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Stability Analyses for Yield and Its Components in Little Millet (*Panicum sumatrense* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Linear regression model of Eberhart and Russell is used to identify high yielding stable little millet genotypes suitable across environments. Pooled analysis of variance revealed significant genetic variability among the little millet genotypes for yield and yield attributing traits. Significant variability among environments confirms the heterogeneity in the locations for the traits. Significant genotype x environment interaction for all the traits indicated differential response of the genotypes for the traits in different locations. Among genotypes BL-6, LMNDL-4, LMNDL-3, OLM 203, VS 13, VS 15, VS 19, VS 25 and VS 6, with a regression coefficient near to unity and non-significant deviation from regression, were considered to be highly stable and suitable to all environments for fodder yield. For grain yield VS10 and VS 19 genotypes recorded regression coefficient near to unity with non-significant deviation from regression were considered to be stable in all the environments. GGE biplot model were used to evaluate stability for important traits; fodder yield and grain yield and test

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location representativeness in little millet genotypes. The testing locations were partitioned into two mega environments (ME) for fodder yield. ME1 was represented by Nandyal and Vizianagaram with OLM 203 as the winning genotype, while in ME 2 which was represented by Perumallapalle with LMNDL 4 performed well. Genotype VS 10 was stable for fodder yield in all the environments.For grain yield over pooled locations, BL 6 performed well at Perumallapalle location while LMNDL 5 performed well at Nandyal. Genotype VS 6 was the best genotype for Vizianagaram. The genotype VS 19 was near to origin and it was considered as stable for all the environments.

Keywords: Little millet; stability; regression coefficient; GGE biplot; yield traits.

1. INTRODUCTION

"Little millet (*Panicum sumatrense*L.) is one of the important millet crops indigenous to the Indian subcontinent. In India, crop is widely grown in tribal areas of Madhya Pradesh, Chhattisgarh, Tamil Nadu, Karnataka, Orissa, Andhra Pradesh, Jharkhand, and Biharmainly as a food source and also for cattle feed" [1]. "The crop is drought tolerant and gives good harvest even in low fertile and unfavorable weather conditions. It is climate resilient and can adopttodifferent growing environments differing in soil, rainfall, and weather factors. Unlike other millets, it is least effected by storage pest besides retaining viability for longer periods even under poor storage conditions" [2]. "The crop is frequently grown in poor soils in different ecological conditions in Andhra Pradesh which leads to low productivity (354 kg/ha). Andhra Pradesh state has a wide environmental variability which can lead to high genotype environment interaction. Wide environmental variability in the state suggested the importance of multi-location testing in varietal development process for identifying high yielding varieties with wide adaptation" [3]. "Enhancing the productivity levels by developing and identifying high yielding varieties which can fit in wide range of environments is essential in little millet" [4]. Very little research is being carried out in developing high yielding little millet varieties with wide adaptation to different environments.

"Development of high yielding varieties has always been the prime objective of plant breeders especially those who do research on neglected crops" [5]. "Although research on the development of high yielding varieties has led to release of large number of new varieties in different crops, genotype by environment interaction (G×E) causes failure of genotypes to keep high performance in all environments" [6]. Multi-environment testing of genotypes provides an opportunity to plant breeders to identify adaptability of genotype to a particular environment along with stability of genotypes over different environments. There are number of statistical methods to assess the genotype x environment interaction and its relationship with stability. From all these methods, regression of mean of each genotype on environment index is one of the most applicable methods. The regression analysis proposed by Finlay and Wilkinson [7] to measure phenotypic stability was improved by Eberhart and Russell [8]. "For determining adaptability and stability of genotypes in this method, parameters like mean, regression coefficients (b_i) and variance of deviation from regression (S^2d_i) are used. In this model, the values of b_i *i.e.*, b_i=1, b_i<1 and b_i>1 expresses high, average, and low stability respectively" [9]. According to this model, a genotype is most stable if its regression coefficient is equal to unit, variance of deviation from regression is the least (non-significant with zero) and its grain yield is the highest.

GGE biplot model has been considered and widely used to identify better genotypes with wide adaptability in different agro climatic regions. The phenotypic value of the genotype is a cumulative measure of genotype main effect (G), environment main effect (E) and genotype by environment interaction effect (G x E). Therefore, for stability analysis, both G and G x E must be considered simultaneously. GGE biplot integrates the G with G x E interaction and effectively detects stable varieties for all the environments. GGE biplotisnot sensitive to several genotypes so that it produces most reliable estimates for evaluation of a small number of genotypes. Therefore, in the present study the stability methods of Eberhart and Russel method and GGE biplot model were utilized for assessment. The prime objective of the study was to identify superior stable little millet genotypes for rainfed cultivation and to investigate the environment specific genotypes which can be suggested for cultivation under varied locations.

2. MATERIALS AND METHODS

The study was conducted to evaluate eleven little millet genotypes in three locations

Table 1. Description of locations used for the evaluation of little millet genotypes

S. No	Location	Latitude and Longitude	Environment Code	Soil type	ECdS/m	PH	Mean yield q/ha
1	RARS, Nandyala	15° 46' 78° 48'	E1 - NDL	Black cotton soils	0.25	8.2	11.10
2	ARS, Perumallapalle	13° 37' 79° 25'	E2 - PPL	Red sandy loam soils	0.32	7.8	17.53
3	ARS, Vizianagaram	18° 7' 83° 23'	E3 -VZM	Red sandy loam soils	0.25	7.2	16.66

RARS: regional agricultural research station ARS: agricultural research station

(Perumallapalle, Vizianagaram and Nandyal) across Andhra Pradesh in rainfedconditions during *Kharif,* 2020. The geographical coordinates and agro-climatic conditions of locations along with codes weregiven in Table 1. In three locations, experiment was raised during *Kharif,* 2020 in randomized complete block design (RCBD) with three replications. Each plot consisted of ten rows of 3 m length with a spacing of 22.5 cm x 7-10 cm. Recommended package of practices were followed to raise the good crop. Observations were recorded for days to maturity, plant height (cm), number of productive tillers per plant, panicle length (cm), fodder yield(t/ha) and grain yield (q/ha).

Stability analysis was carried out using the Eberhart and Russell method and GGE biplot analysis.The mean values for yield and yield contributing traits across the environments were subjected to stability analysis (Eberhart and Russell, 1966) to obtain various stability parameters *i.e.,* mean regression coefficient (b_i) and deviation from their regression (S^2d_i) to assess the response of individual genotype by partitioning the pooled deviation. The significance of the stability parameters such as b_i, its deviation from unity and deviation from regression were tested by using appropriate t and F tests to know their level of significance. Further the multi-environment data was subjected to GGE biplot analysis using the method suggested by Yan and Hunt [10].

3. RESULTS AND DISCUSSION

3.1 Mean Performance and Stability Parameters of the Little Millet Genotypes

Linear regression model of Eberhart and Russell [8] was used for estimating genotype x environment interaction, adoptability and stability of the genotypes. In this model the total variance was divided into genotype and environment + G x E interaction. The environment + G x E interaction further divided into environments (linear), genotype x environments (linear) and deviation from regression.Pooled analysis of variance revealed significant genetic variability among the little millet genotypes studied for yield and yield attributing traits. Significant variability among environments confirms the heterogeneity in the locations for the traits. Significant genotype x environment interaction for all the traits indicated differential response of the genotypes for the traits in different locations. The results were in accordance with KebedeDesselegn et al., [11] and Madhavilatha et al., [3] in finger millet, Kandel*et al.,* 2020 in foxtail millet and Selvi and NirmalaKumari, [2] in little millet. The mean performance of the eleven little millet genotypes and environmental indices in three locations for yield and yield components were presented in Table 2. Environmental index directly reflects the unfavourable and favourable environments based on negative and positive values, respectively. Among the three environments studied, Environment 2 (Perumallapalle) and Environment 3 (Vizianagram) recorded the highest positive index for all the traits except days to maturity indicated more favourable environments for these traits. Environment 1 (Nandyal) registered negative indices for all the traits except days to maturity indicated the unfavourable nature of the environment (Table 2).

Mean performance of the genotypes, magnitude of regression coefficient (bi) and deviation from regression (*S^2di*) for all the traits were presented in Table 3.Stability of little millet genotypes for yield and yield attributing traits was presented in Table 4.For days to maturity, the genotype which required less number of days to mature or short duration genotypes are more desirable. Days to maturity over environments ranged from 78.56 (VS 19) to 86.56 (OLM-203) days with a mean of 82.19 days. The genotypes VS 19 (lowest mean which is desirable) and BL 6 showed regression coefficient near to one and non-significant deviation from regression and were considered to be suitable for all environments. Similar results

Table 2. Mean performance and environmental indices for yield and yield componentsinlittle millet

Code	Genotype	Days to maturity			Plant Height (cm)			No. of tillers per plant			Panicle length (cm)			Fodder Yield (t/ha)			Grain Yield (q/ha)		
		NDL E1	**PPL E2**	**VZM E3**	**NDL E1**	**PPL E2**	**VZM E3**	**NDL E1**	**PPL E2**	**VZM E3**	**NDL E1**	**PPL E2**	**VZM E3**	**NDL E1**	**PPL E2**	**VZM E3**	**NDL E1**	**PPL E2**	**VZM E3**
G1	BL 6	87.33	84.33	84.67	116.53	151.33	149.87	6.87	7.27	10.13	28.27	34.67	24.87	4.15	7.56	6.75	5.96	25.36	12.20
G2	LMNDL - 4	83.00	83.67	79.33	108.13	152.67	138.07	6.00	7.07	11.53	25.40	35.00	23.60	3.60	8.87	8.05	6.43	23.88	12.30
G3	LMNDL - 5	87.67	79.67	69.33	103.53	112.00	115.53	6.07	7.73	14.00	26.00	24.53	26.60	1.97	2.32	5.95	18.99	12.63	19.59
G4	LMNDL – 3	85.33	80.33	86.00	114.67	149.00	140.33	7.20	6.73	11.33	26.67	36.00	25.80	3.55	7.68	7.42	9.24	21.81	12.25
G5	OLM - 203	92.00	78.67	89.00	116.00	152.33	142.27	6.20	6.40	10.13	27.20	33.60	24.27	7.21	7.98	8.26	12.44	24.07	11.46
G6	VS 10	89.33	77.33	74.67	121.93	145.33	157.33	5.93	5.87	11.00	28.33	32.00	23.80	4.30	6.44	6.47	16.33	16.08	19.39
G7	VS 13	80.33	83.67	76.00	108.73	147.00	141.53	6.87	4.87	12.60	21.93	32.93	22.13	4.79	7.37	8.01	7.59	13.81	19.74
G8	VS 15	91.00	86.67	75.67	122.33	143.67	146.47	5.53	5.53	13.47	25.80	31.40	25.20	4.44	5.78	7.09	11.65	14.60	21.13
G9	VS 19	85.33	77.67	72.67	115.33	138.67	156.87	5.40	6.73	12.07	24.87	30.40	27.20	5.63	6.36	6.73	13.72	15.69	18.45
G10	VS 25	86.67	82.67	73.67	121.33	139.67	143.60	6.07	6.00	11.40	26.73	28.00	27.40	5.73	6.11	5.30	15.60	12.43	17.36
G11	VS 6	93.67	80.67	83.33	129.47	146.33	149.53	5.53	5.73	10.33	26.80	31.93	24.53	1.53	7.57	5.60	4.21	12.53	19.45
Environmental index		**4.96**	**-1.07**	**-3.89**	**-18.28**	**8.99**	**9.30**	**-1.90**	**1.69**	**3.59**	**-1.51**	**4.17**	**2.66**	**-16.92**	**7.72**	**9.20**	**-4.00**	**2.43**	**1.56**

Table 3. Mean data over locations and stability parameters for yield and yield components in little millet

Variety	Days to maturity			Plant Height (cm)			No. of tillers per plant			Panicle length (cm)			Fodder Yield (t/ha)			Grain Yield (q/ha)		
	Mean	**b**	**S^2_{di}**	**Mean**	**b**	**S^2_{di}**	**Mean**	**b**	**S^2_{di}**	**Mean**	**b**	**S^2_{di}**	**Mean**	**b**	**S^2_{di}**	**Mean**	**b**	**S^2_{di}**
BL 6	85.44	0.33	0.52	139.24	1.24*	-17.06	8.09	0.57	-0.45	29.27	1.34	0.31	6.15	1.17	26.73	14.51	2.34	61.28*
LMNDL - 4	82.00	0.33	6.02*	132.96	1.35	94.01*	8.20	0.93	-0.11	28.00	1.68**	-1.47	6.84	1.89	38.40	14.20	2.12	46.63*
LMNDL - 5	78.89	1.95	12.52*	110.36	0.37	-12.94	9.27	1.33	0.48	25.71	-0.29	-1.44	3.41	0.91	593.56*	17.07	-0.60	19.58*
LMNDL – 3	83.89	0.07	18.62*	134.67	1.09	21.76	8.42	0.81	-0.29	29.49	1.54	-1.06	6.22	1.57	-9.41	14.43	1.45	33.44*
OLM - 203	86.56	0.64	81.01*	136.87	1.14	35.50	7.58	0.71**	-0.49	28.36	1.29	-0.39	7.82	0.36	-18.91	15.99	1.10	67.50*
VS 10	80.44	1.71	2.19*	141.53	1.08	49.30	7.60	0.95*	-0.45	28.04	1.02	4.31	5.74	0.85*	-21.12	17.27	0.17	4.56
VS 13	80.00	0.33	24.86*	132.42	1.29	-1.57	8.11	1.24	2.06*	25.67	1.70	0.88	6.72	1.15	-10.48	13.72	1.40	24.44*
VS 15	84.44	1.57	23.51*	137.49	0.83	-15.54	8.18	1.47*	-0.44	27.47	0.93*	-1.37	5.77	0.81	49.22	15.79	0.90	25.66*
VS 19	78.56	1.41	0.22	136.96	1.19	140.24*	8.07	1.12	0.12	27.49	0.63	3.31	6.24	0.37	-16.32	15.95	0.50	3.68
VS 25	81.00	1.34	14.71*	134.87	0.74	-11.92	7.82	1.00*	-0.45	27.38	0.13	-1.14	5.71	-0.02	10.46	15.13	-0.20	9.95*
VS 6	85.89	1.32	22.29*	141.78	0.67	-14.30	7.20	0.87**	-0.49	27.76	1.03	-0.87	4.90	1.95	233.64*	12.06	1.81	35.07*
Pooled mean	**82.19**			**134.47**			**8.03**			**27.48**			**5.84**			**15.27**		

Table 4. Stability of little millet genotypes for yield and yield attributing traits (Eberhart and Russel method)

Trait	Genotypes with desirable mean value	Average responsive (Suitable to all environments)	Highly responsive (Suitable for favourable environments)	Low responsive (Suitable for unfavourable environments)
Days to maturity	VS 19 and LMNDL-5	VS-19 and BL-6	-	-
Plant height	LMNDL-5	LMNDL-5, LMNDL-3, OLM-203, VS-10, VS-13, VS-15, VS-25 and VS-6	BL-6	-
No. of tillers per plant	LMNDL-5	BL-6, LMNDL-4, LMNDL-5, LMNDL-3 and VS-19	VS-15 and VS-25	OLM-203, VS-10 and VS-6
Panicle length	LMNDL-3 and BL 6	BL-6, LMNDL-5, LMNDL-3, OLM-203, VS-10, VS-13, VS-19, VS-25 and VS-6	LMNDL-4	VS-15
Fodder Yield	OLM 203	BL-6, LMNDL-4, LMNDL-3, OLM-203, VS-13, VS-15, VS-19, VS-25 and VS-6	-	VS-10
Grain Yield	VS 10 and LMNDL-5	VS-10 and VS-19	-	-

were reported earlier by Yadav and Lal, [12]. For plant height, the genotypes which had optimum plant height are more in demand to minimize the lodging loss at maturity without reducing fodder yield. The plant height over environments ranged from 110.36 cm (LMNDL-5) to 141.78 cm (VS 6) with mean of 134.47 cm. Genotypes;LMNDL-5, LMNDL-3, OLM 203, VS 10, VS 13, VS 15, VS 25 and VS 6 showed regression coefficient near to one and non-significant deviation from regression and were considered to be suitable across environments.

Productive tillers per plant is an important attribute which contribute directly to grain yield. More number of tillers per plant will yield more and *vice versa*. The mean value of productive tillers per plant ranged from 7.20 (VS 6) to 9.27(LMNDL-5) with mean of 8.03. BL 6, LMNDL-4 LMNDL-5, LMNDL-3 and VS 19 showed regression coefficient near to one and non-significant deviation from regression and considered to be highly stable over environments. Panicle length is positively related to yield and is known to contribute directly to grain yield *via* more number of grains per panicle. Panicle length over the environments ranged from 25.67 (VS 13 cm) and 29.27 cm (BL 6) with mean of 27.48 cm. Of all the genotypes,BL-6LMNDL-5, LMNDL-3, OLM 203, VS 10, VS 13, VS 19, VS 25 and VS 6 possessed regression coefficient near to unity and non-significant deviation from regression and were considered to be highly stable for panicle length and suitable to all environments. Genotype LMNDL 4 was highly responsive and suitable for favourable environments. Genotype VS 15 was low responsive suitable for unfavourable environments.

Fodder yield ranged from 3.41 t/ha (LMNDL-5) to 7.82 t/ha (OLM-203) with mean of 5.84t/ha. Out of all the genotypes, BL-6,LMNDL-4, LMNDL-3, OLM 203, VS 13, VS 15, VS 19, VS 25 and VS 6 with a regression coefficient near to unity and non-significant deviation from regression were considered to be highly stable and suitable to all environments. Genotype VS 10 which recorded significant regression coefficient less than unity and non-significant negative deviation from regression and was considered to be suitable for poor environments.Grain yield ranged from 13.72 q/ha (VS 13) and 17.27 q/ha (VS 10) with mean of 15.27 q/ha. Genotypes; VS10 (high mean grain yield) and VS 19with regression coefficient near to unity and non-significant deviation from regression were considered as average responsive, hence suitable to all environments. These results were in agreement with Kavya et al., [13] and Farshadfar [14].

3.2 Mega – Environment Analysis by GGE biplot Analysis

"Stability in the yield performance is the major concern in crop improvement programme which is highly influenced by Genotype x Environment interaction" [15]. "Main attractivefeature of the GGE biplot is to graphically show which-won-where pattern of genotype environment two way data revealing mega-environments" [16]. "Mega-environments on biplot consist of irregular polygon and a set of straight lines that radiatefrom the biplot origin to intersect each of the polygon sides at right angles" [17]. "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" [10]. In the present study GGE biplot model was used to evaluate stability for most important traits, fodder yield and grain yield and test location representativeness in little millet genotypes.

"In the present investigation, for fodder yield the partitioning of GE interaction through GGE biplot analysis showed that PC1 and PC2 accounted for 61.2% and 30.2 % of GGE sum of squares, respectivelywhichexplained90.4 % of the total variance (Fig. 1). Genotype at the vertex is the best performing genotype for the trait in the environment falling in that sector" [18]. "In contrast the genotypes which were located inside the polygon and close to the origin of biplot were not sensitive or stable for changing environments" [19]. The vertex genotypes for fodder yield,LMNDL 5, VS 6, LMNDL 4, OLM 203 and VS 25 formed pentagon. Based on this graphical representation, for fodder yield the testing locations were partitioned into two mega environments (ME). ME1 was represented by Nandyal and Vizianagaram with OLM 203 as the winning genotype, while in ME 2 which was represented byPerumallapalle where LMNDL 4 performed best. Genotype VS 10 was near to the origin and it was stable for fodder yield in all the environments and suitable for cultivation in all three environments.

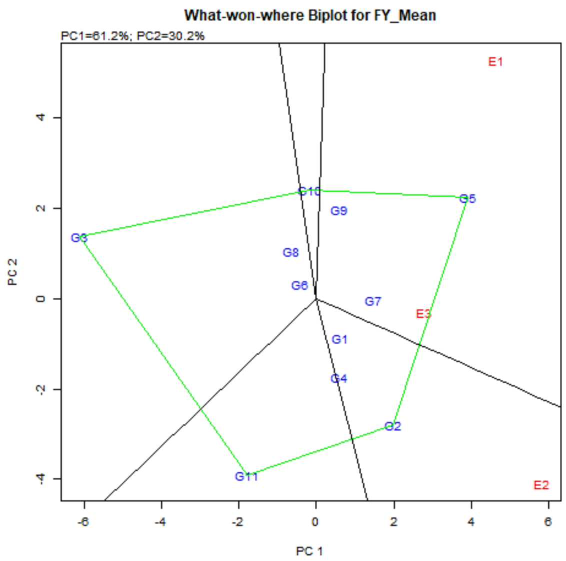

Fig. 1. GGE biplot for fodder yield based on principal components for genotypes and environments

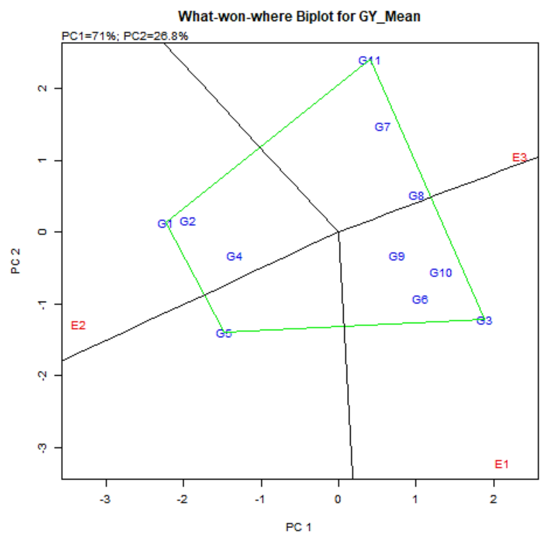

Fig. 2. GGE biplot for fodder yield based on principal components for genotypes and environments

Which-won-where biplot for grain yield over pooled locations was presented in the Fig. 2. The first two principal components for grain yield accounted for 97.8% of the variation with 71% and 26.8% for PC1 and PC2,respectively.For grain yield over pooled locations, the polygon had four genotypes, BL 6, VS 6, LMNDL 5 and OLM 203 at its vertices. The equity lines divided the biplot into four sectors of which three retained in three locationswhichindicated that three tested locations were different and influenced differently on grain yield in the genotypes.BL 6 performed well at Perumallapalle location while LMNDL 5 performed well at Nandyal. Genotype VS 6 is the best genotype for Vizianagaram in the tested genotypes.GenotypeVS 19 was near to origin and it was stable in all the environments [20].

4. CONCLUSIONS

In the study Eberhart and Russel method and GGE biplot model were used to evaluate the stability of little millet genotypes for yield components and test location representativeness in Andhra Pradesh for rainfed conditions. Based on results genotypes VS 10 and VS 19 gave higher yields and shown relatively stable across test environments. The genotype, VS 19 was identified as high yielding and more stable little millet genotype across the locations of Andhra Pradesh based on stability analysis. Therefore this genotype may be recommended for large scale cultivation in farmers' fields to improve little millet productivity levels in Andhra Pradesh state.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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