

**GGE BIPLLOT AND AMMI ANALYSIS OF YIELD OF PROSO MILLET
(*Panicum miliaceum* L.)**

H. U. Z. RAIHAN¹, M. M. BILLAH², M. I. RIAD³, M. B. SARKER⁴
AND M. M. ROHMAN⁵

Abstract

The experiment was conducted using seven proso millet advanced lines including one check variety, BARI Cheena-1 (BC-1) across 3 locations (Gazipur, Jamalpur and Rangpur) of Bangladesh during 2019-20. The objective of this study was to find out stable proso millet lines, and to verify the influence of the environments on the yield at different locations of Bangladesh. The mean sum of squares for the genotypes were significant for grain yield which revealed the presence of genetic variability in the material under studied. The results of the AMMI analysis indicated that the main effects due to genotype (G), environment (E) and GE interaction were significant, representing differential responses of the lines to the varied environments. Based on the AMMI stability parameter BD-1447, BD-1411 and BD-777 were the most stable lines across the environments, of which BD-777 was most stable. Biplot showed that the environment of Rangpur was poor; but that of Gazipur and Jamalpur were better for proso millet cultivation. Results also suggested that BD-1447, BD-1411 and BD-777 could be included in breeding programs due to their higher grain yield.

Keywords: GGE biplot, Yield, Stability, Proso millet, *Panicum miliaceum*.

Introduction

Proso millet (*Panicum miliaceum* L.) is an annual grass, growing from seed each year. Its origin goes back to history as far as 2000 B.C. It was first introduced to Canada in the 17th century, and was used in a limited way as a forage crop in the early 1900's. It apparently did not produce sufficiently high yield of either forage or grain to compete with the established cereals and forages of that time. Therefore, it is considered as a minor cereal of Bangladesh. Proso millet can be grown on sandy loam, slightly acidic, saline, and low-fertility soils (Riley *et al.*, 1989; Changmei and Dorothy, 2014). However, this crop grows poorly on waterlogged soils (Seghatoleslami *et al.*, 2008; Hunt *et al.*, 2011) and on coarse sandy soils (Williams *et al.*, 2007). Proso millet thrives in low pH soils and most of its seeds germinate well on soils with pH of 5.5 to 6.5 (Lyon *et al.*, 2008). However, plants grown on soils with pH above 7.8 show symptoms of iron chlorosis. It is versatile in that it can be successfully grown on many soil types and is probably better adapted than most cultivated crops to poor land, such as land with soils having low water holding capacity and low fertility. For this

^{1, 2 & 5} Plant Breeding Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, ³Regional Agricultural Research Station, BARI, Jamalpur, ⁴Regional Agricultural Research Station, BARI, Rangpur, Bangladesh.

reason, it can be easily cultivated with low input in the char areas of Bangladesh. It is mainly grown for birdseed. It is also desirable for human food because it is easily digestible and gluten-free. It can be ground into flour, used to bake flatbreads, make tabbouleh or for brewing beer. Among the most commonly consumed products are ready-to-eat breakfast cereals made purely from millet flour as well as a variety of noodles and bakery products. In addition, health-promoting phenolic compounds contained in the grains are readily bio-accessible and their high calcium content favor bone strengthening and dental health. In spite of dry land and no-till farming, germination and emergence of proso millet continue throughout the season. So, it is essential for its varietal improvement to meet the challenge that will be occurred due to global warming. This is why this program is undertaken with a view to develop high yielding proso millet variety. In the recent times, we have developed some high yielding proso millet advanced lines, and their yield performances need to check over locations.

To select highly adaptive high yielding genotypes, it needs to find out the interaction between genotypes and environments. The relative performances of the genotypes can be altered with changes in the environments and these different responses are due to the genotype environment interactions (GEI), because there are environments that are either more or less favorable to certain genotypes. Numerous methods for analyzing multi environment trial data have been developed to expose the pattern of G×E interaction, joint regression (Finlay and Wilkinson, 1963, Eberhart and Russel, 1966) and currently AMMI (Gauch, 1992) and GGE biplot (Genotype main effect plus genotype by environment interaction). AMMI (additive main effects and multiplicative interactions) model combines the analysis of variance of genotypes and the environment main effect with principal component analysis of the GEI into a unified approach (Gauch and Zobel, 1996). Analysis of variance as an additive model shows only main effects and informs whether or not the GE interaction is an important source of variation. It does not, however, provide the understanding into the individual genotypes and location which are the components of the interaction (Samonte *et al.*, 2005). AMMI analysis is the combination of ANOVA and principal component analysis (PCA). PCA is used to partition AMMI analysis where the sources of variability in the genotype by environment interaction. The genotype by environment interaction results obtained from AMMI analysis is represented in a biplot which relates genotypic means to the first or some of the principal interaction components. GGE biplot analysis enables visual (graphical) presentation of interaction estimate. The biplot technique is used for the exhibition and estimation of genotypes in different environments (Gabriel, 1971). GGE biplot present the first two principal components (PC1 and PC2) which are found by decomposition of singular values of multi-location trial yield data. GGE analysis assists the identification of the genotypes with the highest yields in across environment, comparison of their performances in different environments. The objective of this study was to assess the stability of some recently developed

advanced proso millet lines to verify the influence of a sample environments at different locations of Bangladesh (Gazipur, Jamalpur and Rangpur) on the productive performance of the genotypes.

Materials and Methods

The experiment was conducted at three locations namely Gazipur (Latitude- 23° 99' N and Longitude- 90° 42' E), Jamalpur (Latitude- 24° 55' N and Longitude- 89° 57' E) and Rangpur (Latitude- 25° 74' N and Longitude- 89° 27' E) districts of Bangladesh during rabi 2019-20. Six selected proso millet germplasm (BD-768, BD-772, BD- 777, BD-780, BD-1411, BD-1447 along with one check variety BARI Cheena-1 were evaluated in this study. The trials were laid out in RCB design with three replications. Seeds of each entry were sown in 4m×3m plot at 25 cm row spacing and continuous sowing. Seeds were sown at Gazipur on 14 December, Jamalpur on 12 December and Rangpur on 10 December, 2019. Thinning was done three weeks after date of sowing. Fertilizers were applied @ 100, 60 and 40 kg/ha of N, P, and K, respectively. Irrigations were applied (2-3 times) as and when necessary. All intercultural operations were done in time to raise the crop uniformly. All the plants were considered for plot yield which later converted into t/ha.

Statistical Analysis

The analysis of variance (ANOVA) was used, and the GE interaction was estimated by the AMMI model (Zobel *et al.*, 1988) to determine the genotype (G), environment (E) and genotype by environment interaction (GE) effects. The AMMI model for the yield of the *i*th genotype in the *j*th environment is (Zobel *et al.* 1988):

$$Y_{ij} = \mu + g_i + a_j + \sum \lambda_k \gamma_{ik} \alpha_{jk} + \rho_{ij} + e_{ij};$$

where μ is the grand mean; g_i is the main effect of the *i*th genotype (G); a_j is the main effect of the *j*th environment (E).

$$GE = \sum \lambda_k \gamma_{ik} \alpha_{jk} + \rho_{ij} + e_{ij}$$

where λ_k is the eigen value of the *n*th interaction principal component analysis (IPCA) retained in the AMMI model; γ_{ik} is the eigen vector for the *i*th genotype from *k*th IPCA, α_{jk} is the eigen vector for the *j*th environment from the *k*th IPCA, ρ_{ij} is the GE interaction residual, and e_{ij} is the random error term.

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 analysis was done by Duarte and Vencovsky (1999). The stability parameters, regression coefficient (b_i) and deviation from regression (S^2_{di}) were estimated according to Eberhart

and Russel (1966). All data were processed and analyzed using statistical analyzing software Crop stat 7.2 program and PB tools.

Results and Discussion

Results of combined analysis of variance for yield of 7 (seven) proso millet lines across 3 (three) environments are presented in Table 1. The mean sum of squares for the genotypes were significant for grain yield which revealed the presence of genetic variability in the material under studied. Environment mean sum of squares were also highly significant which indicated high differential genotypic response across different environments. Analysis of variance for yield at three environments indicated that the effects of genotype, environment and their interactions were significant. Environment relative magnitude was much higher than the genotypic effect, suggesting that the performances of the genotypes was influenced more by environmental factors.

Table 1. Full joint analysis of variance including the partitioning of the $G \times E$ interaction of prosomillet advanced lines for yield

Source of variation	DF	Mean sum of square
		Yield
Genotypes(G)	6	0.23**
Environments (E)	2	0.80**
Interactions (G x E)	12	0.098*
AMMI component 1	7	0.076**
AMMI component 2	5	0.0059
G x E (Linear)	6	0.052
Pool deviation	6	0.041
Pooled error	52	0.053

*, ** indicated at 5% and 1% level of significance;

Stability parameter i.e., regression coefficient (b_i) and deviation from the regression (S^2_{di}) for yield of the proso millet lines are presented in Table 2. In Eberhart and Russel (1966) model, regression coefficient (b_i) is considered as an indication of the response of the genotype to varying environments while deviation from regression (S^2_{di}) is used as the criterion of stability. In the present study, these two criteria were considered simultaneously to identify stable genotypes. A genotype with unit regression coefficient ($b_i=1$) is said to be average responsive to environment and suitable for all environment therefore, more adaptive.

If $b_i > 1$ it is said to be highly responsive and suitable for favorable environment. If $b_i < 1$ it is said to be less responsive and the genotype is suitable for unfavorable environment (Nadarajan and Gunasekaran, 2005).

Yield along with the value of phenotypic index (P_i), regression coefficient (b_i), deviation from the regression (S^2d_i) are presented in table 2. The genotypic means ranged from 1.50 t/ha (BD-768) to 2.15 t/ha (BD 777). In case of environment index, Rangpur location gave the lowest yield (1.51 t/ha) while Gazipur location gave the highest yield (2.19 t/ha).

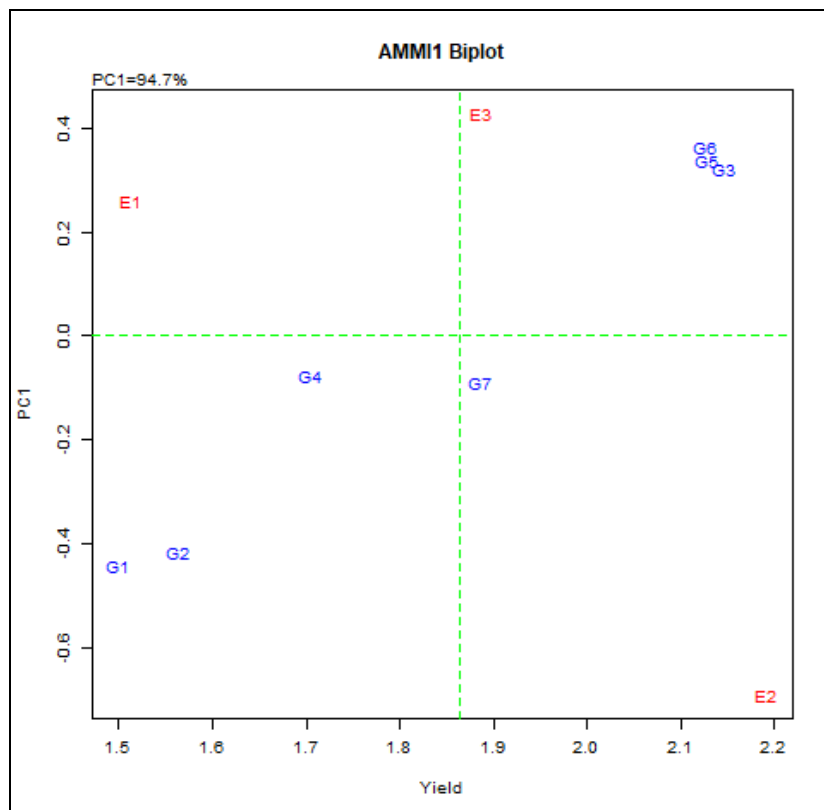
Three genotypes showed negative phenotypic index represent the low yield and the rest four showed positive P_i values representing the high yield among the genotypes. Again, positive and negative environmental index (I_j) reflects the rich or favorable and poor or unfavorable environments for this character, respectively. Thus, the environment of Rangpur and Jamalpur were poor, whereas Gazipur has positive environments for proso millet production. So Gazipur is the most favorable for proso millet cultivation followed by Jamalpur. Results also showed proso millet can be grown with minimum input in Rangpur.

The regression coefficient (b_i) values of these genotypes ranged from 0.51 to 1.65. These differences in b_i values indicated that all the genotypes responded differently to different environments (Table-2). Considering all the three stability parameters i.e mean, b_i and S^2d_i , it was evident that all the genotypes were different in response of adaptability under different environmental conditions. The regression coefficient should be better considered as an indicator for genotypic responses to varying environments (Alberts, 2004) and Solomon *et al.*, 2008). Among the genotypes BD-1447, BD-777 and BD-1411 exhibited higher grain yield with $b_i \sim 1$ and $S^2d_i \sim 0$, which indicated that these genotypes were stable across the environment.

Table 2. Stability analysis for yield (t/ha) of proso millet over 3 environments during 2019-20

SI No.	Entry	Yield (t/ha)				Stability parameter		
		Gazipur	Jamalpur	Rangpur	Overall mean	P_i	b_i	S^2d_i
1	BD-768	2.13	1.36	1.00	1.50	-0.36**	1.65	0.05
2	BD-772	2.17	1.40	1.11	1.56	-0.30*	1.54	0.06
3	BD-777	2.24	2.28	1.91	2.15	0.28*	0.51	0.02
4	BD-780	2.09	1.74	1.28	1.70	-0.16	1.19*	0
5	BD-1411	2.22	2.33	1.84	2.13	0.26*	0.60	0.05
6	BD-1447	2.20	2.33	1.85	2.13	0.26*	0.55	0.05
7	BC-1	2.26	1.78	1.62	1.89	0.021	0.93	0.02
Mean		2.19	1.88	1.51	1.86	-	-	-
Env. Index (I_j)		0.32**	0.02	-0.35	-	-	-	-
LSD (0.05)		0.17	0.31	0.36	-	-	-	-
CV		4.37	9.12	13.50	-	-	-	-

*, ** indicated at 5% and 1% level of significance.



G₁=BD-768, G₂=BD-772, G₃=BD-777, G₄= BD-780, G₅= BD-1411, G₆=BD-1447, G₇=BC1(Check), E1= Gazipur, E2= Jamalpur, E3=Rangpur

Fig. 1. Biplot of the first AMMI interaction (IPCA1) score (Y-axis) plotted against mean yield (X-axis) of seven proso millet advanced lines and three environment.

The AMMI biplot provides a visual expression of the relationship between the first interaction principal component axis (IPCA1) and means of genotypes and environments (Fig. 1) with the biplot accounting up to 94.7% 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 centre of the axis has higher yields than those on the left hand side (Fig.1). The biplot showed four grouping of genotypes, the 1st group was unstable and low yielding having three genotypes i.e., G₁=BD-768, G₂= BD-772 and G₄ = BD-780. The 2nd group was stable and low yielding having no genotypes, While G₆=BD-1447, G₅= BD-1411 and G₃=BD-777 are the high yielding and stable genotypes and high yielding and unstable groups having only one genotype i.e., G₇= BC-1.

The AMMI biplot (Fig. 2) illustrates that some genotypes in one environment have shown higher yield than in other, i.e., genotypes and environments have a specific interaction. Genotypes using PC values near to zero exhibit broader adaptability, and genotypes with higher PC1 values are more suitable for location with PC1 values of the same sign. For example, the genotype G7=BC-1 was suitable in Gazipur. Assessment of individual genotype performances can be based on their positions relative to the X and Y axis. The suitable advanced lines are those which have high yield with stable performances in most locations. The three high yielding genotypes (G6=BD-1447, G5=BD1411 and G3=BD777) proved to be the most desirable. Being high yielding, these are the suitable lines for all the environments.

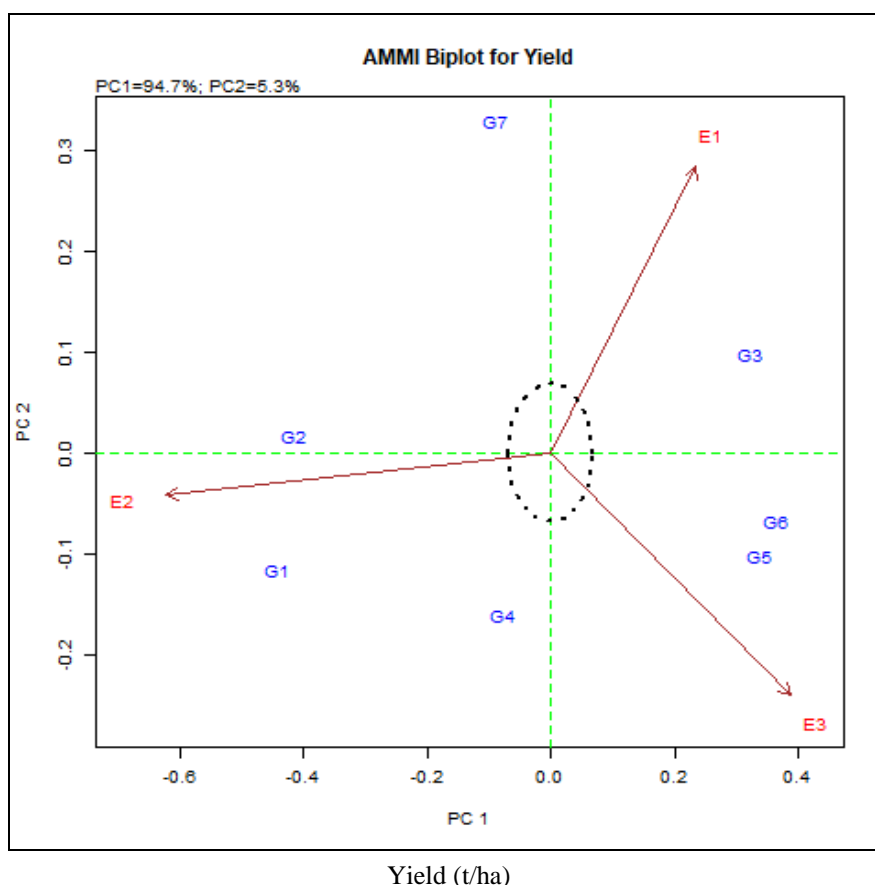


Fig.2. AMMI Biplot 2 interaction (IPCA1 and IPCA2) of seven proso millet advanced lines and three environments.

IPCA2 scores also play a significant role in explaining the GEI; the IPCA1 scores were plotted against the IPCA2 scores for further exploration of adaptation (Fig. 2). Fig. 2 shows that the genotypes, G7=BC-1, G1=BD-768 and G2=BD 772 were unstable due to their dispersed position.

What -won- where biplot for yield

GGE biplot method can be used to identify superior genotypes for target sites. The biplot (Fig. 3) represents a polygon, where some of the hybrids are positioned on the vertexes, while the rest are inside the polygon. As the hybrids positioned on the vertexes have the longest distance from the biplot origin, they are supposed to be the most responsive. Responsive hybrids are either best or the poorest at one or every environment (Yan and Rajcan, 2002).

According to the biplot shown in Fig 3. The corner genotypes that are the most responsive ones can be visually determined. In this figure, Locations are divided into three sectors. The first sector represents Jamalpur and Gazipur, with genotype G₃=BD-777 as the most favorable for Jamalpur. The second sector represents Rangpur, with genotype G₅= BD-1411 and G₆=BD 1447 as the unfavorable. The other corner genotype G₁=BD-768, G₂= BD-772 and G₄= BD780 were the poorest yielder. They were located far away from all of the test locations, reflecting the fact that they yielded poorly at each location.

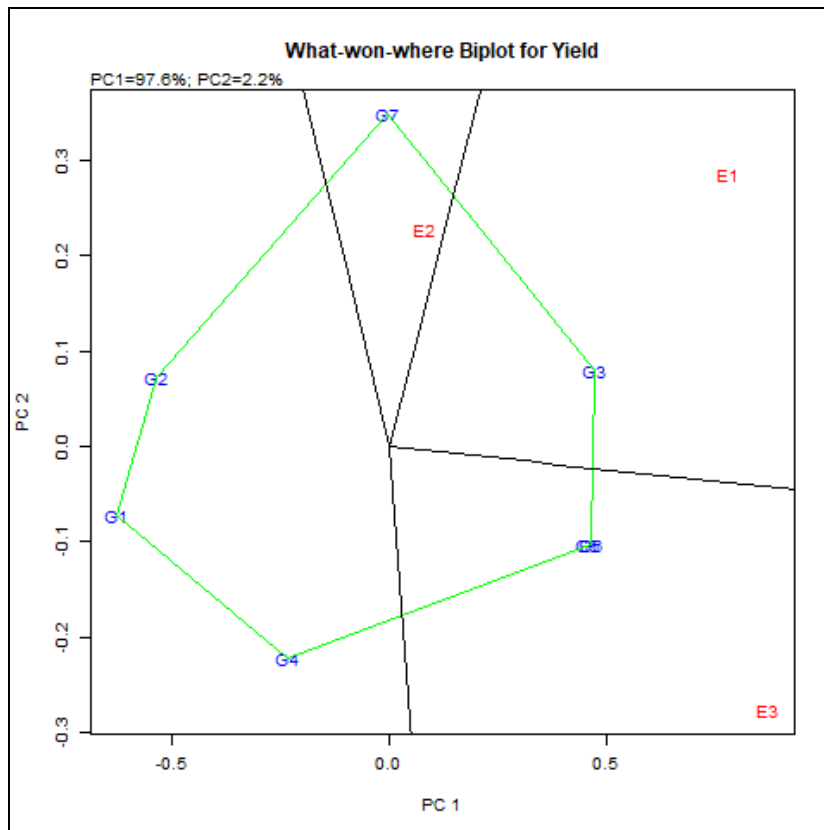


Fig.3. GGE biplot showing “What won where” of the 7 proso millet advanced lines across 3 environments

Conclusion

From the results of the study, it can be concluded that the performances of proso millet advanced lines were strongly influenced by the environments. Among the three environments, Gazipur was found most suitable for proso millet cultivation followed by Jamalpur. Among the lines BD-777 produced the highest yield followed by BD-1447 and BD-1411. Considering the yield potentiality and stability parameter, three genotypes BD-1447, BD-777 and BD-1411 were suitable for all the environments. So, these three genotypes could be selected for release as variety.

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