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

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Abstract
The pearl millet 55 crosses along with eleven inbreds and two checks were used to study stability over four environments *viz.*, E_1: *Kharif*-2013, Dhule, E_2: *Kharif*-2013, Rahuri, E_3: Summer-2014, Dhule and E_4: Summer-2014, Rahuri. In regards to G x E interaction studies, the mean sum of squares due to genotypes was significant for all the eleven characters studied across the environments, which indicated the presence of substantial variation in the material studied. The analysis also indicated significant variation among the environments for all the characters. The values of G x E interaction were significant for grain yield which indicated that genotypes interacted differently with environmental variations for the said characters. Among the 11 parental genotypes, two parents DHLBI 731 and S-12/30060 had average stability for grain yield and would be well adapted to array of environments. The cross combinations six crosses *viz.* RHRBI 138 x RHRBI 458, RHRBI 138 x S-12/30060, DHLBI 967 x DHLBI 731, DHLBI 967 x ICMB 98222, DHLBI 967 x S-12/30088, S-12/30060 x S-12/30074 and check Shanti had average stability and well adaption to all types of environment for grain yield. Hybrid S-12/30109 x S-12/30060 and check Dhanshakti had above average stability and adapted to poor environment, while five cross combination had below average stability for grain yield. Out of six stable cross combinations, three had one of the parent either DHLBI 731 or S-12/30060 which may have genes for average stability for grain yield which can further utilized in crossing programme in order to generate wide genetic variability for developing high yielding and stable hybrids/varieties/population of pearl millet.

Keywords: Grain yield, pearl millet, stability, genotypes, G x E interaction

Introduction
Inbreds concern with the importance of homeostasis in living organism has stimulated plant breeders awareness for the need to develop well-buffered varieties. This has led to a greater emphasis on phenotypic stability in breeding programmes. Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is the most important component of dryland system and grow extensively in *Kharif* season in Maharashtra. Maharashtra, pearl millet covers an area of 6.47 lakh hectares producing 4.20 lakh tones with productivity of 632 kg/ha (Anon., 2019) [3]. The varietal adaptability to environmental fluctuations is important for stabilization of crop production, both over location and seasons. Thus, stability reflects the suitability of a variety/hybrid for general cultivation over wide range of environments. In the evolutionary terms, the breeders objective is to produce populations/varieties/hybrids that are better adapted to given environment (Simmonds 1962) [9]. Therefore, efforts are required to increase production and productivity of pearl millet crop across the diverse environments by providing seed of suitable population/variety/hybrids. Keeping this view in mind, the present investigation was carried out.

Materials and method
The experimental material for the present study comprised of 11 inbred lines obtained from Bajra Research Scheme, College of Agriculture, Dhule and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana. These inbreds were crossed in diallel fashion to obtain F_1's excluding reciprocals during Summer 2013. Sufficient quantity of seed for 55 cross combinations was obtained.
These 55 crosses along with eleven inbreds and two checks were used to study stability over four environments *viz.*, E_1: *Kharif*-2013, Dhule, E_2: *Kharif*-2013, Rahuri, E_3: Summer-2014, Dhule and E_4: Summer-2014, Rahuri. The 68 genotypes were raised in a randomized block design with three replications and two rows (of 3.0m length) plots per replication. Standard agronomic practices were followed for raising and maintenance of plants.

Stability analyses based on the Eberhart and Russell, (1966) [5] model were undertaken using Indostat statistical package at Mahatma Phule Krishi Vidyapeeth, Rahuri.

Results and discussion

The stability analysis following Eberhart and Russell model undertaken to study the behaviour of grain yield indicated that the G x E interaction studies, the mean sum of squares due to genotypes was significant across the environments (Table 1), which indicated the presence of substantial variation in the material studied. The analysis also indicated significant variation among the environments for all the characters. The values of G x E interaction were significant for grain yield which indicated that genotypes interacted differently with environmental variations for the said characters. Highly significant values of mean squares due to environments (linear) for grain yield indicated that the linear responses of genotypes to environment differed significantly for the said characters; while mean square values due to G x E (pooled error) were also significant for all the characters. However, relative magnitude of linear component of G x E interaction was higher than non linear component for all characters. Thus, the present findings are in consonance with those of Baviskar (1990) [4], Suryavanshi *et al.* (1991) [10] and Anarase *et al*. (2000 & 2002) [1, 2] and Patil *et al*. (2014) [7].

Out of 68 genotypes, 27 genotypes had non-significant deviation from linear regression and 35 had higher grain yield per plot than respective mean, out of these 18 genotypes were identified (bi>1 and significant: five, bi=1.00 ns: eight and bi<1 and significant: five) as well adapted to different environments (Table 2). Among the parental genotypes, DHLBI 731 and S-12/30060 had higher mean than parental mean and non-significant regression coefficient and deviation from regression (Mean>population mean, bi=1.00 ns and S^2di=0 ns) and grouped as average stable for grain yield and would be well adapted to array of environments. The three parents RHRBI 458, ICMB 98222 and S-12/30074 had higher mean than parental mean, significant regression coefficient lower than unity and non-significant deviation from regression (Mean>population mean, bi<1.00 and significant and S^2di=0 ns) showed above average stability and might be adopted to poor environment for grain yield.

Among hybrids six hybrids *viz.*, RHRBI 138 x RHRBI 458, RHRBI 138 x S-12/30060, DHLBI 967 x DHLBI 731, DHLBI 967 x ICMB 98222, DHLBI 967 x S-12/30088, S-12/30060 x S-12/30074 and check Shanti had its mean higher than hybrid with check mean, bi and S^2di are non-significant Shanti and grouped as average stable and well adaption to all types of environment for grain yield (Table 3). Whereas five hybrids *viz.*, RHRBI 458 x ICMB 98222, DHLBI 967 x S-12/30109, DHLBI 731 xS-12/30109, DHLBI 731x S-12/30088 and ICMB 98222 x S-12/30069 showed below average stability and suitable for poor environment (Mean>population mean, bi>1.00 and significant and S^2di=0 ns), however hybrid S-12/30109 x S-12/30060 and check Dhanshakti had below average stability and suitable for poor environments (Mean>population mean, bi<1.00 and significant and S^2di=0 ns). Suryavanshi *et al.* (1991) [10], Anarase *et al.* (2000) [1], Pawar *et al.* (2012) [8], Patil *et al.* (2014) [7] and Patel *et al.* (2015) [6] also reported the same result in pearl millet.

Table 1: Analysis of variance and variance components for grain Fe and Zn content in pearl millet (based on Eberhart and Russell model).

Source	DF	Grain yield (kg/plot)
Rep. within Env.	8	0.001
Genotypes	67	0.175@@##**
Environments	3	3.858@@##**
Geno. x Env.	201	0.041##**
Env. + (Geno. x Env.)	69	0.097@@##**
Environments (Lin.)	67	11.574##**
Geno. x Env. (Lin.)	65	0.077##**
Pooled deviation	63	0.023**
Pooled error	204	0.003
Total	1	0.116

@, @@ Significant tested against genotypes x environments (Gx E) at 0.05 and 0.01 levels of probability, respectively
Significant tested against pooled deviation at 0.05 and 0.01 levels of probability, respectively
*, ** Significant tested against pooled error at 0.05 and 0.01 levels of probability, respectively

Table 2: Stability parameters for grain yield per plot (kg).

			Grain yield per plot (kg)		
S. No.	Parents / Crosses	Code	Mean	b_i	S^2d_i
1	RHRBI 138	P_1	0.504	0.073**	0.0027
2	RHRBI 458	P_2	0.660	0.77**	-0.0026
3	DHLBI 967	P_3	0.460	0.218**	0.0061
4	DHLBI 731	P_4	0.599	0.787	0.0052
5	ICMB 98222	P_5	0.637	0.381**	0.00
6	S-12/30069	P_6	0.402	0.238**	-0.003
7	S-12/30109	P_7	0.484	-0.336**	0.0018
8	S-12/30071	P_8	0.608	0.779**	-0.0013
9	S-12/30060	P_9	0.673	0.89	0.0051
10	S-12/30074	P_{10}	0.511	-0.248**	0.0116*
11	S-12/30088	P_{11}	0.485	0.233**	-0.0019
	Parental Mean		0.548		
12	RHRBI 138 **x** RHRBI 458	P_1 x P_2	0.972	1.175	-0.0015
13	RHRBI 138 **x** DHLBI 967	P_1 x P_3	0.876	0.772	0.0273**
14	RHRBI 138 **x** DHLBI 731	P_1 x P_4	1.130	0.589	0.0137**

15	RHRBI 138 **x** ICMB 98222	P_1 x P_5	0.743	-0.335**	0.0082*
16	RHRBI 138 **x** S-12/30069	P_1 x P_6	0.610	0.433**	-0.0029
17	RHRBI 138 **x** S-12/30109	P_1 x P_7	0.578	-0.121*	0.0333**
18	RHRBI 138 **x** S-12/30071	P_1 x P_8	0.730	1.421	0.0382**
19	RHRBI 138 **x** S-12/30060	P_1 x P_9	1.038	0.395	-0.0019
20	RHRBI 138 **x** S-12/30074	P_1 x P_{10}	0.752	0.647	0.0466**
21	RHRBI 138 **x** S-12/30088	P_1 x P_{11}	0.583	-0.375**	0.0168**
22	RHRBI 458 **x** DHLBI 967	P_2 x P_3	0.957	1.005	0.0175**
23	RHRBI 458 **x** DHLBI 731	P_2 x P_4	1.095	1.638	0.1464**
24	RHRBI 458 **x** ICMB 98222	P_2 x P_5	1.239	1.284**	-0.0031
25	RHRBI 458 **x** S-12/30069	P_2 x P_6	0.733	1.081	0.0231**
26	RHRBI 458 **x** S-12/30109	P_2 x P_7	0.862	0.955	0.1031**
27	RHRBI 458 **x** S-12/30071	P_2 x P_8	0.843	1.039	0.0168**
28	RHRBI 458 **x** S-12/30060	P_2 x P_9	1.168	1.413	0.0337**
29	RHRBI 458 **x** S-12/30074	P_2 x P_{10}	0.974	1.811	0.0305**
30	RHRBI 458 **x** S-12/30088	P_2 x P_{11}	0.968	1.849*	0.0225**
31	DHLBI 967 **x** DHLBI 731	P_3 x P_4	1.017	0.436	-0.0024
32	DHLBI 967 **x** ICMB 98222	P_3 x P_5	1.115	1.521	0.0048
33	DHLBI 967 **x** S-12/30069	P_3 x P_6	0.885	1.57	0.023**
34	DHLBI 967 **x** S-12/30109	P_3 x P_7	0.904	1.431*	0.0048
35	DHLBI 967 **x** S-12/30071	P_3 x P_8	0.779	1.325	0.012**
36	DHLBI 967 **x** S-12/30060	P_3 x P_9	1.119	1.708	0.0339**
37	DHLBI 967 **x** S-12/30074	P_3 x P_{10}	1.018	1.275	0.0652**
38	DHLBI 967 **x** S-12/30088	P_3 x P_{11}	0.904	1.195	-0.0008
39	DHLBI 731 **x** ICMB 98222	P_4x P_5	0.844	0.839	0.0275**
40	DHLBI 731 **x** S-12/30069	P_4x P_6	0.933	2.164**	0.0122**
41	DHLBI 731 **x** S-12/30109	P_4 x P_7	1.018	1.728**	0.0018
42	DHLBI 731 **x** S-12/30071	P_4 x P_8	0.833	1.446	0.0081*
43	DHLBI 731 **x** S-12/30060	P_4 x P_9	1.217	2.272**	0.0334**
44	DHLBI 731 **x** S-12/30074	P_4 x P_{10}	0.970	1.961*	0.0247**
45	DHLBI 731 **x** S-12/30088	P_4 x P_{11}	1.038	1.681**	-0.0028
46	ICMB 98222 **x** S-12/30069	P_5 x P_6	0.918	1.664*	0.0052
47	ICMB 98222 **x** S-12/30109	P_5 x P_7	0.869	0.662	0.0409**
48	ICMB 98222 **x** S-12/30071	P_5 x P_8	0.846	1.603**	-0.0018
49	ICMB 98222 **x** S-12/30060	P_5 x P_9	1.239	2.109*	0.0384**
50	ICMB 98222 **x** S-12/30074	P_5 x P_{10}	0.863	1.047	0.065**
51	ICMB 98222 **x** S-12/30088	P_5 x P_{11}	0.983	1.64*	0.0137**
52	S-12/30069 **x** S-12/30109	P_6 x P_7	0.535	0.49	0.0122**
53	S-12/30069 **x** S-12/30071	P_6 x P_8	0.543	0.116**	0.0121**
54	S-12/30069 **x** S-12/30060	P_6 x P_9	0.920	2.219**	0.0227**
55	S-12/30069 **x** S-12/30074	P_6 x P_{10}	0.772	1.128	0.0018
56	S-12/30069 **x** S-12/30088	P_6 x P_{11}	0.652	0.13	0.0555**
57	S-12/30109 **x** S-12/30071	P_7 x P_8	0.708	0.984	0.0242**
58	S-12/30109 **x** S-12/30060	P_7 x P_9	0.949	0.318**	0.0001
59	S-12/30109 **x** S-12/30074	P_7 x P_{10}	0.853	0.862	0.0292**
60	S-12/30109 **x** S-12/30088	P_7 x P_{11}	0.701	0.835	0.0345**
61	S-12/30071 **x** S-12/30060	P_8 x P_9	0.972	1.816*	0.0228**
62	S-12/30071 **x** S-12/30074	P_8 x P_{10}	0.889	1.325	0.0331**
63	S-12/30071 **x** S-12/30088	P_8 x P_{11}	0.701	1.398*	0.0034
64	S-12/30060 **x** S-12/30074	P_9 x P_{10}	1.077	1.356	0.005
65	S-12/30060 **x** S-12/30088	P_9 x P_{11}	0.949	1.254	0.044**
66	S-12/30074 **x** S-12/30088	P_{10} x P_{11}	0.814	0.255*	0.0086*
67	Shanti (Check)		1.136	1.112	0.0049
68	Dhanshakti (Check)		0.993	0.664**	-0.0026
	Hybrid with check Mean		0.900		

*, **Significant at 5% and 1 % level, respectively

Table 3: Classification of pearl millet parents and hybrids based on their well adaptation in average, poor and better environments.

	Average stability and wide/ general adaptability	**Above average stability and adapted to poor environment**	**Below average stability and adapted to better environment**
Parents	DHLBI 731, S-12/30060	RHRBI 458, ICMB 98222, S-12/30071	--
Hybrids	RHRBI 138 x RHRBI 458, RHRBI 138 x S-12/30060, DHLBI 967 x DHLBI 731, DHLBI 967 x ICMB 98222, DHLBI 967 x S-12/30088, S-12/30060 x S-12/30074, Shanti (Check)	S-12/30109 x S-12/30060, Dhanshakti (Check)	RHRBI 458 x ICMB 98222, DHLBI 967 x S-12/30109, DHLBI 731 x S-12/30109, DHLBI 731 x S-12/30088, ICMB 98222 x S-12/30069

E_1: *Kharif*-2013, Dhule, E_2: *Kharif*-2013, Rahuri, E_3: Summer-2014, Dhule and E_4: Summer-2014, Rahuri.

Conclusion

To conclude, the G × E interactions play a significant role in the expression of grain yield in pearl millet. Though linear response to environmental conditions was observed in some of the genotypes, nonlinear response was also equally evident in other genotypes, necessitating multi-location as well as multi season evaluation of genotypes before identifying stable genotypes that can be used as donor parents in breeding for yield in pearl millet. Out of six stable cross combinations, three had one of the parent either DHLBI 731 or S-12/30060 which may have genes for average stability for grain yield which can further utilized in crossing programme in order to generate wide genetic variability for developing high yielding and stable hybrids/varieties/population of pearl millet.

Authors' contribution

Conceptualization of research (VYP, NSK, HTP, GPD); Designing of experiments (VYP, NSK,HTP,GPD); Contribution of experimental material (VYP, HTP); Execution of field experiments and data collection (VYP, NMM, VRA, DGK); Analysis of data and interpretation (VYP, NMM,VRA); Preparation of manuscript (VYP, NSK).

Declaration

The authors declare no conflict of interest.

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