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RESEARCH ARTICLE

STABILITY ANALYSIS FOR YIELD AND YIELD RELATED TRAITS IN PEARL MILLET (PENNISETUM GLAUCUM (L.)R. BR.) HYBRIDS

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ABSTRACT

The present study was investigated to determine the stability performance of grain yield and yield related characters viz., grain yield, thousand grain weight, panicle length and panicle girth of pearl millet in three different environments viz., Sathyamangalam (E1), Gobichettipalayam (E2) and Annamalai Nagar (E3) during 2021-2022. Thirty- six genotypes were evaluated in a randomized block design with three replications. Statistical analysis, including the Eberhart and Russell model and grouping technique (CV) were employed to assess genotype-environment interaction. The analysis of variance (ANOVA) showed significant differences among genotypes, environments and genotype by Environment (G x E) interaction for all morphological characters under study. The analysis of variance indicated that significance of environments suggesting the presence of considerable influence of differential environments on grain yield and grain related traits. Environment (linear) was significant and larger in magnitude, suggesting its importance in expression of grain yield performance in pearl millet and indicating the prediction of performance across the environments is possible. The significant pooled deviation (non-linear component) mean sum of squares for grain yield indicated that the genotypes differed considerably with respect to their stability for this character. Based on performance of ten genotypes studied, over the three environments of study, the genotypes viz., G4, G22 and G31were found stable for grain yield, since these genotypes showed regression coefficient 'bi' nearer to one and values for deviation from regression is as small as possible. These hybrids could be tested further in larger environments for potential use in breeding program.

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INTRODUCTION

Pearl millet (*Pennisetum glaucum*) is a vital cereal crop known for its adaptability to harsh growing conditions. It is cultivated globally, particularly in arid and semi-arid regions. Pearl millet ranks as the sixth most important cereal crop worldwide, due to its ability to thrive in hot and dry climates (Gaoh *et al.,* 2023). It has wide genetic diversity and adaptability, most predominantly cultivated under rainfed conditions (Kalagare *et al.,* 2022). In India, the area, production and productivity of pearl millet during 2021-22 was it 6.84 million ha, 9.78 million tonnes and 1430 kg ha-1 respectively (Indiastat, 2023). Globally, pearl millet ranks as the sixth most significant cereal after wheat, rice, maize, barley, and sorghum, while in India; it stands as the fourth major staple crop following rice, wheat, and maize. Ongoing research and breeding programs aim to enhance pearl millet's productivity, nutritional value, and stress tolerance. These efforts contribute to achieving food security and sustainable agriculture in regions facing climate variability and resource constraints. However, most cultivated pearl millet varieties exhibit relatively low yield potential. The quality and weight of the seed are affected by rate and duration of seed filling (Yang and Zhang, 2006). Hence the selection of genotypes capable of buffering crop production against multiple stresses associated with climate change is crucial. This selection aims to ensure sustainable yields and maximize profitability in the face of evolving environmental challenges (Patil *et al.,* 2020). The inadequate production levels in India highlight the urgent need to develop genetically stable, high-yielding varieties and hybrids with improved adaptability to diverse agro-climatic conditions (Narasimhulu *et al.,* 2023). The extent of genotype–environment (G × E) interaction can be assessed using a range of numerical and graphical stability methods, which also aid in identifying genotypes with superior seed yield and consistency across diverse environmental conditions. Numerical approaches for modelling G × E interactions fall into two broad categories. Among parametric methods, key statistical measures include the regression coefficient (bi), deviation from regression (S^2di), and Francis and Kannenberg's coefficient of variance. Each parametric method interprets G × E interactions uniquely, offering distinct advantages and limitations in selecting desirable genotypes. Consequently, plant breeders integrate multiple parametric approaches to comprehensively evaluate genotype stability and adaptability. The goal of this study was to identify pearl millet genotypes that could consistently exhibit high performance across multiple crop seasons, utilizing various stability parametric statistical measures.

MATERIAL AND METHODS

Plant Materials: The experiment was conducted with 34 pearl millet hybrids and 2 checks namely HHB 299 and NBH 4903. All the materials were collected from Department of Genetics and Plant Breeding, Tamil Nadu Agricultural University, Coimbatore. The experimental materials comprised of pearl millet hybrids were presented in (Table 1).

Experimental site and Design: Thirty- six genotypes were evaluated in three different environments *viz.,* Sathyamangalam (E1) (11.4548°N; 77.4365°E), Gobichettipalayam (E2) (11.3028°N; 76.9383°E) and Annamalai Nagar (E3) (11.5034°N; 77.2444°E) during 2021-2022. The soil was red sandy with pH of 6.92, 6.85, 6.73 and EC of 1.08, 0.85 and 1.02 for the three locations, respectively. The NPK content varied from medium to high for the locations. The average temperatures recorded were 27.02°C, 27.6°C, 26.9°C and rainfall was 824 mm, 720 mm and 751 mm, respectively for the three locations (Table 2). Thirty-four hybrids with two checks were sown at the rate of one seed per hole in a single row of 5 meter length with intra row spacing of 15 cm x 60 cm. The experiments were laid out in Randomized Block Design (RBD) and replicated thrice. For each hybrid, a total of 15 plants per replication were maintained.

Data recorded and statistical procedure: Standard agronomic practices were followed for raising and maintenance of plants. Five plants were randomly selected from each replication for observation of three quantitative traits viz., panicle length (cm), 1000 grain weight (g) and grain yield per plant (g). Eberhart and Russell (1966) model and Francis and Kannenberg's (1978) grouping technique was used to study the stability of genotypes under varying environments.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) results showed that the genotypic and environmental variances were significant ($p < 0.05$) for all the traits. Similarly, the mean sum of squares due to G × E interaction was significant for all of the three traits studied. Furthermore, the partitioning of the combined environment, and hybrids × environment variance into linear and non-linear components showed that environment linear and combined deviation was significant given in (Table 3). The significant G × E interaction for all the traits were also mentioned given by (Shinde *et al*., 2002; Chikurte *et al.,* 2003; Yahaya *et al*., 2006; Dadarwal *et al*., 2018) in pearl millet. In the phenotypic expression of hybrids, the variance owing to E + (G × E) was very significant for all characters against pooled error, indicating the unique nature of locations and G × E interactions. For every character, the environment's (linear) variance was considerable, meaning that the characters' linear genotype responses to their environments varied significantly.

Table 1. List of hybrids used for stability analysis

S. No.	Genotypes	Name of the Hybrids	Source
1	G1	AUBH – 1	Annamalai University
2	G2	AUBH-2	Annamalai University
3	G3	AUBH-3	Annamalai University
4	G4	AUBH-4	Annamalai University
5	G5	AUBH-5	Annamalai University
6	G6	AUBH-6	Annamalai University
7	G7	AUBH-7	Annamalai University
8	G8	AUBH-8	Annamalai University
9	G9	AUBH-9	Annamalai University
10	G10	AUBH-10	Annamalai University
11	G11	AUBH-11	Annamalai University
12	G12	AUBH-12	Annamalai University
13	G13	AUBH-13	Annamalai University
14	G14	AUBH-14	Annamalai University
15	G15	AUBH-15	Annamalai University
16	G16	AUBH-16	Annamalai University
17	G17	AUBH-17	Annamalai University
18	G18	AUBH-18	Annamalai University
19	G19	AUBH-19	Annamalai University
20	G20	AUBH-20	Annamalai University
21	G21	AUBH-21	Annamalai University
22	G22	AUBH-22	Annamalai University
23	G23	AUBH-23	Annamalai University
24	G24	AUBH-24	Annamalai University
25	G25	AUBH-25	Annamalai University
26	G26	AUBH-26	Annamalai University
27	G27	AUBH-27	Annamalai University
28	G28	AUBH-28	Annamalai University
29	G29	AUBH-29	Annamalai University
30	G30	AUBH-30	Annamalai University
31	G31	AUBH-31	Annamalai University
32	G32	AUBH-32	Annamalai University
33	G33	AUBH-33	Annamalai University
34	G34	AUBH-34	Annamalai University
35	C1	HHB 299	CCS HAU, Hisar
36	C_2	NBH 4903	Nuziveedu seeds Ltd.,

This could be due to variations in weather and soil conditions of different locations as also supported by (Dhuppe *et al.,* 2017). As the genotype × environment interaction was found significant it was partitioned in linear and non-linear components (Eberhart and Russell, 1966). The linear component of G × E interaction was significant for all the characters that revealed linear response of genotype to environmental variations. Similar results were reported by (Patil *et al.* 2014; Ishaq and Meseka 2014). Pooled deviation was found significant for all the characters that revealed the non- predictable performance of hybrids across the environments. Similar results have been reported by (Ezeaku *et al.,* 2014; Pabale and Pandya 2010). Among the total variations the variance due to G x E was less but significant for the trait across the environments. Hence, to study the impact of Genotype-Environment Interaction (G x E), the data was subjected to various stability analysis. The stability model proposed by Eberhart and Russell (1966) was adopted to analyses the data over different environments and in this model is the most popular technique of studying Genotype × Environment interaction and genotypic stability. It used two parameters (bi and S^2di) to define stability. S^2di is primarily used to rank the relative stability of cultivars. The indication is that bi may be utilized to depict the standard response to the goodness of environmental conditions though S^2di measures the predictability. According to this model, a stable variety is one that has a high mean (Xi), unit regression coefficient (bi=l) and the deviation from regression as small as possible (S^2di = 0). Table 4 displays the findings of Eberhart

Table 2. Particulars of three environments

Particulars	E1	E2	E3
Location	Sathyamangalam, Tamil Nadu	Gobichettipalayam, Tamil Nadu	Annamalai Nagar Tamil Nadu
Latitude	11.4548 °N	11.3028 °N	11.39 °N
Longitude	77.4365 °E	76.9383 °E	79.76 °E
Season	October 2022	October 2022	November 2022
Soil type	Red sandy	Red sandy	Clay loamy soil
Soil Ph	6.92	6.85	7.2-8.5
EC	1.08	0.85	0.95
		Soil Status	
N	High	Medium	High
P	Medium	Medium	Medium
K	High	High	High
Organic carbon	Low	Low	Low
Fe	Medium	Low	Medium
Zn	Medium	High	Medium
Sulphur	Sufficient	Medium	Sufficient
		Climate	
Avg. Temp (°C)	27.02	27.6	24-32.7
Avg. Rainfall (mm)	824	720	1206.7

Table 3. Analysis of variance for Eberhart and Russell model

Sources	Df	MSS		
		Panicle length (cm)	1000 grain weight (g)	Grain yield per plot (kg)
Genotypes	35	29.85**	5.64**	0.38**
Environments	2	3.58**	0.06**	1.15**
G × E	70	7.70**	0.20**	0.06**
E + (G × E)	72	7.59**	0.20**	0.09**
Environment (Linear)	1	7.16**	0.13**	2.31**
Genotype × Environment (Linear)	35	6.45**	0.29**	0.07**
Pooled deviation	36	8.70**	0.11**	0.04**
Pooled error	210	0.01	0.00	0.00

*: Significant at 5% level; **: Significant at 1% level; MSS- mean sum of squares; Df- degrees of freedom; G× E - genotype × environment

Table 4. Stability parameters for panicle length, 1000 grain weight and grain yield per plot

Genotypes	Panicle Length			1000 grain weight			Grain yield per plot		
	Mean	Bi	S^2di	**Mean**	bi	S^2di	**Mean**	bi	S^2di
G_1	**27.52****	-4.41	2.8	**12.05****	-8.75	0.12	**2.34****	2.36	0.12
G_2	24.07	5.65	5.14	8.9	20.35	0.65	2.09	-0.01	0.02
G_3	26.44	**1.06***	17.97	**12.28****	9.63	**-0.31***	1.9	3.08	0.03
G_4	22.52	2.07	1.36	9.48	**1.40***	0.52	**2.33****	**0.91***	**-0.02***
G_5	26.29	-13.74	0.53	**12.05****	-8.75	0.12	**2.25****	-0.19	0.11
G_6	23.65	-0.12	0.27	**12.94****	**1.37***	0.03	**2.27****	1.63	0.02
G_7	24.45	6.06	**-0.01***	**12.05****	-8.75	0.12	**2.30****	1.79	0.06
G_8	26.99	-1.08	3.87	9.48	**1.40***	0.39	1.99	**1.07***	0.01
G_9	**27.93****	-5.58	6.2	**12.05****	-8.75	0.12	**2.27****	2.24	**-0.01***
G10	**27.36***	-3.12	4.57	**12.94****	**1.37***	**-0.03***	**2.37****	1.89	0.11
G11	25.62	-4.28	2.5	**12.05****	-8.75	0.12	2.11	2.94	0.11
G12	23.18	0.17	0.44	**12.05****	-8.75	0.12	2.13	2.39	0.12
G13	24.56	-2.89	**-0.01***	**11.93***	11.1	0.2	**2.30****	-0.11	**-0.08***
G14	25.43	-2.8	8	**12.80****	-5.83	**-0.05***	1.95	2.15	0.06
G15	22.03	4.32	0.54	9.48	**1.40***	0.09	1.73	1.45	0.19
G16	22.35	-1.28	28.37	**11.95****	-3.89	**-0.02***	1.45	2.34	0.03
G17	23.92	-1.59	2.34	8.9	20.35	0.65	**2.32****	-0.16	0.19
G18	26.45	-5.16	1.08	**12.05****	-8.75	0.12	1.68	1.35	0.03
G19	25.61	-2.32	0.72	9.48	**1.40***	0.29	2.08	-0.03	0.17
G20	26.94	-0.83	0.94	**11.95****	-3.89	0.02	**2.58****	-0.05	0.13
G21	**39.16****	3.49	2.85	8.9	20.35	0.65	1.78	**0.99***	0.02
G22	**28.39****	-7.46	6.83	**11.95****	-3.89	**-0.02***	**2.41****	**1.02***	**-0.01***
G23	24.46	1.84	**-0.04***	9.48	**1.40***	0.33	**2.30****	0.22	**-0.04***
G24	24.09	0.01	1.14	**12.05****	8.71	0.12	1.64	**1.09***	0.05
G25	23.9	9.61	9.62	11.72	-4.82	0.08	2.04	2.53	0.01
G26	**28.01****	11.57	12.8	9.48	**1.40***	0.78	2.01	-0.36	0.05
G27	24.14	**1.13***	57.27	**12.80****	-5.83	0.05	2.07	-0.53	0.05
G28	**29.73****	0.58	26.16	**11.95****	-3.89	0.02	1.74	0.7	0.09
G29	**27.28***	-0.76	23.84	**11.93***	11.1	0.2	1.66	-0.48	0.08
G30	24.02	10.25	3.51	**12.78****	-5.38	0.04	**2.33****	-0.59	0.15
G31	**30.03****	6.36	20.29	**11.93***	11.1	0.2	**2.24****	**1.03***	0.06
G32	26.24	14.67	52.01	9.48	**1.40***	0.36	1.49	-0.58	0.13
G33	**29.46****	0.86	4.05	**11.95****	-3.89	0.02	**2.39****	1.71	0.06
G34	**27.40***	0.05	**-0.03***	**12.80****	-5.83	0.05	**2.75****	0.25	**-0.06***
C_1	23.7	7.56	2.16	11.49	16.3	0.01	**2.73****	**1.01***	0.09
C_2	**30.48****	6.15	3.21	**12.82****	3.41	0.02	**3.11****	**0.99***	0.01
Grand mean	26.22			11.4			2.14		

*: Significant at 5% level; **: Significant at 1% level; b_i - regression coefficient; S^2di – deviation fromr regression

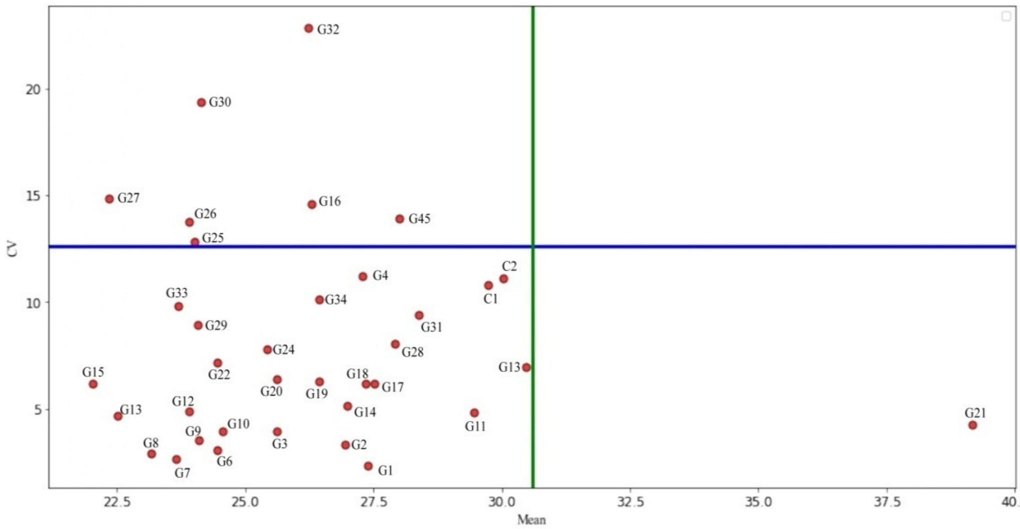

Fig 1. Genotype grouping technique for panicle length

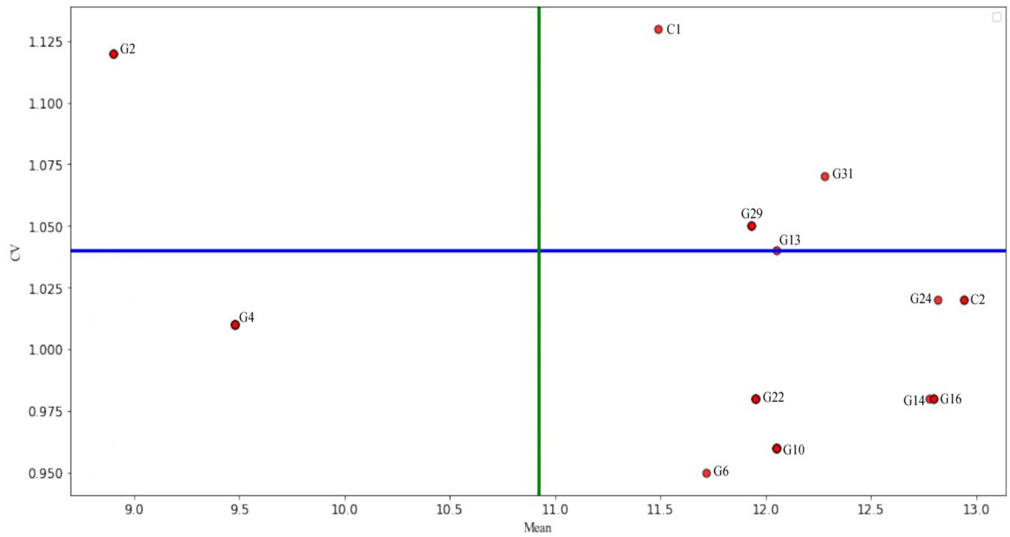

Fig 2. Genotype grouping technique for thousand grain weight

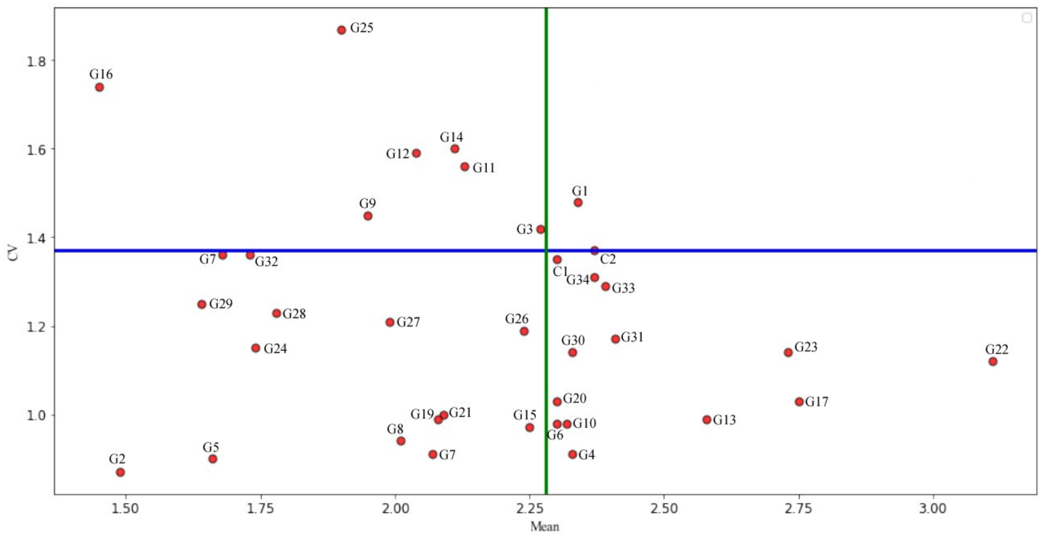

Fig 3. Genotype grouping technique for grain yield per plot

and Russell's investigation. A stable genotype is characterized with the higher mean and a minimal deviation from regression value S^2di. In terms of the population mean, the hybrids G1, G9, G10, G21, G22, G26, G28, G29, G31, G33, G34 and C2 had larger mean values for panicle length. Among the genotypes, G3 and G27 had average stability across environments with moderate panicle length and non significant deviation with regression coefficient value near to 1. The hybrids were G2, G4, G7, G15, G21, G23, G25, G26, G30, G31 and G32 showed higher mean than grand mean with non significant deviation with bi value greater than one which indicated that below average stability in favourable conditions, while G12, G24, G28, G33 and G34 observed with higher mean value with non significant deviation with b value less than one. This indicated that these genotypes could perform better even under unfavourable environment conditions. None of the hybrids were adapted (stable) to all the environments. Similar results were also reported by (Shanthi *et al.,* 2016); Patil *et al.,* 2019).

In terms of the population mean, twenty four hybrids were recorded larger mean values for 1000 grain weight. Among the 36 g hybrids, G4, G6, G8, G10, G15, G19, G23, G26 and G32 had average stability across environments with 1000 grain weight and non significant deviation with regression coefficient value near to 1. The hybrids were G2, G3, G13, G17, G21, G24, G29, G31, C1 and C2 showed higher mean than grand mean with non significant deviation with bi value greater than one which indicated that below average stability in favourable condition. Similar results were also reported by Similar results were also reported by (Thakur *et al,* 2019; Reddy *et al.,* 2022) in thousand grain weight pearl millet. The genotype C2 (3.11 Kg/plot) recorded the maximum grain yield per plot while the genotype G16 recorded the minimum seed yield per plant 1.45 Kg/plot. Eighteen hybrids were showed highly significance above grand mean of 2.14 Kg/plot. Among the 36 hybrids, G4, G22, G31, C1 and C2 had average stability across environments with high grain yield per plot and non significant deviation with regression coefficient value near to 1. The hybrids were G1, G3, G9, G10, G11, G12, G14, G16, G25, G18, G15, G6 and G7 showed higher mean than grand mean with non significant deviation with bi value greater than one which indicated that below average stability in favourable conditions, whereas G28 and G34 observed with higher mean value with non significant deviation with b value less than one. This indicated that these genotypes could perform better even under unfavourable environment conditions. None of the hybrids were adapted (stable) to all the environments. These findings agreed with (Sodhaparmar *et al.,* 2023; Sujitha *et al.,* 2024) reported stable genotypes in bajra by following this criteria. The significant deviation from the regression (S^2di) was observed in nine genotypes and hence these inbreds are considered as unstable (Ezeaku *et al*., 2014).

In genotype grouping technique, thirty-six genotypes were grouped into four groups in which the genotypic mean value was plotted against the coefficient of variation (CV) associated with each genotype (Fig 1, 2, & 3). Hybrids with relatively high mean yield and low coefficient of variability were proposed as stable (Group I). In terms of grain yield, among the hybrids *viz.,* G4 (AUBH-4), G6 (AUBH-6), G10 (AUBH-10), G31 (AUBH-31), G33 (AUBH-33) and G34 (AUBH-34) were classified as stable genotypes since they were in group I with high mean values. Hybrids with mean yield higher than total average and high coefficient of variation (indicating the specific stability) are placed in Group II. Among the hybrid G1 (AUBH-1) was in group II with high mean value for grain yield. Hybrids in Group III (low mean yield and low coefficient of variation) were indicated as stable genotypes due to their low yield and high variability (group IV). The hybrids G10, G11, G14, G20, G22, G25, G28 and G34 were placed in group 1 for panicle girth and thousand grain weight and the hybrid G21 was placed in group 1 for panicle length. The hybrids falling under group II, III and IV are not discussed here as they indicate differential and unpredictable response in various environments (Matin *et al*., 2017).

CONCLUSION

The purpose of this study was to determine the optimal combination of stability parameters for the assessment of the stability and yield performance of high-yield potential and stable cultivars in different environments. The study was concluded using 36 pearl millet hybrids that were evaluated in three environments. Both Eberhart and Russell Model and Grouping technique stability models showed that genotypes G4, G22 and G31 were the most stable genotypes with minimal yield variation across environments. The findings of this study suggest the use of a combination of stability models with respect to parametric stability measure concepts of stability for the selection of "ideal genotypes" of high yield potential and stable cultivars.

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