaluated in these experiments. The experiments were carried out in a randomized complete block design, with three replications. Each experimental plot was comprised of 5 m long rows. Standard agronomic practices were followed [11] and plant protection measures were taken as required. Two border rows were used to minimize the border effects. Ten randomly selected plants were used for recording observations on plant height. All the plants in two rows were considered for plot yield. The grain yield (t ha^{-1}) data was estimated and corrected at 12% moisture.

The analysis of variance (ANOVA) was used and the GE interaction was estimated by the AMMI model [5]. Thus, the mean response of the genotype i in environment j (Yij) is modeled by: $Yij = \mu + gi + aj + \Sigma\lambda k\gamma ik\alpha jk + \rho ij + eij$; where μ is a common constant to the responses (normally the general mean); gi is the fixed effect of genotype i (i = 1, 2,..., g); aj is the fixed effects of environment j (j = 1, 2,..., a); $\Sigma\lambda k\gamma ik\alpha jk$ is the fixed significant effect or pattern of the specific interaction of the genotype i with environment j ($gaij$), where, λk is the k-th singular value (scalar), γik and αjk are the correspondent elements, associated to λk, of the singular vectors (rows vector and column vector) of the matrix of interaction estimated by ANOVA. For the same matrix, ρij is the non-significant effect or noise of $(ga)ij$, which is an additional residue and eij is the pooled experimental error, assumed independent and $eij \sim N(0, \sigma 2)$. In this procedure, the contribution of each genotype and each environment to the GE interaction is assessed by use of the biplot graph display in which yield means are plotted against the scores of the first principal component of the interaction (IPCA1). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russell [2]. Significance of differences among bi value and unity was tested by t-test, between S^2di and zero by F-test. All the data were subjected to analysis using statistical analysis package software Cropstat version 7.2 (AMMI, SSA and BANOVA models).

RESULTS AND DISCUSSION

There were highly significant ($P<0.001$) Mean Squares (MS) for plant height and yield for all sources of variations (Table 1). AMMI analysis in twelve environments (Table 2) shows that AMMI analysis partitioned main effects into genotypes, environments and G×E with all the components showing highly significant effects ($P<0.001$). The highly significant effects of environment indicate high differential genotypic responses across the different environments. The variation in soil structure and moisture across the different environments were considered as a major underlying causal factor for the G×E interaction. Environment relative magnitude was much higher than the genotype effect, suggesting that genotype performance is influenced more by environmental factors.

Results of stability and response of the genotypes under different environments according to Eberhart and Russell are discussed character-wise as follows; stability parameter i.e. regression coefficient (bi) and deviation from regression (S^2di) for plant height and yield of the individual genotypes are presented in Table 3 and 4.

Table 1: Mean squares from combined analysis of variance (ANOVA) for maize yield and yield components analyzed over 4 locations and 3 years

		Mean sum of squares	
Source of variation	*df*	Plant height (cm)	Yield (t ha^{-1})
Year	2	11486.4***	0.79*
Loc	3	4231***	1.72ns
Loc*year	6	5308***	98.08***
Rep*loc*year	24	3290***	0.54ns
Geno	19	1453.3***	0.75***
Loc*geno	57	47.7***	15.99***
Geno*year	38	384.1ns	1.4***
Loc*geno*year	114	52.0***	0.10***
Error	456	307.2	0.08***

***Significant level at p<0.001, ns= Not significant

**Significant level at p<0.005

Table 2: Full joint analysis of variance including the portioning of the G×E interaction of field corn commercial hybrids

		Mean sum of squares	
Source of variation	*df*	Plant height (cm)	Yield (t ha^{-1})
Genotype (G)	19	484.44***	5.33***
Environment (E)	11	2046.01***	9.12***
Interaction (GEI)	209	37.08**	0.14**
AMMI Component 1	29	175.50***	0.41***
AMMI Component 2	27	48.51***	0.31***
AMMI Component 3	25	27.57***	0.29***
AMMI Component 4	23	19.82***	0.42***
G×E (Linear)	19	144.21***	0.43***
Pool deviation	105	1.95	0.02
Pooled error	190	26.36	0.11

***Significant level at p<0.001, **Significant level at p<0.005

Table 3: Stability analysis for plant height (cm) of 20 field corn commercial hybrids over 12 environments

	Environments															
Gn	A	B	C	D	E	F	G	H	I	J	K	L	Over all mean	Pi	bi	S^2d
1	136.0	135.7	136.0	143.3	136.3	143.3	141.0	138.7	141.0	131.0	135.0	131.0	137.4	2.6	0.1*	905.97
2	125.0	158.7	125.0	131.7	120.3	131.7	131.0	121.0	131.0	120.0	121.7	120.0	128.1	-6.7	0.94	3.37
3	124.0	157.1	124.0	130.0	125.0	130.0	128.7	128.7	128.7	119.0	129.3	119.0	128.6	-6.2	0.95	2.01
4	135.7	170.0	135.7	142.0	137.3	142.0	140.7	147.7	140.7	130.7	143.7	130.7	141.4	6.6	1.0	0.00
5	120.7	157.1	120.7	127.7	126.3	127.7	125.7	138.0	15.7	115.3	144.7	115.3	128.8	-6.0	1.1	15.46
6	128.0	177.7	128.0	135.0	128.3	135.0	135.0	129.7	135.0	123.3	137.7	123.3	134.7	-0.1	1.37*	160.61
7	132.0	166.3	132.0	136.7	128.7	136.7	137.0	127.7	137.0	127.0	139.7	127.0	135.6	0.8	0.98	0.22
8	134.0	172.7	134.0	139.7	141.6	139.7	139.0	131.0	139.0	129.0	136.0	129.0	138.7	3.9	1.08	7.19
9	130.3	160.3	130.3	138.7	137.3	138.5	138.7	133.0	138.7	125.3	134.0	125.3	135.9	1.1	0.87	16.67
10	132.7	166.7	132.7	139.5	142.7	139.7	137.7	142.3	137.7	127.7	126.3	127.7	137.8	3	0.95	2.55
11	116.0	162.0	116.0	123.0	135.0	123.0	121.0	143.7	121.0	111.0	137.3	111.0	126.7	-8.1	1.34	130.45
12	122.0	172.0	122.0	128.6	145.0	128.7	127.0	144.0	127.0	117.0	138.3	117.0	132.4	-2.4	1.42*	200.01
13	131.0	160.9	131.0	136.3	139.0	136.3	136.0	133.0	136.0	124.3	147.3	124.3	136.3	1.5	0.93	4.83
14	135.7	158.5	135.7	143.0	138.7	143.0	153.3	128.3	153.3	130.7	141.7	130.7	141.0	6.2	0.70	98.19
15	129.7	162.0	129.7	136.3	136.3	136.3	134.7	128.3	134.7	124.7	146.3	124.7	135.3	0.5	0.93	1.53
16	144.0	164.7	144.0	151.3	140.7	151.3	155.7	133.0	155.7	139.0	145.0	139.0	146.9	12.1	0.63	154.20
17	141.3	162.0	141.3	148.3	133.7	148.3	146.0	143.3	146.0	136.3	146.3	136.3	144.1	9.3	0.64*	142.0
18	132.0	172.0	132.0	137.7	132.7	137.7	137.0	142.3	137.0	127.0	136.0	127.0	137.5	2.7	1.13	19.28
19	120.3	151.9	120.3	127.0	133.9	127.0	125.3	140.3	125.3	115.3	133.0	115.3	127.9	-6.9	0.95	2.73
20	106.0	172.0	106.0	113.0	135.0	113.0	117.7	141.7	117.7	101.0	137.7	101.0	121.8	-13	1.18*	872.84
Mean	128.8	163.0	128.8	135.4	134.7	135.4	135.4	135.8	135.4	123.7	137.9	123.7	134.8			
Ei (Ij)	-6.0	28.2	-6.0	0.6	-0.1	0.6	0.6	1.0	0.6	-11.1	3.1	-11.1				
LSD (0.05)	33.41	25.02	33.41	33.49	11.93	33.49	32.86	14.30	32.86	33.72	13.70	33.72				

Gn=Genotype.

A=Gazipur 1st year, B=Gazipur 2nd year, C=Gazipur 3rd year;

D=Burirhat 1st year, E=Burirhat 2nd year, F=Burirhat 3rd year ;

G=Jessore 1st year, H=Jessore 2nd year,I=Jessore 3rd year;

J=Hathazari 1st year, K=Hathazari 2nd year, L=Hathazari 3rd year.

1= Modhu-2, 2= HP-555, 3=740, 4= Arjun (Safal), 5= Nath Samrat, 6= King-999, 7= Badsha-1, 8= Y-367, 9= NK-46, 10= Heera-405, 11= Five Star, 12= NK-40, 13= G-1921, 14= BHM-3, 15= BHM-5, 16= HIC- 999, 17= Laxmi-999, 18= HIC-32, 19= KH-101, 20= Pacific-60;

Table 4: Stability analysis for yield (t ha^{-1}) of 20 field corn commercial hybrids over 12 environments

	Environments												Over			
Gn	A	B	C	D	E	F	G	H	I	J	K	L	all mean	Pi	bi	S^2d
1	8.37	7.82	8.24	10.58	10.52	10.29	9.47	9.13	8.93	8.05	8.44	8.57	9.04	-0.51	1.34	0.59
2	8.61	8.52	8.70	10.39	10.20	10.14	9.53	9.61	9.74	8.04	8.41	8.34	9.19	-0.36	1.12	0.07
3	8.12	8.29	8.21	10.78	10.48	10.18	8.68	8.72	8.98	9.05	8.92	9.06	9.13	-0.42	1.07	0.03
4	9.95	9.60	9.21	11.29	11.11	10.79	9.61	9.42	9.25	8.9	8.81	8.82	9.73	-0.18	1.25*	0.32
5	9.96	9.67	9.90	10.93	10.68	10.63	10.33	9.95	9.90	9.3	9.27	9.16	9.97	0.42	0.82	0.16
6	8.83	9.07	8.93	10.51	10.79	10.54	9.39	9.15	8.90	8.6	8.45	8.74	9.33	-0.22	1.18*	0.17
7	9.65	9.68	9.6	10.88	10.51	10.26	9.92	9.81	9.74	9.51	9.24	9.2	9.84	0.29	0.71*	0.41
8	9.04	9.29	9.41	10.86	10.59	10.37	10.22	10.13	10.07	9.90	9.8	9.75	9.95	0.40	0.60	0.79
9	10.37	10.53	10.57	11.32	11.36	11.05	10.91	10.98	10.52	10.37	10.39	10.06	10.70	1.15	0.57	0.92
10	9.14	9.05	8.88	10.83	10.40	10.45	11.05	10.46	10.29	8.03	8.01	8.09	9.56	0.01	1.33	0.56
11	8.90	8.73	8.77	11.21	10.99	10.70	9.97	9.57	9.23	8.16	8.09	8.10	9.37	-0.18	1.63*	2.03
12	11.09	11.41	11.06	11.99	11.64	11.43	11.18	10.96	10.41	10.69	10.56	10.28	11.06	1.51	0.64*	0.64
13	9.41	9.48	9.4	10.28	10.13	10.18	9.08	8.81	8.48	8.24	8.07	7.91	9.12	-0.43	1.07	0.03
14	10.39	10.24	10.21	10.79	11.23	10.97	10.21	10.30	9.98	9.6	9.74	9.80	10.29	0.74	0.68*	0.51
15	9.84	10.32	10.31	11.23	11.56	11.08	10.43	10.31	9.81	9.9	9.66	9.88	10.36	0.81	0.87	0.08
16	9.13	9.02	8.69	10.28	10.20	10.01	8.40	8.58	8.39	8.23	8.21	8.13	8.94	-0.61	1.08	0.04
17	8.69	8.56	8.63	10.62	10.43	10.04	8.96	9.03	8.83	8.39	8.34	8.65	9.10	-0.45	1.15	0.12
18	8.50	8.64	8.69	9.93	9.78	9.58	8.63	8.42	8.12	8.17	8.15	8.21	8.74	-0.81	0.93	0.02
19	8.93	8.91	9.02	11.03	10.37	10.21	8.33	8.16	8.34	8.41	8.36	8.6	9.06	-0.49	1.22	0.26
20	9.83	10.33	10.67	11.08	11.46	11.21	10.79	10.75	10.71	10.31	10.15	9.81	10.59	1.04	0.66	0.55
Mean	9.34	9.36	9.35	10.84	10.72	10.51	9.75	9.61	9.43	8.99	8.95	8.96	9.55			
Ei (Ij)	-0.21	-0.19	-0.2	1.25	1.17	0.96	0.2	0.06	-0.12	-0.56	-0.6	-0.59				
LSD (0.05)	1.44		1.4	1.05	0.92	1.15	1.04	1.09	1.22	1.04	1.14					

Gn=Genotype.

A=Gazipur 1st year, B=Gazipur 2nd year, C=Gazipur 3rd year;

D=Burirhat 1st year, E=Burirhat 2nd year, F=Burirhat 3rd year ;

G=Jessore 1st year, H=Jessore 2nd year,I=Jessore 3rd year;

J=Hathazari 1st year, K=Hathazari 2nd year, L=Hathazari 3rd year.

1= Modhu-2, 2= HP-555, 3=740, 4= Arjun (Safal), 5= Nath Samrat, 6= King-999, 7= Badsha-1, 8= Y-367, 9= NK-46, 10= Heera-405, 11= Five Star, 12= NK-40, 13= G-1921, 14= BHM-3, 15= BHM-5, 16= HIC- 999, 17= Laxmi-999, 18= HIC-32, 19= KH-101, 20= Pacific-60;

The hybrids HIC-999, Laxmi-999 and Arjun (Safal) exhibited comparatively higher plant height and Pacific-60 and Five Star was dwarf type. Dwarf type is required to maintain lodging resistance. KH-101, HP-555 and 740 showed negative phenotypic index (Pi), insignificant regression coefficient (bi) and high deviation from regression (S^2di) indicating stability of these three genotypes over all the environments with semi dwarf plant stature. NK-40 and King-999 had negative Pi value, significant bi and non significant S^2di values indicating semi dwarf plant type.

The environmental mean and genotypic mean of grain yield ranged from 8.95 to 10.72 t ha^{-1} and 8.74 to 11.06 t ha^{-1}, respectively. Nine genotypes showed positive phenotypic index while the other genotypes had negative phenotypic index for yield. Thus, positive phenotypic index indicated the higher yield and negative indicated the lower yield among the genotypes. Again, positive and negative environmental index (Ij) reflects the rich or favorable and poor or unfavorable environments for this character, respectively. The environmental index (Ij) directly reflects the poor or rich environment in terms of negative and positive Ij, respectively. Thus the environment Gazipur (excess water stress), Hathazari (Storm at flowering stage), were identified as poor Burirhat as rich environments for fieldcorn hybrid production.

Among the hybrids NK-40 showed highest yield but had significant regression coefficient (bi) which means it is not stable variety and responsive to Burirhat location. Genotypes Nath Samrat, Y-367, NK-46, Local check BHM-5 and Pacific-60 are higher yielding as well as stable over the environments. King-999 and Badsha-1 are two highly stable with moderate yielding hybrids.

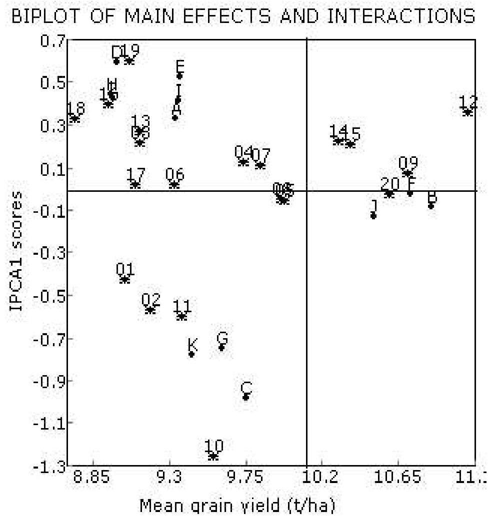

Fig. 1: Biplot of the first AMMI interaction (IPCA1) scores (Y-axis) plotted against mean grain yield (X-axis) for 20 maize hybrids in 12 environments in Bangladesh

A=Gazipur 1st year, B=Gazipur 2nd year, C=Gazipur 3rd year;

D=Burirhat 1st year, E=Burirhat 2nd year, F=Burirhat 3rd year;

G=Jessore 1st year, H=Jessore 2nd year,I=Jessore 3rd year;

J=Hathazari 1st year, K=Hathazari 2nd year, L=Hathazari 3rd year.

1= Modhu-2, 2= HP-555, 3=740.00, 4= Arjun (Safal), 5= Nath Samrat, 6= King-999, 7= Badsha-1, 8= Y-367, 9= NK-46, 10= Heera-405, 11= Five Star, 12= NK-40, 13= G1921, 14= BHM-3, 15= BHM-5, 16= HIC 999, 17= Laxmi 999, 18= HIC 32, 19= KH 101, 20= Pacific 60;

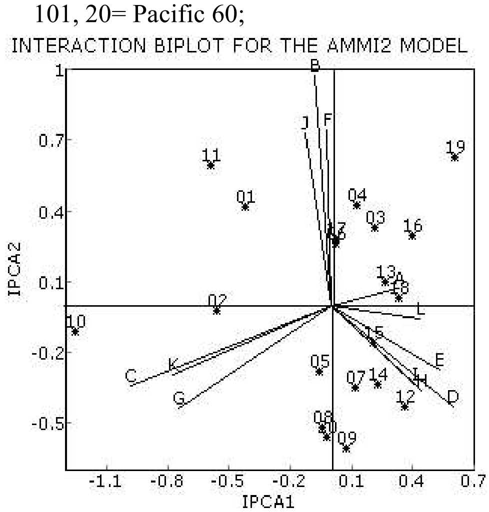

Fig. 2: Graphic of AMMI biplot interaction of twenty genotypes over twelve environments.

Table 5: AMMI mean yield and IPCA1 scores for 20 maize hybrids grown in 12 environments

Genotypes	ID	AMMI mean yield (t ha^{-1})	IPCA1 score
Modhu-2	1	9.04	-0.42
HP-555	2	9.19	-0.56
740.00	3	9.13	0.21
Arjun(Safal)	4	9.73	0.12
Nath Samart	5	9.97	-0.05
King-999	6	9.33	0.02
Badsha-1	7	9.84	0.11
Y-367	8	9.95	-0.04
NK-46	9	10.70	0.07
Heera-405	10	9.56	-0.10
Five Star	11	9.37	-0.59
NK-40	12	11.06	0.36
G1921	13	9.12	0.26
BHM-3	14	10.29	0.22
BHM-5	15	10.36	0.20
HIC 999	16	8.94	0.39
Laxrm 999	17	9.10	0.02
HIC 32	18	8.74	0.32
KH 101	19	9.06	0.60
Pacific 60	20	10.59	-0.02
Environments			
Gazipur	Year1	9.34	0.33
Gazipur	Year 2	9.36	0.52
Gazipur	Year 3	9.35	0.41
Burirhat	Year1	10.84	-0.08
Burirhat	Year 2	10.72	-0.02
Burirhat	Year 3	10.50	-0.12
Jessore	Year1	9.75	-0.48
Jessore	Year 2	9.61	-0.44
Jessore	Year 3	9.43	-0.37
Hathazari	Year1	8.99	0.59
Hathazari	Year 2	8.95	0.44
Hathazari	Year 3	8.96	0.43

The AMMI biplot provides a visual expression of the relationships between the first interaction principal component axis (IPCA1) and means of genotypes and environments (Fig.1) with the biplot accounting up to 97.5% of the treatment sum of squares. The IPCA1 was highly significant and explained the interaction pattern better than other interaction axes. The mean genotypes or environments in AMMI biplot located on the same parallel line, relative to the ordinate, have similar yield, while those located on the right side of the center of the axis has higher yields than those on the left hand side (Fig. 1). The biplot showed four grouping of genotypes Modhu-2, HP-555, Heera-405 and Five star, low yielding and unstable, 740, G-1921, HIC-999, HIC-32 and KH-101 are low yielding but moderately stable, Pacific-60, NK-46, BHM-5, BHM-3 and Nath Samrat, high yielding and stable hybrids. NK-40 is the highest yielder but highly unstable.

Since IPCA2 scores also play a significant role in explaining the GEI, the IPCA1 scores were plotted against the IPCA2 scores for further explore adaptation (Fig. 2). According to figure 2, the hybrids KH101, Five Star, Modhu-2 and NK-40 are unstable due to their dispersed position. Nath Samrat, Y-367, NK-46, Laxmi999 and Pacific-60 showed to be more stable when plotting the IPCA1 and IPCA2 scores.

Genotypes with IPCA1 scores near zero had little interaction across environments while genotypes with very high IPCA1 values had considerable interactions across environments. Of the 20 genotypes, six had negligible interactions characterized by Nath Samrat, King-999, Y-367, NK-46, Laxmi999 and Pacific-60 (Table 5) and are relatively stable showing broad adaptation across environments. Five genotypes with higher IPCA scores were highly interactive and were unstable across environments; these were Modhu-2, HP-555, HIC999 and KH101. The underlying causes of the interaction observed can therefore be based on both the genetic differences between these genotypes and the different environments [12]. Burirhat was more stable than Jessore and had the best performances for grain yield. Both locations were relatively stable environments and highly productive for maize grain yield. Gazipur and Hathazari were characterized with lower grain yield that was mainly due to edaphic and harsh climatic condition experienced there.

CONCLUSION

The AMMI statistical model has been used to diagnose the G×E interaction pattern of grain yield of hybrid maize. Genotypes Nath Samrat, Y-367, NK-46, BHM-5 and Pacific-60 showed broad adaptation with high yield. They were hardly affected by GEI and thus will perform well across a wide range of environments. Burirhat with a relatively stable genotype performance could be regarded as good selection site for identifying broad based and adaptable maize genotypes and other improvement work on maize.

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