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A Lokeshwar Reddy
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India

KD Sehrawat
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India

OP Bishnoi
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India

Susmita Dey
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India

Corresponding Author
A Lokeshwar Reddy
Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India

Assessment of genotype × environment interaction in pearl millet (*Pennisetum glaucum* (L.) R. Br.) hybrids in arid climate of Haryana

A Lokeshwar Reddy, KD Sehrawat, OP Bishnoi and Susmita Dey

Abstract

Genotype × environment interaction in pearl millet was studied for grain yield per plant and other quantitative characters by growing 51 genotypes consisting of 36 hybrids, 13 parents along with two standard checks *viz*., HHB-299 and HHB-67 Improved in RBD with three replications during *Kharif*, 2018 at two different locations creating three environments *i.e.*, Bajra Section, Dept. of Genetics and Plant Breeding, CCSHAU, Hisar (E_1), Dryland Agriculture, CCSHAU, Hisar (E_2) and Regional Research Station, CCSHAU, Bawal (E_3). The nature and extent of genotype × environment interactions were studied. The joint regression analysis indicated the importance of unpredictable components along with predictable components of G × E interaction. Among the crosses ICMA 04888 × A_5R-08-108, 81A_1 × H 1305, 81A_5× A_4RL/13-119, 81A_5 × H 1305, 81A_4 × A_5RL-10-203 and 81A_5 × AC 04/13 were identified as widely stable and best performing hybrids for grain yield and other quantitative characters.

Keywords: Genotype × environment interaction, grain yield and pearl millet

Introduction

Pearl millet is one of the most important coarse cereal crop, primarily grown for grain and fodder purpose in arid and semi-arid regions of the world. In India, it is largely grown during *Kharif* (June-September) as rainfed crop in all dryland regions but in south where irrigation facilities are available it's grown in both seasons such as summer (February-May) and *Rabi* (November-February) under high levels of agronomic management practices to get good yields. Since, pearl millet is more resilient to drought and heat stresses in comparison to other cereals, more research and development is expected to yield good dividends of the climate change. Development of high yielding varieties/hybrids of pearl millet has led to increased productivity and stability largely in the regions with relatively better environments, while regions with arid and semi-arid environment, still suffers from low productivity. This is because most of the hybrids recommended for this region resulted from the parents developed from programme not specifically meant for arid areas and hence lacked the desired adaptability and the characteristics required for these areas. A phenotype is the result of interplay of a genotype and its environment. A specific genotype does not exhibit the same phenotype characteristics under all environments and different genotypes respond differently to a particular environment. This genotype × environment interaction is due to the difference in response of a genotype to a given change or changes in the additive environment. Thus for having an unbiased estimate of genetic variance, the population needs to be studied under different environmental conditions. Most of the literature reported on genotype × environment interactions refers to the differential response of a genotype in a set of environments. However, the G × E interactions, in some cases may also include components like additive × environment and non-additive × environment interactions. Varietal adaptability to environmental fluctuations is important for the stabilization of crop production both over regions and years. Adaptability is the ability of a genotype to produce a relatively narrow range of phenotypes in different environments. This interaction is a result of changes in cultivar's relative performance across environments due to differential responses of the genotype to various edaphic, climatic and biotic factors (Dixon and Nukenine, 1997) [4].

Therefore, the analysis of genotype x environment interaction becomes an important tool employed by breeders for evaluating varietal adaptation. The estimates of genetic parameters obtained in one environment are biased due to the confounding of the G × E interaction effect with the genotype effects. It is therefore, necessary to take into account the G × E interaction while determining the estimates of various genetic parameters to have unbiased picture in the expression of various characters. Considering these facts, the need of the hour is to develop varieties that would give stable production from year to year and place to place. Therefore, for the development of hybrids/varieties, the information regarding G × E interaction is essential to determine the adaptability of different hybrids under different environments. The present study was carried out to examine G × E interactions for grain yield and other quantitative characters in pearl millet.

Materials and Methods

Four Male Sterile lines (Female) and nine genetically diverse restorer lines (Male pollinator) of pearl millet [*Pennisetum glaucum* (L.) R. Br.] crossed into Line × Tester design to develop 36 hybrids during *Kharif*, 2017 at Bajra Section, Dept. of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. These 36 F_1 hybrids along with 13 parents and two standard checks namely, HHB-299 and HHB-67 Improved were evaluated in RBD with three replications during *Kharif*, 2018 at two different locations creating three environments *i.e.*, Bajra Section, Dept. of Genetics and Plant Breeding, CCS HAU, Hisar (E_1), Dryland Agriculture, CCS HAU, Hisar (E_2) and Regional Research Station, CCS HAU, Bawal (E_3). Observations were recorded on 12 characters *viz.*, days to 50 percent flowering, days to maturity, plant height, panicle length, panicle diameter, number of total tillers per plant, number of effective tillers per plant, panicle weight, grain yield per plant, 1000 seed weight, biological yield per plant and harvest index. The stability model proposed by Eberhart and Russell (1966) [5] was used to estimate stability parameters for grain yield per plant. This model provides regression indices (b values) and mean square for deviation from regression minus pooled error (S^2d_i) as indices of a stable genotype. The stable hybrids will be those having high mean yield higher than the average yield of all the genotypes under test, regression coefficient of unity and deviation from regression equal to zero. Pooled error was obtained by averaging the error mean squares from the analysis of variance of individual environments and dividing by the number of replications. The significance of mean squares was tested against the pooled error. For testing significance of mean values; Least Significant Difference (LSD) was computed by using the pooled error. The t-test based on the standard error of regression value was used to test significant deviation from 1.0. To determine whether deviation from regression were significantly different from zero, the F-test was employed *i.e.*, comparing the mean square due to deviation from regression with pooled error.

Results and Discussion

The pooled analysis of variance for yield and other quantitative characters over three environments revealed that the mean sum of squares due to genotypes were found to be significant for all the characters and that due to environments were significant for all the characters when tested against the mean sum of squares due to genotype × environment (Table 1). The mean sum of squares due to genotype × environment was tested against mean sum of squares due to pooled error, found significant for all the characters and as such stability analysis was carried out on these characters. The variance due to genotype × environment were divided into three components *viz.*, variance due to genotype × environment (linear) and that due to pooled deviation (non-linear), revealed that linear component of genotype × environment interaction, as well as the non-linear component when tested against pooled error, were significant for all characters studied. Significant variance for environment (linear) for all the characters suggests the distinct nature of various environments. This distinct behaviour of various environments was further supported by the wide-ranging environmental indices obtained for all the quantitative characters. The significance of variance for environmental (linear) component also implies that there is a linear variation among the environments which signifies a unit change in environment index with each unit change in environmental mean.

Significant variance for genotype × environment interaction (linear) for plant height, panicle weight, grain yield per plant, biological yield per plant and harvest index indicates that the genotypes performed differentially under diverse environments but with considerably varying reaction norms *i.e.*, the linear sensitivity of different genotypes is variable. This shows the existence of significant differences for the regression coefficient of genotypic means on the environmental index and this variation in performance of genotypes, when grown over environments, could be predicted for the concerned characters.

Mean squares due to pooled deviation were significant for all the characters except days to maturity, number of total tillers per plant, number of productive tillers per plant and 1000 seed weight indicating the fluctuation in the performance of the genotypes from their respective linear path of response to the environment. This implies that part of the variation obtained is due to unpredictable cause. This also reflects the considerable genetic diversity in the experimental material and it is likely that the environments used for the study differed in several physical parameters, resulting in the differential response of genotypes to different environmental conditions. Therefore, the stability of individual genotype must be assessed on the basis of both linear and non-linear components of genotype × environment interaction (Acharya and Sharma. 1985) [1].

A stable genotype is one which shows (i) high mean (ii) regression coefficient (b_i=1) equal to unity and (iii) a mean square deviation from regression (S^2_{di}) near to zero according to Eberhart and Russell (1966) [5]. In interpreting the results of the present investigation, S^2d_i was considered as the measure of stability as suggested by Breese (1969) [3]. The estimates of the stability parameters *viz.*, mean (μ), regression coefficient (b_i) and deviation from regression (S^2d_i) of the parents and their hybrids for various characters.

The number of stable genotypes identified for various traits studied along with the number of stable genotypes with high or desirable mean and their categorization as widely adaptable or suitable for only favourable or poor environments, based on the regression coefficient, $b_i$value, is presented in Table 2. The results revealed maximum number of stable genotypes (51) for 1000 seed weight and minimum for panicle weight (31). Further, genotypes with value greater than the general mean and non-significant deviation from regression were higher for days to maturity (21) and minimum for days to 50 per cent flowering and number of total tillers per plant (4). The study also revealed greater number of genotypes with wider adaptability across environments for various traits studied, compared to genotypes adapted to specific environment (poor / favourable). Four hybrids ($81A_1$ × AC 04/13, $81A_4$ × 77/29-2, $81A_4$ × HTP 92/35 and $81A_4$ × H 90/4-5) had shown b_i around unity and hence, were noticed to be early flowering, stable and widely adaptable over environments for the trait. Similarly, 14 hybrids ($81A_1$ × AC 04/13, $81A_1$ × 77/29-2, $81A_1$ × H 90/4-5, $81A_1$ × H1305, $81A_4$ × 77/29-2, $81A_4$ × H 90/4-5, $81A_4$ × 99 HS-23, $81A_4$ × A_5RL-10-203, $81A_5$ × AC 04/13, $81A_5$ × H 90/4-5, $81A_5$ × A_4RL/13-119, $81A_5$ × H1305, ICMA 04888 × 77/29-2 and ICMA 04888 × A_5R-08-108) were noticed to possess high panicle weight in addition to wide adaptability across the environments studied. While, nine hybrids ($81A_1$ × A_4RL/13-119, $81A_1$ × H1305, $81A_4$ × A_5RL-10-203, $81A_5$ × AC 04/13, $81A_5$ × A_4RL/13-119, $81A_5$ × H1305, $81A_5$ × A_5R-08-108, ICMA 04888 × A_5RL-10-203 and ICMA 04888 × A_5R-08-108) were noticed to possess high grain yield per plant in addition to wide adaptability across the environments studied.

None of the hybrids was found to be stable for all the characters. However, six hybrids *viz*., ICMA 04888 × A_5R-08-108, $81A_1$× H 1305, $81A_5$ × A_4RL/13-119, $81A_5$ × H 1305, $81A_4$ × A_5RL-10-203 and $81A_5$ × AC 04/13 expressed stability for panicle weight and grain yield per plant (Table 3). These hybrids showed stability for some other quantitative characters also. The hybrid, ICMA 04888 × A_5R-08-108 showed stability for characters *viz*., days to maturity, plant height, panicle length, panicle diameter, number of total tillers per plant, number of effective tillers per plant, panicle weight and 1000 seed weight and hybrid $81A_5$ × A_4RL/13-119 showed stability for some other quantitative characters *viz*., days to maturity, plant height, number of total tillers per plant, number of effective tillers per plant, 1000 seed weight, biological yield per plant and harvest index. Similarly, characters like days to 50 per cent flowering and panicle length had high mean, regression coefficient less than one (b_i<1) and non-significant deviation from regression suggests that the cross had above average stability and suitability to unfavourable environments. Further, the hybrids $81A_1$ × H 1305, $81A_5$ × H 1305, $81A_4$ × A_5RL-10-203 and $81A_5$ × AC 04/13 revealed stability for days to maturity, plant height, panicle length, number of tillers per plant, number of effective tillers per plant and harvest index. In general, it was observed that the hybrids which showed stability for grain yield plant per plant showed stability for days to maturity, plant height, number of total tillers per plant, number of effective tillers per plant, panicle weight, 1000 seed weight and harvest index. These were found stable across the environment with higher mean values, regression coefficient around unity (b_i=1) and non-significantly deviation from regression. It was observed that the hybrids with wider adaptability across the environments. Bhuri *et al.* (2015) [2] reported stability of hybrids cross the environments for days to 50 per cent flowering, days to maturity, plant height, panicle length, panicle diameter, number of effective tillers per plant, 1000 seed weight, biological yield per plant and harvest index; Munawwar *et al.* (2007) [8] for days to 50 per cent flowering, plant height and grain yield per plant; Ishaq and Meseka (2014) for days to 50 per cent flowering, plant height, panicle length, number of effective tillers per plant, panicle weight, grain yield per plant and 1000 seed weight; Sumathi *et al.* (2017) for days to 50 per cent flowering, plant height, panicle length, panicle diameter, number of effective tillers per plant and grain yield per plant; Lagat *et al.* (2018) [7] for plant height, panicle length, panicle diameter, number of total tillers per plant, number of effective tillers per plant, panicle weight, grain yield per plant and 1000 seed weight.

From the above discussion, among the hybrids studied *viz*., ICMA 04888 × A_5R-08-108, $81A_1$ × H 1305, $81A_5$ × A_4RL/13-119, $81A_5$ × H 1305, $81A_4$× A_5RL-10-203 and $81A_5$ × AC 04/13 recorded high grain yield per plant and were found to be stable over the different environments are presented in (Table 3), which could be used in the breeding programme for the development of high yielding stable genotypes over environments for future use.

Table 1: Analysis of variance for phenotypic stability of parents and hybrids for yield and other quantitative characters in pearl millet

Source of variation	Degrees of freedom	Mean sum of squares											
		Days to 50% flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Panicle diameter (mm)	No. of total tillers per plant	No. of effective tillers per plant	Panicle weight (g)	Grain yield per plant (g)	1000 seed weight (g)	Biological yield per plant (g)	Harvest index (%)
Genotypes	50	47.70**	28.78**	2088.50**	28.43**	32.05**	0.77**	0.65**	490.09**	216.56**	7.47**	2647.82**	38.60**
Environment	2	60.87**	127.52**	44720.23**	66.79**	188.28**	2.07*	1.44*	14104.76**	9424.87**	6.32**	61084.71**	664.43**
Genotype × Environment	100	6.51**	3.43*	149.83**	4.89*	7.61**	0.72*	0.41*	376.96**	123.22**	0.28*	1056.32**	43.11**
Environment + (Genotype × Environment)	102	7.57	3.90**	1023.76**	6.11	11.15	0.64	0.43	646.13	305.61**	0.16**	2233.35**	55.29*
Environment (Linear)	1	121.73**	255.03**	89440.47**	133.58**	376.56**	4.14**	2.88**	28209.52**	18849.74**	12.63**	122169.43**	1328.86**
Genotype × Environment (Linear)	50	4.07	1.89	190.58*	4.77	5.31	0.70	0.41	311.23**	186.27**	0.04	1,517.21**	50.75**
Pooled Deviation	51	8.76**	0.95	106.95**	4.91**	9.72**	0.52	0.39	434.00**	58.99**	0.04	583.76**	34.77**
Pooled Error	300	4.90	2.34	95.61	3.81	4.07	0.68	0.33	71.64	33.68	0.12	318.96	22.56

Table 2: Distribution of stable genotypes with high on the basis of regression coefficient (b_i)

Parameter	Days to 50% flowering	Days to maturity	Plant height (cm)	Panicle length (cm)	Panicle diameter (mm)	No. of total tillers per plant	No. of effective tillers per plant	Panicle weight (g)	Grain yield per plant (g)	1000 seed weight (g)	Biological yield per plant (g)	Harvest index (%)
Stable genotypes identified ($\overline{S^2 d_i}$ =0)	43	50	48	46	46	48	48	31	46	51	44	46
Genotypes with high mean and stability	25	31	27	26	19	25	24	14	26	25	22	25
High mean, stability and wide adaptability (b_i=1)	4	21	18	11	14	4	5	14	9	18	12	10
High mean, stability and suitable for favourable environment (b_i>1)	0	9	9	6	0	7	7	0	12	4	7	5
High mean, stability and suitable for poor environment (b_i<1)	21	1	0	9	5	14	12	0	5	3	3	10

Table 3: Details of promising and stable pearl millet hybrids identified for cultivation over environments

S. No	Grain yield per plant	Mean	b_i	S^2d_i	Other stable characters observed
1.	ICMA 04888 × A_5R-08-108	49.22	1.18	90.98	Days to maturity, plant height (cm), panicle length (cm), panicle diameter (mm), number of total tillers per plant, number of effective tillers per plant, panicle weight (g) and 1000 seed weight (g)
2.	81A_1× H 1305	39.00	1.16	22.18	Days to maturity, panicle weight (g) and harvest index (%)
3.	81A_5× A_4RL/13-119	38.26	1.14	27.18	Days to maturity, plant height (cm), number of total tillers per plant, number of effective tillers per plant, panicle weight (g), 1000 seed weight (g), biological yield per plant (g) and harvest index (%)
4.	81A_5× H 1305	37.89	1.24	84.46	Days to maturity, plant height (cm), panicle weight (g), 1000 seed weight (g), biological yield per plant (g) and harvest index (%)
5.	81A_4 × A_5RL-10-203	36.15	0.78	-7.97	Days to maturity, plant height (cm), panicle weight (g), 1000 seed weight (g) and biological yield per plant (g)
6.	81A_5× AC 04/13	35.11	0.71	28.15	Days to maturity, plant height (cm) and panicle weight (g)

Conclusion

All the genotypes interacted with the environments differently for different characters, but some of the genotypes were identified as stable for various characters studied. The most important quantitative character *i.e.*, grain yield per plant, showed stability for a few of the hybrids, which was cumulative effect of all contributing characters. However, the present study was confined to one season, over three locations and to get more realistic information on stability, the identified promising hybrids are to be tested extensively under different agro-climatic zones and over the seasons for their superiority and stability before recommending for commercial release in arid regions of Haryana.

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