RESEARCH PAPER

Evaluation of rapeseed lines for seed yield stability

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Abstract

Stable performance of rapeseed genotypes at a specific growing environment is critical for obtaining high and stable yield. The objectives of this study were to evaluate seed yield stability of sixteen rapeseed genotypes in diverse environments during 2008-09, 2009-10 and 2010-11 growing seasons, to graphically make a summary of the effects of genotype (G) and genotype environment (GE) interaction and to identify "which won where" and to recommend rapeseed genotypes for a specific growing environment, using GGE biplot. The GGE biplot was effective in recognition that the genotypes G12, G10 and G6 were the highest yielding and consequently the most desirable genotypes for growing in favourable weather condition. The genotype G5 had the lowest seed yield (5.61 g plant^{-1}) and was the least stable across varying environments. This technique can provide as a useful tool for recommendation of rapeseed genotypes for specific growing environment taking into account the specificities of genotypes and growing conditions.

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Introduction

Bangladesh has a great deficit in oilseed production. The production is only 11% of the requirement. To fulfill the requirement, the country imports 1.6 million ton of edible oil (palm oil, soybean and canola/mustard) (MPOC, 2015). Rapeseed, mustard, soybean, groundnut, cottonseed, sesame seed and linseed are the major edible oilseed crops grown in Bangladesh. Rapeseed-mustard production reached 61% of the total oilseed production in Bangladesh followed by soybean 13%, groundnut 11%, cottonseed 8%, sesame seed 7% and linseed 1% (FAO, 2015).

Improved rapeseed (*Brassica napus* L.) cultivars for irrigated environments in Bangladesh are needed to increase rapeseed productivity. The average yield of this crop is around 952 kg ha^{-1} (FAO, 2015). The low yield is a great concern in view of short supply of edible oil in Bangladesh. Seed yield of a genotype is important in determining its superiority but this is not same under different agro climatic conditions. Some genotypes can perform well in certain environments but others cannot do so in the same environment. The ability to develop high yielding and stable cultivars is an ultimate goal in most breeding programs (Boshev *et al.*, 2014). The genotype to environment interaction is particularly important in the improvement and evaluation of plant cultivars. Diverse environments can reduce the stability of plant varieties (Hebert *et al.*, 1995). One of the basic components for characterization of the plant genotype is the estimation of the productivity for stability and adaptability (Raj *et al.* 1997) which is often expressed by realized yield (Kang, 1998). Only stable genotypes can guarantee a good yield with decreased risk of losing production and allow the researchers to make general recommendations for a range of environments. So the present study was designed to select suitable rapeseed genotype with wide adaptation to the climatic conditions of Bangladesh.

Experimental trials are usually conducted in different environments with an aim to evaluate yield stability of different crops under varying environmental conditions (Yan *et al.*, 2000; Yan and Rajcan, 2002). The main environmental effects (E) and genotype environment interaction (GE) have been reported as the most important sources of variation for the measured yield of crops (Dehghani *et al.*, 2006; Yan *et al.*, 2007; Sabaghnia and Sabaghpour, 2008). Although the measured yield is a combined effect of the genotype (G), E and GE interaction, only G and GE are relevant to cultivar assessment. Typically, E explains most (80% or higher) of the total yield variation, while G and GE are usually small (Yan and Kang, 2003). There are number of statistical methods for evaluation of performance hybrids and their genotypic interactions with the environment. They differ in the parameters used in the estimation, the biometric procedures engaged and the analysis.

Other researchers used GGE biplot for the analysis of GE interactions and evaluation of field crops (Yan and Kang, 2003; Butron *et al.*, 2004; Samonte *et al.*, 2005; Fan *et al.*, 2007; Dehghani *et al.*, 2009, Balestre *et al.*, 2009; Oliveira *et al.*, 2010; Tonk *et al.*, 2011). The aim of this study was to i) investigate the stability of seed yield in rapeseed via the GGE biplot, ii) graphically summarize the effects of G and GE interaction.

Materials and methods

Experimental site and materials

The experiment was laid out in a randomized complete block design (RCBD) with three replications at Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh. Sixteen rapeseed genotypes from diverse backgrounds were sown in a RCB design with three replications. The ten A lines were grown in the rabi seasons of 2008-09 (BC$_3$ generation) and 2009-10 (BC$_4$ generation) and 2010-11 (BC$_5$ generation) along with three R lines and three popular varieties with a view to investigate their stability across variable environments. The environments in the three subsequent years were assigned as E1, E2 and E3. The genotypes used for the investigation are presented in Table 1. Distance between the rows was 0.3 m with hills spaced 0.15 m. Size of each unit plot

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was 2.4 m² (4 m × 0.60 m). Plots were overplanted and thinned properly ensuring a single plant hill⁻¹. Two rows from each plot were harvested at maturity, siliquae were shelled, dried and seed weight was measured in each plot.

Statistical analysis

The GGE biplot analysis was carried out using PBTools software version 1.4 (PBTools, 2014). It was used to produce graphs which are viewing (i) "which-won-where" pattern, (ii) ranking of rapeseed lines in respect of yield and stability, (iii) environment vectors, and (iv) assessment of environment to ideal environment (Yan and Kang, 2003). The GGE biplot represents the first two principal components (PC1 and PC2, referred as primary and secondary effects, respectively) derived from subjecting environment centered yield data (yield variation due to GGE), to singular value decomposition (Yan *et al.*, 2000).

Results and discussion

Best genotype in each environment

GGE biplot method can be used to identify superior rapeseed lines (Dehghani *et al.*, 2009). The biplot (Fig. 1) represents a polygon, where some of the genotypes are placed on the peaks, while the remainders are surrounded by the polygon. As the genotypes placed on the peaks have the longest detachment from the biplot origin, they are expected to be the most responsive. Responsive hybrids are

either best or the poorest at one or every environment (Yan and Rajcan, 2002). In the present investigation, the genotypes G6, G10 and G12 had the highest seed yield. The genotypes G8, G9, G15 and G16 also showed higher seed yield than the remainders. The two environments (E1 and E3) were positioned in the same sector on the graph, which suggests that those environments did not vary significantly between themselves. The environment E2 was placed in different sector. The genotype G14 was the highest yielding in E2. None of the environments fell in the sectors with genotypes G1, G2, G3, G4, G5, G7, G11 and G13 indicating that these genotypes were not suitable for growing at these specific environments. Yan *et al.* (2000) stated that ideal genotypes could be considered those that have a large PC1 score (high yielding ability) and small or absolute PC2 score (high stability). Likewise, the perfect test environment should have a big PC1 score which means that it is more selective of the genotypes in terms of the genotypic main effect and small or absolute PC2 score (more representative of the overall environment). While an "ideal" view is drawn (Fig. 2), it can be observed that the genotype G12 was the closest to the ideal genotype, followed by G10 and G6 respectively. According to Yan and Kang (2003), an ideal genotype could be described as one which is the highest yielding across test environments and is absolutely stable in its performance.

Table 1. List of experimental material along with their source.

Genotype code	Rapeseed genotype	Source
A lines		
G1	Nap248A Z1	BSMRAU, Salna, Gazipur
G2	Nap206A Z1	,,
G3	Nap2037A Z1	,,
G4	Nap108A Z2	,,
G5	Nap205A Z2	,,
G6	Nap9904A Z2	,,
G7	Nap9905A Z2	,,
G8	Nap9908A Z2	,,
G9	BS 8A Z2	,,
G10	Nap9904A Z1	,,
R lines		
G11	Nap130R(!)	,,
G12	Nap9906R(!)	,,
G13	Nap94006R(!)	,,
Popular varieties		
G14	BARI Sarisha-7	,,
G15	BARI Sarisha-8	,,
G16	BARI Sarisha-13	,,

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Average yield and stability of genotypes

The average grain yield of the genotypes vs. their stability is displayed in Fig. 2. The performance line (average environmental axis, AEA) passes through the biplot origin. The open blue circle with an arrow indicating it marks the point of average environment coordinates for environments. The closed blue dot in Fig. 2 represents an "ideal" genotype.

The genotypes positioned the closest to the circle are the highest yielding; those on the upper area of the line are stable, and those in the lower fraction of the biplot are unstable. Considering this, the genotype G12 has the highest average grain yield (10.06 g plant^{-1}), as holding the highest projection on the performance line, followed by G10 (9.67 g plant^{-1}) and G6 (9.46 g plant^{-1}), which are located very close to the genotype G12 (Table 2).

Table 2. Mean seed yield (g plant^{-1}) of sixteen rapeseed genotypes across three environments at BSMRAU, Gazipur and their average seed yield.

Genotype code	Genotype	E1	E2	E3	Average seed yield (g plant^{-1})	Rank
G1	Nap248A Z$_1$	5.32	5.55	6.49	5.79	15
G2	Nap206A Z$_1$	6.33	7.33	6.33	6.66	11
G3	Nap2037A Z1	5.94	5.81	7.40	6.38	12
G4	Nap108A Z2	5.49	6.77	5.47	5.91	13
G5	Nap205A Z2	5.90	5.88	5.06	5.61	16
G6	Nap9904A Z2	9.31	9.78	9.30	9.46	3
G7	Nap9905A Z2	6.49	7.99	6.65	7.04	9
G8	Nap9908A Z2	9.16	7.94	7.69	8.27	8
G9	BS 8A Z2	8.65	9.12	8.64	8.80	6
G10	Nap9904A Z1	9.46	10.11	9.45	9.67	2
G11	Nap130R(!)	6.32	5.07	6.31	5.90	14
G12	Nap9906R(!)	9.72	10.72	9.73	10.06	1
G13	Nap94006R(!)	7.81	6.74	6.54	7.03	10
G14	BARI Sarisha-7	10.06	10.14	7.80	9.33	4
G15	BARI Sarisha-8	8.77	9.39	8.17	8.78	7
G16	BARI Sarisha-13	9.03	9.86	8.23	9.04	5

It could also be observed that these genotypes are not stable over all environments (such as E2). Consequently, these genotypes may be considered for growing in favourable environments (E1 and E3). The genotype 5 had the lowest seed yield (5.61 g plant^{-1}).

In Fig. 2 the center of the concentric circles is where an ideal genotype should be; its projection on the AEA X-axis was designed to be equal to the highest vector of all genotypes, and its projection on the AEA Y-axis was clearly zero, representing that it is completely stable.
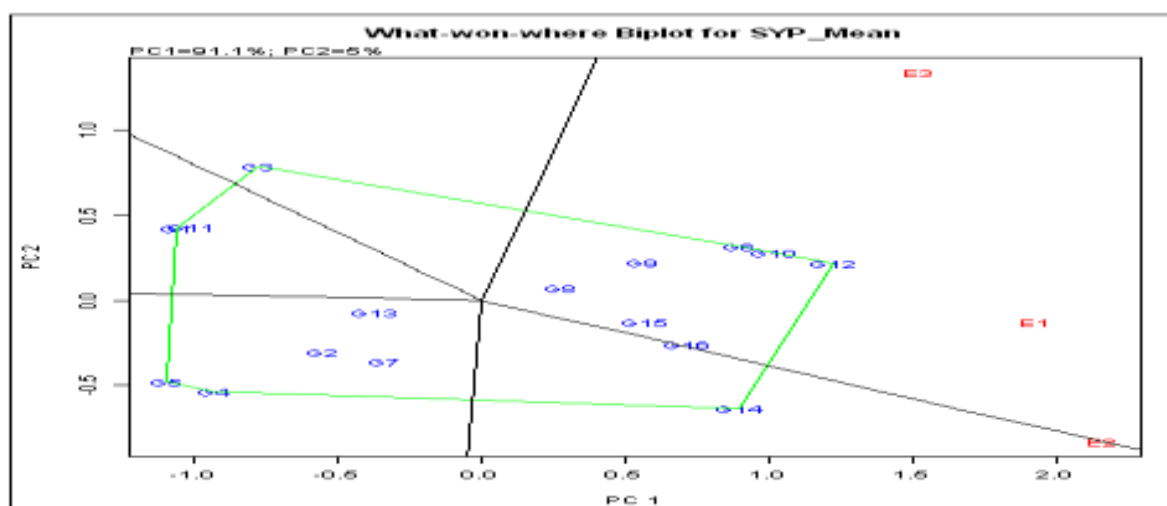

Fig. 1. A genotype + genotype × environment interaction biplot showing genotypes performance in each environment.

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Therefore, the lesser the distance from a genotype to such a virtual genotype, the most ideal the genotype is. Thus, genotype $G12$ was the closest to the concentric center. Genotype $G10$ did not seem to be meaningfully different from genotype $G12$, while the genotype $G5$ was the least stable across the environments.

Ranking of environment

Discriminating ability and representativeness of the environments is presented in Fig. 3. An ideal environment is the one that is most discriminating for genotypes (longest distance between the marker of the environment to the plot origin, is a measure of its discriminating ability) and is representative (shortest projection from the marker of location onto the AEA Y-axis is the measurement of its representativeness) of all other environments (Yan, 2001; Yan and Kang, 2003).
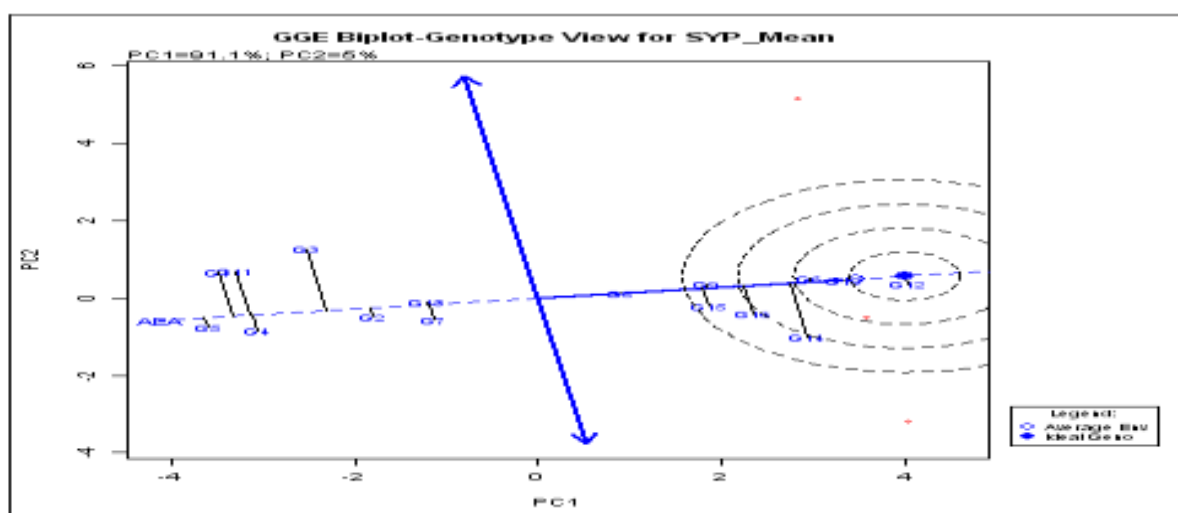

Fig. 2. Comparison of genotypes with the ideal genotype showing environmental axis (AEA) the GGE biplot. Environments and genotypes are denoted by 'E' and 'G', respectively. AXIS1 and AXIS2 are the first and second principal components, respectively.

Considering this, E_1 was the most discriminating as well as most typical, as it is far away from the plot origin and had the shortest projection onto AEA Y-axis, respectively. The other favourable environment E_2 was positioned close to E_1, which indicates that stable production of rapeseed is possible in this environment. According to Tonk *et al.* (2011), those are the best environments for genetic differentiation of experimental genotypes. On the other hand, the unfavourable environment didn't have the discriminating ability (was not far away from the origin) and was not representative, as it had large projection onto the AEA Y-axis (Fig. 3).

Relationship among environments

Association among the test environments is pointed out in Fig. 4. It represents the vectors of all three environments, facilitating the determination of the relationship between environments. The vector length also represents the discriminating ability of the respective environment, and the cosine of the angle between two environments shows the relationship among them (Yan, 2001). Both E_2 and E_1 had the longer vectors, thus they were the best for genetic discrimination of genotypes. E_3 was the least representative environment in this investigation. The minimum angles between the vectors of E_1 and E_2 indicated that they had a strong relationship.

An essential target in a breeding program is to accommodate authentic indication that will satisfy as a guide for selection of the best genotypes that have to be planted in the following seasons and to be capable to forecast yield as exactly as possible based on limited experimental data. GGE biplot effectively identified the rapeseed lines which should be

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considered for growing in Gazipur region. Furthermore, using this technique it was obviously confirmed that high and stable yields could be achieved only in favourable environment. Other researchers observed that GGE biplot analysis is a handy tool for detecting test environments to select outstanding genotypes in field crops as well (Balestre *et al.*, 2009; Ilker *et al.*, 2009; Oliveira *et al.*, 2010; Tonk *et al.*, 2011; Khalil *et al.*, 2011; Beyene *et al.*, 2011, Nzuve *et al.*, 2013; Mortazavian *et al.*, 2014).
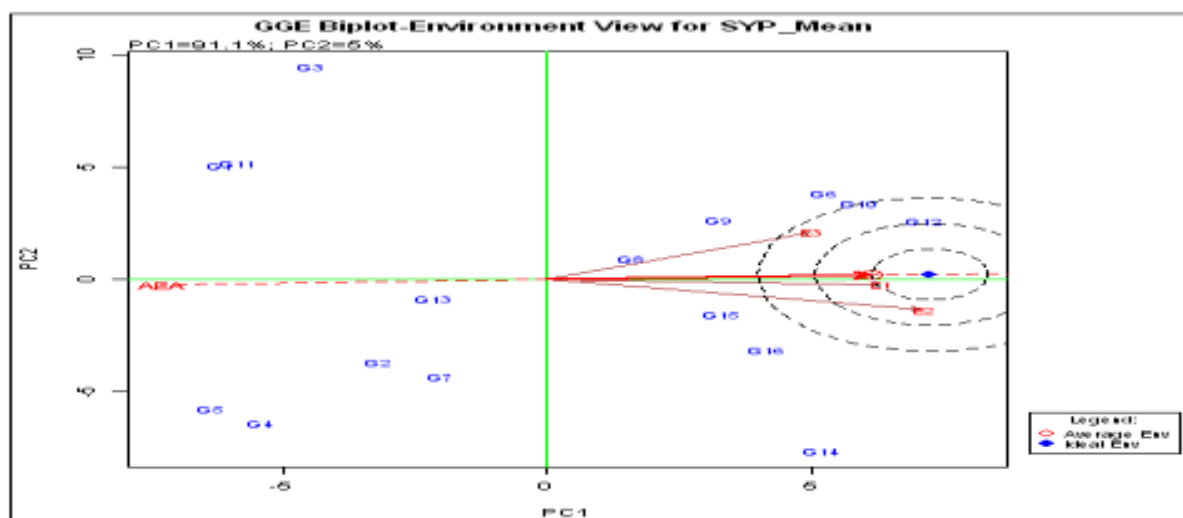

Fig. 3. Comparison of environments with an ideal environment. The genotypes and environments are indicated by G and E, respectively.
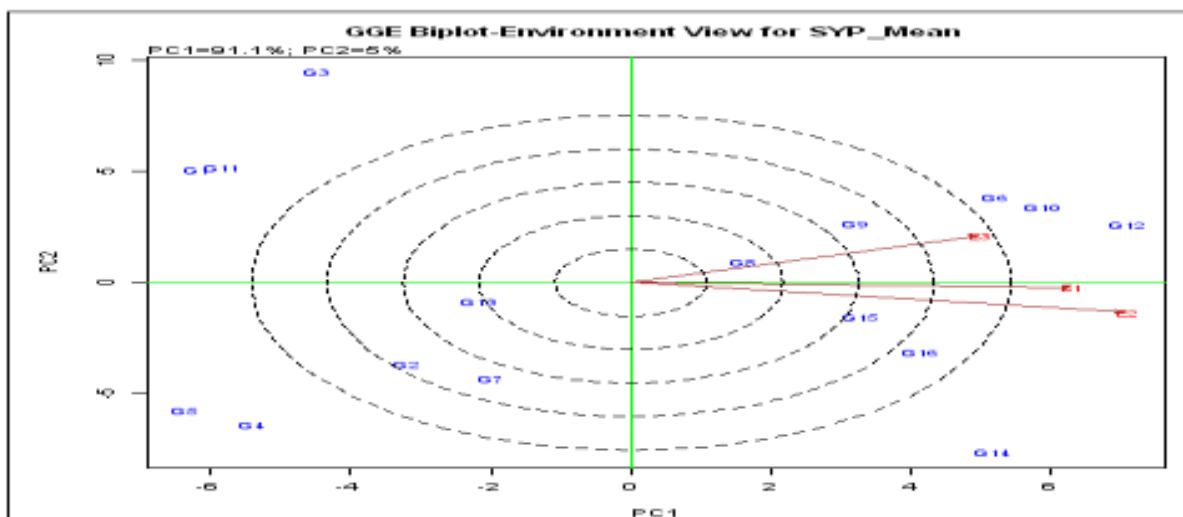

Fig. 4. A genotype + genotype × environment interaction biplot showing relationships among three environments.

Conclusion

The GGE biplot analysis identified the genotypes G12, with an average grain yield of 10.06 g plant[-1], G10 (9.67 g plant[-1]) and G6 (9.46 g plant[-1]) to be the most desirable genotypes for growing in favourable environment. The rapeseed genotype G5 had the lowest seed yield (5.61 g plant[-1]) and was the least stable across diverse environments. In addition, the GGE biplot methodology was valuable device for detection of environments in which rapeseed genotypes will have an optimal performance. This method can give out as an effective tool for recommendation of rapeseed genotypes for specific growing environment taking into account the specificities of genotypes and growing conditions.

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