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Research Article

GGE biplot analysis in finger millet [*Eleusine coracana* (L.) Gaertn.] genotypes across agro-climatic zones of Andhra Pradesh

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Abstract
The main focus of the study is to identify promising finger millet genotypes with yield stability and adaptability for wide range of environments as well as to identify ideal mega-environments using genotype plus genotype and environment interaction (GGE) biplot method. Grain yield of finger millet genotypes were remarkably influenced by environment (E), genotypes (G) and their interaction (G x E). The genotype and environment interaction was significant though comparatively less than location and genotype effects. The study has spotted the best varieties suitable for cultivation across five zones of finger millet growing areas of Andhra Pradesh. The cultivar PPR-1152 is recognized as the perfect genotype as it showed higher grain yield and stability compared with other cultivars in all places. Among locations Vizianagaram was the best discriminative and better representative location than other locations and perfect testing site for choosing finger millet cultivars effectively for adaptation in Andhra Pradesh.

Keywords: Finger millet, GGE biplot analysis, Multi-location testing, Yield stability.

INTRODUCTION

Finger millet is a small millet crop widely grown as major food crop in arid areas of Africa and Asian countries. In India it stands third in importance among the millets next to sorghum and pearl millet (Chavan *et al*., 2018). The crop is valued for nutritionally rich food grains and its adaptability to wide range of geographical areas and agro-ecological diversity, with minimal inputs. It is a hardy crop that can be grown in varied environments from almost at sea level in south India to high lands of Himalayas and from poor soils on hill slopes to rich soils in the Indo-gangetic plains. In India it is cultivated in 1,004,800 ha with a production of 1,755,000 tonnes having productivity of 1747 kg/ha (Directorate of Economics and Statistics 2019-2020). Even though the crop is having yield potential up to 3000-3500 kg/ha, the recorded national as well as state productivity levels are low. In Andhra Pradesh productivity in finger millet crop is lower (1324 kg/ha) when compared with national average. Lower productivity in finger millet is mainly due to lack of stable high yielding varieties, poor management and other biotic and abiotic factors (Bezawuletaw *et al.,* 2006). Andhra Pradesh state has a wide environmental variability which can lead to high genotype environment interaction. Wide environmental variability in the state strengthens the importance of multi environment / location experiments in variety development process for identifying high yielding varieties with wide adaptation (Madhavilatha *et al.,* 2020). There is a need to increase the overall productivity levels of this crop in the state by enhancing the genetic yield potential of the newly developed finger millet varieties along with stable performance (Madhavilatha and Subba Rao, 2015). Yield is a composite trait which is highly governed by genotype, environment and genotype and environment interaction (Simmonds, 1991). The expression of genotypes may vary with different environments as it is highly influenced by abiotic and biotic factors of the environments. Genotype environment interactions (GEI) are important sources of variation in any crop, and the term stability is used to characterize a genotype, which shows a relatively constant yield, independent of changing environmental conditions (Sood *et al.,* 2016). Varietal development process became complicated because of the involvement of Genotype environment interactions (GEI) wherein the selection of genotypes with wide adaptability is difficult. Multi-environment trials are widely used by plant breeders to evaluate relative performance of newly improved genotypes for environments (Delacy *et al.*, 1996). In order to identify superior cultivars with wide adaptation, evaluation of the cultivars at many environments to study GEI is necessary (Yan, 2001 ; Yan *et al.,* 2007). Superior cultivars for a targeted environment can be identified by understanding the GEI through ranking of genotypes across environments (Ebdon and Gauch, 2002). The prime objectives of the experiment were to analyse yield stability and adaptability of finger millet cultivars and to assess discrimination and representativeness of test environments.

MATERIALS AND METHODS

The experimental material consists of eleven newly developed promising finger millet genotypes from three research stations of Andhra Pradesh (four genotypes *viz.,* PPR 1094, PPR 1096, PPR 1152, PPR 1163 from Agricultural Research Station, Perumallapalle, four genotypes *viz.,* PR 1506, PR 1639, PR 1643, PR 1731 from Agricultural Research Station, Peddapuram and three genotypes *viz.,* VR 1112, VR 1117 and VR 1118 from Agricultural Research Station, Vizianagaram) along with three popular varieties as checks (Godavari, Srichaitanya and Vakula). Five experimental sites (Perumallapalle, Chintapalle, Peddapuram, Utukuru and Vizianagaram) had chosen for the study representing the broad range of environments of Andhra Pradesh. The details of the environmental conditions of the locations are listed in **Table 1**. Field experiments were conducted with three replications in a Complete Randomized Block Design during *Kharif,* 2020 at all locations. Twenty one days seedlings were transplanted with plot size of 6.75 sq. m for each genotype in each replication with 10 rows of 3 m length. The spacing of 22.5 cm between rows and 10 cm within the row between plants was followed. All the recommended agronomic practices were followed to raise the crop under irrigated dry condition. At harvesting grain yield data was recorded for all the genotypes in all locations in kg/ha.

The most effective method to evaluate the genotypes in different locations/seasons and also to identify superior cultivars is GGE biplot (Ding *et al*., 2007). This method is being widely used by crop breeders to identify high yielding genotypes with stable performance (Kang *et al*., 2006) and also to discriminate test locations (Dimitrios *et al*., 2008). In the current study GGE bi-plot analysis was used for analysing the yield stability of promising finger millet genotypes. Pooled analysis of variance (ANOVA) for grain yield was derived by using mean data of fourteen genotypes evaluated in five locations. Graphical interpretation of the data to identify the effects of environment (E), genotype (G) and GE interactions was calculated by using the GGE biplot software (Yan 2001). Biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al*., 2000) present in GGE biplot methodology was utilized to graphically visualize the finger millet multi environmental data. Graphs were generated to (i) View the mega environments and their winning genotypes by 'which-won-where' pattern, (ii) Ranking of genotypes for mean performance of yield and stability, (iii) Genotypic evaluation compared to ideal genotypes, (iv) Environmental evaluation compared to ideal environments, (v) Environmental relations and (vi) Genotypic comparisons.

RESULTS AND DISCUSSION

The mean grain yield and ranking of finger millet genotypes in multi-locations were presented in **Table 2**. The average grain yield for the genotypes differed from 3660 kg/ha (PPR 1152) to 2330 kg/ha (Vakula). In five locations the average grain yields were observed from 2692 (Peddapuram) to 3815.74 (Chintapalli). Manoj Kandel *et al.* (2020) and Madhavilatha *et al.* (2020) reported similar results of superior grain yields by finger millet entries than the checks in MLTs. The combined AMMI model analysis of variance was carried out to

Table 1. Geographical details of five experimental locations

Location	Soil type	Altitude	Rainfall (mm) during crop season (June to October 2020)	Latitude	Longitude
Chintapalli	Red sandy loam soils	839 m	1292	17° 87'	82° 35'
Peddapuram	Laterite soils	35 m	877	17° 08'	82° 13'
Perumallapalle	Red sandy loam soils	182.29 m	912	13° 37'	79° 25'
Utukur	Alfisols	138 m	911	14° 47'	78° 82'
Vizianagaram	Red sandy loam soils	74 m	858	18° 7'	83° 23'

Table 2. Mean grain yield (kg/ha) of finger millet genotypes across five different locations

Genotypes	Code	Locations					Mean
		Chintapalli	Peddapuram	Perumallapalle	Utukur	Vizianagaram	
		E1	E2	E3	E4	E5	
Godavari*	G1	4089	2314	3542	2803	3307	3211
PPR 1094	G2	4658	2407	4302	3395	3540	3660
PPR 1096	G3	4124	2333	4223	2819	3796	3459
PPR 1163	G4	3530	2289	2812	1750	2088	2494
PPR 1152	G5	4347	2805	3562	3596	3992	3660
PR 1506	G6	4058	3370	3137	3205	3584	3471
PR 1639	G7	4244	2426	3433	2729	3470	3260
PR 1643	G8	3359	3366	3393	2734	3181	3207
PR 1731	G9	3907	3244	3690	3141	3559	3508
Srichaitanya*	G10	3346	2963	3374	2485	3459	3125
Vakula*	G11	2656	2296	3413	1290	1995	2330
VR 1112	G12	3896	3630	3197	3523	3507	3550
VR 1117	G13	2720	2059	2170	2618	3315	2576
VR 1118	G14	4483	2192	3098	2824	3244	3168
Mean		3815	2692	3382	2779	3288	
C.D.		536.7	280.23	399.64	449.55	446.52	
SE(m)		183.61	95.87	136.72	153.79	152.76	
C.V.		8.335	6.167	7.002	9.583	8.045	

* Checks

determine the effect of environments, genotypes and their interaction (G x E) on grain yield of finger millet genotypes (**Table 3**). Pooled analysis of variance for grain yield showed highly significant differences for the environments, genotypes and their interaction (G x E). Similar results were reported earlier by Prabhu *et al.,* (2020) in barnyard millet. Higher contribution of the treatment than the error shows the reliability of the multi-location experiment. In total variation environments (42.32 %) contributed larger followed by genotypes (29.78 %) and G x E (27.90 %). A large yield variation shown by environments indicated that the environments are diverse with large differences among environmental means causing most of variation in grain yield and showed a significant role in expression of grain yield by the genotypes. This explains the greater fluctuations among the cultivars with change in environment and moreover the significant GE indicates that the genotypes showed varied performances across locations. In GGE biplot analysis, the complex GEI are simplified in different PCs and if the first two PCs explain more than 60% of the (Genotype and Genotype x Location) variability in the data, and the combined (Genotype and Genotype x Location) effect account for more than 10% of the total variability, then the biplot adequately approximates the variability in G × E data (Rakshit *et al.,* 2012). In the present study, the first two PCs explained 80.9% variation for grain yield. Hence, graphical representation of biplots can be used for deriving stable and ideal genotypes and ideal environments. Genotypes also differed significantly which indicated that the genotypes are genetically different. Several similar results were earlier reported in finger millet by Wedajo Gebre *et al*. (2018), Amare Seyoum *et al*. (2019) and Birhanu *et al.* (2016).

In the **Fig. 1**, the horizontal axis (PC1) showed main effects of genotypes and the vertical axis (PC 2) indicated the effect of G x E interaction. Small circle on the average environment axis (AEA) indicated the average environment. The length of environmental vectors is proportional to the standard deviation of the genotypes in the environments. The longer environmental vectors indicated that the environment was more differentiating for grain yield among the genotypes. Another important criterion in evaluating environments is the test of their representativeness. The average environment coordinate (AEC) line crosses the centre of the biplot the medium environment, and the angle of each vector with the AEC axis is a criterion for identifying the sample environment (Yan and Kang, 2003). Environments with smaller angles with the AEC axis are most representative of the average test environments. A suitable environment should have the two criteria at the same time: distinctive and a target environment. Vizianagaram location was closest to the average environment and thus is the most discriminating environment followed by Utukur location. Genotypes that are near to the biplot origin are not sensitive to the

Table 3. Combined analysis of variance for grain yield (kg/ha) of finger millet genotypes evaluated across five locations

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Percent of total sum of squares
Environment (E')	4	834.241	208.56	122.21***	42.32
Replications (Environment)	10	17.066	1.707		
Genotypes (G)	13	587.147	45.165	45.17***	29.78
G x E	52	549.945	10.576	10.58***	27.90
Error	130	130	1		
Total	209	2118.40			

*** Significant at 0.1% probability level; Total sum of squares is G + E + (G x E)

environments and those far from the origin are sensitive to the environments having larger interactions with environment. While ranking the genotypes in the near average environment Vizianagaram, the pre-release cultivar PPR-1152 developed from Perumallapalle research station had recorded higher grain yield and found highly stable.

The polygon view of GGE biplot (**Fig. 2**) is the best way for the identification of ideal genotypes for each location with visualizing the interaction patterns between genotypes and environments (Yan and Kang, 2003) in multi environmental trials data analysis, which is helpful in estimating the possible existence of different mega environments (Gauch and Zobel, 1997). Which-won-where graph was constructed by joining the farthest genotypes in a polygon. From the origin of the biplot, perpendicular lines referred to as equity lines were drawn to the sides of the polygon separating the polygon into several sectors (Yan, 2001). In the present investigation, the partitioning of GE interaction through GGE biplot analysis showed that PC1 and PC2 accounted for 61.3 per cent and 19.6 per cent of GGE sum of squares, respectively, explained 80.9 per cent of the total variance (**Fig. 2**). Genotype at the vertex is the best performing genotype for the trait in the environment falling in that sector (Yan and Tinker, 2006). In contrast the genotypes which were located inside the polygon and close to the origin of biplot were not sensitive to changing environments (Dimitrios *et al.,* 2008). Which-won-where biplots for grain yield over pooled locations are presented in the **Fig. 2.** For grain yield over locations, the pentagon has five genotypes, PPR-1094, PPR-1152, VR-1112, VR-1117 and Vakula, at its vertices. The equity lines divided the biplot into five sectors of which three retained five locations. Based on this graphical representation, for grain yield the testing

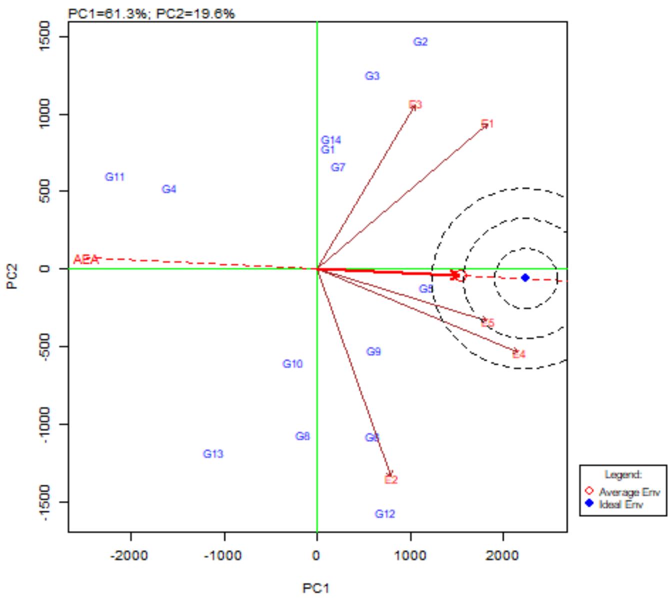

Fig. 1. Average environment coordination (AEC) in view of GGE biplot graph based on principal components for environments. AE is "the average environment"

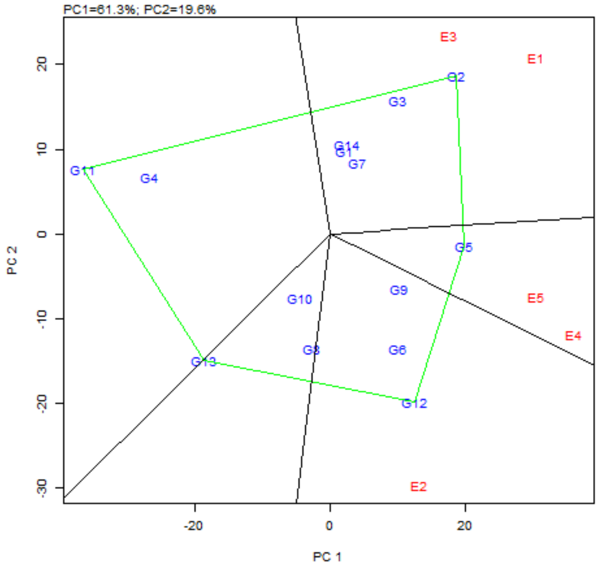

Fig. 2. Polygon view of GGE biplot based on principal components for genotypes and environments

locations were partitioned into three mega environments (ME). ME1 was represented by Perumallapalle and Chintapalli with PPR-1094 as the winning genotype. For ME1, Perumallapalle can be selected as the most representing environment. The ME2 consisted of the locations Utukur and Vizianagaram with PPR-1152 as the winning genotype and Vizianagaram being most representative environment. The ME3 consisted of Peddapuram location with VR-1112 performing better for this location.

The environment centered biplot without scaling for grain yield is presented in **Fig 3**. The first two PCs explained 80.9 per cent variation for grain yield. AEC abscissa passes through the biplot origin and acts as a marker for average environment and points towards higher mean values (Yan, 2001). The perpendicular lines to the AEC passing through the biplot origin are referred to as AEC ordinate. The greater the absolute length of the projection of a cultivar, the less stable it is. Furthermore, the average yield of genotypes is approximated by the projections of their markers to the AEC abscissa (Kaya *et al.,* 2006). Accordingly, PPR-1152 was the best performing genotype in terms of grain yield followed by PPR-1094, VR-1112, and PR-1731 while Vakula, PPR-1163 and VR-1117 were limited by lower yield. VR-1117 was also least stable for grain yield with higher projection from the AEC abscissa. The variety PPR-1152 was most stable among the high yielding genotypes. A genotype is considered ideal if it has high mean yield and is less variable across locations

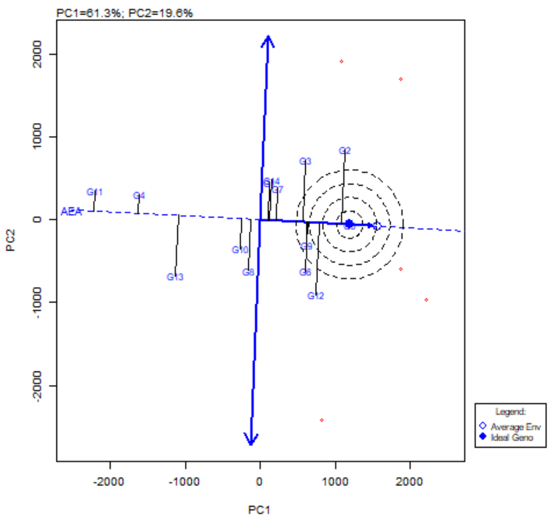

Fig. 3. Mean and stability of genotypes in view of GGE biplot based on principal components

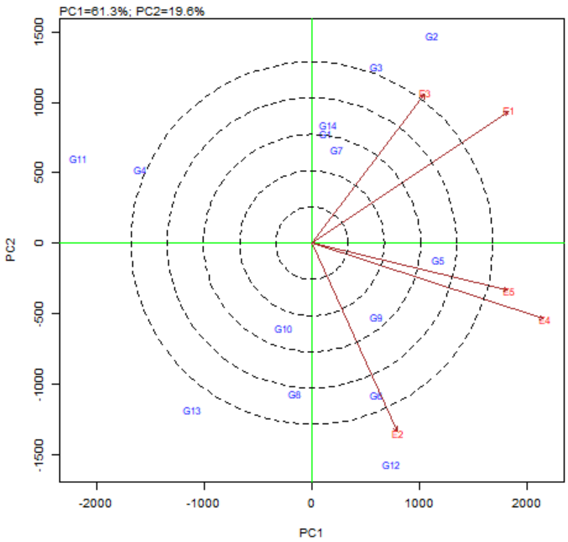

Fig. 4. Environment comparison GGE biplot for grain yield of finger millet genotypes

and seasons. It is evident from **Fig. 3** that the advanced promising cultivar PPR-1152 was highest grain yielder with high stability. The pre-release cultivar PPR-1152 performed exceptionally well for mean performance as well as stability as compared to proven and popularly cultivated Godavari, Sri Chaitanya and Vakula. Hence, the pre-release cultivar PPR-1152 is identified as the ideal genotype for cultivation across all regions of Andhra Pradesh.

Combined analysis of variance for grain yield (**Fig. 4**) in different environments showed that the majority of the angles between their vectors are acute. Acute vector angles are indicative of closer relationship among the environments (Yan and Tinker, 2006). Thus, majority of the locations were highly correlated except Peddapuram location with that of Perumallapalle and Chintapalli locations showing no-relationship between them as the angle was 90°. Distance between two environments measures their ability in discriminating the genotypes. Thus, five locations could be divided into three groups for grain yield; one with Peddapuram, second with Utukur and Vizianagaram and the third group with Chintapalle and Perumallapalle. The groupings did not correlate with geographical identity.

The study has identified PPR 1152 as the best finger millet variety suitable for cultivation across five locations (major finger millet growing areas) of Andhra Pradesh. Among locations, Vizianagaram location had the best discrimination and representativeness than other locations. Therefore, Vizianagaram is the ideal test-site for preliminary selection of finger millet cultivars for adaptation across Andhra Pradesh based on the current study. The stable genotype PPR 1152 was also found to be blast resistant which may be promoted for cultivation in Andhra Pradesh.

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