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Jigeeshaben M Patel
P.G. Student, C.P. College of Agriculture, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Mukeshbhai S Patel
Associate Research Scientist, Centre for Crop Improvement, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Hardikkumar N Patel
P.G. Student, C.P. College of Agriculture, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Nishitbhai V Soni
Assistant Research Scientist, Department of Genetics and Plant Breeding, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Niteshbhai N Prajapati
Assistant Research Scientist, Crop Improvement, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Correspondence
Jigeeshaben M Patel
P.G. Student, C.P. College of Agriculture, S.D. Agril. University, Sardarkrushinagar, North Gujarat, India

Stability analysis in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

Jigeeshaben M Patel, Mukeshbhai S Patel, Hardikkumar N Patel, Nishitbhai V Soni and Niteshbhai N Prajapati

Abstract
An experiment was conducted to study the stability of thirty pearl millet accessions including inbreds and hybrids procured from ICRISAT, Hyderabad during summer 2017 over three dates of sowing *viz.*, 1st March, 16th March and 31st March. The G × E interaction was significant for days to flowering, plant height, number of effective tillers per plant, earhead girth, seed setting on main tiller, leaf area, grain yield per plant and harvest index when tested against pooled error. The results of estimates of environmental index (Ij), suggested that E_1 (Date of sowing 1st March, 2017) was most favourable environment. From the stability analysis, the nine genotypes possess average stability and showed wider adaptability for grain yield per plant also displayed either average or above or below average stability for other characters. The hybrids *viz.*, ICMA 98444 × 18587 R, ICMA 98222 × 17369 R, ICMA 99222 × 17829 R and ICMA 98444 × 17369 R were identified average stable for most of traits studied in the present investigation.

Keywords: G × E interaction, yield, stability, pearl millet

Introduction
Pearl mille is an important staple food crop in arid and semi arid regions of India. It is an annual tillering, cross pollinated, diploid (2n = 14) crop belong to family *poaceae,* sub-family *panicoideae,* tribe- *paniceae* and genus *Pennisetum* is believed to be originated to north-western Africa. It is well adapted to growing areas characterized by drought, low soil fertility *panicoideae,* tribe- *paniceae* and genus *Pennisetum* is believed to be originated to north-western Africa. It is well adapted to growing areas characterized by drought, low soil fertility and high temperature. It was grown on 7.5 million ha with an average production of 9.73 million tonnes with productivity of 1305 kg/ha during 2016-17 (Anon., 2018) [2]. The major pearl millet growing states are Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana which account for more than 90 per cent of pearl millet acreage in the country.

The protogynous flower morphology of pearl millet makes it a highly cross pollinated crop with extent of out crossing above 85 per cent and thereby it is highly heterozygous and heterogeneous. In relation to yield, quality traits have also important role for increasing value addition because pearl millet grain is richer source of iron (18-87 ppm) and zinc (22-88 ppm) (Devart *et al.,* 2011) [7]. It is rich in methionine, but poor in sulphur containing amino acids (Nambiar *et al.,* 2011) [11].

Unfortunately, the potential performance of improved genotypes under marginal conditions is always obscured by the effect of genotype by environment interaction (Yan & Racjan, 2002) [14]; leading to selection of genotypes not suitable for particular environments (Cooper & Delacy, 1994) [5] and subsequently leading to low yield. It is therefore important to assess genotype by environment interaction effect before releasing varieties (Gupta & Ndoye, 1991; Haussmann *et al.,* 2012) [9, 10]. Hence, it may be useful to determine the most suitable environment that may allow maximum expression of the genes controlling quantitative characters. The degree of genotype-environment interaction involved in the expression of a given character not only helps the plant breeder in planning the future breeding programmes, but also useful in determining the environments and number of tests to be conducted for evaluation of breeding material.

Materials and Methods
The experimental material used in the present investigation comprised of 30 genotypes, including hybrids and advance lines of pearl millet.

The experiment was laid out in randomized block design with two replications over three dates of sowing *viz.*, 1st March, 16th March and 31st March during the summer, 2017 at Centre for Crop Improvement, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat. The spacing of 45 × 10-15 cm was maintained and all the cultural practices were adopted to raise the crop. The observations were recorded on five randomly selected plants from each replication for twelve traits *viz.*, plant height (cm), earhead length (cm), earhead girth (mm), number of total tillers per plant, number of effective tillers per plant, seed setting on main tiller (%), leaf area (cm^2), dry fodder yield per plant (g), grain yield per plant (g), harvest index (%), test weight (g) and protein content (%), while two characters, namely, days to flowering and days to maturity were recorded on plot basis. Stability analysis was carried out as per Eberhart and Russell (1966). For each genotype, stability is described by three parameters *viz.*, mean performance, the regression of mean performance on an environmental index and the mean square deviation from regression. Eberhart and Russell (1966) suggested that ideal genotype is one which has a high mean ($\bar{X}$), unit regression co-efficient ($b_i = 1$) and the least deviation from regression ($S^2d_i = 0$).

Results and Discussion

It generally happens that many varieties of different crops do not exhibit similarity in their performance when tested under different environmental conditions. This is because of the presence of G × E interactions, which results in changes of relative ranking in term of yield and component traits of different genotypes and also alters the magnitude of differences between genotypes from one environment to another. However, even with this refinement of technique, the interactions of genotypes with environments within same year remain very large (Allard and Bradshaw, 1964) [1].

Analysis of variance

Mean squares due to genotypes were found to be highly significant for all the fourteen characters. It indicates that there is significant variation among genotypes, which can be further studied for their interaction with different environments to identify for their suitability for cultivation. Analysis of variance for stability (Table 1) revealed that mean squares due to genotypes, environments and environment (linear) were highly significant for most of characters, indicating that presence of wide genetic variation for different characters in the genetic material and environment used was quite differ from each other. The G × E interaction was significant for all the characters except days to maturity, number of total tillers per plant, earhead length, dry fodder yield per plant, test weight and protein content when tested against pooled error, because genotypes reacted differently in different environments. These results are in agreement with earlier reports of Ramamoorthi *et al.* (1996) [12] and Bikash *et al.* (2013) [3]. The G × E (linear) was observed significant for days to flowering, plant height, number of total tillers per plant, number of effective tillers per plant, earhead girth, seed setting on main tiller, leaf area, grain yield per plant, harvest index and test weight when tested against pooled deviation. This indicated that major portion of interaction was in linear in nature and prediction over environments for these character would be possible. The variance due to pooled deviation was significant for all characters except number of effective tillers per plant which suggested the importance of non linear component for all the characters except number of effective tillers per plant.

Environmental indices

Breeze (1969) [4] pointed out that the estimates of environment index can provide the basis for identifying the favourable environment for the expression of maximum potential of the genotype. The positive and negative value of environmental index indicates the favourable and unfavourable situations, respectively for each character (De *et al.*, 1992) [6]. The results of estimates of environmental index (Ij) given in Table 2 suggested that E_1 (Date of sowing 1st March, 2017) was most favourable environment whereas E_3 (Date of sowing 31st March, 2017) was most unfavourable environment for all the characters under study. The E_2 (Date of sowing 16th March, 2017) was favourable for plant height, earhead girth, seed setting on main tiller, leaf area, grain yield per plant, harvest index and protein content. The results are in agreement with Yahaya *et al.* (2006) [13] and Bikash *et al.* (2013) [3].

Stability parameters

Days to flowering

The deviation from regression (S^2d_i) was significant for eleven genotypes and hence these genotypes were unstable. Seventeen genotypes exhibited lower mean value than the general mean (50.80). Out of these, eight genotypes had non-significant regression co-efficient and deviation from regression ($S^2d_i = 0$) indicating average stability of these genotypes. The early flowering genotypes, ICMA 99222 × 18196 R and ICMB 99222 had significant unit regression ($b_i > 1$) and non-significant S^2d_i were responsive to favourable environment.

Plant height

Fifteen genotypes recorded higher mean value of plant height than the populations mean (157.97). Out of these, nine genotypes had non significant regression (b_i) and non-significant deviation from regression (S^2d_i) indicating average stability over different environments. The ICMA 99222 × 18196 R and 17398 R genotypes had significant unit regression ($b_i < 1$) and non-significant S^2d_i were good for poor environment.

Number of effective tillers per plant

The eleven genotypes had non significant regression (b_i) and non-significant deviation from regression (S^2d_i) indicating average stability of over different environment. The genotypes ICMA 99222 × 18196 R and ICMB 05444 had significant unit regression ($b_i > 1$) and non-significant S^2d_i were responsive to favourable environment.

Earhead girth

The genotype 18511 R exhibited higher than mean value and above significant regression co-efficient ($b_i < 1$) and non-significant deviation from regression indicating their responsiveness to poor environment. The genotype, 18805 R had below significant regression co-efficient ($b_i > 1$) and non-significant deviation from regression was good for favourable environment. The deviation from regression (S^2d_i) was significant for four genotypes and hence these genotypes were unstable.

Seed setting on main tiller

Twenty genotypes recorded higher mean value of seed setting on main tiller than the general mean (85.99). Out of these, thirteen genotypes had non-significant regression (b_i) and non-significant deviation from regression (S^2d_i) indicating average stability of genotypes over different environments. The genotypes *viz.*, ICMA 98222 × 17369 R, ICMA 99222 × 18196 R and 17398 R had significant regression ($b_i < 1$) and non-significant deviation from regression were good for low yielding environment.

Leaf area

Seven genotypes had non significant regression (b_i) and non-significant deviation from regression (S^2d_i) indicating average stability of over different environment. The genotypes, ICMA 10777 × 18587 R and ICMB 10777 had significant unit regression ($b_i > 1$) and non significant S^2d_i were responsive to favourable environment. The genotypes *viz.*, ICMA 96222 × 17398 R and ICMA 99222 × 17829 R had significant ($b_i < 1$) and non significant deviation from regression were good for low yielding environment.

Harvest index

The deviation from regression (S^2d_i) was significant for six genotypes and hence these genotypes were unstable. Sixteen genotypes recorded higher mean value of harvest index than the populations mean (29.89). Out of these, eleven genotypes had higher mean values with non-significant unit regression (b_i) and non-significant deviation from regression (S^2d_i) indicating average stability over different environments.

Grain yield per plant

Thirteen genotypes recorded higher mean value of grain yield per plant than the population mean (18.12). Out of these, nine genotypes (Table 3) had higher mean values with non-significant unit regression (b_i) and non-significant deviation from regression (S^2d_i), indicating average stability of genotypes over different environments. The deviation from regression (S^2d_i) was significant for four genotypes and hence these genotypes were unstable.

An overall study of stability parameters (Table 4) revealed that none of the genotypes was stable for all the characters. Similar was the situation pertaining to mean performance and responsiveness. Hence, any generalization regarding stability and responsiveness of genotype for all the characters was not possible. From the stability analysis, the nine genotypes possess average stability and showed wider adaptability for grain yield per plant also displayed either average or above or below average stability for other characters. Among them, the genotype 18587 R showing average stability for grain yield per plant as well as earhead girth, seed setting on main tiller and leaf area and also its hybrid ICMA 98444 × 18587 R showing average stability for grain yield per plant alongwith days to flowering, plant height, number of effective tillers per plant, earhead girth and seed setting on main tiller, leaf area and harvest index. The hybrids *viz.*, ICMA 98444 × 18587 R, ICMA 98222 × 17369 R, ICMA 99222 × 17829 R and ICMA 98444 × 17369 R were identified average stable for most of traits studied in the present investigation. The hybrids *viz.*, ICMA 98444 × 17369 R and ICMA 99222 × 18805 R showed average stability for days to flowering, plant height, number of effective tillers per plant, earhead girth and seed setting on main tiller components could be considered in future breeding programme so as to develop stable hybrids or population for grain yield per plant and other components in pearl millet.

From the stability analysis, it was revealed that genotypes showed stability for grain yield per plant also simultaneously average, above or below average stability for one or more yield components. It can therefore be suggested that, while making selections, attention should be paid to the phenotypic stability of characters directly related to grain yield and genotypes having average stability for different characters could be used in developing stable hybrid or population.

Table 1: Analysis of variance (Mean square) for phenotypic stability for fourteen characters in pearl millet

Sources of variation	d.f.	DF	DM	PH	TT	ET	EL	EG	SS	LA	FY	GY	HI	TW	PC
Genotype (G)	29	71.71**	37.47**	4227.97**	1.59**	0.19**	23.58**	66.85**	262.96**	963708.30 **	878.10**	142.48**	99.43**	7.73**	3.53**
Environment (E)	2	416.50**	1208.17**	561.98 **	2.24**	2.24**	24.08**	63.19**	2279.01**	775493.40 **	31.23	702.74**	379.37**	12.87**	0.78
G × E	58	3.58*	5.10	75.85 *	0.27	0.05**	1.38	2.98*	53.60**	62696.53 **	21.49	12.71**	14.76**	0.84	0.43
Environment (linear)	1	833.01**	2416.35**	1123.97**	4.48**	4.48**	48.16**	126.38**	4558.03**	1550987.00 **	62.46	1405.49**	758.75**	25.75**	1.56*
G × E (linear)	29	5.43**	4.44	112.10**	0.38*	0.08**	1.47	4.34**	90.87**	104938.40**	10.59	21.43**	22.67**	1.16*	0.51
Pooled deviation	30	1.66**	5.56**	38.28**	0.16**	0.02	1.24**	1.56**	15.80**	19772.85**	31.31**	3.86*	6.63**	0.50**	0.34*
Pooled error	87	0.37	1.56	16.52	0.05	0.01	0.38	0.64	2.76	6407.48	5.18	2.13	2.79	0.24	0.18

* and ** : Significant at 5 and 1 per cent levels of significance, respectively.

DF : Days to flowering, DM : Days to maturity, PH : Plant height (cm), TT : Number of total tillers per plant, ET : Number of effective tillers per plant, EL : Earhead length (cm), EG : Earhead girth (mm), SS : Seed setting on main tiller (%), LA : Leaf area (cm^2), FY : Dry fodder yield per plant (g), GY : Grain yield per plant (g), HI : Harvest index (%), TW : Test weight (%) and PC% : Protein content (%).

Table 2: Estimates of environmental index (Ij) for fourteen characters under different environments expressed as deviation of grand mean

Sr. No.	Characters	Environments		
		E_1	E_2	E_3
1	Days to flowering	3.98	-0.58	-3.40
2	Days to maturity	6.84	-1.15	-5.69
3	Plant height (cm)	4.10	0.41	-4.52
4	Number of total tillers per plant	0.27	-0.002	-0.27
5	Number of effective tillers per plant	0.30	-0.09	-0.21
6	Earhead length (cm)	1.03	-0.50	-0.53
7	Earhead girth (mm)	1.44	0.01	-1.46
8	Seed setting on main tiller (%)	6.45	3.45	-9.91

9	Leaf area (cm^2)	154.35	12.15	-166.51
10	Dry fodder yield per plant (g)	1.06	-0.96	-0.10
11	Grain yield per plant (g)	4.62	0.39	-5.02
12	Harvest index (%)	3.43	0.23	-3.67
13	Test weight (g)	0.72	-0.16	-0.55
14	Protein content (%)	0.11	0.06	-0.18

Table 3: Stability parameters of various genotypes for grain yield per plant in pearl millet

Sr. No.	Genotypes	Grain yield per plant (g)		
		Mean	b_i	S^2d_i
1	ICMA 10777 × 17398 R	22.31	1.24	10.48*
2	ICMA 10777 × 18587 R	25.49	2.75	0.71
3	ICMA 96222 × 17398 R	21.38	1.05	9.53*
4	ICMA 98222 × 17369 R	27.03	0.81	-1.15
5	ICMA 98444 × 17369 R	24.43	0.84	5.16
6	ICMA 98444 × 18587 R	26.02	0.91	-0.10
7	ICMA 99222 × 18196 R	31.29	1.45	9.19*
8	ICMA 99222 × 17829 R	26.59	-0.04	-1.81
9	ICMA 99222 × 18805 R	32.68	2.17	4.54
10	ICMB 04999	9.94	0.73	-2.01
11	ICMB 05444	8.75	0.59	-0.83
12	ICMB 10777	10.43	1.40	-0.93
13	ICMB 94555	6.85	0.20*	-1.94
14	ICMB 95444	11.34	-0.04	-1.75
15	ICMB 96222	11.02	0.93	-2.00
16	ICMB 97111	18.08	0.39	6.12
17	ICMB 98222	14.89	1.18	0.87
18	ICMB 98444	14.23	0.59	-1.26
19	ICMB 99222	16.20	1.08	3.11
20	15990 R	9.63	0.42	-1.73
21	17369 R	16.14	0.46*	-2.12
22	17398 R	17.33	0.12	0.45
23	17548 R	20.86	0.89	-2.10
24	17829 R	17.00	1.14	-1.94
25	18196 R	20.43	2.51	28.05**
26	18488 R	11.19	1.21	1.36
27	18511 R	15.49	1.27	-1.44
28	18587 R	23.44	1.54	-1.34
29	18805 R	19.06	1.66	-1.92
30	18818 R	14.25	0.56	-1.12
Mean		18.12		
S.Em.±		1.38		

* and ** : Significant at 5 and 1 per cent levels of significance, respectively.
When H0 : bi = 1

Table 4: Stable genotypes for grain yield per plant along with stability for component traits

Sr. no.	Genotypes	Stability parameters	stability for other characters							
			GY	DF	PH	ET	EG	SS	LA	HI
1	ICMA 98444 × 18587 R	Mean	26.02	49.67	205.13	1.63	27.91	93.13	2661.06	32.00
		b_i	0.91	1.03	0.28	-0.49	0.79	0.55	1.81	-0.67
		S^2d_i	-0.10	0.11	-7.64	-0.01	-0.27	-2.33	1898.00	-1.42
2	ICMA98222 × 17369 R	Mean	27.03	44.17	190.87	1.70	29.17	92.60	1216.73	33.92
		b_i	0.81	0.79	-1.10	0.70	1.37	0.56*	2.06	0.27
		S^2d_i	-1.15	0.58	-8.10	-0.01	-0.55	-2.67	-5511.00	-0.86
3	ICMA98444 × 17369 R	Mean	24.43	48.50	204.73	1.60	28.04	92.90	2655.86	32.64
		b_i	0.84	1.31	-0.98	0.89	0.64	0.64	0.55	0.82
		S^2d_i	5.16	0.45	-12.97	0.00	-0.06	-2.28	86872.00**	25.49**
4	17548 R	Mean	20.86	54.17	141.60	1.10	27.90	92.77	1415.94	35.41
		b_i	0.89	0.39	1.76	0.62	0.27	0.04	2.52*	0.81
		S^2d_i	-2.10	0.10	-14.03	-0.01	8.14**	24.6**	-6256.00	-2.02
5	ICMA99222 × 17829 R	Mean	26.58	44.50	182.67	1.37	28.19	93.23	1696.69	35.43
		b_i	-0.04	0.77	-1.41	0.84	-0.64	0.37	-2.13*	-0.09
		S^2d_i	-1.81	2.82**	-11.89	0.01	1.63	-1.84	-3933.00	-2.00
6	ICMA10777 × 18587 R	Mean	25.48	54.00	208.50	1.57	30.20	87.33	1769.54	22.89
		b_i	2.75	0.63	5.37	1.65	1.84	1.65	2.18*	2.17
		S^2d_i	0.71	10.23**	8.47	0.00	5.42**	8.42*	-5923.00	1.06
7	ICMA99222 ×	Mean	32.67	47.67	189.50	2.07	34.04	92.23	1100.97	29.81
		b_i	2.17	1.62	1.44	2.62	2.79	0.52	1.56	1.30

	18805 R	S^2d_i	4.54	-0.26	-16.46	0.00	0.67	-0.11	1222.00	9.70**
8	18587 R	Mean	23.44	53.17	202.43	1.80	26.64	88.57	2200.80	28.54
		b_i	1.54	0.58	3.05	1.47	2.33	1.43	1.11	1.40
		S^2d_i	-1.34	2.31**	153.17**	0.08**	0.86	0.51	44523.00**	-2.38
9	18805 R	Mean	19.06	53.50	184.53	1.40	28.14	84.03	1023.78	24.11
		b_i	1.66	1.01	2.35*	1.66	1.60*	1.35	1.51	1.49
		S^2d_i	-1.92	-0.37	-16.33	-0.01	-0.63	34.98**	4237.00	-1.74

Where,
* and ** : Significant at 5 and 1 per cent levels of significance, respectively.
DF : Days to flowering, PH : Plant height (cm), ET : Number of effective tillers per plant, EG : Earhead girth (mm), SS : Seed setting on main tiller (%), LA : Leaf area (cm^2), GY : Grain yield per plant (g), HI : Harvest index (%).

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