academicJournals

Vol. 12(37), pp. 2795-2806, 14 September, 2017
DOI: 10.5897/AJAR2017.12314
Article Number: 9496E5565977
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Stability analysis for yield and yield contributing characters in hybrid maize (*Zea mays* L.)

M. Q. I. Matin[1*], Md. Golam Rasul[2], A. K. M. Aminul Islam[2], M. A. Khaleque Mian[2], J. U. Ahmed[3] and M. Amiruzzaman[1]

[1]Plant Breeding Division, Bangladesh Agricultural Research Institute (BARI), Gazipur City, Bangladesh.
[2]Department of Genetics and Plant Breeding, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh.
[3]Department of Crop Botany, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh.

Received 15 March, 2017; Accepted 4 July, 2017

Twenty one hybrids along with two check varieties of maize were assessed for genotype environment interaction (GEI) and stability for selection of the best hybrid maize in three different Agro-Ecological Zones (AEZ) of Bangladesh during rabi season 2014/2015. The experiment was laid out in Randomized Complete Block Design with 3 replications. The additive main effects and multiplicative interaction (AMMI) model was used to analyze the genotype-environment interaction over three locations to select the hybrids having higher yield (yld) and other potential attributes. The mean sum of square for genotypes was highly significant for the studied characters. Similarly, environmental variances were also highly significant for all characters. Variances due to genotype × environment interaction were highly significant for cob length and thousand seed weight (TSW). AMMI Component 1 showed variation for TSW. But AMMI Component 2 and G×E (Linear) revealed insignificant variation for all the characters. The highly significant effects of environment indicated high differential genotypic response across the different environments. The environments of Gazipur (Ij=-1.42) and Barisal (Ij=-0.068) were poor but Rangpur (Ij=1.49)) was a favourable environments due to positive environmental index for tested maize hybrids. Considering the mean, bi and S^2di for all the parameters, it was evident that all the genotypes showed different response of adaptability under different environmental conditions. Among the hybrids , WL4×WL5, WL1×WL3, WL2×WL3, WL1×WL4 and the check NK 40 exhibited the higher grain yield; bi~1 and S^2di~0 indicated that these hybrids were stable across the environment. All the hybrids showed insignificant values for regression co-efficient and also deviation from regression except WL1×WL5. The AMMI biplot showed four grouping of genotypes having none of them, low yielding and unstable; one hybrid was low yielding but moderately stable; eight were high yielding and stable hybrids, and fourteen were high yielder but highly unstable.**

Key words: Additive main effects and multiplicative interaction (AMMI) model, hybrid maize, stability analysis.

INTRODUCTION

Maize *(Zea mays* L.; 2n=20) is a monoecious, C4 plant which belongs to the tribe Maydeae of the family Poaceae. It is a tall, robust, annual, usually with a single dominant stem, although there may be few tillers in some genotypes and environments. Its leaves are districhous (two ranks of single leaves borne in alternate position)

with overlapping sheaths and relatively long broad leaves.

Maize is a crop with versatile nature. It grows in a wide range of landscapes and agro-ecological settings across the world. This crop has brought an agricultural revolution in the United States (U.S.) and is the first crop in the world that had high-yielding varieties within a decade of the Mendelian discovery in 1900 (Dasgupta, 2014).

Presently maize is cultivated in 165 countries on 184 million hectares, and has a production of 1,016 million tons (t) and productivity of 5.52 t/ha globally. In terms of production, India, with 9.4 million hectare, ranks fourth globally, after the USA States (35.5 million hectare), China (35.3 million hectare) and Brazil (15.4 million hectare) (Yadav et al., 2014)

DAE (2015) showed that production was 11.37, 13.70, 15.52, 19.54, 21.78 and 25.16 lac metric ton in the year of 2008-09, 2009-10, 2010-11, 2011-12, 2012-13 and 2013-14 with an area occupying 1.74, 2.02, 2.27, 2.83, 3.12 and 3.64 lac ha in Bangladesh. The yield (yld) was 6.53, 6.78, 6.84, 6.90, 6.98 and 6.91 t/ha respectively.

In Bangladesh, although maize can be grown in both kharif (monsoon) and rabi (winter) seasons but the potentiality of realizing very high yields is possible only during the rabi season. In kharif cultivation, farmers face various problems such as waterlogging, high infestation of diseases and pests, etc. Due to this reason it is now extensively being grown in *rabi* season under irrigated conditions. However, kharif cultivation is also possible in some suitable areas; the area of growth is now gradually increasing mainly due to T. Aman-potato-maize cropping pattern (Mondal et al., 2014)

Maize in Bangladesh is becoming an important crop in the rice based cropping system. It is the third important cereal crop after rice and wheat. In recent year's maize is gaining popularity among the farmers mainly due to high yield, more economic return and versatile uses; it is the highest yielding grain crop having multiple uses. The need for demand of maize is increasing gradually. The area and production of maize is increasing day by day in Bangladesh and it continues to expand rapidly at an average rate of 20% year^{-1} (CIMMYT, 2008).

Stability refers to the consistency of phenotype in varying environment. It is one of the most important properties of a genotype to be released as a variety for wide cultivation. For quantitative traits like yield the relative performance of different genotypes often varies from one environment to another. Thus, genotype×environment interaction does exist when phenotypic response made by a change in environment is not the same for all genotypes (Comstock and Moll, 1963). Stability analysis helps to select genotypes adaptable for wide and specific environments and divides large geographical areas into subareas. It provides effective allocation of resources for testing genotypes across location years.

A commercial variety must have stable performance and broad adaptation over a range of environments in addition to high yield potential. But its evaluation becomes complicated due to genetic heterogeneity, a complex biological basis, and genotype × environment interactions (Austin and Lee, 1988). Thus, genotype × environment interaction limits the effectiveness of selection when selection is done based only on mean yields (Dehganpour and Moghadam, 1999). The potential of genotypes and stability of their performance can be judged by multi environment testing (Mahajan and Khehra, 1992). It is more practical to develop and release varieties which are adapted to more than a single environment and can be successfully grown over a range of environments.

The analysis of G×E, therefore, 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 (AMMI) model 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 (Gauch, 1993). Considering these the experiment was laid out with the following objectives:

(i) To estimate G×E interaction of single cross hybrids and
(ii) To identify stable single cross hybrids for yield and yield related characters.

MATERIALS AND METHODS

The experiment was carried out at three different Agro -Ecological Zones (AEZ) of Bangladesh such as Gazipur, Barisal and Rangpur during rabi season 2014/2015. Twenty one hybrids and two check varieties were evaluated in this study. The experiment was laid out in randomized complete block design with 3 replications. The twenty one hybrids were developed from seven parental lines using diallel mating without the reciprocals during the rabi season in 2012 to 2013. The source materials were from both BARI and CIMMYT such as WL1=BIL20, WL2=BML36, WL3=BIL77, WL4=BIL106, WL5=CLQRCY44, WL6=BIL79 and WL7=BIL 31. The hybrids developed through diallel mating design were as follows: WL1×WL2, WL1×WL3, WL1×WL4, WL1×WL5, WL1×WL6, WL1×WL7, WL2×WL3, WL2×WL4, WL2×WL5, WL2×WL6, WL2×WL7, WL3×WL4, WL3×WL5, WL3×WL6, WL3×WL7, WL4×WL5, WL4×WL6, WL4×WL7,WL5×WL6, WL5×WL7 and WL6×WL7.

Seeds of each entry were sown in 2 rows, 4 m long plots with 60 and 20 cm spacing between rows and hills, respectively. Seeds

*Corresponding author. E-mail: quamrul_islam76@yahoo.com.

Table 1. Full joint analysis of variance including the portioning of the G×E interactions of maize hybrids.

Source of variation	Mean sum of squares				
	df	CL (cm)	CD (cm)	TSW (g)	Yield (t/ha)
Genotype (G)	22	7.686**	0.149**	1516.07*	4.802**
Environments (E)	2	671.309**	4.305**	21519**	48.505**
Interaction G×E	44	1.188**	0.015	1445.51*	0.777
AMMI Component 1	23	2.259	0.026	1825.88**	1.001
AMMI Component 2	21	0.016	0.026	1028.91	0.532
G×E (Linear)	22	2.313	0.025	1106.18	0.545
Pooled deviation	22	0.064	0.053	1784.83**	1.009
Pooled Error	136	2.017	0.049	850.872	1.047

CL, Cob length; CD, Cob diameter; TSW, Thousand seed weight. *Significant at 5% level; **Significant at 1% level.

were sown at Gazipur on 24 November, Barisal on 27 November, Rangpur 1 December. One healthy seedling per hill was kept after thinning. Fertilizers were applied at the rate of 250, 55, 110, 40, 5 and 1.5 kg/ha of N, P_2O_5, K_2O, S, Zn and B, respectively. Standard agronomic practices were followed (Quayyum, 1993) and plant protection measures were taken as required. Two border rows at both end of each replication were used to minimize the border effect. Data on cob length (CL), cob diameter (CD), thousand seed weight (TSW) and yield (t/ha) were recorded. All the plants in two rows were considered for plot yield and converted to t/ha.

The analysis of variance (ANOVA) was used and the GE interaction was estimated by the AMMI model (Zobel et al., 1988). In this procedure, the contribution of each genotype and each environment to the GE interaction was assessed by use of the biplot graph display in which yield means were plotted against the scores of the first principal component of the interaction (IPCA1). The computational program for AMMI analyses was supplied by Duarte and Vencovsky (1999). The stability parameters, regression coefficient (bi) and deviation from regression (S^2di) were estimated according to Eberhart and Russel (1966). Significance of differences among bi value and unity was tested by t-test while between S^2di and zero by F-test. All the data were processed and analyzed using Cropstat 7.2 program and PB Tools.

RESULTS AND DISCUSSION

Analysis of variance

Twenty one single cross maize hybrids and two check hybrids [BARI Hybrid Maize7 (BHM 7) and NK 40] were evaluated in three AEZ for four characters. The combined analysis of variance for four characters was presented in Table 1. The mean square for genotypes was highly significant for the characters studied. Similarly, environmental variances were also highly significant for all characters. Variances due to genotype × environment interaction were highly significant for cob length and TSW. AMMI Component 1 showed variation for TSW. But AMMI Component 2 and G×E (Linear) revealed insignificant variation for all the characters. The pooled deviation (nonlinear portion of variance) which is unpredictable portion of G×E interaction was significant for only TSW. The highly significant effects of environment indicated high differential genotypic response across the different environments. Environment relative magnitude was much higher than the genotypic effect, suggesting that performance of each genotype was influenced more by environmental factors. Significant differences in Genotype (G), Environments (E), Interaction G×E and Pooled deviation of maize were also recorded in the studies of Shiri (2013), Patel and Kathiria (2016), Banik et al. (2010), Lata et al. (2010), Miah et al. (2011), Islam et al. (2011), Rahman et al. (2010), Fan et al. (2007), Akbar et al. (2009) and Kaundal and Sharma (2006).

Cob length (cm)

Cob length (cm) along with the value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) were presented in Table 2. The environmental mean and genotypic mean ranged from 18.91 to 28.9 and 19.29 to 28.15 cm, respectively.

The highest overall mean for CL was recorded in WL6×WL7 (28.15 cm) followed by WL3×WL4 (26.16 cm), WL1×WL7 (26.12 cm) and WL3×WL6 (26.03 cm) and WL4×WL6 (25.59 cm) indicating dwarf hybrids. The lowest CL was found in WL1×WL5 (19.29 cm).

Thirteen hybrids including one check (BHM 7) showed positive phenotypic index while the other ten hybrids including the check (NK 40) had negative phenotypic index for CL. Thus, positive phenotypic index represented higher yielder and negative index represented lower yielder hybrids.

Among the twelve, nine hybrids such as WL6×WL7, WL3×WL4, WL1×WL7, WL3×WL6, WL2×WL3, WL2×WL6, WL2×WL5, WL1×WL2 and WL1×WL3 having positive phenotypic index, coupled with near unit regression co-efficient and non-significant deviation from regression recorded stable. Though the hybrid WL4×WL6 had positive phenotypic index, deviation from regression (S^2di)=0, but the regression coefficient (bi) was significant, so it was the unstable one.

Again, positive and negative environmental index (Ij)

Table 2. Stability analysis for cob length (cm) of maize hybrids over three environments.

Entry	CL (cm)						
	Location			Overall mean	P. Index (Pi)	bi	S^2di
	Gazipur	Barisal	Rangpur				
WL1×WL2	28.22	20.3	26.86	25.13	0.03	0.78	0.03
WL1×WL3	30.33	17.96	28.97	25.75	0.66	1.26	0.09
WL1×WL4	27.11	20.32	25.85	24.43	-0.66	0.67	0.05
WL1×WL5	22.56	14.13	21.18	19.29	-5.81**	0.84	0.02
WL1×WL6	29.78	19.3	28.2	25.76	0.67	1.05	0.00
WL1×WL7	30.45	18.83	29.08	26.12	1.03	1.18	0.05
WL2×WL3	29.33	20.48	27.97	25.93	0.83	0.88	0.01
WL2×WL4	27.33	18.48	25.97	23.93	-1.17	0.88	0.01
WL2×WL5	30.11	18.66	28.75	25.84	0.74	1.16	0.04
WL2×WL6	29.33	20.5	27.97	25.93	0.84	0.88	0.01
WL2×WL7	27.67	18	26.63	24.1	-0.99	0.98	0.07
WL3×WL4	30.43	18.98	29.07	26.16	1.07	1.16	0.04
WL3×WL5	29.99	16.67	28.6	25.09	-0.07	1.36	0.15
WL3×WL6	30.33	18.8	28.95	26.03	0.94	1.17	0.04
WL3×WL7	28	19.48	26.63	24.7	-0.39	0.85	0.01
WL4×WL5	28.33	18.47	26.63	24.48	-0.61	0.98	0.05
WL4×WL6	30	18.47	28.31	25.59	0.50	1.15*	0.00
WL4×WL7	27.11	19.17	25.75	24.01	-1.08	0.79	0.03
WL5×WL6	29.89	19.3	28.52	25.9	0.81	1.07	0.01
WL5×WL7	27.78	18.63	26.07	24.16	-0.93	0.90	0.09
WL6×WL7	33	19.83	31.63	28.15	3.06**	1.34	0.15
BHM-7	29.99	19.5	28.62	26.04	0.94	1.06	0.01
NK 40	27.54	20.65	25.68	24.62	-0.47*	0.65	0.44
Mean	28.9	18.91	27.47	-	-	-	-
E. Index(Ij)	3.80**	-6.18**	2.38	-	-	-	-
LSD(0.05)	2.49	1.94	2.53	-	-	-	-

reflects the favourable environment and unfavourable environment for this character, respectively. The environment Gazipur (Ij =3.80) and Rangpur (Ij =2.38) were favourable for hybrids and Barisal (Ij = -6.18) was an unfavourable environments for cob length.

The regression coefficient (bi) and deviation from regression (S^2di) values of these hybrids ranged from 0.67 to 1.36 and 0.00 to 0.15, respectively.

Cob diameter (cm)

Cob diameter (cm) along with the value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) were presented in Table 3. The environmental mean and genotypic mean ranged from 4.10 to 4.95 and 3.83 to 4.75 cm. The highest overall mean for CD was recorded in WL3×WL4 and WL4×WL7 (4.75 cm) followed by WL2×WL3 (4.69 cm), WL4×WL6 (4.66 cm) and WL4×WL5 (4.56 cm) and WL1×WL3 (4.56 cm) higher yields of the hybrids. The lowest CD was found in WL1×WL5 (3.83 cm). Twelve hybrids including two checks showed positive phenotypic index while the other eleven hybrids had negative phenotypic index for CD. Thus, positive phenotypic index represented higher yield and negative index represented the lower yield hybrids.

Among the twelve, six hybrids such as WL4×WL7, WL3×WL4, WL2×WL3, WL3×WL6, WL1×WL3 and WL1×WL4 have positive phenotypic index, coupled with near unit regression co-efficient and non-significant deviation from regression recorded stable. Though the hybrid WL4×WL6 had positive phenotypic index, deviation from regression (S^2di)=0, but the regression coefficient (bi) was significant, so it was the unstable one according to Eberhart and Russel (1966).

Again, positive and negative environmental index (Ij) reflected the favourable environment and unfavourable environment for this character, respectively. The environment Barisal (Ij = 0.47) was favourable and Gazipur (Ij =-3.80) and Rangpur (Ij =-0.86) were unfavourable environments for this character of hybrids.

Table 3. Stability analysis for cob diameter (cm) of maize hybrids over three environments.

Entry	CL (cm)						
	Location			Overall mean	P. Index (Pi)	bi	S^2di
	Gazipur	Barisal	Rangpur				
WL1×WL2	3.96	5.03	4.28	4.42	-0.05	1.27	0.00
WL1×WL3	4.07	5.22	4.38	4.56	0.07	1.37	0.01
WL1×WL4	4.04	5.10	4.36	4.5	0.02	1.26	0.00
WL1×WL5	3.45	4.28	3.76	3.83	-0.65**	0.97	0.00
WL1×WL6	3.87	4.48	4.18	4.18	-0.31**	0.69	0.01
WL1×WL7	4.09	4.68	4.39	4.39	-0.09	0.67	0.01
WL2×WL3	4.42	4.90	4.74	4.69	0.21**	0.53	0.01
WL2×WL4	4.07	4.90	4.34	4.44	-0.04	0.98	0.00
WL2×WL5	3.94	4.75	4.26	4.32	-0.16	0.94	0.00
WL2×WL6	4.00	4.78	4.27	4.35	-0.13	0.92*	0.00
WL2×WL7	3.94	4.68	4.36	4.33	-0.15*	0.83	0.02
WL3×WL4	4.34	5.32	4.60	4.75	0.27**	1.17	0.00
WL3×WL5	4.07	4.55	4.34	4.32	-0.16*	0.54	0.01
WL3×WL6	4.23	5.17	4.53	4.64	0.16*	1.10	0.00
WL3×WL7	4.09	4.98	4.42	4.49	0.01	1.04	0.00
WL4×WL5	4.16	5.03	4.50	4.56	0.08	1.01	0.00
WL4×WL6	4.34	5.05	4.59	4.66	0.18*	0.83*	0.00
WL4×WL7	4.25	5.43	4.57	4.75	0.27**	1.41	0.01
WL5×WL6	4.17	4.85	4.19	4.4	-0.07	0.85	0.03
WL5×WL7	4.00	5.02	4.27	4.43	-0.05	1.21	0.01
WL6×WL7	4.02	5.22	4.34	4.52	0.04	1.43	0.01
BHM-7	4.55	5.37	4.86	4.92	0.45**	0.96	0.00
NK 40	4.16	5.05	4.52	4.57	0.09	1.04	0.00
Mean	4.10	4.95	4.39	-	-	-	-
E. Index(Ij)	-0.38**	0.47**	-0.86	-	-	-	-
LSD(0.05)	0.31	0.39	0.27	-	-	-	-

The regression coefficient (bi), deviation from regression (S^2di) values of these hybrids ranged from 0.53 to 1.41 and 0 to 0.03, respectively.

Thousand seed weight (TSW)

The thousand seed weight (TSW) along with the value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) were presented in Table 4. The environmental mean and genotypic mean ranged from 338.2 to 397.9 and 330.11 to 405.89 g.

In Gazipur, the highest TSW was found from WL1×WL7 (432 g) followed by WL1×WL6 (426.7 g) and WL1×WL3 (424 g) and WL3×WL5 (420 g). In Barisal, WL3×WL4 produced the highest TSW (457.7 g) followed by WL2×WL7 (447.7 g) and WL1×WL2 (442.7 g) in Rangpur the maximum production recorded in WL3×WL6 (377.7 g) which was identical with WL2×WL6 (368 g) and WL1×WL2 (364.7 g). But the cross WL1×WL5 produced the lowest TSW in Gazipur and Rangpur. The hybrid WL1×WL6 was the lowest yielder in Barisal.

Eleven hybrids including one check NK 40 showed positive phenotypic index while the other eleven genotypes had negative phenotypic index for yield. Thus, positive phenotypic index revealed the higher TSW and negative index represented the lower TSW among the genotypes. Again, positive and negative environmental index (Ij) reflected the rich or favourable and poor or unfavourable environments for this character, respectively. Thus the environment of Gazipur and Barisal were rich whereas Rangpur was negative environments for this character. Barisal was highly suitable for hybrid maize cultivation followed by Gazipur.

The regression coefficient (bi) deviation from regression (S^2di) values of these genotypes ranged from -0.02 to 2.04 and 33.11 to 10457.82, respectively. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di three parameters, it was evident that all the genotypes showed different response of adaptability under different environmental

Table 4. Stability analysis for TSW (g) of maize hybrids over three environments.

Entry	TSW (g)						
	Location			Overall mean	P. Index (Pi)	bi	S^2di
	Gazipur	Barisal	Rangpur				
WL1×WL2	373.3	442.7	364.7	393.56	21.56	1.12	1327.39
WL1×WL3	424.0	342.7	326.7	364.44	-7.56	0.63	4704.03
WL1×WL4	377.0	390.0	273.7	346.89	-25.11	2.04	310.58
WL1×WL5	330.7	357.7	302.0	330.11	-41.89	0.89	65.72
WL1×WL6	426.7	285.0	328.7	346.78	-25.22	-0.19	10457.82
WL1×WL7	432.0	367.7	369.0	389.56	17.56	0.25	2589.47
WL2×WL3	384.0	427.7	307.7	373.11	1.11	1.98	34.88
WL2×WL4	365.3	387.7	366.0	373.00	1.00	0.30	157.93
WL2×WL5	402.7	352.7	344.0	366.44	-5.56	0.37	1754.12
WL2×WL6	341.3	375.0	368.0	361.44	-10.56	-0.02	630.74
WL2×WL7	382.7	447.7	362.7	397.67	25.67	1.26	979.76
WL3×WL4	392.0	457.7	368.0	405.89	33.89	1.34	943.09
WL3×WL5	420.0	360.0	329.0	369.67	-2.33	0.81	3048.34
WL3×WL6	330.7	432.7	377.7	380.33	8.33	0.56	4619.26
WL3×WL7	397.3	410.0	392.0	399.78	27.78	0.27	33.11
WL4×WL5	357.3	400.0	350.0	369.11	-2.89	0.72	481.35
WL4×WL6	345.3	396.7	289.7	343.89	-28.11	1.71	229.02
WL4×WL7	381.3	435.0	327.7	381.33	9.33	1.71	285.97
WL5×WL6	302.7	410.0	311.7	341.44	-30.56	1.32	3818.19
WL5×WL7	417.3	402.7	374.0	398.00	26	0.58	344.72
WL6×WL7	338.7	415.0	348.0	367.22	-4.78	0.89	1993.62
BHM-7	386.7	417.7	238.3	347.56	-24.44	3.10	340.16
NK 40	428	437.7	360.7	408.78	36.78**	1.35	117.06
Mean	379.9	397.9	338.2	-	-	-	-
E. Index(Ij)	7.87	25.88**	-33.75	-	-	-	-
LSD (0.05)	64.83	49.86	18.56	-	-	-	-

conditions. Among the hybrids , WL3×WL4, WL3×WL7, WL5×WL7, WL1×WL2, WL1×WL7 and check NK 40 exhibited the higher TSW, bi~1 and S^2di~0 indicating that the hybrids were stable across the environment according to Eberhart and Russel (1966).

Grain yield (t/ha)

The grain yield along with the value of phenotypic indices (Pi), regression coefficient (bi) and deviation from regression (S^2di) were presented in Table 5. The environmental mean and genotypic mean ranged from 7.58 to 10.48 t/ha and 3.94 to 10.49 t/ha, respectively.

In Gazipur, the highest yield was found from WL1×WL6 (9.61 t/ha) followed by WL4×WL5 (9.02 t/ha) and WL3×WL5 (8.71 t/ha). In Barisal, WL4×WL5 produced the highest yield (10.61 t/ha) followed by WL1×WL4 (10.28 t/ha) and WL2×WL7 (10.22 t/ha). The maximum production recorded in WL4×WL5 (11.83 t/ha) in Rangpur which was identical with WL1×WL3 (10.82 t/ha) and WL1×WL4 (10.28 t/ha). But the cross WL1×WL5 (3.61-4.31 t/ha) produced the lowest yield in all three locations.

Thirteen hybrids showed positive phenotypic index while the other eight genotypes had negative phenotypic index for yield. Thus, positive phenotypic index represented the higher yield and negative index represents the lower yield among the genotypes. Again, positive and negative environmental index (Ij) reflected the rich or favourable and poor or unfavourable environments for this character, respectively. Thus the environment of Gazipur and Barisal were poor whereas Rangpur was positive environments for hybrid maize production. Rangpur was highly suitable for hybrid maize cultivation followed by Barisal.

The regression coefficient (bi), deviation from regression (S^2di) values of these genotypes ranged from 0.242 to 1.924 and 0.00 to 4.17, respectively. These differences in bi values indicated that all the genotypes responded differently to different environments. Considering the mean, bi and S^2di three parameters, it was evident that all the genotypes showed different response of adaptability under different environmental

Table 5. Stability analysis for yield (t/ha) of maize hybrids over three environments.

Entry	Yield (t/ha)						
	Location			Overall mean	P. Index (Pi)	bi	S^2di
	Gazipur	Barisal	Rangpur				
WL1×WL2	7.72	10.00	10.05	9.26	0.26	0.784	0.96
WL1×WL3	8.38	10.13	10.82	9.78	0.78	0.829	0.25
WL1×WL4	8.02	10.28	10.28	9.53	0.53	0.758	0.96
WL1×WL5	3.61	3.91	4.31	3.94	-5.05**	0.242*	0.00
WL1×WL6	9.61	7.92	11.35	9.63	0.63	0.642	4.17
WL1×WL7	8.01	7.50	10.53	8.68	-0.31	0.894	1.89
WL2×WL3	7.80	9.45	11.23	9.49	0.50	1.181	0.00
WL2×WL4	6.63	9.23	10.15	8.67	-0.32	1.195	0.62
WL2×WL5	8.05	7.32	10.95	8.77	-0.22	1.034	2.87
WL2×WL6	6.60	6.59	10.30	7.83	-1.16*	1.304	1.99
WL2×WL7	7.37	10.22	10.23	9.28	0.28	0.961	1.54
WL3×WL4	7.81	9.42	10.96	9.40	0.40	1.084	0.01
WL3×WL5	8.71	8.80	10.94	9.48	0.49	0.784	0.59
WL3×WL6	7.62	9.08	10.25	8.98	-0.01	0.904	0.04
WL3×WL7	6.55	8.63	10.51	8.56	-0.43	1.361	0.04
WL4×WL5	9.02	10.61	11.83	10.49	1.49**	0.961	0.05
WL4×WL6	6.33	8.03	11.15	8.50	-0.49	1.67	0.19
WL4×WL7	7.10	9.82	10.84	9.25	0.26	1.272	0.64
WL5×WL6	5.05	9.81	10.73	8.53	-0.46	1.924	3.00
WL5×WL7	7.54	9.27	10.44	9.08	0.09	0.993	0.10
WL6×WL7	8.67	9.23	11.07	9.66	0.66	0.836	0.21
BHM-7	8.31	10.38	9.96	9.55	0.56	0.546	1.13
NK 40	9.74	9.66	12.13	10.51	1.52**	0.842	0.94
Mean	7.58	8.93	10.48	-	-	-	-
E. Index(Ij)	-1.42**	-0.068	1.49	-	-	-	-
LSD(0.05)	1.63	2.08	1.18	-	-	-	-

conditions. Among the hybrids , WL4×WL5, WL1×WL3 , WL2×WL3, WL1×WL4 and check NK 40 exhibited the higher grain yield, bi~1 and S^2di~0 indicated that the hybrids are stable across the environment. All the hybrids showed insignificant values for regression co-efficient except WL1×WL5 and also deviation from regression.

In the present study, it was found that the level of stability for a particular genotype was not similar for all characters. Grada and Ciulca (2012), Patel and Sanghi (1989) and Sharma and Hore (1991) reported that the levels of stability were not similar to any genotype for all characters, no uniform pattern of association between stability of yield and yield components and stress components could be established for individual genotype.

Figure 1 represents the Q-Q plot, histogram and scatter plot which revealed distribution pattern of the data. Figure 2 indicated yield range of hybrid maize.

AMMI biplot

The AMMI biplot provides a visual expression of the relationships between the first interaction principal component axis (IPCAI) and means of genotypes and environments (Figure 3) with the biplot accounting up to 95.3% 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, had similar yield, while those located on the right side of the center of the axis had higher yields than those on the left hand side (Figure 1).

The biplot showed four grouping of genotypes having none of them, low yielding and unstable; 4(WL1×WL5) was low yielding but moderately stable, 17(WL4×WL6), 21(WL6×WL7), 13(WL3×WL5), 10(WL2×WL6), 6(WL1×WL7), 9(WL2×WL5), 5(WL1×WL6) and 23(NK 40-check) were high yielding and stable hybrids. 15(WL3×WL7), 14(WL3×WL6), 20(WL5×WL7), 12(WL3×WL4), 7(WL2×WL3), 8(WL2×WL4), 2(WL1×WL3), 16(WL4×WL5), 22(BHM7-check), 4(WL1×WL5), 1(WL2×WL3), 18(WL4×WL7), 11(WL2×WL7) and 19(WL5×WL6) were high yielder but highly unstable.

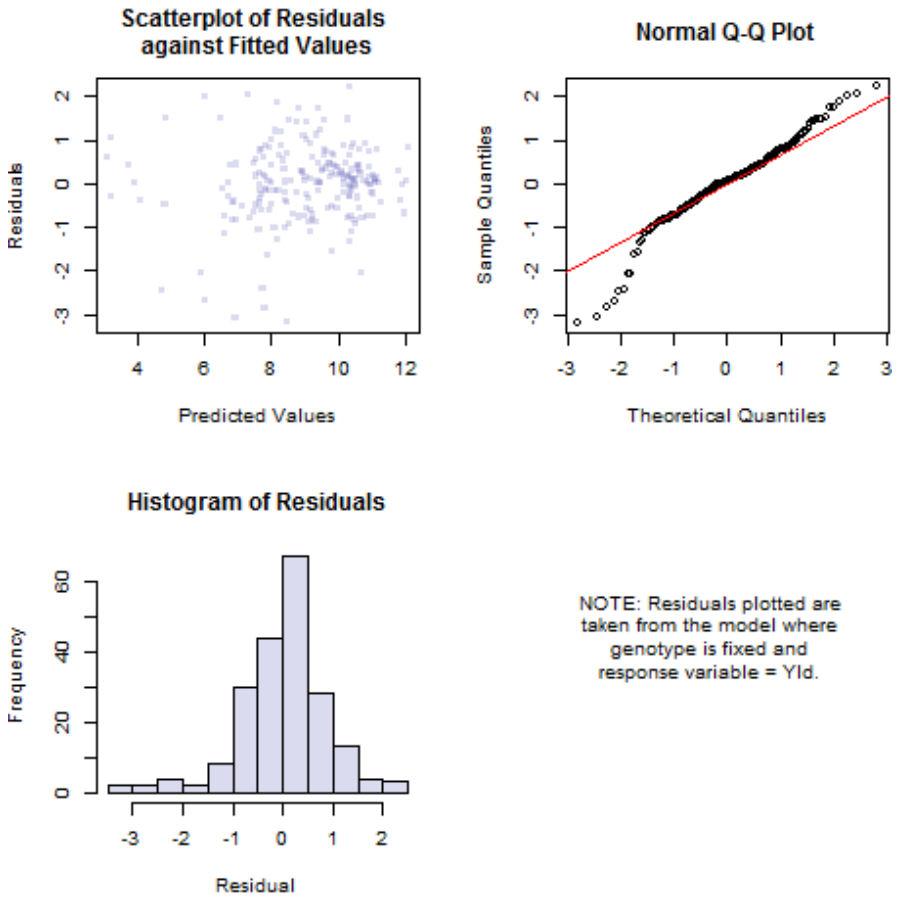

Figure 1. Normality test of the data for yield of maize.

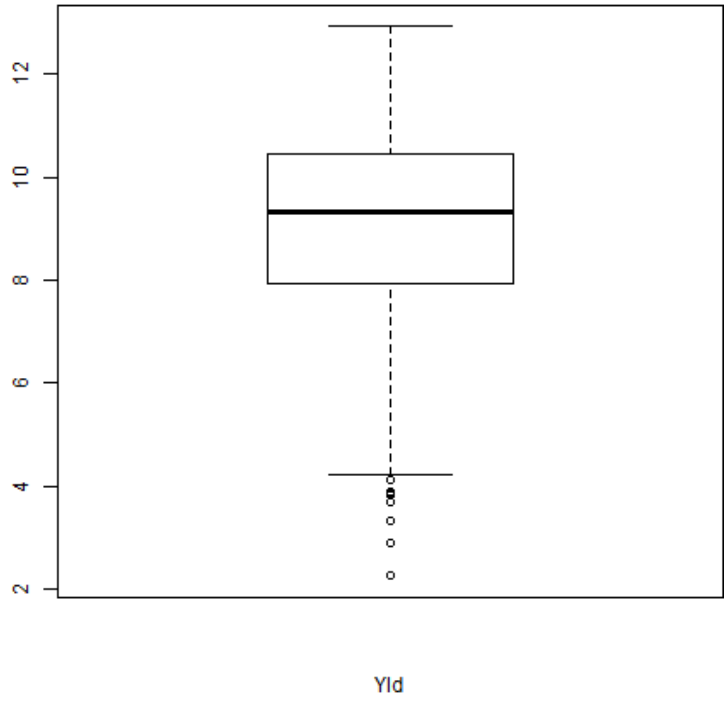

Figure 2. Boxplot showing yield range of hybrid maize.

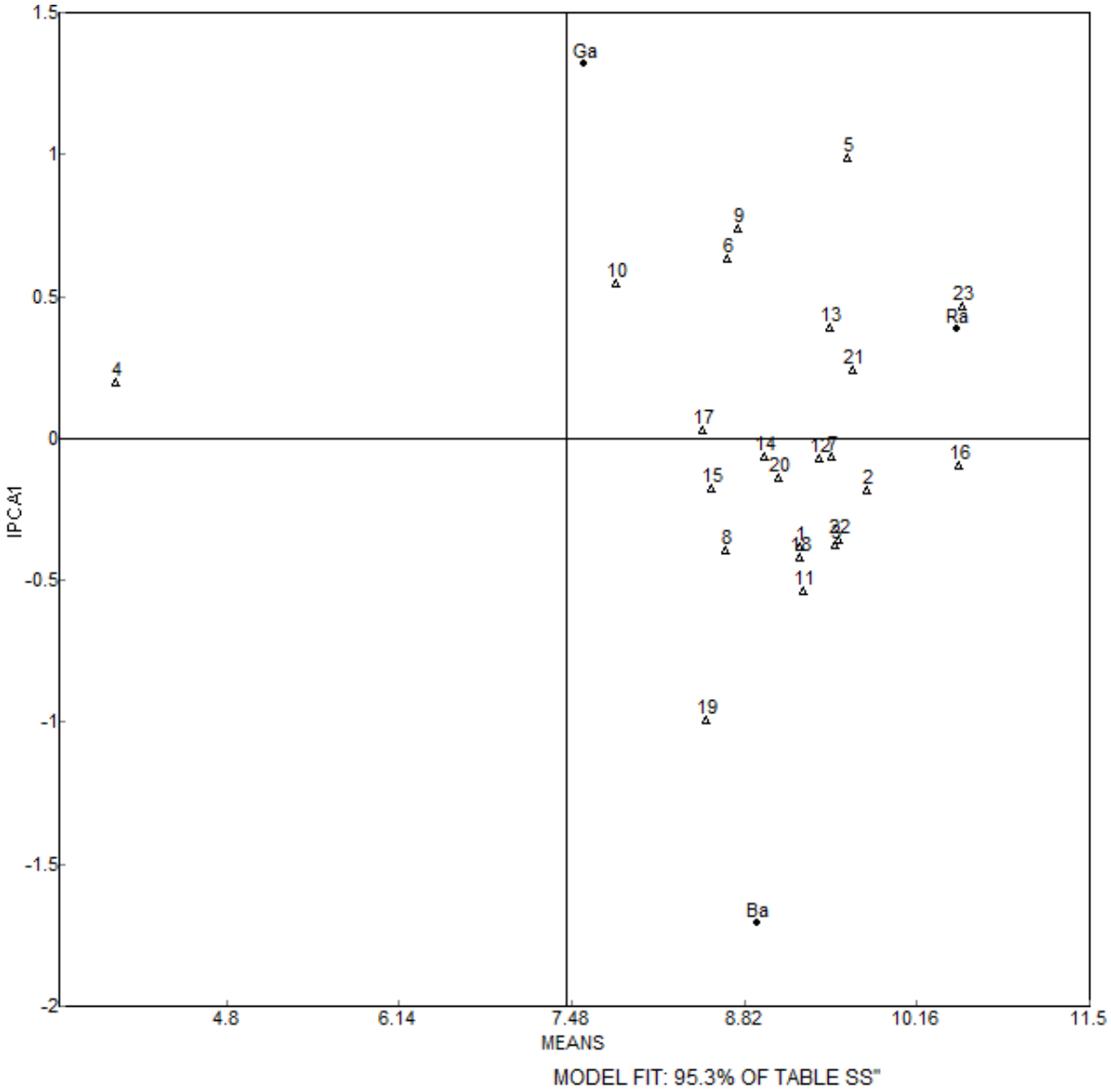

Figure 3. Biplot of the first AMMI interaction (IPCA1) score (Y-axis) plotted against mean yield (X-Axis) of twenty three maize hybrids and three environments.

Since IPCA2 scores also played a significant role in explaining the GEI; the IPCA1 scores were plotted against the IPCA2 scores for further exploring adaptation (Figure 4). According to Figure 4, the hybrids 19 (WL5×WL6), 22(BHM7- check), 4 (WL1×WL5), 17(WL4×WL6), 10(WL2×WL6) and 11 (WL2×WL7) were unstable due to their dispersed position. 23 (NK 40-check), 10(WL2×WL6), 16(WL4×WL5), 12(WL3×WL4), 7(WL2×WL3), 6(WL1×WL7), 8(WL2×WL4), 21(WL6×WL7), 13 (WL3×WL5) and 5(WL1×WL6) showed more stability when plotting the IPCA1 and IPCA2 scores. The present findings were in accordance with Banik et al. (2010) and Oliveira et al. (2010).

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 23 hybrids, six had negligible interactions characterized by 16(WL4×WL5), 20(WL5×WL7), 14(WL3×WL6), 12(WL3×WL4), 21(WL6×WL7) and 13(WL3×WL5) and were relatively stable showing broad adaptation across environments. Six hybrids with higher IPCA scores were highly interactive and were unstable across environments; such as 19(WL5×WL6), 4(WL1×WL5), 22((BHM7-check)), 5(WL1×WL6), 10(WL2×WL6) and 11(WL2×WL7). The underlying causes of the interaction observed can therefore be based on both the genetic differences between these genotypes and the different environments (Wallace et al., 1995).

As shown in Figure 5, criss cross line reflected high

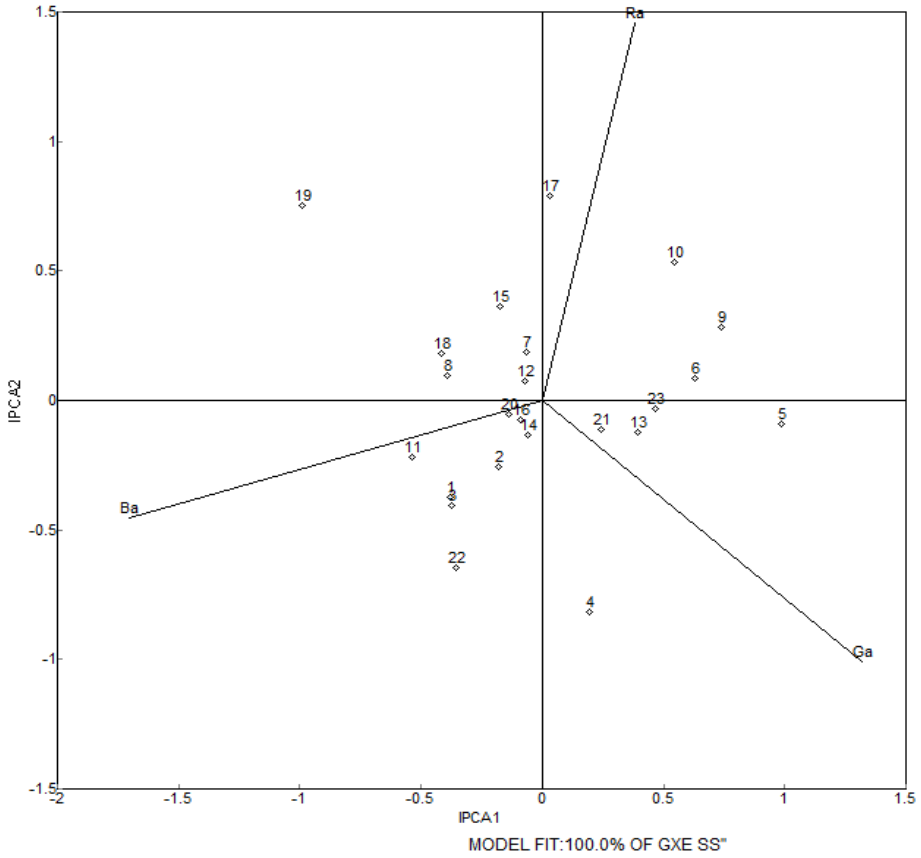

Figure 4. Biplot of the first AMMI interaction (IPCA2) score (Y-axis) plotted against AMMI interaction (IPCA1) (X-Axis) of twenty three maize hybrids and three environments.

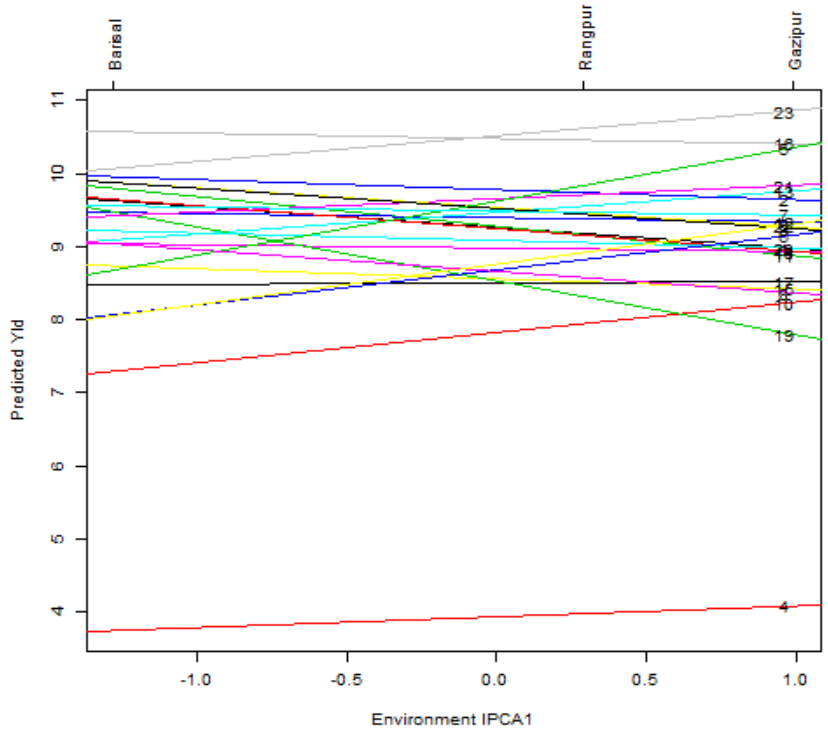

Figure 5. Adaptation map of maize hybrids in three locations.

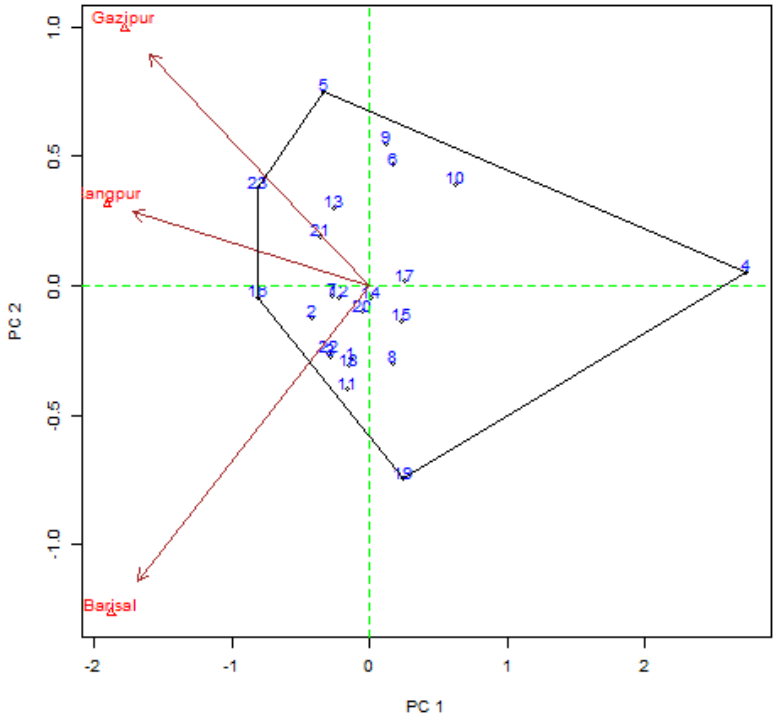

Figure 6. GGE biplot showing 'mean vs. stability' of 23 hybrids across three environments.

interaction with environment but parallel line less interaction. The hybrid 23(NK40), 18(WL4×WL7), 5(WL1×WL6) and 19(WL5×WL6) were less influenced by the environment comprised of higher yield. But the entry 4(WL1×WL5) had the least yield.

Figure 6 showed which won where. The hybrids 23(NK40), 5(WL1×WL6), 18(WL4×WL7) and 19(WL5×WL6) were stable in all locations; 23(NK40) was suitable for Gazipur and Rangpur location and 18(WL4×WL7) best adapted to Rangpur and Barisal location. The hybrid 4(WL1×WL5) was unstable in all locations.

Conclusion

Among the hybrids , WL4×WL5, WL1×WL3, WL2×WL3, WL1×WL4 and check NK 40 exhibited higher grain yield; bi~1 and S^2di~0 indicated that the hybrids found stable across the environment. All the hybrids showed insignificant values for regression co-efficient and also deviation from regression except WL1×WL5. The AMMI biplot showed four grouping of genotypes having none of them, low yielding and unstable; one hybrid was low yielding but moderately stable; eight hybrids including check NK 40 are high yielding and stable hybrids; 14 hybrids including BHM7-check were high yielder but highly unstable. Rangpur was highly suitable for hybrid maize cultivation followed by Barisal and Gazipur.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Akbar M, Saleem M, Ashraf MY, Hussain A, Azhar FM, Ahmad R (2009). Combining ability studies for physiological and grain yield traits in maize at two temperatures. Pak. J. Bot. 41(4):1817-1829.

Austin DF, Lee M (1988). Detection of quantitative trait loci for grain yield and yield components in maize across generations in stress and non-stress environments. Crop Sci. 38(5):1296-1308.

Banik BR, Khaldun ABM, Mondal AA, Islam A, Rohman MM (2010). Assessment of Genotype-by-Environment interaction using additive main effects and multiplicative interaction model (AMMI) in maize (*Zea mays* L.) hybrids. Acad. J. Pl. Sci. 3(4):134-139.

Comstock RE, Moll RH (1963). Genotype-environment interactions. Statistical Genotype and Plant Breeding. Nat. Acado Sci. Res. Counc. Pub. No. 982. Washington, D. C. pp.164-196.

CIMMYT (International Maize and Wheat Improvement Center) (2008). Achievements of the Bangladesh-CIMMYT partnership for agricultural research and development. CIMMYT-Bangladesh, Banani, Dhaka. pp. 1-9.

Dasgupta S (2014). Maize in Asia: Drivers of change. 12th Asian Maize conference and expert consultation on 'Maize for food, feed, nutrition and environmental security' 30 Oct- 1Nov, 2014. Bangkok, Thailand.

DAE (2015). Department of Agricultural Extension (DAE), Ministry of Agriculture, Khamarbari, Farmgate, Dhaka.

Dehganpour Z, Moghadam A (1999). Simultaneous selection for yield and stability in early and very early maturity hybrids of maize. Seed Pl. 15(3):206-217.

Duarte JB, Vencovsky R (1999). Interayao Gen6tipos ×Ambientes Uma Introduyao a Analise "AMMI". Serie Monografias, n.9. Sociedade Brasileira de Genetica, Ribeirao Preto.

Eberhart SA, Russel WA (1966). Stability parameters for comparing varieties. Crop Sci. 6(1):36-40.
Fan XM, Kang MS, Chen H, Zhang Y, Tan J, Xu C (2007). Yield stability of maize hybrids in multi- environment trials in Yunnan, China. Agron. J. 99:220-228.
Gauch HG (1993). Matmodel Version 2.0: AMMI and related analysis for two-way data matrices. Micro computer power, Ithaka, New York, USA.
Grada F, Ciulca S (2012). Evaluation of grain yield stability for some maize hybrids using regression analysis. J. Hortic. For. Biotechnol. 16(1):123-126.
Islam MA, Matin MQI, Alam A, Banik BR (2011). Evaluation of CIMMYT inbred (LETTLW) lines of maize. Annual Research Report, Plant Breeding Division, BARI, Gazipur-1701.
Kaundal R, Sharma BK (2006). Genotype × Environment interaction and stability analysis for yield and other quantitative traits in maize (*Zea mays* L.) under rainfed and high rainfall valley areas of the sub mountain. Res. Crops 7:171-180.
Lata S, Guleria S, Dev J, Kanta G, Sood BC, Kalia V, Singh A (2010). Stability analysis in maize (*Zea mays* L.) hybrids across locations. Electronic J. Plant Breed. 1(3):239-243.
Mondal MAA, Ahmed S, Amiruzzaman M, Talukdar MZA (2014). Maize in Bangladesh Trends, Prospects and Constraints. 12th Asian Maize conference and expert consultation on 'Maize for food, feed, nutrition and environmental security' 30 Oct- 1Nov, 2014. Bangkok, Thailand.
Miah MA, Matin MQI, Uddin S, Islam MA, Alam MZ (2011). Stability analysis in quality protein maize (QPM) inbred lines. Annual Research Report, Plant Breeding Division, BARI, Gazipur-1701.
Mahajan V, Khehra AS (1992). Stability analysis of kernel yield and its components in maize *(Zea mays* L.) in winter and monsoon seasons. Indian J. Genet. 52(1):63-67.
Oliveira RL, Pinho RGV, Balestre M, Ferreira DV (2010). Evaluation of maize hybrids and environmental stratification by methods AMMI and GGE biplot. Crop Breed. Appl. Biotechnol. 10:247-253.
Patel DR, Sanghi AK (1989). Stability analysis of oil and other characters in maize. BAU Res. J. 15(1):30-35.
Patel PC, Kathiria KB (2016). Stability analysis for quality traits in maize (*Zea mays* L.). Electron J. Plant Breed. 7(3):634-639.
Quayyum MA (1993). Bhuttar Chash Paddhati (in Bengali). In: Chowdhury MK, Islam MA (ed.). Bhuttar Utpadan O Babohar. Bangladesh Agricultural Research Institute, Gazipur. pp. 43-48.
Rahman H, Durreshawar S, Ali S, Iftekhar F, Khalil IH, Shah SMA, Ahmad H (2010). Stability analysis of maize hybrids across North West of Pakistan. Pak. J. Bot. 42(2):1083-1091.
Shiri MR (2013). Grain yield stability analysis of maize (*Zea mays* L.) hybrids under different drought Stress conditions using GGE biplot analysis. Cbjournal.spii.ir
Sharma SB, Hore DK (1991). Stability performance of maize (*Zea mays* L.) germplasm lines in acidic and phosphorus deficient soils. Indian J. Agric. Sci. 61(12):904-908.
Wallace DH, Oilstone KSY, Baudoin JP, Beaver J, Coyne DP, White JW, Zobel RW (1995). Photoperiod x Temperature Interaction Effects on the Days to Flowering of Beans *(Physaelous vulgaris* L) In: Handbook of Plant and Crop Physiology. Mohammed Pessaraki (Ed.) pp. 863-891.
Yadav OP, Karjagi GC, Kumar B, Jat SL, Chawla JS, Kaul J, Huda KS, Kumar P, Yadav P, Dhillon BS (2014). Maize improvement in India. 12th Asian Maize conference and expert consultation on 'Maize for food, feed, nutrition and environmental security' 30 Oct- 1Nov, 2014. Bangkok, Thailand.
Zobel RW, Wright AJ, Gauch HG (1988). Stability analysis of a yield trial. Agron. J. 80:388-393.