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AMMI AND GGE BIPLOT ANALYSIS FOR YIELD STABILITY OF PROMISING BREAD WHEAT GENOTYPES IN BANGLADESH

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Abstract

Identification of stable and high yielding varieties under different environmental conditions prior to release as a variety is the major steps for plant breeding. Eight promising wheat genotypes were evaluated against two standard checks across five locations under terminal heat stress condition. The experimental design was an RCBD with three replications in over one year. AMMI analyses exhibited significant ($p<0.01$) variation in genotype, location and genotype by location interaction with respect to grain yield. The ASV value revealed that GEN4, GEN9, and GEN8 were stable, while GEN5, GEN1, and GEN6 were the most sensitive genotypes. The GGE results also confirmed GEN3, GEN7, GEN8, GEN9 and GEN4 were the most stable cultivars. Five distant mega-environments were identified including Dinajpur and Jamalpur with GEN3, GEN7 and GEN8 as the most favorable, Joydebpur, Rajshahi and Jessore with GEN4 and GEN9 as the most favorable. Genotype GEN7 and GEN8 showed highly resistant to BpLB, GEN3 and GEN4 showed moderately resistance to BpLB, and GEN9 showed moderate susceptible to BpLB. On the other hand, these five genotypes performed resistance to leaf rust. The genotype GEN7 (BAW 1202) was released as BARI Gom 32. Considering all analysis, GEN3 (BAW 1194), GEN7 (BAW 1202) and GEN8 (BAW 1203) demonstrated more stable genotypes with high mean yield, resistant to BpLB and leaf rust. Thus it is indicated that these genotypes can be used as suitable plant material for future breeding programs.

Key words: GEI; GGE; AMMI; Multi-environment trials; Bread wheat; Bangladesh.

Abbreviations

GEI- Genotype-by-environment interaction; GGE-Genotype main effect and genotype x environment interaction; AMMI- Additive main effects and multiplicative interaction; ASV- AMMI stability value; BARI-Bangladesh agricultural research institute; BpLB- Bipolaris leaf blight; PCA- Principal component analysis; METs- Multi-environment trials; ANOVA- Analysis of variance; IPCA- Interaction principal component Axis; DLA-Diseased leaf area; TSS- Total sum of square; GESS- Genotype x environment sum of square; BAW- Bangladesh advanced wheat; ATC- Average tester coordinate; GGL- genotype main effect and genotype x location interaction.

Introduction

Among cereals consumed in Bangladesh, wheat ranks second after rice and its production is increasing rapidly. Wheat is grown in Bangladesh at a relatively high temperature than temperate climate with a short winter period. The minimum mean temperature of the coolest month, January in Bangladesh ranges from 17-19^{o}C. It is 1-2 degrees higher in December and February and 5-6 degrees higher in March and April (Barma *et al.*, 2011). Depending on altitude and mean temperature, Fischer & Beyerlee (1991) mentioned the winter of Bangladesh as a hot environment in global perspective. The optimum time of wheat planting in Bangladesh is 15-30 November for high grain yield. About 80-85% of wheat in Bangladesh is planted after transplanting aman rice and about 60% of wheat is planted late due to delayed harvesting of rice (Barma *et al.*, 2011). During grain filling stage of wheat, the late planted wheat often faces high-temperature stress, causing drastically yield reduction. There is a significant yield decline in Bangladesh, at the rate of 1.3% per day when plant late instead of optimum time (15-30 November) (Saunders, 1988). The top research priority has given on heat stress for major wheat growing locations of the developing countries including Bangladesh (Anon., 1995). Thus, in Bangladesh major emphasis has been given to breeding late or terminal heat tolerant wheat cultivars in the national wheat breeding program.

Spot blotch or Bipolaris leaf blight (BpLB) caused by *Bipolaris sorokiniana* (teliomorph: *Cochliobolus sativus*) is the most devastating disease of wheat in Bangladesh for its nature of damage and wide occurrence throughout the country. The pathogen also causes seedling blight, head blight and black point disease of wheat (Goswami & Kistler, 2004). Under the agro-climatic conditions of Bangladesh, late-sown wheat is affected more than the timely sown crop. The disease becomes more severe if the crop is lodged and rainfall occurs during grain filling period (Alam *et al.*, 1994). Leaf or brown rust caused by *Puccinia triticina* is also the most important disease of wheat in Bangladesh. The disease usually appears in mid February with increasing severity between mid and late March. Late-planted wheat is affected more than those planted in optimum times (15-30 November). The yield loses of wheat due to leaf rust generally below 10%, but can be increased up to 30% or more depending on the level of susceptibility, environmental conditions and the stage of crop development(Malaker & Reza, 2011; Singh *et al.*, 2002). Under the agro-climatic conditions of

Bangladesh, losses due to leaf rust would be significant if a susceptible variety is grown under terminal heat stress condition. Use of resistant variety is the most dependable and economic approach for the control of rust diseases (Alam *et al.*, 2013).

There are several statistical tools are available to analyze and determine the results of multi-location trials and GEI data (Malosetti *et al.*, 2013). However, there are two multivariate analysis such as Additive main effect and multiplicative interaction (AMMI) and genotype plus genotype by environment interaction (GGE) biplot analysis has been performed in this study. These two statistical tools (AMMI and GGE) have broader importance for agricultural researchers because they affect to any two-way data matrices. Crossa (1990) pointed out that the Additive main effect and multiplicative interaction (AMMI) model has proved as an important tool in diagnosing GEI patterns. AMMI analysis can also be used to find out the stability of the genotypes across locations using the PCA (principal component axis) scores and ASV (AMMI stability value). Moreover, the GGE model is a valuable method to analysis genotype and genotype by environment interaction which based on principal component analysis (PCA) to fully discover multi-environment trials (METs). GGE analysis partitions genotype plus genotype by environment interaction into principal components by singular value coalesce of environmentally centered yield data (Yan, 2001). The major objectives of the present study were to assess the stability and yield performance of promising wheat genotypes evaluated in multi-environmental conditions and discover stable high yielding candidate variety (ies) for possible release using various statistical tools.

Materials and Methods

Plant materials: Ten genotypes (Table 1) were used in this study, 8 (BAW1194, BAW1195, BAW1196, BAW1200, BAW1202, BAW1203, BAW1205 and BAW1206) of which were advanced lines developed by the national wheat breeding programme of Wheat Research Centre (WRC), BARI, whereas the other two genotypes were commercially popular mega varieties, used as checks, namely Shatabdi and BARI Gom 26 which were released in 2000 and 2010, respectively.

Table 1. The wheat germplasm used in the study.

Entry	Accession No.	Cross/Pedigree
GEN1	BAW 936 (check)	SHATABDI
GEN2	BAW 1064 (check)	BARI Gom 26
GEN3	BAW 1194	SHATABDI/ PRODIP BD(DI)1691S-0DI-6DI-0DI-0DI-2DI
GEN4	BAW 1195	G.162/BL1316//297/BL 1883 BD(JE)1446-0DI-1DI-0DI-0DI-6DI
GEN5	BAW 1196	A6/GLEN//NL297*2/LR25 BD02JA884S-0JA-1JA-6JA-4JA-3JA-3JA-5JA
GEN6	BAW 1200	MINIVET/PRODIP// SHATABDI BD(DI)1539T-0DI-7DI-0DI-0DI-3DI
GEN7	BAW 1202	SHATABDI/GOURAB BD(DI)1686S-0DI-1DI-0DI-0DI-3DI
GEN8	BAW 1203	SHATABDI/GOURAB BD(DI)1686S-0DI-1DI-0DI-0DI-3DI
GEN9	BAW 1205	SHATABDI/BAW 1037 BD(DI)1581S-0DI-14DI-010DI-1DI-0DI
GEN10	BAW 1206	PRODIP/BAW 451 BD(DI)1500S-0DI-11DI-010DI-010DI-1DI-0DI

Field methods and data collected: The experimental design was RCBD with 3 replicates at five locations viz., Dinajpur, Jamalpur, Jessore, Joydebpur and Rajshahi. Experimental seeds were sown under irrigated late sown condition to screen for the performance in terminal heat stress condition at each location. Seeds of each genotype were sown continuously in 5m long 8-rows plot with a row spacing of 20 cm on 24 December 2013 in Dinajpur and Joydebpur, 21 December 2013 in Jessore, 23 December 2013 in Jamalpur and 22 December 2013 in Rajshahi, respectively. Fertilizers were applied @ 100-27-50-20-1-4.5-5000 kg ha^{-1} as N-P-K-S-B-Zn-Cow, respectively. The trials were irrigated 3 times at tillering stage, booting stage and grain filling stage. The standard cultural management practices like hand weeding for weed control, proper drainage system to avoid water stagnant etc. were done. The data collected include grain yield, number of days to heading, number of days to maturity, number of grains per spike, number of spike m^{-1} and 1000- grains weight. At maturity, the middle five-meter long five rows were harvested to estimate yield. The grain yield (t ha^{-1}) data was estimated and calculated at 12% moisture.

AMMI and GGE biplot analysis: Combined ANOVA across environments was used and the GEI was estimated by the AMMI model (Zobel *et al.*, 1988). The contribution of a genotype and an environment were estimated in this model by GEI biplot graph display where yield means were plotted against the scores of the IPCA1 (Zobel *et al.*, 1988). Regression coefficient (bi), deviation from regression (S^2di) and the stability parameters were estimated according to Eberhart and Russell (1966). A significance of differences among bi value and unity was tested by using student´s t-test, between S^2di and zero by F-test (Eberhart & Russell, 1966). All the data were analyzed by using software Cropstat version 7.2.

There is no provision in the AMMI model to measure of quantitative stability, but the measurement of quantitative stability is necessary to quantify and rank genotypes according their yield stability. So, Purchase (1997) proposed the following equation:

$$ASV = \sqrt{\left[\frac{IPCA1 \, sum \; of \; squre}{IPCA2 \; sum \; of \; squre}(IPCA1 \; score)\right]^2 + [IPCA2 \; score]^2}$$

The grain yield data were analyzed for GE interaction using the GGE biplot analysis according to Yan (2001) and Yan & Kang (2003) (i) to show graphs as ‘‘which-won-where’’ patterns for multi-environment analysis, (ii) to make genotypes rank on the basis of yield and stability (iii) to compare different genotypes with an ideal genotype (iv) to evaluate given locations for the ability of discriminating and representativeness (v) to estimate the correlation between genotypes and test locations (vi) to estimate highest yield of rank genotypes relation to environment, and (vii) to select best locations relation to genotype with the highest-yielding performance.

Evaluation of disease reactions

Evaluation of wheat genotypes resistance to Bipolaris leaf blight (BpLB): All of these genotypes including resistant (Shatabdi) and susceptible (CIANO 79) checks were grown in one meter long two row-plots with 20cm spacing between rows and 30 cm between entries in Wheat Research Centre (WRC), Dinajpur on last week of December, 2013 with recommended agronomic practices for normal crop growth. Plants were inoculated by spraying with conidial suspension (10^4 conidia/ml water) of 15-day-old PDA culture of *B. sorokiniana* after heading and incubated under polyethylene cover for 48 hrs. Before covering, the plants were watered to maintain high humidity inside. Data on BpLB severity were recorded as percent diseased leaf area (% DLA) (Hetzler, 1992) from ten flag leaves of ten main tillers selected randomly in each plot. Disease assessment was done after 25 days of inoculation. The genotypes were graded for disease reaction based on % DLA (Sharma & Duveiller, 2003).

$$\% \; DLA = D_1/9 \; X \; D_2/9 \; X \; 100$$

where, D_1 = First digit, representing relative disease height
D_2 = Second digit, indicating disease severity on the foliage

Evaluation of wheat genotypes resistance to leaf rust: All the genotypes including susceptible (Morocco) and resistant checks (Shatabdi) were grown in one meter long two row-plots with 20 cm spacing between rows and 30 cm between entries in WRC, Dinajpur on 22nd December 2013. Susceptible variety Morocco was planted in two rows after each pair of test lines and the nursery was surrounded by spreader rows. Recommended agronomic practices were followed for normal crop growth. Test entries and spreader rows were inoculated by spraying with aqueous suspension of urediospores at booting stage of the crop. Disease assessment was done twice between early and soft dough stages following modified Cobb scale (Stubbs *et al.*, 1986) representing severity and infection types. Lines were graded into resistance category (Singh *et al.*, 2009) based on final disease severity.

Results and Discussion

Agronomic performance

Additive main effect and multiplication interaction (AMMI) analysis: Genotype, location and genotype by locations interaction were assessed by the additive main effect and multiplicative interaction (AMMI) model (Table 2). Variance analysis of AMMI model for grain yield showed significant effects for genotype, location and genotype by locations interaction. The effect of location was responsible for the largest part of the variation, tailed by genotype and genotype by location interaction. Tarakanovas and Ruzgas (2006) also found similar results in different wheat cultivars in Lithuania by AMMI analysis. The GEI was highly significant ($p<0.01$) accounting for 37.10% of the sum of squares implying the differential response of the genotypes to locations. The GEI was also partitioned into four parts of interaction principal component analysis axis (IPCA). The IPCA 1, IPCA 2 and IPCA 3 score were highly significant explaining 49.90%, 25.10% and 16.50% of the variability relating to GEI at late sown condition. The IPCA 4 was insignificant accounting for 6.60% of the variability.

The yield performances of the 10 genotypes for each environment as well as their average performance across five environments are presented in Table 3. All of these genotypes also performed the disease reactions (BpLB and leaf rust) in one location (Dinajpur). Significant ($p<0.01$) differences among genotypes were encountered at the location of Dinajpur, Joydebpur and Jessore but not at Jamalpur and Rajshahi. The check Shatabdi showed the highest yield in all sites except Dinajpur and Rajshahi. The other check BARI Gom 26 showed the lowest yield in all sites except Joydebpur. GEN4 was showed high yield in all sites and was leading at Jamalpur. The severity of BpLB expressed as % DLA on flag leaf under inoculated condition and ranged from 6% in check Shatabdi to 75% in susceptible CIANO 79. Based on disease severity of BpLB, three genotypes were resistant, three were moderately resistant, three were moderately susceptible and the rest two were highly susceptible. The severity of leaf rust under inoculated condition varied from 0 in check Shatabdi to 100S in Morocco. Among the genotypes, seven were resistant, two were moderately resistant and other two were susceptible (Table 3).

The genotypes showed significant ($p<0.01$) variation, considering the combined average performance of grain yield over environments. GEN3 and GEN7 gave the highest average yield, which was 4.391 and 4.342 t/ha, respectively. GEN9, GEN8 and GEN4 gave higher yield than check Shatabdi. The genotypes GEN10 and GEN5 showed the lowest yield level i.e., 3.57 t/ha.

Table 2. Mean squares from AMMI and the percentage of G x E explained by each IPCA for grain yield (t ha^{-1}) of 10 wheat genotypes grown at 5 environments (2013-2014) in Bangladesh.

Source of variation	df	Mean of square	F-value	Variations explained (%)
Genotypes (G)	9	0.432944**	23.94	29.40% of TSS
Environment (E)	4	1.107120**	61.23	33.50% of TSS
Interaction G X E (GEI)	36	0.136507**	7.55	37.10% of TSS
AMMI component 1	12	0.311749**	17.24	49.90% of GESS
AMMI component 2	10	0.0630182**	3.49	25.10% of GESS
AMMI component 3	8	0.0524079**	2.90	16.50% of GESS
AMMI component 4	6	0.0206353	1.14	6.60% of GESS
G X E (Linear)	9	0.0307256	1.70	5.60% of GESS
Pool deviation	27	0.171767**	9.50	94.40% of GESS
Pooled error	100	0.01808207		

*, **: Significant at 0.05 and 0.01 probability level, respectively

Table 3. Wheat grain yield (t ha^{-1}) obtained by 10 genotypes in different location- and their average performance in Bangladesh.

Entry	Environments						Average performance		Disease reaction			
	Genotypes	Dinajpur	Joydebpur	Jessore	Jamalpur	Rajshahi	Mean	Rank	BpLB (%DLA)	Reaction (BpLB)	Leaf rust	Resistance category[1]
GEN1	SHATABDI	3.708	4.415	4.172	4.659	3.450	4.081	6	6	R	0	R
GEN2	BARI Gom 26	3.631	4.234	4.366	3.494	3.408	3.827	8	43	MS	30MSS	MR
GEN3	BAW 1194	4.165	4.555	4.376	4.760	4.100	4.391	1	27	MR	10MSS	R
GEN4	BAW 1195	3.935	4.279	4.677	4.109	3.867	4.173	5	27	MR	10MSS	R
GEN5	BAW 1196	2.861	4.423	4.331	2.355	3.892	3.572	9	64	S	60S	S
GEN6	BAW 1200	3.708	4.234	4.239	4.567	3.575	4.065	7	17	MR	tMSS	R
GEN7	BAW 1202	4.187	4.609	4.642	4.547	3.725	4.342	2	7	R	tR	R
GEN8	BAW 1203	4.104	4.528	4.557	4.282	3.533	4.201	4	8	R	tR	R
GEN9	BAW 1205	3.629	4.403	4.724	4.233	4.142	4.226	3	32	MS	10MSS	R
GEN10	BAW 1206	3.393	4.381	3.472	3.283	3.325	3.571	10	43	MS	20MSS	MR
	Mean	3.732	4.406	4.356	4.029	3.702	4.045					
	E index (Ij)	-0.313	0.361	0.311	-0.016	-0.343						
	Significant level	**	**	*	NS	NS						
	CV (%)	4.8	3.6	8.3	2.2	8.3						
	LSD (0.05)	0.30	0.27	0.62	0.15	0.52						

*, **: Significant at 0.05 and 0.01 probability level, respectively

[1] Resistance category: Resistant (R) = 0-10%, moderately resistant (MR) = 20-30%, moderately susceptible (MS) = 40-50%, Susceptible (S) = 60-100% severity

Highly significant differences were found among the genotypes for yield components and yield contributing characters. The CV ranged from 1.2% for days to heading to 6.3% for spike per square meter. Days to heading ranged from 58.1 days for the GEN3 up to 67.8 days for the check Shatabdi. Days to maturity ranged from 98.3 days for GEN4 up to 104.9 days for Shatabdi. Plant height ranged from 88.4 cm for GEN7 up to 104.2 cm for the check Shatabdi. The check BARI Gom 26 showed the highest number of spikes per square meter whereas the lowest value was shown by the genotype GEN7. The line GEN5 showed the highest value for number of grains per spike (52.4) whereas GEN3 gave the lowest value (40.3). GEN10 gave the highest value for 1000-grains weight (51.9 g) whereas the lowest value was shown by Shatabdi (45.3 g). The genotype GEN7 gave higher average yield in all locations, resistant to BpLB and leaf rust and short plat strature; therefore, this genotype was released as variety in February 2017 with the name of BARI Gom 32.

Stability performance

AMMI analysis: The stability results and genotypes response under different locations, discussed according to Eberhart and Russel (1966) character-wise as follows; stability parameter i.e., regression coefficient (bi), deviation from regression (S^2di), IPCA scores and AMMI stability value (ASV) for yield of the individual genotypes are presented in Table 4. The genotypes GEN4 and GEN9 showed the lowest scores in the IPCA1, followed by GEN8 and GEN10. The check GEN2 and genotype GEN7 showed medium scores in the IPCA1. GEN5 scored the highest IPCA1. In the view of the AMMI stability value (ASV), the genotype GEN4 showed lowest (0.31) ASV value among the genotypes. The genotype GEN9 became the second lowest in ASV. Both of these two genotypes showed lowest IPCA1 scored ranked first and second. Among the genotypes GEN3 showed highest yield and lower regression coefficient (bi) and higher ASV value than GEN4 and GEN9. These three genotypes GEN3, GEN4 and GEN9 had low deviation from regression (S^2di), insignificant regression coefficient (bi≈1.00) and low ASV value indicating stability all over the studied environments. With regards to locations, Dinajpur and Jessore gave the lowest IPCA 1 scores whereas Joydebpur and Rajshahi gave medium score and Jamalpur scored the highest IPCA 1 value.

Table 4. IPCA axes scores for genotypes and environments, AMMI stability value (AVS) and mean performance for grain yield (t ha^{-1}) of 10 wheat genotype grown at 5 environments in Bangladesh.

Entry	Genotypes	Grain yield	Rank	IPCA1 Score	IPCA2 Score	ASV	Rank	bi	S^2di	Environment	IPCA1 Score
GEN1	SHATABDI	4.081	6	0.4664	-0.07675	2.77	9	1.068	0.16	Dinajpur	0.2523
GEN2	BARI Gom 26	3.827	8	-0.2012	0.0365	1.19	4	1.185	0.05	Joydebpur	-0.4159
GEN3	BAW 1194	4.391	1	0.3256	-0.06699	1.93	7	0.495	0.06	Jessore	-0.3912
GEN4	BAW 1195	4.173	5	-0.01264	0.3002	0.31	1	0.848	0.03	Jamalpur	1.111
GEN5	BAW 1196	3.572	9	-1.128	0.04533	6.70	10	1.524	0.79	Rajshahi	-0.5565
GEN6	BAW 1200	4.065	7	0.4029	0.1089	2.39	8	0.873	0.11		
GEN7	BAW 1202	4.342	2	0.2485	-0.00549	1.48	6	1.009	0.05		
GEN8	BAW 1203	4.201	4	0.1755	-0.05374	1.04	3	1.099	0.05		
GEN9	BAW 1205	4.226	3	-0.09658	0.4189	0.71	2	0.981	0.07		
GEN10	BAW 1206	3.571	10	-0.1800	-0.7069	1.28	5	0.917	0.16		

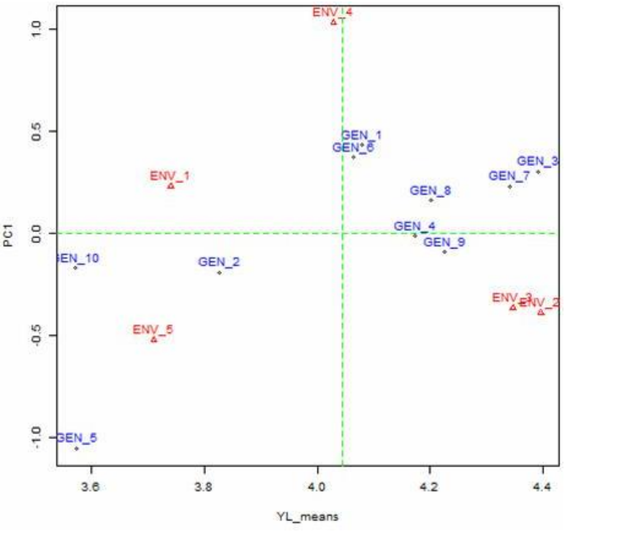

Fig. 1. AMMI 1 model for grain yield (kg ha^{-1}) showing the means of varieties and locations against their respective IPCA 1 scores. ENV1 = Dinajpur, ENV2= Joydebpur, ENV3= Jessore, ENV4= Jamalpur, ENV5= Rajshahi.

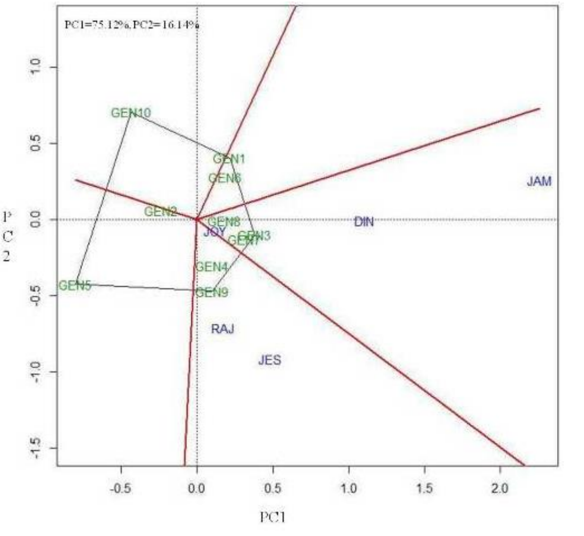

Fig. 2. GGE biplot identification of winning genotypes and their related mega-environments.
DIN=Dinajpur, JOY= Joydebpur, JES= Jessore, JAM= Jamalpur, RAJ= Rajshahi.

Visualization of mean performance and stability for grain yield: A graphical representation of grain yield showed in AMMI biplot, the relationship between the first interaction principal component axis (AMMI component 1) and mean of cultivars and locations (Kempton, 1984), with the biplot according to 91.1% of the treatment sum of squares (Fig. 1). Cultivars and locations on the same equivalent line, obtain similar yields and a cultivar or location on the right-hand side of the midpoint of this axis gave higher yields than those on the left-hand side (Zobel *et al.*,1988). The location Rajshahi, Jamalpur and Dinajpur-unlike and diverge from the stability zone and the location of Joydebpur and Jessore represent high yield as well as close from the stability zone. Joydebpur and Jessore displayed similar interaction effects and they were remaining the lower right quadrant with negative interaction scores and above average wheat yield. In the same way, Jamalpur and Dinajpur environments displayed similar interaction effects but they were remaining the upper half with positive scores; however, these two locations Jamalpur and Dinajpur were in the left quadrant with below average yield, hence, it could be treated as low-yielding environment. Location Rajshahi was in the left quadrant with negative interaction score as well as below average yield hence, it could also be regarded as low-yielding environment. The genotypes GEN4, GEN7, GEN8 and GEN9 were close to the horizontal line (zero interaction effect) and remained on the right hand of the midpoint of the axis, hence, these would be the most stable with above average yield. The genotypes GEN2 and GEN10 were low yielding and unstable. The genotypes GEN6, GEN3, and check GEN1 were unstable and diverge from mid-axis; however, as they showed above than average yield, they were adapted to some high yielding environments. Alam *et al.* (2015) and Hagos and Abay (2013) also stated the significant difference among genotypes, location and genotype-location interaction in bread wheat by AMMI biplot analysis.

According to the biplot shown in Fig. 2, the corner genotypes from the midpoint that are the most responsive genotypes, can be visually determined. These corner genotypes were GEN1, GEN3, GEN5, GEN9 and GEN10. In this figure, locations were divided into two sectors. The first sector represents Dinajpur and Jamalpur, with genotype GEN3, GEN7 and GEN8 were the most favorable. The second sector represents Joydebpur, Rajshahi and Jessore, with genotype GEN9 was the most favorable. The three other corner genotypesviz: GEN1, GEN5 and GEN10 were the poorest-yielding (Fig. 2). These three genotypes were placed far away from all of test locations, reflecting poorly yielded at each location. If mega-environments are pointed out by different winning genotypes according to Gauch & Zobel, 1997, Fig. 2 mentioned that the existence of two mega-environments for late planting wheat in Bangladesh, namely the GEN3-winning niche (cold climatic regions) and GEN9-winning niche (moderate climatic region).

According to Fig. 3, mean yield and stability performance is possible to assess through a biplot graph. An average tester coordinate (ATC) horizontal axis (X-axis) passes through the midpoint of the biplot as well as the average location. The average yields of genotypes were assessed by projections of their parameters on to the ATC X-axis. Thus, genotype GEN3 had the highest average yield, and GEN10 had the lowest (Fig. 3). Stability exploration of each genotype is depending by its projection onto the ATC Y-axis. The smaller distance from mid line to genotype, the more stable it is. Thus, genotypes GEN5 and GEN10 were less stable and genotype GEN3, GEN8, GEN7, GEN2, GEN4 and GEN9 were the most stable. However, considering yield stability with mean yield, genotype GEN3 following to GEN7, GEN8, GEN4 and GEN9 could be regarded as the most favorable. Plant breeders discover varieties that find out yield stability as well as high yield across environments (Kang, 2004). Assess for yield stability derived from the analysis of GE interaction and the significant GE interaction found the result of the changes in magnitude of differences among genotypes through different locations (Hill *et al.*, 1998). If no GE interaction find, the mean difference among the concern genotypes summoned by the observed phenotypes in different locations will constant.

A summary of interrelationships among concern locations is presented in Fig. 4. The lines of location vectors that connect between to the midpoint of biplot, marked of concern locations, angle among the locations was related to the correlation coefficient. In a similar way, the correlation coefficient among test locations is the cosine of the angle approximates (Kroonenberg, 1995). The five locations were grouped into two groups, based on the vector angles of test locations. One group consists of the location Joydebpur, Rajshahi and Jessore while the other group consists of Jamalpur and Dinajpur. This result was synchronized with the geographic pattern belonging to different location types. Similarly, the interrelationships among 10 wheat genotypes were estimate by this tool (Fig. 5). The overall picture of inter-relationships among genotypes mentioned that there were different genotypic groups' presents in this study. In other words, these concern genotypes had various characteristics as well as good performance for grain yield and stability and this could be related to different environmental sources of the genotypes (Table 1). GEN8, GEN7, GEN4 and GEN9 had strong positive associations with the most favorable genotype (GEN3). The dissimilarity was predicted because the GGL biplot explained 91.26% rather than 100% of the total variation due to G+L+GL sources.Consequently, all data of this experiment contained negligible error. Yan and Hunt (2002) and Yan and Tinker (2006) also made a conclusion based on the overall pattern of the whole dataset, and these predictions were more reliable than individual observations.

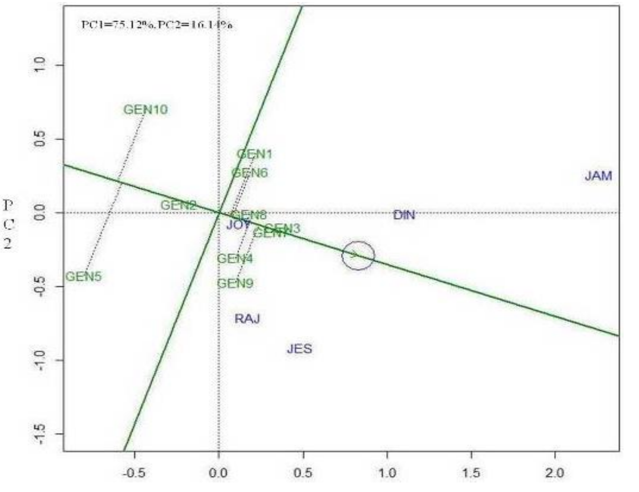

Fig. 3. GGE biplot of mean and stability of 10 wheat genotypes for yield and specific genotype × environment interactions.
DIN=Dinajpur, JOY=Joydebpur, JES= Jessore, JAM= Jamalpur, RAJ= Rajshahi

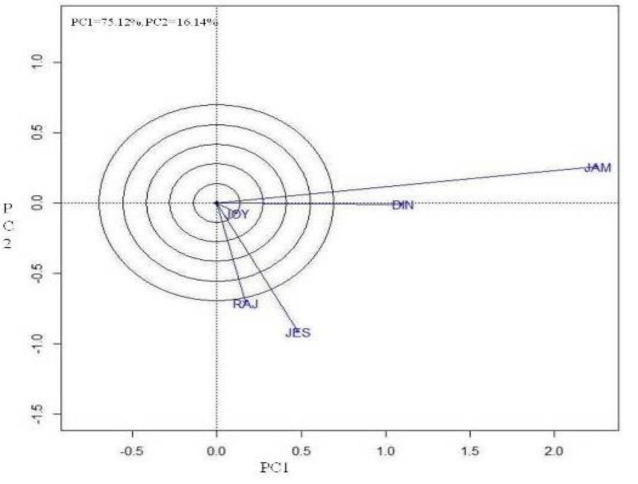

Fig. 4. Vector view of GGE biplot for relationships among locations.
DIN=Dinajpur, JOY= Joydebpur, JES= Jessore, JAM= Jamalpur, RAJ= Rajshahi

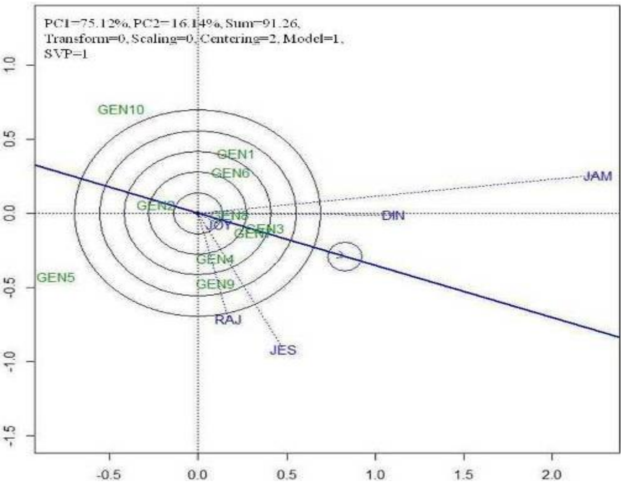

Fig. 5. Vector view of GGE biplot for relationships among genotypes.
DIN=Dinajpur, JOY=Joydebpur, JES= Jessore, JAM= Jamalpur, RAJ= Rajshahi

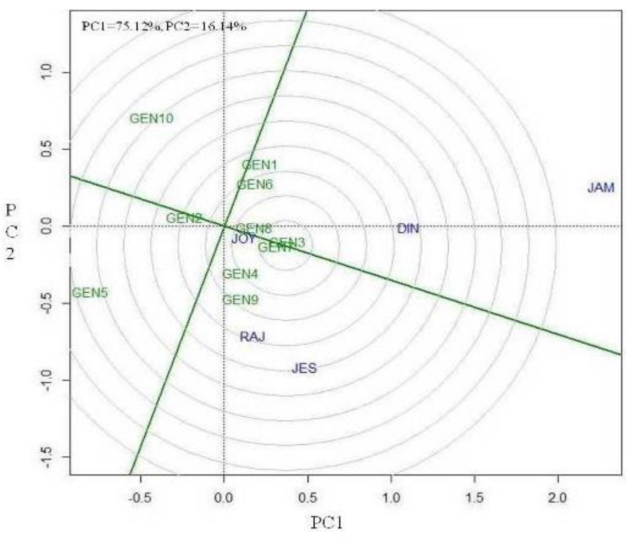

Fig. 6. GGE biplot of ideal genotype and comparison of the genotypes with the ideal genotype.
DIN=Dinajpur, JOY= Joydebpur, JES=Jessore, JAM= Jamalpur, RAJ= Rajshahi

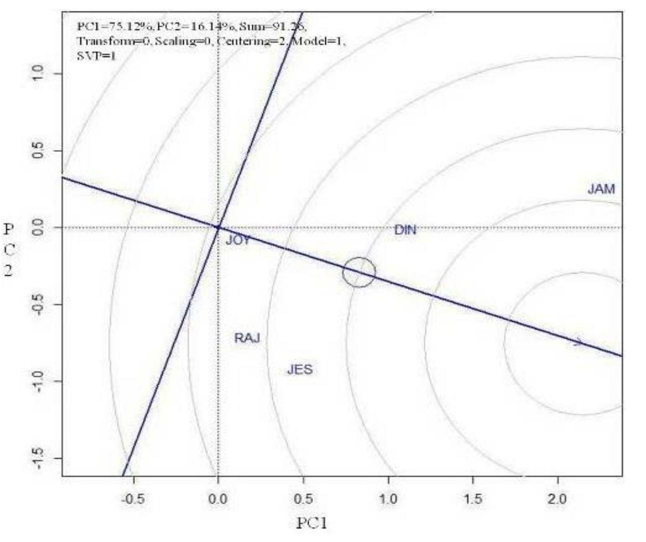

Fig. 7. GGE biplot of ideal location and comparison of the location with the ideal location.
DIN=Dinajpur, JOY= Joydebpur, JES=Jessore, JAM= Jamalpur, RAJ= Rajshahi

An ideal genotype (most stable and high mean yield) should be placed on the nearest to the center of concentric circles (Fig. 6). In other words, the representation of an ideal genotype on the ATC Y-axis would be obviously zero (most stable) and its placement on the ATC X-axis is equal to the longest vector of all genotypes. As a result, a negligible distance between genotype and the virtual ideal genotype, represent an ideal genotype. Therefore, genotype GEN3 following to genotypes GEN7, GEN8, GEN4 and GEN9 were closest to the concentric center, but genotype GEN5 and GEN10 were the discriminate to this position (Fig. 6). Also, genotypes GEN6 and GEN1 did not seem significantly different from other genotypes, such as GEN5, GEN10 and GEN2 that were apparently inferior. In other words, to identify an ideal genotype, it is also possible to identify an ideal location or environment based on ranking of test locations according to their discriminating ability and suitability of representation. Fig. 7 showed where an ideal location will be, based on the centers of the concentric circles. The projection of an ideal location, closer with ATC X-axis and its projection on the ATC Y-axis was zero. Therefore, Joydebpur, Dinajpur and Jamalpur were the best environments and do not found significantly different from each other (Fig. 7). Also Jessore and Rajshahi were low stable location based on the discriminating ability and suitability of representation.

Conclusions

Five distant mega-environments were identified for terminal heat stress condition including Dinajpur and Jamalpur with GEN3, GEN7 and GEN8 as the most favorable, Joydebpur, Rajshahi and Jessore with GEN4 and GEN9 as the most favorable under late sowing condition. Genotype GEN3 and GEN4 showed moderately resistance to BpLB and GEN9 showed moderately susceptible to BpLB. On the other hand, these three genotypes showed resistance to leaf rust. Genotype GEN3, GEN7 and GEN8 demonstrated a high mean yield as well as stability presenting suitable good plant material for future breeding programs. Furthermore, the GGE biplot analysis is a valuable tool for visual explanation of the complex GE interaction and yield stability in plant breeding programs.

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