

Original Research Article

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Identification of Stable Inbreds through GGE Biplot Analysis in Maize (*Zea mays* L.)

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ABSTRACT

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Genotype + genotype x environment (GGE) biplot models is adopted to uncover GEI patterns and effectively identify high yielding genotypes with stable performance across environments. The components of GGE biplot analysis PCA 1 and PCA 2 together accounted for more than 95 percent of total variation which is more satisfactory to explain genotype + genotype x environment interaction for days to maturity, ear length, number of kernels per row, 100 seed weight and grain yield per plant. Heypool was identified as the winning inbred for ear length and 100 seed weight in all the seasons; grain yield per plant in *kharif* and *rabi* and number of kernels per row in *kharif* and summer. For number of kernels per row, DFTY was found more responsive in *kharif* and summer. Summer season was found to have more discriminating ability for days to maturity, number of kernels per row, 100 seed weight and grain yield, while *rabi* had the discriminating power for ear length. *Kharif* season was found to be more representativeness for ear length, number of kernels per row, 100 seed weight and grain yield per plant and *rabi* for days to maturity. The inbreds viz., DFTY, PDM 1452, Heypool and PDM 1474 with high mean and stability for ear length, number of kernels per row and 100 seed weight in were close the ideal genotype. Inbreds viz; DFTY, PDM 1452 and PDM 1474 with moderate stability in performance over seasons may be recommended for improving parental lines and also developing high yielding hybrids in maize.

Introduction

Performance of a genotype depends on the genotype and the nature of the production environment which is a function of genotype, environment and the genotype × environment interaction (GEI). Multi-environment trials have demonstrated the existence of GEI (Badu-Apraku *et al.*, 2011 and Stojakovic *et al.*, 2015). Presence of a

significant GEI complicates the selection of superior genotypes and the best testing environment for identifying superior and stable genotypes.

Thus, it necessitates the breeders to evaluate genotypes in more than one environment not only to identify high yielding and stable genotypes but also to identify ideal testing environments.

Despite several biometrical and statistically techniques are available to assess the GEI pattern, of-late, the utility of genotype + genotype $\times$ environment interaction (GGE) biplot technique has become more prominent for analyzing multi-environmental trial data. GGE an effective method based on principal component analysis (PCA) and allows visual examination of the relationships among the test environments, genotypes and the GE interactions in multi-environment trials. Yan *et al.*, (2000) proposed a methodology known as genotype and genotype by environment (GGE) biplot for graphical display of GE interaction pattern of MET data. The analysis considers both genotype (G) and GE interaction effects and graphically displays GE interaction in a two way table.

GGE biplot is a specific version of a biplot that provides information on genotype main effects and genotype $\times$ environment interaction at the same time. The typical multivariate stability analysis methods consider only G $\times$ E interaction, while GGE biplot method includes genotype main effects (G) plus genotype by environment (GGE) interaction. Further, in most of the stability analysis trials, the main effect of environment which is not a controllable factor is high and the main effect of genotypes and genotype $\times$ environment interactions are low. Hence, both Genotype + G $\times$ E interaction sources of variation are used in the GGE biplot to obtain more reliable results (Yan *et al.*, 2000 and Yan *et al.*, 2001). GGE biplot method graphically displays G $\times$ E interaction effects and helps plant breeders to assess genotypic stability and combinations of genotypic stability and yield under different environments.

Materials and Methods

Ten inbred lines viz., BML 2, BML 6, BML 7, BML 15, DFTY, Heypool, PDM 1416, PDM 1428, PDM 1452 and PDM 1474 were evaluated in a randomised block design with three replications for three seasons viz., *rabi* 2016-17, summer 2017 and *kharif* 2017 seasons at Agricultural Research Station, Perumallapalli, Tirupati district. Data were recorded for five characters viz., days to maturity, ear length (cm), number of kernels row⁻¹, 100 seed weight (g) and grain yield per plant. Analysis of data was carried out following the standard statistical procedures (Panse and Sukhatme, 1985). Data was subjected to GGE biplot GUI package (Bernal and Villardon, 2016) in the 'R' programme (R core team, 2020). The GGE biplot graphs were generated based on 1. Polygon view of GGE biplot for the identification of winning hybrids on "which

won where" pattern. 2. Evaluation of genotypes based on mean and stability in performance. 3. Testing of seasons for representativeness and discriminative power. 4. Ranking of hybrids in relation to ideal genotype.

A GGE biplot is constructed by plotting the first principal component (PC1) scores of the genotypes and the environments against their respective scores for the second principal components (PC2) that result from singular value decomposition (SVD) of environment-centered or environment standardized G $\times$ E data (for a single trait) (Yan *et al.*, 2001). A polygon is formed by connecting the markers of the genotypes that are farther away from the biplot origin such that all other genotypes are contained in the polygon. The polygon view of a biplot is the best way to visualize the patterns of interaction between genotypes and environments and to effectively interpret a biplot. It clearly shows which genotype won in which environments, thus facilitating mega-environment identification (Yan *et al.*, 2000 and Dimitrios *et al.*, 2008).

The biplot graphs in the GGE model were generated through the simple dispersion of *gi1* and *gi2* to assess the genotypes and of *ej1* and *ej2* to evaluate the environments based on the Singular Value Decomposition (SVD). The polygon view of GGE biplot aid in the identification of winning genotypes and mega environments by "which won where" pattern. It also facilitates comparison of relationship between environments and rearrangement of target environments. Determining and grouping of target environments is one of the most important applications of the GGE biplot method. The environments evaluated are grouped in to different groups with the same genotype reaction.

GGE biplot technique is an efficient technique to identify productive and stable genotypes in single analysis. The PC 1 axis indicates the environments with greater capacity for discrimination of genotypes and the PC 2 axis, the most representative environments of the group (Yan *et al.*, 2000). The GGE biplot method specifies the position of "Ideal genotype" that has the highest average value of all genotypes and absolutely stable, which expresses no G $\times$ E interaction. A genotype that is located at the centre of the circle or closest to the hypothetical genotype is considered as superior genotype with high mean and good stability (Kuchanur *et al.*, 2015). It enables to predict the mean genotypic value for specific environment and identifying the most stable genotype for the location.

Results and Discussion

GGE biplot analysis was carried out in ten inbreds for four important yield related characters viz., days to maturity, ear length, number of kernels row-1 and 100 seed weight in addition to grain yield plant-1. The results obtained were presented for inbreds and hybrids on character wise here under.

Grain Yield Plant-1

The inbreds, seasons and inbreds $\times$ seasons interactions were significant for this character. Seasons (55.56 %) followed by inbreds (31.36 %) and inbreds $\times$ seasons (4.43 %) contributed to the total variation (Table 1). PC 1 contributed a maximum of 87.84 %, while PC 2 contributed 9.72 % to the genotype + genotype $\times$ environment interaction in GGE biplot analysis. The PC 1 and PC 2 together accounted for 97.56 % of genotype + genotype $\times$ environment interaction which is more satisfactory (Table 2).

Out of six sectors, all the three seasons were distributed in two sectors. *kharif* and *rabi* fell into one sector, while summer fell into a separate sector. The wining (vertex) inbred for this character during *kharif* and *rabi* seasons was Heypool indicating that this inbred was more responsive in the respective seasons for this character (Fig 1.).

The test environments showing long vectors were the ones better separating the genotypes, whereas the shorter vectors provided little, or none, information about differences between genotypes (Yan *et al.*, 2007). The test environments presenting shorter angles with AME were the most representative ones (Yan and Tinker, 2006). Summer was the discriminative season, while *kharif* was the most representative season for this character (Fig2.). Mean yield performance and stability were worked out using an average environment coordination (AEC) method (Yan *et al.*, 2001 and Yan and Hunt, 2002). None of inbreds were found to be stable over seasons for grain yield plant-1. However, the inbreds viz., DFTY, Heypool, PDM 1452 and PDM 1474 registered moderate stability with high mean performance (Fig. 3).

The ideal genotypes as virtual genotype is one that has both high mean performance of that particular trait across test environments and is absolutely stable in performance (Yan and Rajcan, 2002; Yan and Kang, 2003). A

genotype is more desirable if it closer to 'ideal genotype' (Kaya *et al.*, 2006 and Mitrovic *et al.*, 2012). A genotype that is located at the center of the circles or is the genotype closest to the hypothetical genotype is considered a superior genotype with high means per se and good stability. The inbred Heypool followed by DFTY, PDM 1452 and PDM 1474 recorded higher mean and phenotypic stability over seasons in that order and were close to the ideal genotype (Fig 4.) The GGE biplot is considered effective in identifying the best performing genotype(s) in a given environment, most suitable environment(s) for each genotype, consistently performing (stable) genotypes and suitable test environments for comparing pairs of genotypes in individual environments (Yan and Kang, 2003; Yan and Tinker, 2006; Yan *et al.*, 2007 and Yan, 2014).

Days to maturity

Mean sum of squares were significant among inbreds, seasons and also inbreds $\times$ seasons interaction for this character. The seasons (76.83 %) followed by inbreds (9.95 %) and inbreds $\times$ seasons interaction (7.29 %) contributed much to the total variation of G $\times$ E interaction (Table 1). PCA 1 contributed maximum (61.85 %), while PCA 2 contributed 32.50 % and PC 1 and PC 2 together contributed 94.35% which is satisfactory to explain the genotype + genotype $\times$ environment interaction (Table 2).

Kharif and *rabi* fell into one sector, while summer fell in another sector. The winning inbred BML 7 in *rabi*, whereas PDM 1452 in summer for this character. For days to maturity, summer season was the most discriminating season, while *rabi* was the representative season. The inbred PDM 1428 was the most stable inbred with high mean performance over seasons, whereas BML 6 and BML 7 displayed moderate stability with high mean performance for this character. The inbred PDM 1452 followed by BML 6 were the more desirable inbreds with high average mean and relatively stable in performance in comparison to ideal genotype (Table 2).

Ear length (cm)

The differences were significant among inbreds, seasons and inbreds $\times$ seasons for ear length character (Table 1). The seasons (42.50 %) followed by inbreds (28.32 %) and inbreds $\times$ seasons (4.36 %) contributed to total variation. In the GGE biplot analysis, PC 1 contributed 92.84 %, while PC 2 accounted for 5.77 % to the total variation of genotype + genotype $\times$ environment

interaction. PC 1 and PC 2 together contributed 98.61 % which is satisfactory to explain GGE biplot graphs (Table 1). All three seasons fell into one sector. The vertex genotype (winning inbred) for all the three seasons was Heypool. *Rabi* season was found to be the most discriminating season based on differential response of inbreds for ear length, whereas *kharif* was the representative season for this character.

The inbred which recorded high stable performance and average mean over seasons include PDM 1474, while the inbreds viz., Heypool, PDM 1452 and DFTY registered high mean and moderate stability for this character. The inbred Heypool followed by DFTY, PDM 1452 and PDM 1474 with high mean were the most desirable stable inbreds as they were closely located to the ideal genotype (Table 2).

Table.1 Pooled analysis of yield and yield related characters of 10 inbreds tested over three seasons

S.No	Character(s)	Inbreds (df=9)			Seasons (df=2)			Inbreds × Seasons (df=18)			Total (df=89)
		SS	MSS	% Contr.	SS	MSS	% Contr.	SS	MSS	% Contr.	SS
1	Days to maturity	71.73	7.97*	9.95	553.62	276.81**	76.83	52.56	2.92**	7.29	720.58
2	Ear length (cm)	97.11	10.79**	28.32	145.74	72.87**	42.50	14.94	0.83**	4.36	342.91
3	Number of kernels row ⁻¹	226.71	25.19**	63.12	33.35	16.68**	9.28	16.42	0.91	4.57	359.15
4	100 seed weight (g)	459.36	51.04**	72.53	144.54	72.27**	22.82	9.04	0.50**	1.43	633.37
5	Grain yield plant ⁻¹ (g)	2299.95	255.55**	31.36	3596.90	1798.45**	55.56	286.74	15.93*	4.43	6473.95

Table.2 Results of GGE biplot analysis for yield related characters in inbreds of maize

S. No	Character	Contributions of PCA I	Contributions of PCA II	Vertex inbreds / season	Discriminative season	Representative season	Stable inbreds	Moderately stable inbreds	Ranking of inbreds in relation to ideal genotype
1	Days to maturity	61.85	32.50	BML7: Rabi PDM 1452: Summer	Summer	Rabi	PDM 1428	BML 6, BML 7	PDM 1428> BML 6
2	Cob length	92.84	5.77	Heypool : All seasons	Rabi	Kharif	PDM 1474	Heypool, PDM 1452 and DFTY	Heypool> DFTY> PDM 1452> PDM 1474
3	No. of kernels per row	94.23	5.29	DFTY and Heypool	Kharif and summer	Summer, kharif	DFTY,	Heypool, PDM 1474, PDM 1452, BML 7	Heypool> DFTY > PDM 1474> PDM 1452> BML 7
4	100 kernel weight	98.14	1.64	Heypool: all seasons	Summer	Kharif	Heypool	DFTY, PDM 1474	Heypool> DFTY> PDM 1474
5	Grain yield per plant	87.84	9.72	Heypool : kharif and rabi	Summer	Kharif	-	DFTY , Heypool, PDM 1452, PDM 1474	DFTY >PDM 1452>PDM 1474

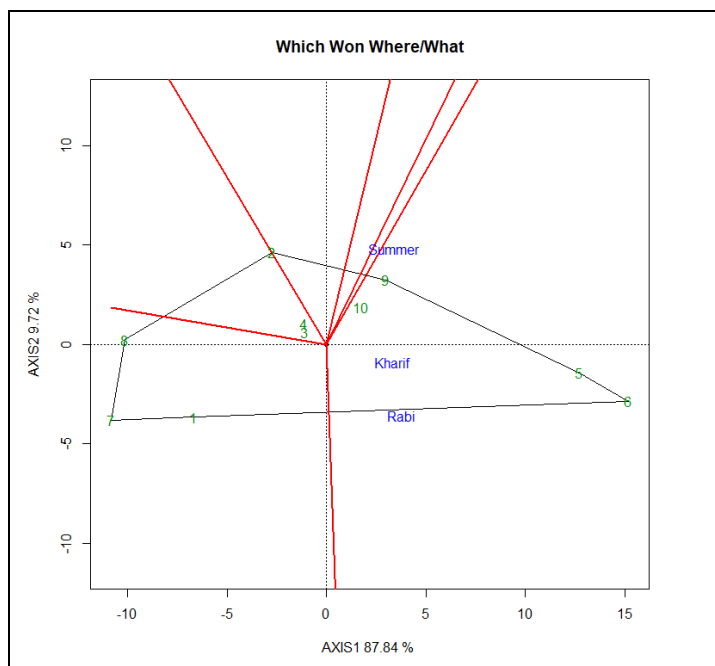


Fig.1a GGE biplot analysis on which won where/ what pattern for grain yield plant-1 (g) in inbreds

1 = BML 2 2= BML 6 3= BML 7 4= BML 15 5= DFTY 6= HEYPOOL 7= PDM 1416 8= PDM 1428 9= PDM 1452 10= PDM 1474

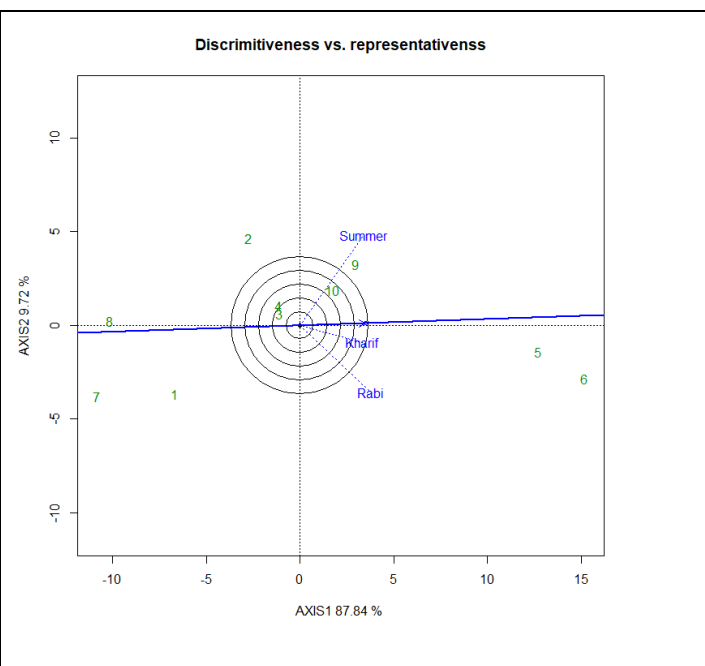


Fig.1b GGE biplot analysis on discriminativeness and representativeness for grain yield plant-1 (g) in inbreds

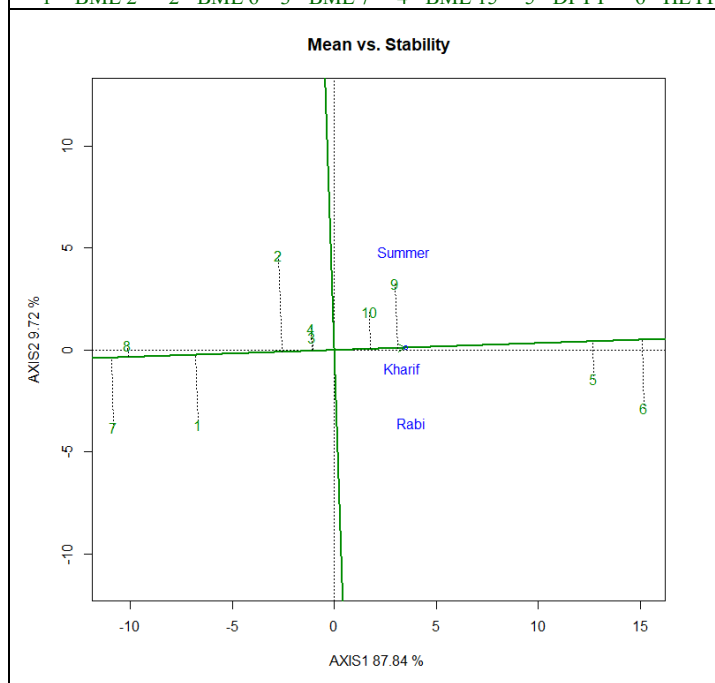


Fig.1c GGE biplot analysis on mean vs stability for grain yield plant⁻¹ (g) in inbreds

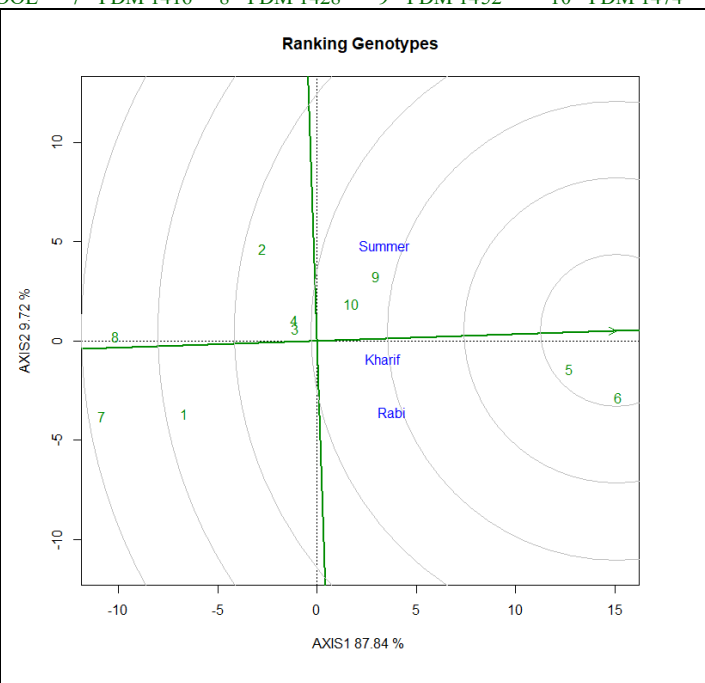


Fig.1d GGE biplot analysis on ranking of inbreds grain yield plant⁻¹ (g) in inbreds

Number of Kernels Row-1

Mean sum of squares were significant among inbreds and seasons. The inbreds (63.12 %) followed by seasons (9.28 %) and inbreds $\times$ seasons interaction (4.57 %) contributed much to the total variation of G $\times$ E interaction (Table 1). PCA 1 contributed maximum (94.23 %), while PCA 2 contributed 5.29 % and PCA.1 and PCA2 together contributed 99.52 % which is satisfactory to explain the genotype + genotype $\times$ environment interaction (Table 2).

Kharif and summer fell into one sector, while *rabi* fell into another sector. The winning inbreds were DFTY and Heypool in *kharif* and summer for this character. For number of kernels row-1, summer season was the most discriminating season, while *kharif* was the representative season.

The inbred DFTY was the most stable inbreds with high mean performance over seasons, whereas inbreds viz., Heypool, PDM 1474, PDM 1452 and BML 7 displayed moderate stability with high mean performance for this character. The inbred Heypool followed by DFTY, PDM 1474 PDM 1452 and BML 7 were the more desirable inbreds with high average mean and relatively stable in performance in comparison to ideal genotype (Table 2).

100 seed weight (g)

The inbreds (72.53 %) followed by seasons (22.82 %) and inbreds $\times$ seasons interaction (1.43 %) contributed much to the total variation of G $\times$ E interaction. PCA 1 contributed maximum (98.14 %), while PCA 2 contributed 1.64 % and PC 1 and PC 2 together contributed 99.78 % which is satisfactory to explain the genotype + genotype $\times$ environment interaction (Table 1).

All the three seasons fell into one sector out of total seven sectors. If all the environment markers fell in to a single vector, indicates that, a single cultivar had the highest performance in all environments (Yan and Kang, 2003).

The winning inbred was Heypool in all three seasons for this character. For 100 seed weight, summer season was the most discriminating season, while *kharif* was the representative season. The inbred Heypool was the most stable with high mean performance over seasons, whereas DFTY and PDM 1474 displayed moderate stability with high mean performance for this character.

The inbreds Heypool followed by DFTY and PDM 1474 were the more desirable inbreds with high average mean and relatively stable in performance in comparison to ideal genotype. (Table 2)

The stable maize inbreds suitable for the region can be determined through this study. The inbreds viz; DFTY, PDM 1452 and PDM 1474 were identified with moderate stability in performance over seasons. These inbreds should be evaluated on-farm on large scale and may be recommended for improving parental lines and developing high yielding hybrids in maize.

Data availability

The data used to support the findings of this study are included within the article.

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Author Contributions

N. Sabitha: Investigation, formal analysis, writing—original draft. D. Mohan Reddy: Validation, methodology, writing—reviewing. D. Lokanatha Reddy:—Formal analysis, writing—review and editing. P. Sudhakar: Investigation, writing—reviewing.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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