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GGE Biplot and Genotype x Environment Interaction Analysis in Eggplant (*Solanum melongena* L.) under Subtropical Conditions of Jammu

Anil Bhushan, Sonali Sharma, R.K. Samnotra, Bupesh Kumar[1] and Sanjeev Kumar

Division of Vegetable Science and Floriculture, [1]Division of Plant Breeding & Genetics
Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu-180 009, India
**E-mail: anilbhushan2008@gmail.com*

Abstract: Additive Main Effects and Multiplicative Interaction (AMMI) and GGE biplot analysis are widely used now a days to delineate stable genotypes under different environments, across different seasons, locations or years. The present study was undertaken to decipher nature and magnitude of Genotype x Environment Interaction (GEI) among 25 eggplant genotypes across six different environments. The individual experiment was conducted in randomized complete block design with three replications and uniform, healthy seedlings were planted on ridges maintaining inter and intra row spacing of 90 x 60 cm, respectively. Results revealed the presence of Genotype x Environment interaction (GEI) and the first two principal components accounted for 84.99 per cent variation viz., 55.31 and 29.68 per cent respectively for yield per plant thereby, indicating that genotypes may be selected for adaptation with respect to specific environments. With respect to ranking of environments, the discriminating ability of V_3 and V_6 was closest to the ideal environment. The stability mean of genotypes revealed that G_1 (Rajni), G_9 (Shamli) and G_{23} (PPC) were the best performing genotypes whereas, Nisha Improved was found to be most unstable genotype. 'Which-won-where' analysis depicted three mega environments (ME) among the test locations with ME1 represented by four locations V_1 (Autumn-winter, 2013), V_2 (Spring-summer, 2014), V_4 (Autumn-winter, 2014) and $\mathbf{V_7}$ with G_1 (Rajni) as winning genotype and second ME (ME2) consisting of V_3 (Rainy, 2014) and V_6 (Rainy 2015) with G_{15} (Arka Nidhi) and G_{16} (Arka Neelkanth) as winning genotypes. Third ME (ME3) was represented by V_5 (Spring-summer, 2015) with G_8 (Nisha Improved) as winning genotype.

Keywords: AMMI, Eggplant, GEI, GGE Biplot

Eggplant (*Solanum melongena* L.), is a popular and principal vegetable crop widely grown in tropics and subtropical parts of India. India is the second largest producer of brinjal in the world next to China and produces 13154 '000 MT from an area of 758 '000 ha (Anonymous 2021 a). In Union Territory of J&K, brinjal is grown over an area of 1.67' 000 ha, with total production of 34.40'000MT (Anonymous 2021b). There are numbers of commercially grown varieties and hybrids available in the market, released by both public and private sector. However, a genotype possessing considerably high yield potential coupled with stable performance in different environments has great value for its adaptation on large scale and in plant breeding programme (Bora et al 2011). There is an utmost need for development of high yielding stable varieties and hybrids for specific environments. Stability in productivity, therefore, is a major and important consideration to identify brinjal genotypes capable of performing well across the environments and seasons. Most of the economic characters in brinjal are quantitative in nature and thus, susceptible to environmental fluctuations. Various statistical models like principle component analysis (pca) and linear regression have been suggested over time to understand the complex GEI. Genotype (G) main effect plus GE interaction (GGE) biplot is a biplot) based on environment-centered data, which removes the environment main effect and integrates the genotypic main effect with the GE interaction effect of a GE dataset (Yan et al 2000). It is a robust method to visualize and interpret multi environment data graphically as well. The GGE biplot analysis combines the additive effect of genotype with the multiplicative effect of the GEI, building the biplot graphics from the main components (MC), in order that the first component represents the proportion of products obtained from the genotype traits, and the second component shows the ratio of the production that occurs due to the GEI (Yan and Holland 2010). AMMI model is also considered better at explaining the effects of G×E interactions as compared to other models of stability analysis, thereby defining clarification of multi-environmental data set. The precision in this model is achieved by separation of structural variation from uproar and it has been widely used in the evaluation of the stability of yield-related traits (Bhartiya et al 2017). Earlier work show the efficiency and superiority of the GGE biplot analysis and AMMI model for the recommendation of genotypes (Hongyu et al 2015, Koundinya et al 2019 , Pardeshi et al 2021). Therefore, the present investigation was undertaken to have an insight into the nature and magnitude of GEI among 25 brinjal genotypes across six environments using GGE biplot analysis as well as identification of mega environments within the test locations.

MATERIAL AND METHODS

Agro-climatically, the Jammu location represents Zone V of Jammu and Kashmir and is characterized by subtropical climate. The place experiences hot dry summer, hot and humid rainy season and cold winter months, the maximum temperature goes up to 45° C during summer (May to June) and minimum temperature falls to 1° C during winters. The mean annual rainfall is about 1000-1200 mm. The experimental material comprised of 25 brinjal genotypes including 10 F_1 hybrids namely, Rajni,PPL-74, Navkiran Improved, Sandhya, MH-80, Chhaya, PBH-3, Nisha Improved, Shamli, and Abhishek, and fifteen open pollinated varieties i.e. Punjab Sadabahar, Arka Shirish, Arka Kusumkar, Arka Keshav, Arka Nidhi, Arka Neelkanth, Pusa Shyamala, Pusa Kranti, Pusa Ankur, Pusa Uttam, PPL, PPR, PPC, BR-14 and Puneri Kateri collected from different parts of the country (Table 1) were tested under six environments comprised of three seasons of sowing spreading across two years during 2013-2014 and 2014-2015 (V_1- Autumn-winter, 2013; V_2- Spring-summer, 2014; V_3 -Rainy, 2014; V_4- Autumn-winter, 2014; V_5- Spring-summer, 2015 and V_6- Rainy, 2015). The individual experiment was conducted in randomized block design with three replications. The uniform, healthy seedlings were planted on ridges maintaining inter and intra row spacing of 90 x 60 cm, respectively. All standard crop management practices were followed to raise a healthy crop. The total weight of fruits from each plot was obtained from each picking and pooled. The fruit yield per plant (kg) and fruit yield per hectare (q) was calculated on the basis of total plot yield. The data so generated was analyzed using R studio software. GEI was analyzed by the use of biplot graph in which the yield means are plotted against the scores of first principal component of interaction (IPCA1) (Yan et al 2000). Similarly, data was analyzed for discrimitiveness *vs* representativeness ranking of environments and ranking of genotypes relative to ideal environment and ranking of environment based on ideal genotype was also performed. Mega-environments and winning genotypes in given set of environments was identified by using option 'which-won-where'.

RESULTS AND DISCUSSION

The presence of GEI was clearly demonstrated by AMMI model and the interaction was partitioned among the first two interaction principal component axis (IPCA), as 55.31% and 29.68% respectively, and the cumulative variance was 84.99 % for fruit yield per plant (kg) (Table 2) while, for fruit yield per hectare (q) the first two interaction principal component axis (IPCA) were portioned as 53.60 % and 30.77% respectively

Table 1. List of eggplant genotypes included in the experiment

Genotypes	Fruit shape	Source
F_1 Genotypes		
Rajni	Round	Nunhems Seeds
PPL-74	Long	Century Seeds
Navkiran Improved	Round	Sungrow Seeds
Sandhya	Round	Nunhems Seeds
MH-80	Round	Mahycco Seeds
Chhaya	Long	Nunhems Seeds
PBH-3	Oblong	PAU, Ludhiana
Nisha Improved	Oblong	Century Seeds
Shamli	Long	Seminis Seeds
Abhishek	Round	Nunhems Seeds
Open pollinated genotypes		
Punjab Sadabahar	Long	PAU, Ludhiana
Arka Shirish	Long	IIHR, Banglore
Arka Kusumkar	Oblong	IIHR, Banglore
Arka Keshav	Long	IIHR, Banglore
Arka Nidhi	Long	IIHR, Banglore
Arka Neelkanth	Long	IIHR, Banglore
Pusa Shyamla	Oblong	IARI, New Delhi
Pusa Kranti	Oblong	IARI, New Delhi
Pusa Ankur	Round	IARI, New Delhi
Pusa Uttam	Round	IARI, New Delhi
PPL	Long	IARI, New Delhi
PPR	Round	IARI, New Delhi
PPC	Oblong	IARI, New Delhi
BR-14	Round	IIVR, Varanasi
Puneri kateri	Oblong	Safal Seeds Co., Jalna

Table 2. Additive main effects and multiplicative interaction (AMMI) analysis of variance for fruit yield per plant (kg) of brinjal genotypes across six environments

Source of variation	df	MS	Variation explained (%)
Environment	5	3782516.17***	
Genotype	24	151513.24	
G x E Interaction	120	283346.17	84.99
IPCA 1	28	671628.39	55.31
IPCA 2	26	388165.79	29.68
Error	66	77327.81	

and the cumulative variance was 84.37% (Table 3) thereby, demonstrating that genotypes may be selected for adaptation to specific environments. These results are in harmony with the findings of Koundinya et al (2019) and Pardeshi et al (2021) on G x E interactions effects in eggplant and vegetable soyabean, respectively. There were significant differences among environments for both the traits viz., fruit yield per plant (kg) and fruit yield per hectare (q) which indicated that the environments under study were different from each other (Table 2, 3). The model was additive and the results of AMMI analysis were represented in the form of graphs called biplots (Gauch and Zobel 1996). Further Gauch (1988) recommended that the most accurate model for AMMI can be predicted by using first two principal component analysis. Admassu et al (2008), in accordance with Zobel et al (1988), proposed that two interaction principal component axes for the AMMI model were sufficient for a predictive model. Thus, the interaction of 25 eggplant genotypes with six environments was predicted by the first two components of genotypes and environments (Akhtar et al 2019). Stable genotypes were identified by graphical representation (GGE biplot) which uses genotype and G x E components and identifies G x E interaction pattern of multi-environment data and clearly shows which variety performs best in which environment (Heldari et al 2016). According to Khan et al (2021), Biplots are frequently used to graphically depict the interactions between genotypes (G), environments (E), and GEIs, as well as to reveal interaction patterns and indicate the genotypes that are comparatively stable across environments.

Identification of stable genotypes with highest mean performance: The complex GEI was divided into many principle components (PCs) in GGE biplot, and the data are graphically displayed against PCs as presented in Figure 1. GGE biplots used PC1 (45.84%) and PC2 (19.02%) to capture 64.86% of the variation. The projection of a genotype's absolute length is used to assess the stability of the genotype. The GGE biplot abridgment mean performance and stability of different genotypes has been depicted. Thus, G_1, G_9 and G_{23} were the best performing genotypes followed by G_{16}, G_{24} and G_{15}. G_8 was observed as most unstable genotype and considered as good performer only in specific environment. The genotype, G_1 was closest to the "ideal genotype" followed by G_9, G_{23}, G_{16} and G_{24} which is denoted by small circle at the centre of concentric rings (Fig. 2). The genotypes best suited to a particular environment within a multi-environment are chosen by plant breeders using data from yield performance tests based on mean and stability, whereas genotypes close to the ideal genotype are also more promising or appropriate. Khan et al (2021) observed similar findings in 30 Bambara groundnut across 4 environments as evidence of our result.

Table 3. Additive main effects and multiplicative interaction (AMMI) analysis of variance for fruit yield per hectare (q) of brinjal genotypes across six environments

Source of variation	df	MS	Variation explained (%)
Environment	5	36359.07***	
Genotype	24	1196.20	
G x E interaction	120	2481.90	84.37
IPCA 1	28	5700.77	53.60
IPCA 2	26	3524.93	30.77
Error	66	705.43	

*** indicate significance at $p<0.0001$

Environment evaluation: Angles between environment vectors in biplots indicate their relationship as the cosine of the vector angles is indicative of their correlation. Acute angle between two environment vectors indicates positive correlation while an obtuse angle indicates negative correlation and right angle suggests no relation. Environments show complex relationship among themselves. The 'ideal environment' is denoted by a small circle at the centre of the concentric rings. Maximum discriminating ability and representativeness with highest vector length indicates an "ideal environment". V_1 with V_2, V_4 with V_7 and V_3 with V_6 having acute angles (Fig. 3 and 4) were positively correlated with ideal environment. Environments generating similar information may be removed from multi-location testing as they will provide similar results. This will help in optimum allocation of limited resources during multi-location trials. Obtuse angled vectors show negative correlation with ideal environment for instance V_5 with V_6. Discrimination ability of the environments was measured by the length of the environment vectors and the testing environment could be ranked from top to bottom as $V_6>V_3>V_4>V_7>V_2>V_1>V_5$. V_3 and V_6 was considered to be close to an "ideal environment".

"Which-won-where" and mega environment identification: "Which-won-where' 'analysis involving GEI, mega-environment differentiation, specific adaptation of genotypes etc. are graphically addressed (Fig. 6). Genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environments (Yan and Kang, 2003). In the current study 'Which-won-where" biplots gave rise to a hexagon with six genotypes, G_8, G_{25}, G_{12}, G_{14}, G_{15} and G_{16} at vertices. The equality lines divided the biplot into six sectors effectively. Six testing environments were spread within the biplot, three in one and remaining three in other sector. Testing environment could be partitioned into mega-environment (ME). Three out of six sectors had no single environment and hence it did not reflect any separate ME and could be merged into nearest MEs. First ME (ME1) was represented by V_1, V_2, V_4 and V_7 with G_1 as winning genotype and second ME (ME2) was composed of V_3 and V_6 with G_{15} and G_{16} as another winning genotype.

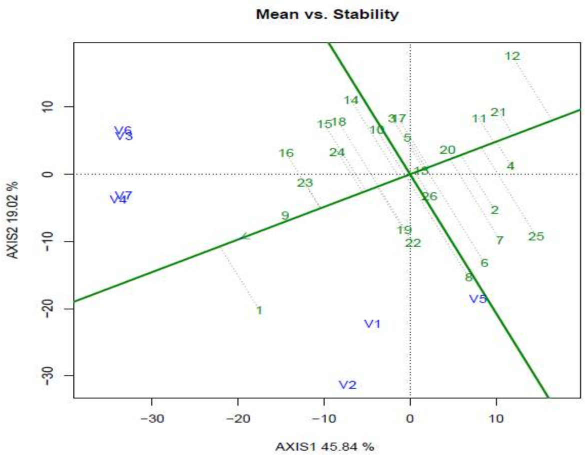

Fig. 1. GGE Biplot of combined analysis for yield: Mean vs. Stability of genotypes

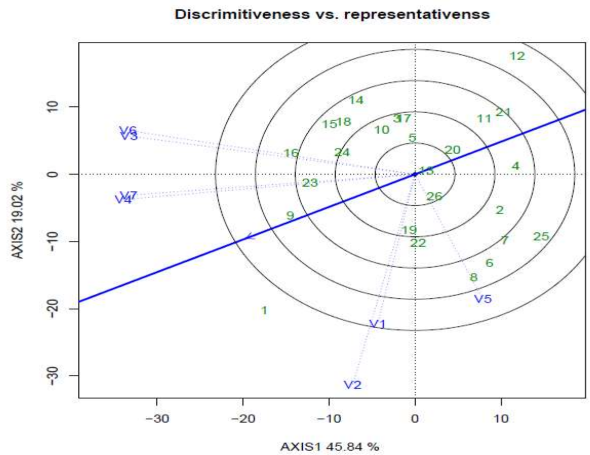

Fig. 4. Ranking of environments based on discriminating ability and representativeness

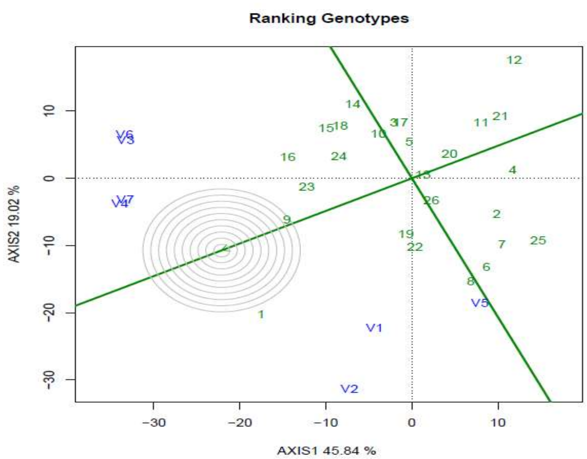

Fig. 2. Ranking of genotypes

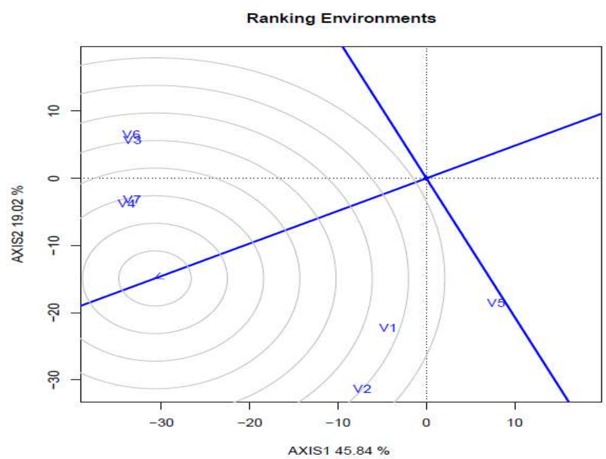

Fig. 5. Ranking of environment

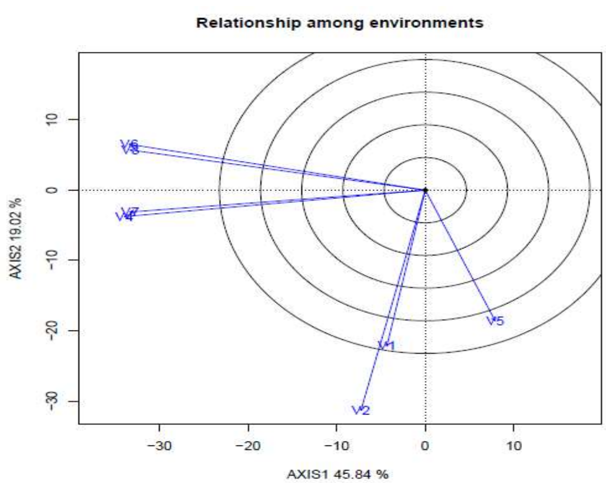

Fig. 3. GGE Biplot combined analysis: Relationship among environments

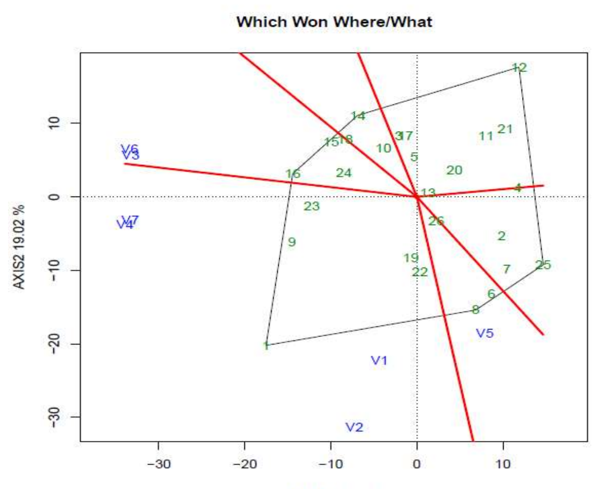

Fig. 6. GGE Biplot combined analysis: 'Which-won-where'

Third ME (ME3) was represented by V_5 with G_8 as winning genotype. Thus, this study established the effectiveness of GGE biplot analysis in identifying stable and superior genotypes. Similar findings and interpretation have been made by Hashim et al (2021) in rice and Bana et al (2022) in eggplant.

CONCLUSION

Present investigation deciphered the influence of G x E interaction on yield of eggplant while, discriminating ability of rainy season was found to be closest to the ideal environment as per the ranking. Rajni, Shamli and PPC were identified as stable genotypes whereas, Nisha Improved was found to be the most unstable genotype. 'Which-won-where' analysis depicted three mega environments viz., ME1 represented by four locations, V_1 (Autumn-winter, 2013), V_2 (Spring-summer 2014), V_4 (Autumn-winter 2014) and V_7 with G_1 (Rajni) as winning genotype and second ME (ME2) consisting of V_3 (Rainy 2014) and V_6 (Rainy 2015) with G_{15} (Arka Nidhi) and G_{16} (Arka Neelkanth) as winning genotypes. Third ME (ME3) was represented by V_5 (Spring-summer 2015) with G_8 (Nisha Improved) as winning genotype.

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