Bangladesh Rice J. 23 (2) : 77-85, 2019, doi.org/10.3329/brj.v23i2.48250

Identification of Ideal Trial Sites and Wide Adaptable T. Aus Rice Genotypes Suitable for Bangladesh

M Khatun[1*], M M E Ahmed[2], M A Syed[3], F Akter[4], S Das[5], M E Haq[5] and S S Dipti[6]

ABSTRACT

GGE biplot study is an effective tool for many crops including rice to identify mega-environments, ideal trial site and suitable genotypes for general and specific adaptation. An attempt was made to find promising T. Aus rice genotypes having suitable grain quality, better agronomic parameters and ideal test location for T. Aus rice growing areas. In this study, a total of 11 promising genotypes along with two popular cultivars BR26 and BRRI dhan48 were tested across six locations; Cumilla, Gazipur, Rajshahi, Rangpur in T. Aus 2016 and 2017 whereas Habiganj and Kushtia only in T. Aus 2017 season. From GGE biplot study, BRRI RS, Rajshahi (E8) was the most discriminating and ideal location for evaluating T. Aus rice genotypes in Bangladesh condition while BRRI RS, Cumilla 2016 (E1) showed the least discriminating ability and the least representative location. From two years combination data, BR9011-19-1-2 (G6) recorded the highest average grain yield (5.11±0.68 t ha^{-1}) but BR9011-46-2-2 (G2) was the most stable genotype having grain yield (4.97±0.62 t ha^{-1}) and other stable genotypes with above average yield were BR9011-67-4-1 (G5), BR9011-34-3-2 (G1), BRRI dhan48 (G13), BR9039-28-3-2 (G9) and BR9039-9-1-3 (G8) indicated that these genotypes adapted to favourable environments. BR26 (G12) was found highly variable and less stable across the test environments. In addition, agronomic trait (plant height, growth duration) and grain quality traits were also considered for suitability and wider adaptation in T. Aus growing areas in Bangladesh. BR9011-46-2-2 (G2) and BR9011-19-1-2 (G6) were the better genotypes in most of the locations but, considering all of the parameters, the newly developed rice breeding line BR9011-67-4-1 (G5) has been identified as suitable genotype to release as a new variety for sustainable T. Aus rice production in Bangladesh.

Key words: GGE biplot analysis, ideal trial sites, stability, T. Aus rice, wider adaptation

INTRODUCTION

Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall, high temperatures and high humidity. The dominant food crop of Bangladesh is rice; around 67 percent of the country's cultivated land area is used for rice production (Shelly *et al.*, 2016). Rice grows our three seasons in Bangladesh namely; Aus, Aman and Boro. Aus rice is sown in April, benefits from summer rains (April and May), matures and harvest during July to August, Aman cultivated in wet (monsoon) season and Boro cultivated in dry season applying irrigation. Therefore, T. Aus rice is also called partially irrigated rice that means irrigation requires only at the time of land preparation and initial crop establishment in April while limitation of rainfall and growing period has sufficient rainfall in the rainy season (mid-June to mid-August). There are two Aus dominating cropping pattern in Bangladesh. Boro-Aus-T. Aman is the major cropping pattern occupied 0.21 million hectares land of 47 districts including Cumilla, Bogura, Habiganj, Naogaon, Kishoreganj,

[1]PSO, Plant Breeding Division, BRRI, Gazipur; [2]SO, Plant Breeding Division, BRRI; [3]SSO, BRRI RS, Barishal; [4]SO, BRRI RS, Rajshahi; [5]SO, TRB-BRRI Project; [6]PSO, Grain Quality and Nutrition Division, BRRI. *corresponding author's E-mail: mahmuda.breeding@gmail.com

Jashore, Bhola, Kushtia etc. The Aus based cropping pattern Fallow-Aus-T. Aman ranking 2nd and possessed 0.19 million hectares land of 30 districts namely Sylhet, Moulovibajar, Habiganj, Jhalkathi, Noakhali, Barishal etc. (Nasim *et al.*, 2017). It is short duration crop having field duration only 80-85 days. It is grown only in 7% of farm land compared to mega season Boro (55%) and Aman (38%) in Bangladesh (The Daily Star, 2017). This area is increasing day by day as farmers are being motivated to cultivate Aus rice due to less irrigation, less fertilizer and least management requirement. In 2017, rice production in Boro experienced a loss of 20 lakh tons due to flashflood in *haor* areas and fungal attacks (mainly blast) in some northern parts of the Bangladesh. In addition, 6.11 lakh hectares area of Aman rice was completely damaged by heavy flood but, this loss was compensated by harvesting 23 lakh tons of Aus rice from 10 lakh hectares area (The Daily Star, 2017). Recently, Aus season is becoming popular due to favourable environment throughout the growing period especially less rainfall in harvesting period to ensure post-harvest activities (drying and storage).

Genotype-environment interactions are major importance to the plant breeders for developing improved genotypes. Even for similar ecological conditions, general adaptability is an important quality of a variety. According to Sharma (1994), adaptability refers to the capacity of a genotype to macro-environmental factors in its favour in order to a consistent performance over time and locations. Development of location specific variety has been considered for future challenge and sustainable food production. Performance of a genotype in diverse environments is a true evaluation of its inherent potential adaptiveness (Panday *et al.*, 1981).

Plant Breeding Division of BRRI has been working extensively to develop short duration T. Aus rice variety with high yielding performance and good acceptance to farmers. In accordance with this, a number of field trials are being conducted across promising T. Aus growing areas of Bangladesh. Thus, ideal trial site and genotype identification is needed through effective statistical tools. In biplot study, both G (genotype main effects) and G × E (genotype × environment interaction) are considered simultaneously for genotype and environment evaluation (Yan *et al.,* 2003). Through data visualization, a 'which-won-where' view of biplot helps to mark distinct mega-environments to identify the best performing genotypes in the respective environments (Gauch *et al.,* 1997). Additionally, ranking of environments and genotypes means stability and comparing the genotype with the popular cultivar and the biplot analysis paved the way to more reliable and proper data interpretation in multi-location trials.

Thus, the present study was undertaken to identify best location as a representative of T. Aus growing areas as well as select stable and superior genotypes for commercial cultivation.

MATERIALS AND METHODS

Plant materials and testing locations

A total of 11 advanced breeding lines were evaluated across six locations of Bangladesh in two consecutive years. In the study, BRRI developed two popular T. Aus rice varieties namely, BR26 and BRRI dhan48 were used as standard checks. Plant height (95-112cm) and growth duration (111-114 days) of the promising T. Aus genotypes were in the acceptable range (Table 1**)** except for BR8776-17-4-2 and BR8781-5-2-3 (117 days). Yield range of the advanced lines was 4.64-5.11 t h^{-1} that was higher than the check BR26 but similar to the check BRRI dhan48 (Table 1).

Table 1. List of the partially irrigated (T. Aus) rice genotypes with some important features.

Genotype	Parentage	Plant height (cm)	Growth duration (day)	Yield (t h^{-1})
BR9011-34-3-2	MLT-145-2/HR17512-11-2-3-1-4-2-3	106±6.14	111±5.63	5.05±0.67
BR9011-46-2-2	"	105±9.42	113±6.58	4.97±0.62
BR9011-48-4-3	"	109±5.83	114±7.19	4.76±0.65
BR9011-64-1-2	"	108±5.35	111±6.01	4.70±0.82
BR9011-67-4-1	"	107±3.49	112±6.88	4.83±0.81
BR9011-19-1-2	"	109±4.67	114±6.59	5.11±0.68
BR9011-9-4-2	"	104±6.50	114±7.55	4.71±0.59
BR9039-9-1-3	BR26/BRRI dhan48	95±5.04	114±5.82	4.84±0.67
BR9039-28-3-2	"	95±4.55	111±5.23	4.93±0.92
BR8776-17-4-2	MOROBEREKAN/BR5563-3-3-4-1	112±7.36	117±6.76	4.64±1.09
BR8781-5-2-3	MOROBEREKAN/IR50	107±7.76	117±6.70	4.68±0.83
BR26 (ck.)	IR18348-36-3-3/IR25863-61-3-2//IR58	103±9.65	112±5.27	4.02±0.94
BRRI dhan48(ck.)	BR1543-9-2-1/IR13249-49-3-2-2	106±6.34	109±4.46	4.90±0.56

In the first year (2016), yield trials were conducted in four locations (Cumilla, Gazipur, Rajshahi and Rangpur) as an initial multi-location trial. In the second year (2017), same lines were tested in the same locations with an addition to Habiganj and Kushtia as a trial site. The ten locations/environments belong to two T. Aus growing conditions such as BRRI regional station (RS) Cumilla (E1 and E2) under stagnant water condition and rest of the environments such as BRRI headquarter (HQ), Gazipur (E3 and E4), BRRI RS Habiganj (E5), BRRI RS, Kushtia (E6) and BRRI RS, Rajshahi (E7 and E8) and BRRI RS, Rangpur (E9 and E10) under favourable condition (Table 2).

Field experiment and experimental design

The experiment was conducted in T. Aus season in the year 2016 and 2017. Seeding was done at different sites from mid-April to last week of April and transplanting was done from first to third week of May. Three-week-old seedlings were transplanted at a spacing of 20 × 15 cm with 2-3 seedlings per hill. The unit plot size was 5.4 m × 2.4 m. The field layout was in RCB design with three replications. Fertilizers were applied @ 195:50:75:40:5 kg urea, TSP, MP, gypsum, zinc sulphate/ha respectively. The fertilizers, other than urea, were applied as basal during final land preparation. Urea was applied in three splits at final land preparation, 4-5 tillering stage (10 DAT) and 5-7 days before PI stages (30 DAT). Crop management such as weeding, irrigation etc was done in time. Insects, diseases and other pests were controlled properly.

Table 2. Locations/Environments and year of the trials of high yielding T. Aus rice genotypes in Bangladesh.

Code	Location/Environment	Season	Remark
E1	BRRI RS, Cumilla	Transplanted Aus	Stagnant water
E2	BRRI RS, Cumilla	"	Stagnant water
E3	BRRI HQ, Gazipur	"	Favourable
E4	BRRI HQ, Gazipur	"	Favourable
E5	BRRI RS, Habiganj	"	Favourable
E6	BRRI RS, Kushtia	"	Favourable
E7	BRRI RS, Rajshahi	"	Favourable
E8	BRRI RS, Rajshahi	"	Favourable
E9	BRRI RS, Rangpur	"	Favourable
E10	BRRI RS, Rangpur	"	Favourable

STATISTICAL ANALYSIS

The grain yield data for 13 genotypes in ten environments were used to perform combined analysis of variance (ANOVA) to determine the effects of environment (E), genotype (G) and their interactions. Combined analysis of variance, standard error of mean, co-efficient of variation was measured by STAR software (version 2.0.1) and broad sense heritability for each trial was generated by PB Tools software (version 1.3). Pooled analysis was performed with two years combination data. GGE biplot was constructed through principal component analysis by R Programming (R development core team, 2013).

RESULTS AND DISCUSSION

Combined analysis of variance

Combined analysis of variance was performed using two years yield data. In combined analysis, the results indicated that the effects of genotype, environments and genotype × environment were significant at 1% level (Table 3). The highly significant G × E effects suggest that genotypes may be selected for adaption to specific environments, which is in harmony with the findings of Aina *et al*. (2009) and Xu-Fei *et al.* (2014). The significant genotype × environment interaction effects clearly exhibited that genotypes responded differently to the variation in environmental conditions of the locations. It indicates the necessity of testing rice varieties at multiple locations. In the present study, highly significant mean squares were found which indicated presence of sufficient variability among the genotypes and environments for grain yield of rice. Similar results were reported by Iftekharuddaula *et al.* (2002) and Hossain *et al.* (2007) in rice.

The quality of the data could be considered reliable due to considerable CV (8.79%) and moderate broad sense heritability (0.69) in pooled analysis (Table 4).

Table 3. Combinedanalysis of variance of grain yield for 11 T. Aus rice genotypes in different sites of Bangladesh.

Source of variation	Degree of freedom (df)	Sum of square (SS)	Mean square (MS)	F value
Environment (E)	9	91.5514	10.1724**	55.15
Replication within	26	6.5161	0.2506	1.36
Genotype (G)	12	25.7723	2.1477**	8.57
Genotype × Environment	108	83.7586	0.7755**	4.20
Pooled error	221	40.7661	0.1845	
CV %		8.79		

**Indicate significant at the confidence level of 1%.

Table 4. Standard error of mean, co-efficient of variation (CV) and heritability in broad sense (h^2) of 13 T. Aus rice genotypes in ten different environments.

Code	Locations and year	Std. error of mean	CV (%)	Trial heritability in broad sense (h^2)
E1	Cumilla 2016	0.330894	10.89	0.67
E2	Cumilla 2017	0.380046	15.33	0.57
E3	Gazipur 2016	0.306069	9.07	0.90
E4	Gazipur 2017	0.199357	7.05	0.58
E5	Habiganj 2017	0.092910	2.85	0.90
E6	Kushtia 2017	0.186051	6.85	0.90
E7	Rajshahi 2016	0.289159	8.16	0.91
E8	Rajshahi 2017	0.161457	5.77	0.68
E9	Rangpur 2016	0.227355	8.73	0.68
E10	Rangpur 2017	0.213196	7.16	0.83
Pooled			8.79	0.69

Evaluation of test environments

Multi-location trials are being conducted by plant breeders around the respective trial sites to assess superior genotypes with wider adaptability. A numerous studies have been reported on GGE analysis in rice, cotton, sorghum and sugarcane (Krishnamurthy *et al.*, 2017; Mohammadi *et al.*, 2013; Samonte *et al.*, 2004; Luo *et al.*, 2015). In the present study, the portioning of GE interaction through GGE biplot analysis showed that PC1 and PC2 accounted for 31.78% and 18.36% of GGE sum of squares, respectively, explained 50.14% of the total variation of the tested environments in two years (Fig. 1).

Three distinct clusters were observed in the GGE biplot study. Among them, Cumilla 2017 (E2), Gazipur 2016 (E3), Habiganj 2017(E5), Rajshahi 2017 (E8) and Rangpur 2017 (E10) comprised in the first cluster, the second cluster consisted of Cumilla 2016 (E1), Rajshahi 2016 (E7) and Rangpur 2016 (E9) and the remaining environments Gazipur 2017 (E4) and Kushtia 2017 (E6) were included in the third cluster (Fig. 1). Among ten environments, the closest association was observed between the environments Habiganj 2017 (E5) and Rangpur 2017 (E10) which belongs to first cluster. Considering all clusters only Cumilla 2016 (E1) showed negative correlation therefore, it can be considered as distinct compared with above locations (Fig. 1). Yan *et al.* (2003) described that the degree and causes of G × E interaction is useful for identifying ideal test locations and best performing genotypes from multi environment trials.

Identification of ideal location

In the present study, Rajshahi 2017 (E8) had the narrowest angle with average environment axis (Fig. 2). Thus, it was highly representative location followed by Rangpur 2017 (E10) and Habiganj (E5). On the other hand, Cumilla 2016 (E1) showed the least discriminating ability and was the least representative location. Yan and Tinker (2006) explained that the narrower angle of two arrows means the closer relation between two environments. The wider angle of two arrows means the more different of results, because of the bigger effect of G × E of the observed traits.

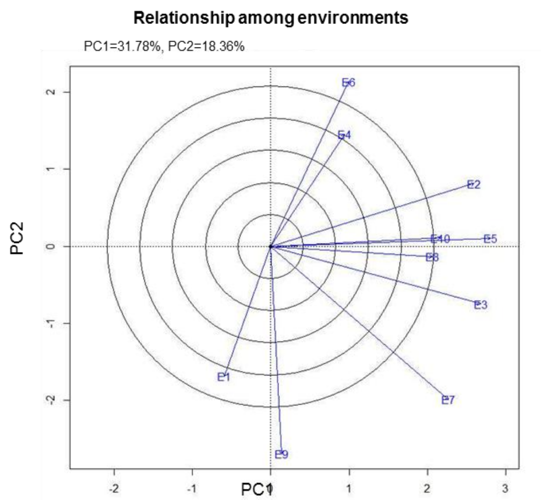

Fig. 1. Association among the test environments of 2016 and 2017 growing season combinations.

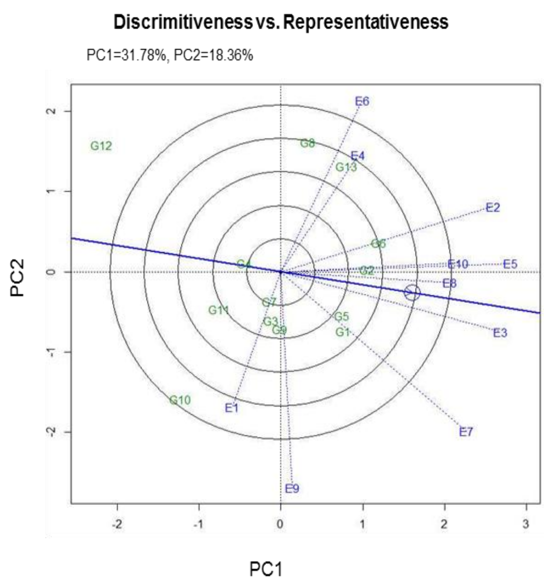

Fig. 2. GGE Biplot power to discriminate (*discrimitiveness*) and power of representation of an environment (*representativeness*).

Ideal test environment is a virtual environment that has the longest vector of all test environments (most discriminating) and it is located on the AEA (Yan *et al.,* 2000). In the present study, BRRI RS, Rajshahi (E8) was identified as the most ideal location with significant discriminating ability. Eventhough Gazipur 2016 (E3), Rajshahi 2016 (E7) and Rangpur 2016 (E9) had the bigger angles to AEA, the locations laid in the same quadrant and tended to have the same results with Rajshahi (E8). Jambormias (2008) reported that locations laid in the same quadrant which is the same with AEA vector line had the same tendency of results. It agreed with the variance analysis of yield in E8, E10, E5, E3, E7 and E9 which had lower average standard error compared to the environment from different quadrant (E1, E2, E4 and E6) (Table 4). Coefficient of variation (CV%) of Cumilla 2016 (E1) and Cumilla 2017 (E2) 10.89 and 15.33 respectively, was higher than other sites. It might indicated that more sever stagnant condition tend to give higher variation on the observed trait (Table 4).

Identification of 'which-won-where' and mega environment (Mega-E)

Mega-E is environmental group which has similarity to support performance of some genotypes simultaneously (Crossa *et al.* 2002). Mega-E is determined by the vertex genotype, i.e. the highest yield genotypes in each quadrant developed by GGE analysis visualization (Yan and Hunt, 2001). Position of the vertex were connected by connecting lines, i.e. a linear line started from the base of biplot that cross perpendicularly each connecting line and separated the biplots into some sectors. Sectors containing environments, i.e. sectors containing dots representing environments, called as mega-E (Jambormias, 2011). In the present study, biplot showed four sectors including all the test environment combinations which indicated four mega environments (Fig.3). Firstly, Mega-E1 had five locations namely Cumilla 2017 (E2), Gazipur 2016 (E3), Habiganj 2017 (E5), Rajshahi 2017 (E8) and Rangpur 2017 (E10).

The second (mega-E2) consisting of Cumilla 2016 (E1) and Rangpur 2016 (E9) and the third (mega-E3) had Gazipur 2017 (E4) and Kushtia 2017 (E6). Finally, fourth (mega-E4) had only one location Rajshahi 2016 (E7). Thus, mega-E4 could not be termed as a mega environment. In GGE study, genotypes located nearer to the ideal genotype are preferable in most cases. In the Mega-E1, BR9011-46-2-2 (G2) and BR9011-19-1-2 (G6) were the winning genotypes indicating the advanced lines were widely adaptable in most of the environments. On the other hand, BR8776-17-4-2 (G10) was the winner in the mega-E2. The genotype BR8776-17-4-2 (G10) having taller plant height (112±7.36) might be benefitted to adapt in the stagnant water condition of the environment Cumilla 2017 (E2) (Table 1). Lastly, BR9039-9-1-3 (G8) and the popular variety BRRI dhan48 (G13) were the winning genotypes in the mega-E3 that was consisting of two environments Gazipur 2017 (E4) and Kushtia 2017 (E6) indicating the genotypes showed their specific adaptability in these locations (Fig. 3).

Performance and stability of genotypes across the test environments

Visualization of GGE biplot is very useful to evaluate and find the most stable genotypes (Farshadfar *et al.*, 2013). Genotypes laid in the concentric area were more stable in giving the yield compared to the genotypes laid outside, even though the environmental effect was very strong. Figure 4 shows the average environment axis (AEA) view of GGE biplot of grain yield for two years combinations (2016 and 2017). In this figure, the genotype BR9011-19-1-2 (G6) produced the highest yield average of 5.11±0.68 t ha^{-1} (Table 1) based on the average from all the environments, and it was visualized by its position in the most right end of AEA line, indicating that the genotype was stable (Fig. 4).

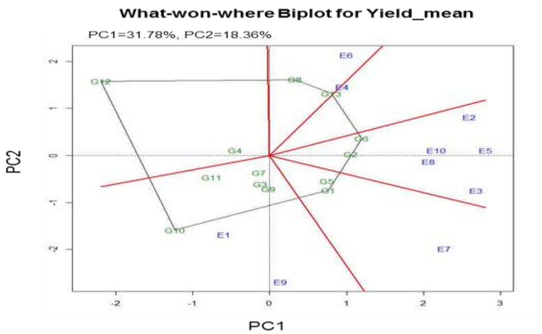

Fig. 3. Visualization of the difference of Mega-E on GGE biplot on yield trait of 13 T. Aus rice genotypes.

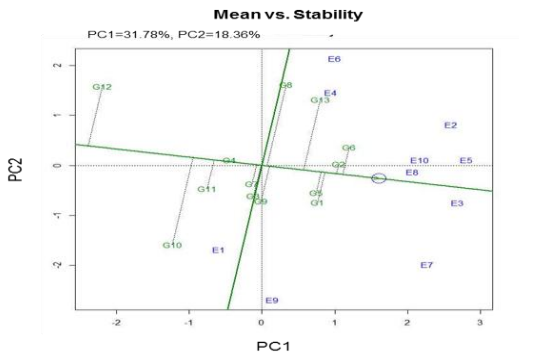

Fig. 4. Visualization of GGE biplot showing the stability of genotypes in which the linear line showing the axis of environment mean and interrupted circle is confidential range.

There were other five genotypes laid in the right end of AEA line, i.e. BR9011-34-3-2 (G1), BR9011-67-4-1 (G5), BRRI dhan48 (G13), BR9039-28-3-2 (G9) and BR9039-9-1-3 (G8) had yield above the average and were considered as relatively stable. These results are in agreement with those obtained by Susan to *et al.* (2015) in rice. The other genotype, BR9011-46-2-2 (G2) had the shortest vector which produced the yield average of 4.97±0.62 t ha^{-1} (Table 1). Therefore, it was identified as the most stable genotype based on GGE biplot study. It meant that BR9011-46-2-2 (G2) had the widest adaptability and stable yield across the environment compared to other 11 genotypes. These results are in agreement with those obtained by Akter *et al.* (2015) in hybrid rice. Akmal *et al.* (2014) reported that genotype with the highest yield average was not necessarily be the most stable and vice versa. The T. Aus variety BR26 (G12) was located far from the AEA and was found highly variable and less stable across the test environments.

Table 5 presents the physicochemical properties such as total milled rice (%), head rice (%), L/B ratio, size and shape, chalkiness and cooking properties viz amylose (%), elongation ratio (ER) and imbibition ratio (IR). Ranges of total milled rice (%) was 62.7-68.7, head rice (%) 21.4-59.9, L/B ratio 2.5-3.4, amylose % 20.5-27.9, elongation ratio (ER) 1.1-1.5, Imbibition ratio (IR) 2.6-3.3 and most of the genotypes having long slender grain (Table 5).

Table 5. Physico-chemical and cooking properties of the advanced T. Aus genotypes.

Designation	Total milled rice (%)	Head rice (%)	L/B ratio	Size and shape	Chalkiness	Amy-lose (%)	Elongation ratio (ER)	Imbibition ratio (IR)
BR9011-34-3-2	59.6	49.0	3.4	LS	Wb9	23.0	1.2	3.3
BR9011-46-2-2	68.7	50.7	3.2	LS	Wc5	26.7	1.3	2.9
BR9011-48-4-3	68.0	58.1	3.2	LS	Wb1	26.8	1.1	2.7
BR9011-64-1-2	67.7	57.7	3.1	LS	Wb1	27.3	1.2	2.7
BR9011-67-4-1	66.0	51.6	3.2	LS	Wb1	27.9	1.3	2.9
BR9011-19-1-2	68.0	50.7	3.1	LS	Wb5	22.4	1.3	2.6
BR9011-9-4-2	68.7	55.3	3.2	LS	Wb5	20.5	1.2	2.9
BR9039-9-1-3	65.0	56.0	3.2	LS	Wb5	26.8	1.5	3.0
BR9039-28-3-2	62.7	21.4	3.4	LS	Wb5	20.7	1.3	3.0
BR8776-17-4-2	67.2	59.9	2.5	MB	Wb5	25.6	1.2	2.9
BR8781-5-2-3	67.5	59.0	2.8	LB	Wb1	26.4	1.3	2.9
BR26 (ck)	65.1	52.4	3.9	LS	Wb1	22.7	1.1	2.9
BRRI dhan48 (ck)	66.3	58.4	2.7	MB	Wb5	26.0	1.3	2.9

Wb1- White belly; Wc- White center; Tr- Translucence; L/B ratio- Length/Breadth ratio

It is well known that the preference of Bangladeshi people is high amylose content (%) as well as non-sticky rice. Therefore, developing an adoptable variety should have high yield with acceptable grain qualities. The acceptable grain qualities such as amylose content must have more than 25%, total milled rice more than 66%, head rice more than 50% with some additional traits viz long slender grain (LS), high elongation ratio (ER) and no-chalk or translucence (Tr) are to ensure high market price. In the study, the genotype BR9011-19-1-2 produced the highest yield on average but amylose content was low (22.4%) (Table 5). Another genotype, BR9011-46-2-2 was observed an adoptable genotype but considering grain quality having chalkiness (Wc_5), it should not be identified as promising one. Therefore, the next adoptable genotype BR9011-67-4-1 was the most acceptable promising line considering higher grain yield (4.83±0.81 t ha^{-1}), intermediate plant height (108±5.35 cm), shorter growth duration (112±6.88 days) and high amylose (27.9%), milling outturn (66%), long slender grain with moderate elongation (1.3) and imbibition ratio (2.7) (Tables 1 and 5).

However, plant breeders need to develop not only high yielding stable genotypes but also consider higher acceptability (high amylose percentage, export quality grain and short duration) to farmers for faster adaptation. In this regards, agronomic traits and physico-chemical properties could help us to draw better inferences for selecting most outstanding genotype with better grain quality. Considering yield, some agronomic characters (plant height, growth duration) and grain quality, the promising line BR9011-67-4-1 was the superior genotype. Thus, the newly developed rice breeding line BR9011-67-4-1(G5) could be further advanced to release as a new T. Aus rice variety for commercial cultivation in Bangladesh.

CONCLUSIONS

From GGE biplot study, the environment of BRRI RS, Rajshahi (E8) was the most discriminating one and could be used as an ideal test site for evaluating newly developed T. Aus genotypes. The genotype, BR9011-67-4-1 (G5) had the above average yield with stability compared to popular cultivar BRRI dhan48 (G13). Thus, the line could be promoted for commercial cultivation across T. Aus growing areas in Bangladesh. The present study supported the fact that which-won-where can be used to identify winners from multi-location trials but agronomic and grain quality traits should also be considered to identify adaptable genotype for making them acceptable to farmers.

ACKNOWLEDGEMENT

Authors are thankful to Bangladesh Rice Research Institute (BRRI) authority, all the researchers and scientific assistants of Plant Breeding Division and concerned scientific members who conducted the yield trial in different locations, BRRI.

REFERENCES

Aina, O O, A G O Dixon, llona Paul and E A A kinrinde. 2009. G × E interaction effects on yield and yield components of cassava (landraces and improved) genotypes in the savanna regions of Nigeria. African Journal of Biotechnology, 8 (19), pp. 4933-4945.

Akmal, C, Gunarsih and M Y Samaullah. 2014. Adaptation and stability of aromatic rice lines in North Sumatera (in Indonesian). Food Crop Res. J. 33 (1): 9-16.

Akter, A, M JamilHasan, Umma Kulsum, M H Rahman, M Khatun and M R Islam. 2015. GGE biplot analysis for yield stability in multi-environment trials of promising hybrid rice (*Oryza sativa L.*). *Bangladesh Rice J.* 19(1): 1-8.

Crossa, J, P L Cornelius and W Yan. 2002. Biplots of linear-bilinear models for studying crossover genotype ×

environ-ment interaction. Crop Sci. 42 (2): 619-633. doi: 10.2135/cropsci2002.6190.

Farshadfar, E, M Rashidi, M MJowkar and H Zali. 2013. GGE biplot analysis of geno-type × environment interaction in chickpea genotypes. Euro. J. Exp. Bio. 3 (1): 417-423.

Gauch, H G & R W Zobel. 1997. Identifying mega environments and targeting genotypes. Crop Sci. 37, 311-326

Hossain, M A, K M Akhter, M A Salam, M Khatun, and M E Hoque. 2007. Yield stability of some T. Aus rice genotypes. Bangladesh J. Prog. Sci &Tech.. 5(1):173-176.

Iftekharuddaula, K M, K Akter, M S Hasan and M A Badshah. 2002. Genotype-Environment interaction in irrigated rice in Bangladesh. Thai Journal of Agricultural Science. 35(3):229-236.

Jambormias, E and J Riry. 2008. Application of GGE biplot for stability and adaptation evaluation of genotypes with multi-environment trials data (in Indonesian). J. Agric. 4 (2): 84-93.

Jambormias, E. 2011. Describing of GGE-biplot graphics to evaluate genotypes performance and changes of environmental stress in small islands (in Indonesian). Proceedings of National Conference: Development of Small Islands (PERMAMA). University of Pattimura. Ambon. p. 299-310.

Krishnamurthy, S L, P C Sharma, D K Sharma, K T Ravikiran, Y P Singh, V K Mishra, D Burman, B Maji, S Mandal, S K Sarangi, R K Gautam, P K Singh, K KManohara, B C Marandi, G Padmavathi, P B Vanve, K D Patil, S Thirumeni, O P Verma, A H Khan, S Tiwari, S Geetha, M Shakila, R Gill, V K Yadav, S K B Roy, M Prakash, J Bonifacio, Abdelbagi Ismail, G B Gregorio and Rakesh Kumar Singh. 2017. Identification of mega environments and rice genotypes for general and specific adaptation to saline and alkaline stresses in India. Scientific Reports volume 7, Article number: 7968.

Luo, J, Y Pan, Y Que, H Zhang, M P Grisham and L Xu. 2015. Biplot evaluation of test environments and identification of mega-environment for sugarcane cultivars in China. *Sci. Rep.*5, 15505.

Mohammadi, R and AAmri. 2013. Genotype × environment interaction and genetic improvement for yield and yield stability of rainfed durum wheat in Iran. *Euphytica*192, 227–249.

Nasim, M, S M Shahidullah, A Saha, M A Muttaleb, T L Aditya, M A Ali and M S Kabir. 2017. Distribution of crops and cropping patterns in Bangladesh. *Bangladesh Rice Journal, 2017, 21 (2), 1-55.*

Pandey, B P, S K, Srivastava and R A S Lal. 1981. Genotype × Environment interaction in lentil. Lens. 8:14-17.

Samonte, S O, L T Wilson, A M McClung and J C Medley. 2004. Targeting Cultivars onto Rice Growing Environments Using AMMI and SREG GGE Biplot Analyses. *Crop Sci*., 45:2414-2424.

Sharma, J R. 1994. Principles and practice of plant breeding. Tata Mc.Grow-Hill Publishing Co. Ltd. New Delhi. 599 p.

Shelley, I J, M Takahashi-Nosaka, M Kano-Nakata, M S Haque, and Y Inukai. 2016. Rice cultivation in Bangladesh: present scenario, problems, and prospects. *Journal of International Cooperation for Agricultural Development* 14, 20-29.

Susanto U, W R Rohaeni, S B Johnson and A Jamil. 2015. GGE Biplot Analysis for Genotype × Environment Interaction on Yield Trait of High Fe Content Rice Genotypes in Indonesian Irrigated Environments. *Agrivita* 37(3), 265-275.

The Daily Star. 2017. Seedlings crisis worries farmers. *In:* The Daily Star on 28 August 2017 (https://www.thedailystar.net/frontpage/seedlings-crisis-worries-farmers-1455001). Accessed 2020 March 11.

Xu, Fei-fei, TANG Fu-fu, SHAO Ya-fang, CHEN Ya-ling, TONG chuan and BAO Jing-song. 2014. Genotype × Environment Interaction for Agronomic Traits of Rice Revealed by Association Mapping. Rice Sci. 21(3): 133-141.

Yan, W and L A Hunt. 2001. Interpretation of genotype × environment interaction for winter wheat yield in Ontario. *Crop Sci.* 41, 19–25.

Yan, W and M S Kang. 2003. GGE Biplot Analysis: A graphical tool for breeders, geneticists, and agronomists. CRC Press, Boca Raton, FL.

Yan, W and N A Tinker. 2006. Biplot analysis of multi-environment trial data: Principles and applications. Can. J. Plant Sci. 86: 623-645.

Yan, W, L A Hunt, Q Sheng and Z Szlavnics. 2000. Cultivar evaluation and mega-environment investigation based on GGE biplot. *Crop Sci.* 40, 597–605.