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Genetic Analysis of Grain Yield and its Components in Pearl Millet

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The genetic analysis was carried out to determine mode of inheritance of yield and its contributing trait under two environments in irrigated and rainfed conditions. The study was undertaken with the help of six generations P_1, P_2, F_1, F_2, B_1, and B_2 in three crosses, viz, 863B x P 7-7 (1), 843B x P 7-4 (2), and 81B x ICMP 451 (3) of pearl millet in two environments Varanasi (Irrigated) (E_1) and Mirzapur (Rainfed) (E_2) using six generations. Simple additive-dominance model failed to explain the genetic variation of most of the characters. The estimates for mean and dominance were reduced in Rainfed environment of Mirzapur, though all type of digenic interactions were prevalent, the dominance x dominance gene effects with duplicate epistasis were pronounced. It is suggested that cyclic breeding particularly reciprocal recurrent selections should be practised to improve yield and its attribute traits in Pearl millet rather than going only for simple selections methods.

Keywords: Pearl millet, Rainfed, Irrigated, Generation Mean Analysis, Genetics.

Pearl millet (*Pennisetum typhoides* (Burn) Stapf and C.E. Hubbard) is one of the important crops of semi-arid tropical regions of Asia, Africa, and America supplying food and fodder under the most trying farming conditions. It is particularly adaptable to nutrient-poor soil and low rainfed conditions, yet it is capable of rapid and vigour growth under favourable conditions (Maiti and Bidinger, 1981). This is crop is grown primarily for grain production on 26 million ha in the arid tropical region of Asia and Africa (Rai *et al.* 2007) but in USA and Europe, it is mainly grown as fodder crop (Poehlman and Borthakur, 1969). In India, it is cultivated in 7.95 million hectare with an annual production of 8.80 million tonnes (Annual Report of Government of India, Ministry of Agriculture, 2013-14). Nevertheless, not only the productivity remained low (11.38 q/ha) but also there are wide year to year fluctuations in terms of production and productivity. Therefore, yield improvement of varieties particularly under rainfed situation is of paramount importance. Genetic variability for yield and its component traits is the key component of the breeding programme for broadening gene pool of crops. However, genetic variability for many traits is limited in germplasm (Sabu *et al.* 2009). The overall performance of a genotype may vary due to changes in the environment, and if the heritability for the traits is higher, the selection process will be simpler and response to selection will be greater (Govindaraj *et al.* 2010; Larik *et al.* 1997 & 2000; Singh and Sagar 1989 & 2001; Soomro *et al.* 2008).

The genetic improvement of crops for quantitative traits requires reliable estimates of genetic variability, heritability and genetic advancement of breeding materials (Dudely and Moll, 1969; Izge *et al.* 2006; Chand *et al.* 2008; Govindaraj *et al.* 2010). The information on variability and heritability of characters is essential

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for identifying characters amenable to genetic improvement through selection (Govindaraj *et al.* 2010). In the present study attempt has been made to study the genetics of important quantitative characters including yield using generation mean analysis. The generations mean analysis is one of the important methods to understand the nature and magnitude of genetic variance.The gene effects, variability parameters, heritability and genetic advance for yield and its important attributing traits have been estimated and results discussed.

MATERIALS AND METHODS

The study was conducted involving six generations viz, P_1, P_2, F_1, F_2, B_1 and B_2 of three Pearl Millet crosses viz., 863B x P 7-7 (1), 843B x P 7-4 (2), and 81B x ICMP 451 (3) at two locations. The parents of the crosses were stable inbreds with good genetic-agronomic base and combining ability. The six generations of each cross were grown in randomized complete block design with three replications at two locations. The two locations were Agriculture Research Farm of Banaras Hindu University under irrigated conditions (E_1) and Rajiv Gandhi South Campus under rainfed condition (E_2) during *Kharif* 2011-12. Two rows for each parent (P_1, P_2), three for each of F_1 and backcrosses (B_1, B_2) and eight for F_2, were grown in each replication. The rows were 4 m long with 45 cm row to row and 20 cm plant to plant distance. Observations were recorded on five competitive plants on seven quantitative characters in each row. The means and variances of a population worked out in a replication were used to calculate the weighted mean and variance over the replication. The Joint Scaling Test (Cavalli, 1952) was performed using the weighted least squares. The estimates of various genetic parameter was obtained by Jinks and Jones (1958) model. The estimates of the components of genetic variance were obtained following Mather (1949). Heritability and Genetic Advance were estimated according to Allard (1960).

RESULTS AND DISCUSSION

The mean values for seven quantitative characters of six generations of the three crosses 863B x P 7-7 (1), 843B x P 7-4 (2), and 81B x ICMP 451 (3) in two environments, Agriculture Research Farm of Banaras Hindu University under irrigated conditions (E_1) and Rajiv Gandhi South Campus under rainfed condition (E_2) are presented in Table 1. In general, the performance of the three crosses of various characters over different generations was better in Varanasi ($E_{1)}$ than in Mirzapur ($E_{2)}$. The poor performance in Mirzapur ($E_{2)}$ was mainly due to poor fertility and low water holding capacity of the soil. All these characters exhibited reduced expression under water stress; however, this was less for such characters as plant height and ear length. These observations confirm earlier findings of Govindaraj *et al.* (2010); Van Oosterom *et al.* (2006); Singh and Sagar (1989 & 2001); Soomro *et al.* (2008). The F_1s of all the crosses performed better than both the parents and mid-parents in both the environments for all the characters, except for days to maturity in crosses 843B x P 7-4 and 81B x ICMP 451 in Varanasi. This indicated prevalence of heterobeltosis, which could arise due to true over-dominance or dispersion of completely or incompletely dominant genes. Negative heterosis for days to maturity indicated dominance for earliness. Higher heterosis in case of pearl millet, an allogamous species, is expected. Virk (1986) has noted positive heterosis for quantitative characters including grain yield (-56.62 to 424.16%), but negative heterosis for days to flowering. The better performance of F_1 than both the parents for grain yield and other attributes even under moisture stress shows that hybrids will withstand moisture stress. The F_2 means, lesser than the F_1 in both the environments for all the characters and crosses except for ear length for cross 843B x P 7-4 in Varanasi indicated high amount of inbreeding depression. Smaller F_2 mean than F_1 could be due to elimination of dominance effects, as in all the crosses the dominant exceeded the additive component and may be responsible for bringing reduction in F_2 mean. The F_2 mean exceeding all other generations for ear length could be due to transgression and fixable epistatic effects. Both the backcrosses exceeded the respective recurrent parents in most of the cases, indicating the prevalence of allelic and non-allelic interactions for genetic control of important traits in pearl millet. Govindaraj *et al.* (2010); Gupta and Phul (1981); Girgla *et al*. (1985); Singh and Sagar (2001) also reported similar results.

To study the genetics and gene interactions, the data was subjected to three parameter model of Cavalli (1952) and later six parameter model of Jinks and Jones (1958). The estimates of six parameter model along with their significance have been presented in Table 2. The analysis revealed the inadequacy of additive-dominance model for all the seven traits studied. Some of the traits such as ear weight and grain yield per plant for cross 843B x P 7-4 indicated significant X^2 values. This analysis lead to the conclusion that variability present in the material could not be ascribed to only additive and

Table. 1: Mean performance of six generations of seven quantitative traits in two environments.

Cross	Generation	Environment	Plant Ht(cm)	Tillers /Plant	EarSize	Days to mat	Ear weight	Grain Yield	Dry yield	fodder
1	2	3	4	5	6	7	8	9	10	
Cross1										
	863B (P_1)	E1	181.0	1.99	18.8	74.5	27.6	12.9	75.1	
		E2	106.7	1.57	15.3	68.5	11.5	8.5	15.5	
	P7-7(P_2)	E1	200.3	2.30	20.1	71.7	26.2	13.5	77.8	
		E2	128.8	1.66	17.9	55.5	14.5	6.7	14.5	
	F_1	E1	216.6	2.83	21.5	75.6	56.5	31.9	96.3	
		E2	155.1	2.01	20.4	55.7	13.3	10.7	17.5	
	B_1	E1	213.3	2.60	20.8	68.6	47.6	27.0	85.1	
		E2	148.7	2.35	21.2	56.7	8.6	4.4	19.9	
	B_2	E1	174.9	2.27	23.2	70.9	48.3	28.6	87.0	
		E2	137.4	1.69	20.1	54.9	15.8	6.1	12.6	
1	2	3	4	5	6	7	8	9	10	
Cross 2										
	843B (P1)	E1	190.0	2.36	15.1	67.0	41.4	20.9	34.5	
		E2	130.8	1.20	14.1	61.0	5.5	3.4	7.5	
	P7-4(P2)	E1	199.3	2.44	17.1	70.7	50.5	38.8	94.4	
		E2	127.9	2.11	16.1	69.0	7.5	7.3	10.8	
	F1	E1	230.2	3.71	21.6	70.5	91.5	60.4	99.6	
		E2	166.9	3.11	15.7	69.5	10.4	6.5	11.4	
	F2	E1	220.3	3.62	25.3	71.1	44.8	22.3	69.0	
		E2	150.3	1.40	14.3	61.5	5.8	4.4	9.1	
	B1	E1	230.3	3.91	19.1	71.8	47.0	25.6	80.3	
		E2	150.0	1.85	15.7	69.1	7.1	6.0	11.6	
	B2	E1	221.3	3.90	20.3	71.1	60.1	25.3	87.1	
		E2	161.5	1.61	16.8	72.5	6.8	5.6	11.0	
1	2	3	4	5	6	7	8	9	10	
Cross 3										
	81B (P1)	E1	165.7	2.07	15.3	78.9	26.5	14.4	80.6	
		E2	103.1	1.03	11.6	67.1	4.4	3.3	6.	
	ICMP 451(P2)	E1	197.7	3.65	17.9	81.8	28.2	50.7	90.3	
		E2	157.4	1.60	14.2	76.1	4.1	3.2	7.5	
	F1	E1	242.7	4.23	21.7	81.9	61.0	37.7	107.5	
		E2	156.5	3.23	18.8	71.5	6.7	5.7	18.9	
	F2	E1	217.5	2.25	17.4	78.7	53.6	27.6	69.3	
		E2	135.4	1.75	19.7	71.5	7.5	6.3	8.8	
	B1	E1	213.5	2.58	16.3	79.5	54.5	24.2	111.1	
		E2	131.6	1.79	19.5	67.6	7.6	4.7	12.4	
	B2	E1	232.5	3.90	21.8	80.3	52.2	25.1	80.8	
		E2	151.5	2.18	17.9	79.5	7.6	8.4	21.4	

Table. 2: Gene effect of six-parameter model for seven yield and component traits of Pearl Millet in two environments

Character	Cross	Environment	M	D	H	I	J	L	Type of Epistasis
1	2	3	4	5	6	7	8	9	10
	1	E_1	152.09	6.33**	58.51**	40.90**	80.56**	7.1	
			6.96	±0.99	±16.57	±6.88	±4.33	±10.18	
		E_2	120.86	10.53**	58.01**	-3.6	41.63**	-28.81	
			±10.12	±1.42	±24.28	±10.13	±6.28	±14.86	
Plant Height	**2**	E_1	180.13	1.13	112.47**	21.00**	21.25**	-61.45**	D
			±9.62	0.94	±21.38	±8.57	±6.30	±11.49	
		E_2	108.44	4.53**	121.79**	17.90**	-1.64	-65.30**	D
			±3.79	±0.33	±8.90	±3.78	±2.13	±5.43	
	3	E_1	157.59	12.50*	148.64**	31.58**	-23.66**	-53.56**	D
			±7.92	±0.96	±18.63	±7.86	±4.55	±11.19	
		E_2	85.02	14.53	129.72	39.64	3.07	-57.35**	D
			±8.68	±0.68	±20.84	±7.64	±4.27	±12.09	
	1	E_1	3.34	0.23	-2.03	-1.34	1.14*	1.52	
			±0.73	±0.15	±1.87	±0.71	±0.58	±1.21	
		E_2	0.06	0.07	4.44	1.38	1.87**	1.82	
			±0.73	±0.15	±2.93	±1.25	±0.67	±1.72	
Number of effective tillers per plant	**2**	E_1	2.52	0.14	3.26	-0.22	-0.87	-2.21	
			±0.85	±0.13	±2.00	±0.84	±0.41	±1.26	
		E_2	0.37	-0.47**	1.43	1.3	1.43**	1.35	
			±1.11	±0.09	±2.64	±1.11	±0.64	±1.67	
	3	E_1	-2.22	0.80**	10.53**	5.02**	-1.1	-4.18	D
			±0.93	±0.14	±2.23	±0.92	±0.59	±1.38	
		E_2	-0.87	0.23	5.11	1.34	-0.41	-1.21	
			1.19	±0.14	±2.75	±1.18	±0.66	±1.67	
	1	E_1	16.68	1.17**	12.69**	2.21*	-2.72	-7.51**	D
			±1.02	±0.15	±2.54	±1.01	±0.72	±1.62	
		E_2	7.31	0.80**	26.19**	8.12	3.78**	-7.1	D
			±1.64	±0.21	±3.91	±1.72	±1.00	±2.46	
Ear length	**2**	E_1	16.45	1.90**	10.92**	2.78	3.13**	-4.43**	D
			±1.26	±0.20	±2.98	±1.24	±0.79	±1.75	
		E_2	3.58	1.27**	27.67**	12.21**	0.41	-12.53	D
			±1.82	±0.20	±4.21	±1.81	±0.99	±2.55	
	3	E_1	12.99	1.30**	13.82**	2.23	-4.03**	-6.11**	D
			±1.38	±0.17	±3.27	±1.32	±0.81	±2.21	
		E_2	13.84	1.30**	17.36**	0.06	1.84	-11.41	D
			±1.99	±0.24	±4.76	±1.97	±1.22	±3.06	
	1	E_1	109.09	1.64	-84.78**	-39.36**	-1.43*	50.15**	D
			±0.85	±0.16	±2.03	±0.84	±0.56	±1.27	
Days to maturity	**2**	E_1	66.12	2.34	11.65**	2.22**	5.25**	-7.23**	D
			±0.85	±0.98	±2.30	±0.97	±0.57	±1.40	
	3	E_1	71.47	1.47**	18.40**	8.17**	2.51	-7.97**	D
			±1.44	±0.26	±0.26	±1.42	±0.94	±2.13	
1	2	3	4	5	6	7	8	9	10
	1	E_1	31.75	0.14	30.48**	-3.61	-4.97*	13.51**	C
			±3.50	±0.64	±8.38	1.44	±2.30	±5.28	
Ear weight per plant		E_2	10.63	0.87*	-8.25	-1.81	1.33	10.41**	
			±1.97	±0.27	±4.59	±1.95	±1.13	±3.28	
	2	E_1	11.43	3.03**	45.44**	34.06**	-24.44**	39.11**	C

			±7.31	±0.96	±17.45	±7.11	±4.22	±10.11	
		E_2	4.94	0.93**	-3.22	1.66	2.33	8.44**	
			±2.25	±0.30	±5.29	±2.23	±1.22	±3.26	
	3	E_1	36.95	0.34	38.67**	-9.27	-5.34	-9.21	
			±5.69	±0.49	±13.11	±4.67	±3.11	±6.27	
	1	E_1	20.37	0.3	15.26	-7.20**	-6.60**	2.24	
			±3.47	±0.60	±8.36	±3.42	±2.30	±5.23	
Grain yield		E_2	6.32	0.54**	-6.99*	-1.26	-0.39	9.11**	D
per plant			±1.45	±0.23	±3.43	±1.43	±0.78	±2.20	
	2	E_1	11.88	3.00**	-12.06	12.22	6.51	59.31**	
			±7.04	±0.94	±16.42	±6.98	±4.08	±9.86	
	3	E_1	27.13	0.5	-1.86	-10.96**	-2.08	7.27	
			±3.38	±0.33	±8.05	±3.36	±2.11	±4.87	
	1	E_1	15.29	0.83	114.30*	61.66**	5.83	-23.27	
			±9.18	±1.36	21.61	±9.08	±5.53	±13.36	
		E_2	5.64	0.43	50.77**	16.54**	17.40**	-32.66**	D
Dry fodder yield per plant			±6.47	±1.07	±15.40	±6.38	±4.12	±9.51	
	2	E_1	30.43	5.44**	77.24	59.54**	-1.79	-0.07	
			±26.10	±1.83	±60.63	-26.03	14.1	±35.71	
		E_2	4.07	1.07**	37.15**	12.80**	-4.71*	-21.68**	D
			±3.76	±0.33	±8.90	±3.78	±2.13	±5.43	
	3	E_1	-8.24	4.33**	161.38**	89.23**	53.01**	-12.26	
			±20.29	±1.10	±47.24	±22.26	±11.92	±22.99	
		E_2	-23.01	1.64**	86.33**	24.11**	-25.65**	-25.17**	D
			±3.17	±0.28	±7.49	±2.24	±1.82	±4.69	

* Significant at 5 per cent level; ** Significant at 1 per cent level; D Duplicate; C Complementary epistasis

dominance effects of the gene effects, albeit the epistatic gene effects also played an important role in genetic control of the characters studied. The present study also revealed that only additive effect was not sufficient and significant to explain the variability for all the traits. Further, significant dominance effects were important for only ear weight per plant for cross 81B x ICMP 451 in Varanasi environment. In general preponderance of dominant variation was observed for all the traits in both the environments and all the three crosses. Similar observations were made in Pearl Millet by Virk (1986); Singh and Sagar (1989); Govindaraj *et al.* (2010). The comparative analysis of simple vs. higher order of gene integrations indicated that while additive effect were less effective than the dominant effects when compared with their corresponding digenic or higher order of integrations. This indicated that the expression of the additive effects was affected at the cost of their digenic interactions. In few cases additive and additive x additive effects was important such as fodder yield in case cross 843B x P 7-4; and 81B x ICMP 451 in Varanasi environment. This suggests that fixable nature of variation could be exploited by simple selection for these specific characters and crosses. Additive x dominance type was the other lone significant digenic integrations for number of effective tillers per plant for cross 863B x P 7-7 in both the environments. The dominance x dominance type of digenic interactions was high and significant in a number of cases. This type of epistasis advocate for searching desirable specific cross combinations. In general additive x additive and additive x dominance integrations were observed for grain yield in cross 863B x P 7-7 in Varanasi environment, while three and four parameter combinations of simple and digenic interactions were found to be significant in a number of cases, but all the five parameters exhibited significance in case of ear weight for the cross 843B x P 7-4 in Varanasi environment. Days to maturity for cross 863B x P 7-7 and 843B x P 7-4 in Varanasi environment, ear length for cross 863B x P 7-7 in Varanasi environment, plant height for crosses 843B x P 7-4 in Mirzapur environment

Table. 3: Estimates of components of genetic variance for 7 characters in pearl millet.

Character	Cross	Additive (D)	Dominance (H)		Epistasis	(E)	
		E_1	E_2	E_1	E_2	E_1	E_2
Plant height	1	57.00	90.50	170.64	370.52	31.02	61.14
	2	199.12	127.46	204.50	545.60	35.12	21.44
	3	90.87	112.05	178.14	313.36	27.28	17.05
Number ofEffectiveTillers/plant	1	1.66	1.76	2.52	1.35	0.50	0.51
	2	1.12	1.18	1.04	4.61	0.58	0.61
	3	0.57	1.12	3.08	4.21	0.61	0.68
Ear length	1	0.74	1.64	2.08	9.76	0.77	1.82
	2	1.82	8.66	3.36	3.08	1.28	1.75
	3	2.10	1.44	6.52	14.60	1.02	3.02
Day toMaturity	1	0.91	1.33	1.76	0.92	0.74	2.22
	2	1.84	1.32	0.76	0.67	0.56	2.23
	3	1.81	1.51	3.52	2.22	1.89	2.32
Ear weightPlant	1	11.74	8.99	16.87	3.82	11.11	2.51
	2	19.64	7.36	238.60	12.36	29.74	3.12
	3	31.02	8.40	153.36	12.08	9.09	2.27
Grain YieldPlant	1	7.24	3.22	37.40	1.36	11.51	2.14
	2	29.72	22.02	175.68	27.04	22.75	2.10
	3	3.33	1.84	61.76	52.96	4.40	2.72
Dry fodderYield/plant	1	126.26	27.68	169.32	110.16	61.28	37.79
	2	455.18	21.88	327.64	48.36	121.43	15.21
	3	622.28	17.38	151.48	35.20	71.80	5.12

Table. 4: Estimates of heritability and genetic variance, for quantitative characters in pearl millet.

Character	Cross	h^2 (BS)		h^2(NS)	Genetic advance (as % of mean)		
		E_1	E_2	E_1	E_2	E_1	E_2
Plant height	1	65.91	71.05	20.88	23.01	4.38	4.71
	2	71.81	85.96	53.41	25.73	6.31	5.39
	3	75.26	90.51	37.10	34.50	3.80	6.30
Number of effective tillers/ plant	1	64.47	85.13	47.82	81.58	48.95	191.36
	2	55.15	71.16	37.72	44.48	26.77	55.13
	3	62.80	70.30	25.85	34.45	21.91	52.28
Ear length	1	52.61	61.15	21.21	17.15	3.47	4.23
	2	54.75	71.45	30.03	63.21	5.19	24.74
	3	44.43	55.13	28.38	9.74	6.12	2.77
Days to maturity	1	44.76	67.43	34.19	37.89	1.01	22.72
	2	71.98	88.72	47.29	65.24	1.97	12.13
	3	52.91	65.32	22.26	43.34	1.20	-20.75
Ear weight/plant	1	45.11	67.42	20.01	57.82	52.34	36.68
	2	63.32	65.45	9.79	36.21	5.50	42.91
	3	81.85	91.08	24.64	43.22	6.50	41.64
Grain yield/plant	1	51.72	55.45	13.04	37.90	3.77	27.69
	2	71.28	81.74	18.04	38.28	15.79	55.24
	3	81.28	82.60	8.69	1.75	3.66	6.24
Dry fodderYield/plant	1	67.27	78.51	35.35	24.79	17.21	35.64
	2	88.35	80.78	20.54	34.76	21.01	47.39
	3	87.28	72.82	41.50	27. 01	35.67	29.07

exhibited siginficance for four parameter. Even the six parameter model failed to detect the significance of any of five genetic parameters for tillers per plant for crosses 843B x P 7-4 and 81B x ICMP 451 in Varanasi Environment and Mirzapur environment, respectively. While the three parameter model was found to be inadequate in both the environments. The discrepancy for the significance of parameters studied in 3 and 6 parameters model may be due to non-orthognaility nature of the estimates in the former model. The present study indicates that dominance and epistatic effects were important in explaining the variability in the present material. The present finding supports the earlier findings of Singh and Sagar (2001) and Singh *et al* (1990a) but contradicts the findings of Grafius (1959). The Grafius observed that non-allelic interactions prevail for yield but not for its components. The digenic and trigenic epistasis and linked digenic integrations have been observed by Gupta and Phul (1981) in Peral millet. The study revealed that characters such as plant height, ear length, ear weight, days to maturity, and dry fodder yield are complex traits as controlled by number of parameters significant in the 3 crosses in two environments. As reported earlier grain yield and tiller number are also complex traits, the significance of only one or two parameters in present materials are probably due to non availability of enough variability for these traits in present genetic materials. The study indicated that dominance (h) and dominance x dominance (l) interactions accounted for high proportions of total genetic variability and even increased under moisture stress conditions in most of the cases. This indicated that hybrids will perform better even under moisture stress conditions. This is in conformity with earlier findings such as, Singh and Sagar (2001); Govindaraj *et al.* (2010). It is suggested that cyclic breeding particularly reciprocal recurrent selections should be practised to improve pearl millet rather than going only for simple selections methods.

The estimates of components of genetics variance viz., additive (D), dominance (H), environmental (E) are given in Table 3. The dominance variance exceeded the additive variance indicating thereby preponderance of dominance gene action for all the characters of all the cross in both the environments except for tillers per plant for crosses 863B x P 7-7 in Mirzapur environment and cross 843B x P 7-4 in Varanasi environment, for ear length for cross 843B x P 7-4 in Mirzapur environment, days to maturity for cross 843B x P 7-4 in Varanasi environment and ear weight for cross 863B x P 7-7 in Mirzapur environment. This concedes the nature of heterobeltiosis observed from the generations mean analysis. The magnitude of dominance gene effects was comparably higher than additive gene effect in 3 as well as 6 parameter model. The preponderance of dominant gene effects in pearl millet has been observed by Singh and Sagar (1989); Virk (1986); Sheoran *et al.* (2000); Govindaraj *et al.* (2010). In general importance of dominance effect was observed in the present materials except in some cases like fodder yield in cross 843B x P 7-4, grain yield in cross 81B x ICMP 451, where additive and additive x additive effects were important and this indicated that variation in these crosses were fixable nature and simple selection can improve these characters of particular crosses

The heritability values broad and narrow sense along with their genetic advance have been presented in Table 4. In general, both the type of heritability was low in Varanasi than in Mirzapur environment. Broad sense heritability estimates were generally high for all the characters for all the three crosses in both the environments. Low narrow sense heritability estimates support the prevalence of epistatic effects as also noted from the generations means. The high estimates of heritability in Mirzapur (rainfed) environment are encouraging and offer greater scope of selection in that environment, but further studies are necessary in this direction. The high estimates under water stress may be due to either narrowing down of the variance under stress, as is usually observed and has been reported by Johnson and Frey (1967); Moeljopaviro and Ikehashi (1981); Govindaraj *et al.* (2010); Larik *et al.* (1997 & 2000); Singh and Sagar (1989 & 2001); Soomro *et al.* (2008). Estimates of expected genetic advance expressed as percentage of mean were low to medium for all the characters including grain yield. But very high gain was obtained for number of effective tillers (191.36%) for cross 863B x P7-7 and high estimates for gain yield (55.24%) for cross 843B x P7-4 in Mirzapur environment. It suggested greater scope for improvement of these characters.

In general the study suggest that the sufficient variability exist in the present pearl millet breeding materials with preponderance of dominant simple and higher order of gene action effects (dominance x dominance and dominance x additive) with high heritability of important traits. This suggest cyclic breeding with reciprocal recurrent selections should be adopted to improve pearl millet rather than going only for simple selections methods.

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