Received: 28 Jun 2023 | Revised:16 Apr 2024 | Accepted: 19 Apr 2024

Electronic Journal of Plant Breeding

Research Article

Genotype × environment interactions and stability analysis for grain yield in pearl millet [*Pennisetum glaucum* (L.) R. BR.]

A. L. Patel[1*], D. A. Patel[2], Rumit Patel[3], D. J. Parmar[4] and Kalyanrao Patil[5]

[1]Directorate of Research, Anand Agricultural University, Anand-388 110, Gujarat, India
[2]Department of Agricultural Biotechnology, Anand Agricultural University, Anand-388 110, Gujarat, India
[3]Department of Agricultural Biotechnology, Anand Agricultural University, Anand-388 110, Gujarat, India
[4]Department of Agricultural Statistics, Anand Agricultural University, Anand-388 110, Gujarat, India
[5]Department of Seed Science and Technology, BACA, Anand Agricultural University, Anand-388 110, Gujarat, India
***E-Mail: anilchaudharypbg@gmail.com**

Abstract

The present investigation was carried out at Regional Research Station, Anand Agricultural University, Anand during the years 2019-20 to 2020-21 to study the phenotypic stability for grain yield in pearl millet genotypes. The experimental materials consisted of 91 genotypes; comprising 70 hybrids developed using line × tester design, five CMS lines and 14 testers, and two standard check hybrids GHB 538 and GHB 732. The mean square due to genotypes × environment interactions were significant for grain yield per plant, which revealed that genotypes interacted considerably with environment. Higher magnitude of G × E (linear) variance compared to G × E (non-linear) variance for grain yield per plant indicated that major portion of interaction was predictable in nature. The hybrids ICMA$_1$-04999 × J-2587, ICMA$_1$-98222 × J- 2604, ICMA$_1$-98222 × 110-SB-15, ICMA$_1$-98222 × 69-SB-18, ICMA$_1$-98444 × J-2290, JMSA$_1$-20158 × J-2479, JMSA$_1$-20158 × J-2539, JMSA$_1$-20158 × ICMR-15758, JMSA$_1$-20159 × J-2479, JMSA$_1$-20159 × J-2590 and JMSA$_1$-20159 × 69-SB-18 were identified as stable and widely adapted for grain yield per plant.

Keywords: Pearl millet, G × E interaction, Regression , Deviation from regression

INTRODUCTION

Pearl millet (*Pennisetum glaucum* R. Br.) is an important staple and nutritious food crop in India ranking fourth in acreage next to rice, wheat and sorghum. It is an annual C4 crop having diploid chromosome number (2n=14). Pearl millet is a highly cross-pollinated crop with a protogynous nature. It belongs to family Poaceae and believed to have originated in West Africa (Vavilov, 1950) from where it spread to India and other countries.

In India, it is mainly grown in Rajasthan, Uttar Pradesh, Gujarat, Haryana and Maharashtra states. Pearl millet occupies an area of 6.71 million ha with a production of 9.23 million tonnes and productivity of 1376 kg/ha in the country (Anonymous, 2020a), while, in Gujarat, it is grown in 0.46 million ha with a production of 1.04 million tonnes and productivity of 2281 kg/ha (Anonymous, 2020b).

Phenotype is a linear function of genotype (G), environment (E) and G × E interaction effects which indicates that phenotypic performance of a genotype depends on its genetic makeup and environment under which it is tested. So, the performance of the genotypes varies under different environmental conditions. Hence, the study of G × E interaction serves as a guide for various environmental niches. It helps to identify such genotypes which are stable for high yield at different environments. An ideal variety is one which performs better under favourable environments and responds well even under average or poor environmental conditions. The evaluation of G × E interactions gives the picture of stability or buffering ability of the material under investigation. Hence, the knowledge of magnitude and nature of G × E interaction is very useful to a breeder for proper assessment of the material under investigation. The present study was conducted to evaluate and identify the pearl millet hybrids with wider adaptation over a range of environments using stability analysis.

MATERIALS AND METHODS

The experimental materials consisted of 91 genotypes; comprising 70 hybrids developed using line × tester design, 5 lines and 14 testers along with two standard check hybrids GHB 538 and GHB 732. All the genotypes were evaluated in randomized block design (RBD) replicated thrice in four environments *viz*., *Kharif*-2019 (E_1), Summer-2020 (E_2), *Kharif*-2020 (E_3) and Summer-2021 (E_4). The statistical analysis for the G × E interaction and stability parameters *viz*., mean ($\bar{X}_i$), regression coefficient (bi) and mean square deviation (S^2di) for each genotype was carried out as per the method of Eberhart and Russell (1966).

Stability Parameters were estimated as:

Mean ($\bar{X}_i$)

The mean value of i^{th} genotype over all the environments for each genotype was calculated using the following formula:

$$\bar{x}_i = \frac{\sum_{j=1}^{n} Y_{ij}}{n}$$

Environmental Index (I_j)

Environmental index was calculated as the mean of all genotypes in the j^{th} environment minus the grand mean for all the environments.

$$I_j = \left[\frac{\sum_{j=1}^{n} Y_{ij}}{n}\right] - \left[\frac{\sum_{i=1}^{g} \sum_{j=1}^{n} Y_{ij}}{gn}\right]$$

Where,

$$\sum_{j=1}^{n} I_j = 0$$

g = Number of genotypes
n = Number of environments

Regression coefficient (b_i)

The regression coefficient (b_i) for each genotype was calculated using following formula:

$$b_i = \frac{\sum_{j=1}^{n} Y_{ij} I_j}{\sum_{j=1}^{n} I_j^2}$$

Mean square deviation from linear regression (S^2d_i)

The mean square deviation from linear regression (S^2d_i) *i.e.*, non-linear component of Genotype ×Environment interaction for each genotype was calculated using the following formula:

$$S^2d_i = \frac{\sum_{j=1}^{n} \delta_{ij}^2}{n-2} - \frac{\sigma_e^2}{r}$$

Where,

$$\sum_{j=1}^{n} \delta_{ij}^2 = \left[\sum_{j=1}^{n} Y_{ij}^2 - \frac{Y_{i.}^2}{n}\right] - \left[\frac{\left(\sum_{j=1}^{n} Y_{ij} I_j\right)^2}{\sum_{j=1}^{n} I_j^2}\right]$$

σ^2_e = Estimate of pooled error
n = Number of environments
r = Number of replications
Y_{ij} = Genotype mean over replication
$Y_{i.}$ = Total over environments
I_j = Environmental index

A stable genotype would be one which has non-significant deviation from regression ($S^2di=0$), non-significant regression coefficient equal to unity (bi=1) and the mean value of the genotype over all the environments must be higher than the population mean.

RESULTS AND DISCUSSION

It generally happens that many varieties/genotypes of different crops do not exhibit similar performance when tested under different environmental conditions. This is due to G × E interactions, which alters the magnitude of differences between genotypes from one environment to another.

Analysis of variance for stability: The mean sum of square due to genotypes and genotypes × environment interactions were found significant for grain yield per plant, which revealed that genotypes interacted differently with array of environments for grain yield per plant. Highly significant values of mean square due to environments (linear) for grain yield per plant indicated that environments differed considerably among different sowing season.

The variance due to G × E (linear) was higher in magnitude as compared to G × E (non-linear) for grain yield per plant (**Table 1**). This indicated that major portion of interaction was predictable in nature. The results were in accordance with findings of Bashir *et al*. (2014), Gebre

Table 1. Analysis of variance (mean sum of square) for phenotypic stability for grain yield plant in pearl millet

S. No.	Source of variations	Mean sum of square
1	Genotypes (G)	563.86**
2	Environments (E)	1878.29**
3	Genotypes × Environments (G × E)	63.51**
4	E + (G × E)	83.45**
5	Environments (Linear)	5634.87**
6	G × E (Linear)	87.64**
7	Pooled Deviation	50.88**
8	Pooled Error	11.10

*, ** significant at 5% and 1% levels, respectively

et al. (2014), Mustapha and Bakari (2014), Shanthi *et al*. (2016), Sujatha *et al*. (2016), Lubadde *et al*. (2017), Lagat *et al*. (2018), Katariya *et al*. (2019), Patel *et al*. (2019), Pawar *et al*. (2019), Kumar *et al.* (2020), Asungre *et al*. (2021) and Sara *et al*. (2021) as they reported significant mean square value of G × E interaction for grain yield per plant.

Stability Parameters for grain yield per plant: Out of the 91 genotypes investigated, significant deviations from regression estimates were represented by 45 genotypes, indicating that their performance for a particular environment cannot be predicted and hence they were considered unstable. While, remaining 46 genotypes had non-significant deviation from regression (S^2di=0), so their performance was considered as predictable in nature and as stable in expression.

Out of the 46 genotypes with a non-significant deviation from regression (S^2di=0), 31 genotypes were found significant at bi=0, indicating that there might be some linear relationship found between genotypes and environments for those genotypes. Among the 31 genotypes, 16 and 15 genotypes were significant and non-significant at bi=1, respectively. The estimation of the stability parameters collectively indicated that 11 genotypes (hybrids) *i.e.*, ICMA$_1$-04999 × J-2587, ICMA$_1$-98222 × J- 2604, ICMA$_1$-98222 × 110-SB-15, ICMA$_1$-98222 × 69-SB-18, ICMA$_1$-98444 × J-2290, JMSA$_1$- 20158 × J-2479, JMSA$_1$-20158 × J-2539, JMSA$_1$-20158 × ICMR-15758, JMSA$_1$-20159 × J-2479, JMSA$_1$-20159 × J-2590 and JMSA$_1$-20159 × 69-SB-18 exhibited grain yield higher than the overall mean (41.04 g) coupled with unit regression coefficient (non-significant at bi=1) and non-significant deviation from regression (S^2di=0), which suggested that these genotypes were stable and widely adapted over all the environments studied, for grain yield per plant.

Out of the 15 genotypes which showed significance at bi=1, 14 genotypes *viz*., ICMA$_1$-04999 × 103-SB-15, ICMA$_1$-04999 × 69-SB-18, ICMA$_1$-98222 × J-2582, ICMA$_1$-98222 × J-2587, JMSA$_1$-20158 × J-2590, JMSA$_1$-20158

Table 2. Estimates of stability parameters of individual genotype for grain yield per plant (g) in pearl millet

S. No.	Genotypes	Pooled Mean ($\bar{X}$)	b_i	S^2d_i
Lines				
1	ICMA$_1$-04999	14.95	0.40^{++}	-8.01
2	ICMA$_1$-98222	19.40	0.79	4.76
3	ICMA$_1$-98444	10.95	0.03^{++}	-8.62
4	JMSA$_1$-20158	13.60	0.51	3.07
5	JMSA$_1$-20159	19.33	0.83	31.63*
Testers				
6	J-2290	29.55	0.77	1.16
7	J-2469	26.20	-0.92	61.07**
8	J-2479	20.57	-0.45^{++}	-2.53
9	J-2532	16.87	-0.61^{+}	19.38
10	J-2539	25.45	0.15	59.78**
11	J-2582	29.93	1.59	116.11**
12	J-2587	32.97	3.31	317.70**

Table 2 contd..

S. No.	Genotypes	Pooled Mean ($\bar{X}$)	Bi	S^{2}di
13	J-2590	17.92	0.61	47.76**
14	J- 2604	27.28	0.76	39.53*
15	ICMR-15758	27.82	0.76	42.96**
16	AIB-29	29.10	0.40	-4.72
17	103-SB-15	19.02	-0.11^{++}	-9.37
18	110-SB-15	28.63	-1.25*$^{++}$	5.26
19	69-SB-18	36.78	2.62*	97.98**
Hybrids				
20	ICMA$_1$-04999 × J-2290	47.87	0.73	119.60**
21	ICMA$_1$-04999 × J-2469	38.38	0.87*	-0.36
22	ICMA$_1$-04999 × J-2479	34.88	-1.53*$^{++}$	22.85*
23	ICMA$_1$-04999 × J-2532	42.28	-1.25^{+}	69.17**
24	ICMA$_1$-04999 × J-2539	37.75	-1.57	304.51**
25	ICMA$_1$-04999 × J-2582	46.60	1.47	43.10**
26	ICMA$_1$-04999 × J-2587	60.97	1.31**	-3.08
27	ICMA$_1$-04999 × J-2590	37.88	0.21	92.15**
28	ICMA$_1$-04999 × J- 2604	50.48	0.37	-2.37
29	ICMA$_1$-04999 × ICMR-15758	37.45	-0.01	98.29**
30	ICMA$_1$-04999 × AIB-29	44.02	-0.11^{+}	2.72
31	ICMA$_1$-04999 × 103-SB-15	50.63	2.16**$^{++}$	-7.00
32	ICMA$_1$-04999 × 110-SB-15	35.65	0.34	52.14**
33	ICMA$_1$-04999 × 69-SB-18	52.15	2.13**$^{++}$	-9.77
34	ICMA$_1$-98222 × J-2290	39.45	0.64	54.11**
35	ICMA$_1$-98222 × J-2469	35.32	0.88**	-5.49
36	ICMA$_1$-98222 × J-2479	44.18	0.35	13.45
37	ICMA$_1$-98222 × J-2532	36.08	1.46**	-4.54
38	ICMA$_1$-98222 × J-2539	37.82	-1.31^{+}	56.98**
39	ICMA$_1$-98222 × J-2582	49.23	2.24**$^{+}$	5.62
40	ICMA$_1$-98222 × J-2587	55.10	1.57**$^{++}$	-8.84
41	ICMA$_1$-98222 × J-2590	41.88	0.56	28.34*
42	ICMA$_1$-98222 × J- 2604	44.52	1.24*	12.15
43	ICMA$_1$-98222 × ICMR-15758	29.13	1.78	87.93**
44	ICMA$_1$-98222 × AIB-29	42.10	-0.27	95.04**
45	ICMA$_1$-98222 × 103-SB-15	39.98	-0.24	76.69**
46	ICMA$_1$-98222 × 110-SB-15	41.87	1.21*	7.35
47	ICMA$_1$-98222 × 69-SB-18	44.20	1.63**	9.78
48	ICMA$_1$-98444 × J-2290	43.15	0.71*	-4.41
49	ICMA$_1$-98444 × J-2469	30.20	-0.43^{++}	-7.73
50	ICMA$_1$-98444 × J-2479	44.32	-0.32	134.09**
51	ICMA$_1$-98444 × J-2532	35.43	-0.90	52.02**
52	ICMA$_1$-98444 × J-2539	42.05	-0.08	58.34**
53	ICMA$_1$-98444 × J-2582	37.42	1.18**	1.39
54	ICMA$_1$-98444 × J-2587	51.35	-0.21	71.62**
55	ICMA$_1$-98444 × J-2590	32.95	-0.73	83.71**

Table 2. contd..

S. No.	Genotypes	Pooled Mean ($\bar{X}$)	Bi	S^2di
56	ICMA$_1$-98444 × J- 2604	52.10	1.23	15.43
57	ICMA$_1$-98444 × ICMR-15758	31.88	1.93**	11.64
58	ICMA$_1$-98444 × AIB-29	42.35	0.22	59.76**
59	ICMA$_1$-98444 × 103-SB-15	41.12	0.18	29.73*
60	ICMA$_1$-98444 × 110-SB-15	41.70	1.01	20.80
61	ICMA$_1$-98444 × 69-SB-18	53.35	2.33*	49.40**
62	JMSA$_1$-20158 × J-2290	46.43	2.05*	48.11**
63	JMSA$_1$-20158 × J-2469	42.62	1.86	69.79**
64	JMSA$_1$-20158 × J-2479	48.38	1.00**	-11.05
65	JMSA$_1$-20158 × J-2532	48.80	2.93*	100.74**
66	JMSA$_1$-20158 × J-2539	47.27	0.83**	-10.47
67	JMSA$_1$-20158 × J-2582	46.87	2.49	94.93**
68	JMSA$_1$-20158 × J-2587	43.07	-1.09	72.27**
69	JMSA$_1$-20158 × J-2590	48.92	2.27**++	-5.24
70	JMSA$_1$-20158 × J- 2604	55.45	2.47**++	3.46
71	JMSA$_1$-20158 × ICMR-15758	43.17	1.75**	16.05
72	JMSA$_1$-20158 × AIB-29	60.82	2.56**++	-9.80
73	JMSA$_1$-20158 × 103-SB-15	45.17	2.38	168.39**
74	JMSA$_1$-20158 × 110-SB-15	43.82	1.43**++	-10.16
75	JMSA$_1$-20158 × 69-SB-18	52.15	2.08	116.86**
76	JMSA$_1$-20159 × J-2290	61.35	2.22**++	-4.78
77	JMSA$_1$-20159 × J-2469	43.17	1.61	110.70**
78	JMSA$_1$-20159 × J-2479	51.83	0.63**	-7.93
79	JMSA$_1$-20159 × J-2532	51.93	3.52**++	23.70*
80	JMSA$_1$-20159 × J-2539	59.10	1.30	41.29**
81	JMSA$_1$-20159 × J-2582	44.03	2.78*	82.63**
82	JMSA$_1$-20159 × J-2587	65.63	1.64**+	-5.90
83	JMSA$_1$-20159 × J-2590	50.85	2.21**	13.11
84	JMSA$_1$-20159 × J- 2604	56.48	1.97**+	1.77
85	JMSA$_1$-20159 × ICMR-15758	43.93	2.28*	40.04*
86	JMSA$_1$-20159 × AIB-29	55.33	3.05**	61.50**
87	JMSA$_1$-20159 × 103-SB-15	53.75	2.14*	34.84*
88	JMSA$_1$-20159 × 110-SB-15	44.55	2.06**+	0.08
89	JMSA$_1$-20159 × 69-SB-18	57.97	1.80**	-0.75
Checks				
90	GHB 732	53.40	1.58**++	-10.40
91	GHB 538	44.82	2.04**++	-9.62
	General mean	41.04		

Where, $\bar{X}$, b_i and S^2d_i are pooled mean, regression coefficient and deviation from regression, respectively

*, ** Significant at 5% and 1% levels, respectively when Ho: bi = 0

+, ++ Significant at 5% and 1% levels, respectively when Ho: bi = 1

Table 3. Classification of genotypes based on stability parameters for grain yield per plant in pearl millet

Character	Stable and widely adapted to all environments	Stable and specifically adapted to the favourable environment	Stable and specifically adapted to the unfavourable environment
Grain yield per plant	**11 genotypes**	**14 genotypes**	---
	ICMA$_1$-04999 × J-2587, ICMA$_1$-98222 × J- 2604, ICMA$_1$-98222 × 110-SB-15, ICMA$_1$-98222 × 69-SB-18, ICMA$_1$-98444 × J-2290, JMSA$_1$-20158 × J-2479, JMSA$_1$-20158 × J-2539, JMSA$_1$-20158 × ICMR-15758, JMSA$_1$-20159 × J-2479, JMSA$_1$-20159 × J-2590 and JMSA$_1$-20159 × 69-SB-18	ICMA$_1$-04999 × 103-SB-15, ICMA$_1$-04999 × 69-SB-18, ICMA$_1$-98222 × J-2582, ICMA$_1$-98222 × J-2587, JMSA$_1$-20158 × J-2590, JMSA$_1$-20158 × J- 2604, JMSA$_1$-20158 × AIB-29, JMSA$_1$-20158 × 110-SB-15, JMSA$_1$-20159 × J-2290, JMSA$_1$-20159 × J-2587, JMSA$_1$-20159 × J- 2604, JMSA$_1$-20159 × 110-SB-15, GHB 732 and GHB 538	---

× J- 2604, JMSA$_1$-20158 × AIB-29, JMSA$_1$-20158 × 110-SB-15, JMSA$_1$-20159 × J-2290, JMSA$_1$-20159 × J-2587, JMSA$_1$-20159 × J- 2604, JMSA$_1$-20159 × 110-SB-15, GHB 732 and GHB 538 had significant bi above unity, non-significant S2di and higher mean value. So, these genotypes were considered as stable and specifically adapted to the favourable environment. While remaining one genotype 110-SB-15 was stable, but mean value was less than the population mean hence, it was considered as poor in performance (**Table 2**).

Based on stability for grain yield per plant the genotypes were categorized and the same is furnished in **Table 3**.

REFERENCES

Anonymous, 2020a. Data bank of crops unit – I, crops division. Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation & Farmers Welfare, Govt. of India, pp. 1-96.

Anonymous, 2020b. Final advance estimate of area, production and yield of major *kharif/rabi/* summer crops of Gujarat state for the year 2020-21. Directorate of Agriculture, Gujarat State, Gandhinagar.

Asungre, P. A., Akromah, R., Kena, A. W. and Gangashetty, P. 2021. Genotype by environment interaction on grain yield stability and iron and zinc content in OPV of pearl millet in Ghana using the AMMI method. *International Journal of Agronomy,* **2021**:1-10. [Cross Ref]

Bashir, E. M. A., Ali, A. M., Ali, A. M., Ismail, M. I., Parzies, H. K. and Haussmann, B. I. G. 2014. Patterns of pearl millet genotype-by-environment interaction for yield performance and grain iron (Fe) and zinc (Zn) concentrations in Sudan. *Field Crops Research,* **166**: 82–91. [Cross Ref]

Eberhart, S. L. and Russell, W. A. 1966. Stability parameters for comparing varieties. *Crop Science*, **6**:26-40. [Cross Ref]

Gebre, W. 2014. Evaluation of pearl millet (*Pennisetum glaucum* L.) genotypes for yield and yield stability in south Omo and west Hararghe. *Journal of Biology, Agriculture and Healthcare,* **4**(8):99-121.

Katariya, H. M., Khanpara, M. D., Vora, Z., Parmar, R., Patel, J. B., Kulkurni, G. U., Raval, L. J., Mehta, D. R. and Kumar, R. 2019. Stability analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *International Journal of Chemical Studies,* **7**(2):242-251.

Kumar, A., Singh, D., Bhangarwa, S. K. and Yadav, M. K. 2020. Genotype x environment interactions and stability analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *International Journal of Chemical Studies*, **8**(1):669-675. [Cross Ref]

Lagat, N., Kimurto, P., Kiplagat, O., Towett, B. K., Jeptanui, L., Gatongi, I., Njogu, N., Ojulong, H., Manyasa E. and Simbi 2018. Evaluation of genotype x environment interaction and stability of grain yield and related yield components in pearl millet [*Pennisetum glaucum* (L.) R.Br.]. *Journal of Experimental Agriculture International,* **21**(1):1-18. [Cross Ref]

Lubadde, G., Tongoona, P., Derera, J. and Sibiya, J. 2017. Analysis of genotype by environment interaction of improved pearl millet for grain yield and rust resistance. *Journal of Agricultural Science*, **9**(2):188-195. [Cross Ref]

Mustapha, M. and Bakari, H. R. 2014. Statistical evaluation of genotype by environment interactions for grain yield in millet (*Pennisetum glaucum (L)* R. Br.). *The International Journal of Engineering and Science,* **3**(9):7-16.

Patel, P. R., Jain, S. K., Chauhan, R. M. and Patel, P. T. 2019. Stability analysis for fodder yield and its contributing traits in forage sorghum [*Sorghum bicolor* (L.) Moench] hybrids. *Electronic Journal of Plant Breeding*, **10**(2):353-363. [Cross Ref]

Pawar, V. Y., Magar, N. M., Awari, V. R., Kute, N. S., Patil, H. T., Deshmukh, G. P. and Kanawade, D. G. 2019. Genotype × environment interactions for grain yield in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Journal of Pharmacognosy and Phytochemistry*, **8**(3):2156-2159.

Sara, G. S., Raj, R. N., Gokulakrishnan, J. and Prakash, M. 2021. Stability analysis for yield and related traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.] hybrids. *Journal Research ANGRAU*, **49**(3):13-20.

Shanthi, P., Reddy, B. S. and Rao, M. S. 2016. Grain yield stability of pearl millet [*Pennisetum glaucum* (L.) R. Br.] in scarce rainfall region of Andhra Pradesh under rainfed situation. *The Andhra Agricultural Journal*, **63**(4):806-812.

Sujatha, K., Pushpavalli, S. N. C. V. L. and Shivani, D. 2016. Stability of yield and related traits in the land races of *rabi* sorghum [*Sorghum bicolor* (L.) Moench]. *Electronic Journal of Plant Breeding*, **73**(3): 620-625. [Cross Ref]

Vavilov, N. I. 1950 The origin, variation, immunity and breeding of cultivated plants. *Chronica Botanika*, **13**:1-366.