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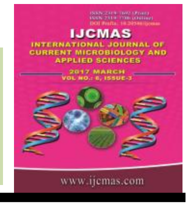

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Estimation of Heterosis for Grain Yield and Yield Components in Pearl Millet (*Pennisetum glaucum* (L.) R. Br.)

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An experiment comprised of six male sterile lines, eight inbred testers of pearl millet, their 48 hybrids and two standard check (GHB-538 and GHB-558) was conducted at Regional Research Station, Anand Agricultural University, Anand, Gujarat in Kharif 2014 for studying the extent of hybrid vigour in F1 for grain yield and its components. The cross JMSA-9904 x AIB-15 showed highest and significant standard heterosis for total effective tillers, ear head girth, grain yield per plant and panicle harvest index. Among 48 hybrids studied, three hybrids namely JMSA-9904 x AIB-15, JMSA-9904 x AIB-30 and ICMA99555 x AIB-30 selected as best crosses since they expressed high standard heterosis over standard hybrid for many of the traits studied for high grain yield**.**

Introduction

Pearl millet (*Pennisetum glaucam* (L.) R. Br., 2n=2x=14, Family: Poaceae) is warm season, annual, C_4 a highly cross-pollinated crop with the advantages of huge genetic variability and availability of efficient cytoplasmic genetic male sterility system. 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 India, it is mainly cultivated in Rajasthan, Uttar Pradesh, Gujarat, Haryana and Maharashtra, which shares about 91.87 per cent of total pearl millet production. Pearl millet occupies an area of 7.20 million hectares with a production of 8.74 million tones and productivity of 1214 kg ha^{-1} in the country. While, in Gujarat, it is grown in 1.07 million hectares with a production of 1.23 million tones and productivity of 1226 kg ha^{-1} (Anonymous, 2010).

Exploitation of hybrid vigour is considered to be one of the outstanding achievements in this crop. In heterosis breeding program, it is essential to study and evaluate available promising diverse parental lines for their hybrids nicking ability for grain yield and its components. Recognition of a potential hybrid combination through the magnitude and direction of heterotic effects is of paramount importance.

Materials and Methods

Present study involving six CGMS inbred lines *viz* JMSA 9904, JMSA-101, ICMA-08111, ICMA-92777, ICMA-96333 and ICMA-99555,obtained from Main Pearl Millet Research Station, Jamnagar, eight restorer pollinators *viz*. AIB-6, AIB-10, AIB-14, AIB-15, AIB-17, AIB-20, AIB-28 and AIB-30; developed at Regional Research Station, AAU, Anand and two standard check hybrids GHB-538 and GHB-558. The parental lines and testers were crossed in line x tester mating design during summer 2014, and evaluated in randomized complete block design at the Regional Research Station, Anand Agricultural University, Anand during *kharif* 2014.

Five competitive plants from each experimental unit of every replication were selected randomly for recording observations on component characters *viz.*, Days to 50 % flowering, days to physiological maturity, plant height(cm) ,number of total tiller per plant, number of effective tillers per plant, ear head length(cm), ear head girth(cm), ear head weight(g), grain yield per plant, test weight (g) ,panicle harvest index and protein content (%). Protein estimation was done with Near Infrared Spectrophotometer. Panicle harvest index was calculated as:

$$PHI = \frac{\text{Grains yield per plant}}{\text{Earheads weight per plant}} \times 100$$

Analysis of variance was performed to test the significance of difference among the genotypes for the characters studied, as suggested by Panse and Sukhatme, (1957). The expression of heterosis in 48 hybrids involving six CGMS lines and eight testers was measured in terms of heterobeltiosis in relation to better parent and standard heterosis in comparison with standard check GHB-538 and GHB-558.

Results and Discussion

Analysis of variance

The analysis of variance for yield and its components traits in RCBD revealed that the mean square values due to genotypes were highly significant for all the characters, which indicated existence of sufficient genetic variability in the experimental material for all the characters (Table 1).

Mean values of grain yield and yield component characters of parents (lines and testers) and their hybrids is presented in table 2. The range of heterobelteiosis and standard heterosis as well as number of hybrids showing significant heterosis in desirable direction is presented in table 3.

Estimation of HB and SH

Heterobeltiosis (HB) and standard heterosis (SH) in negative direction for days to 50% flowering are desirable for earliness. The hybrid JMSA-101 x AIB-20 (-13.16%) exhibited the least estimate of HB followed by hybrids JMSA-9904 x AIB-17 (-12.90%) and ICMA-99555 x AIB-6 (-11.95%). None of the hybrids registered significant and negative SH. The results are in accordance with findings of (Arulselvi *et al*., 2006) and (Patel *et al*., 2016) for Heterobelteiosis and (Dangaria *et al*., 2009) and (Snedecor *et al*., 1967) for SH. Negative estimates of heterobeltiosis (HB) and standard heterosis (SH) for days to physiological maturity of grain are desired. The estimates of HB ranged from -12.50 (ICMA-99555 x AIB-6) to 7.14 per cent (ICMA-08111 x AIB-28). The cross ICMA-99555 x AIB-6 (-12.50%) exhibited the least heterotic effect. only two crosses exhibited significant and negative heterotic effect. The results are in conformity with reports of HB as well as SH. None of the hybrid registered significant and negative heterobelteiosis as well as standard heterois for plant height. The minimum and maximum values for heterobeltiosis were -14.29 (JMSA-101 x AIB-17) and 35.59 (JMSA-9904 x AIB-15) per cent for number of total tiller per plant. Only one hybrid, JMSA-9904 x AIB-20(16.67 %) had significant estimates of SH. For number of effective tillers per plant minimum and maximum values for heterobeltiosis were -27.91 (ICMA-08111 x AIB-28) and 44.13 (JMSA-9904 x AIB-17) per cent, respectively. Only one hybrid ICMA-08111 x AIB-28 (13.94%) was significantly superior over check hybrid GHB-558.The findings are in accordance with reports of (Dangaria *et al*., 2009) for HB, and with (Patel *et al*., 2016) and (Vetriventhan *et al*., 2008) for SH. For ear head length minimum and maximum values of heterobeltiosis were -27.35 (JMSA-101 x AIB-29) to 38.32 (ICMA-08111 x AIB-17) per cent, respectively. Total 37 F_1S had significant estimate of HB of which 27 F_1S registered positive HB. The other F_1S with high HB were ICMA-92777 x AIB-14 (33.82%), ICMA-96333 x AIB-14 (32.93%) and ICMA-08111 x AIB-6 (32.71%).

The estimates of standard heterosis over check hybrid GHB-538 varied from 11.49 (JMSA-9904 x AIB-20) to 64.28 (JMSA-101 x AIB-28) per cent. Total 22 F_1S exhibited significant heterobeltiosis for ear head girth of which 12 F_1S had positive heterotic effect. None of the F_1S exhibited significant positive standard heterosis; whereas 20 F_1S depicted significant and negative standard heterosis over check hybrid GHB-558 for ear head girth. The results are in agreement with the findings of (Patel *et al*., 2008) for HB. For ear heads weight per plant the heterobeltiosis varied from -18.27 (JMSA-101 x AIB-10) to 52.37 (ICMA-08111 x AIB-17) per cent. The estimates of heterosis over standard check hybrid GHB-558, varied from -61.00 (ICMA-08111 x AIB-28) to 19.27 (JMSA 101 x AIB-6) per cent. Out of 13 significant cross, 5 crosses depicted positive estimates of SH. The results are in agreement with the findings of (Vagadiya *et al*., 2010). For grain yield per plant heterobeltiosis, the estimates varied from -22.66 (ICMA-08111 x AIB-10) to 93.78 per cent (JMSA-9904 x AIB-30). Total 30 F_1S depicted significant heterotic effect, of which, 29 had positive estimates. The F_1 JMSA-9904 x AIB-30 (93.78%) exerted the highest heterobeltiosis followed by ICMA-99555 x AIB-30 (88.16%), and JMSA-101 x AIB-28 (75.65%). The estimates of standard heterosis over hybrid GHB-558 varied from -60.30 (ICMA-08111 x AIB-28) to 14.11 (JMSA-9904 x AIB-15) per cent. Out of 22 significant F_1S, only 3 F_1S exhibited significant and positive standard heterosis. The other F_1S with significant and positive SH were JMSA-9904 x AIB-30 (13.75%) and ICMA-99555 x AIB-30 (11.17%). The results are in accordance with findings of (Arulselvi *et al*., 2006; Patel *et al*., 2008, 2016) for HB, as those found positive magnitude of HB, and with reports of Vetriventhan *et al*., (2008), for SH as they found negative magnitude of SH.

For dry fodder yield per plant ,values of heterobeltiosis varied from –47.74 (ICMA-99555 x AIB-20) to 115.40 (JMSA-9904 xAIB-14) per cent, whereas, estimates of standard heterosis varied from -140.34 (ICMA-99555 x AIB-14) to.22.68 (ICMA-96333 x AIB-20) percent. Total 33 hybrids exhibited significant standard heterosis, of which only 10 hybrids exerted positive heterotic effect (Table 4).

The hybrids with high positive standard heterosis were ICMA-96333 x AIB-20(22.68 %), JMSA-9904 x AIB-15 (19.73%) and ICMA-96333 x AIB-15 (19.32%). Crosse ICMA-92777 x AIB-30(104.95 %) had highest estimate of HB for test weight. The estimates of standard heterosis over better check hybrid GHB-558 varied from -56.86 (ICMA-96333 x AIB-30) to 20.40 per cent (ICMA-08111 x AIB-17). For panicle harvest index the values of heterobelteiosis varied from -14.64 (ICMA-08111 x AIB-10) to 47.75 (ICMA-92777 x AIB-30) per cent.

Table.1 Analysis of variance for various characters

Source of variation	**D.F**	**Ear head Girth**	**Ear heads weight per plant**	**Grain yield per plant**	**Dry fodder yield per plant**	**Test weight**	**Panicle harvest index**	**Total protein content**
Replications	2	0.92	89.87	40.65	50.95	0.18	12.37	0.56
Genotypes	63	2.52**	808.47**	493.02**	5976.21**	10.65**	190.08**	2.73**
Parents	13	3.83**	1136.36**	554.79**	5491.63**	4.54**	269.06**	5.27**
Lines	5	2.67**	201.63**	49.85**	291.23*	1.08**	222.36**	5.31**
Testers	7	3.81**	257.48**	100.46**	4880.1**	3.94**	127.59**	4.06**
Lines*vs.*Testers	1	9.51**	11962.10**	62597.97**	35754.36**	26.10**	1491.3**	9.81**
Hybrids	47	1.91**	327.36**	203.56**	4081.38**	5.76**	108.08**	2.24**
Parents *vs.* Hybrids	1	10.46**	20510.02**	13854.6**	111168.5**	319.53**	3156.3**	.004
Checks *vs.* Hybrids	1	1.31**	1.11	2.66	0.001	0.870**	1.57	0.001
Between Checks	1	4.03**	320.03**	105.23***	1060.54**	2.53**	6.36	0.001
Error	126	0.30	45.62	23.41	111.73	0.122	19.88	0.19

Table.2 Mean values of lines, testers and hybrids

Traits	Mean values				
	Lines	Testers	Hybrids	CD at 5%	CV
Days to 50 % flowering	51.56	54.29	50.03	2.43	2.97
Days to maturity	84.22	85.75	84.11	2.80	2.07
Plant height	125.72	178.16	196.69	15.23	5.03
Total number of tillers	3.93	4.33	4.82	0.76	10.16
Total effective tillers per plant	2.14	2.53	2.67	0.49	11.67
Ear head length	21.44	20.77	24.75	1.78	4.65
Ear head girth	7.59	8.56	8.71	0.91	6.25
Ear head weight per plant	29.70	63.80	74.30	9.82	10.94
Grain yield per plant	14.44	39.16	49.20	7.81	10.77
Fodder yield per plant	67.30	159.48	159.48	17.07	7.20
Test weight	6.51	8.10	10.56	0.55	3.45
Panicle harvest index	49.60	61.62	66.30	7.21	6.95
Total protein content	11.21	10.23	10.63	0.69	4.06

Table.3 Range of heterosis and number of crosses showing significant heterosis in desirable direction in pearl millet

Characters	Heterosis % over better parent		Heterosis % over standard check	
	Range	Number of significant crosses	Range	Number of significant Crosses
Days to 50 % flowering	-13.16 to 8.28	22	-3.65 to 24.09	-
Days to maturity	-12.50 to 7.14	14	-4.57 to 12.03	2
Plant height	15.36 to 172.42	-	-7.74 to 30.52	-
Total number of tillers	-14.29 to 35.59	12	15.28 to 16.67	1
Total no of effective tillers	-27.91 to 44.13	7	-27.91 to 13.94	1
Ear head length	-27.35 to 38.52	27	-11.49 to 64.28	26
Ear head girth	-30.05 to 27.80	12	-28.49 to 4.46	-
Ear head weight per plant	-18.27 to 53.37	24	-61.00 to 19.27	5
Grain yield per plant	-22.66 to 93.78	29	-60.30 to 14.11	3
Fodder yield per plant	-47.74 to 115.40	31	-140.30 to 22.68	33
Test weight	-8.55 to 104.95	45	-56.86 to 20.40	15
Panicle harvest index	-14.64 to 47.75	15	-56.41 to 6.92	-
Total protein content	-21.65 to 33.83	9	-14.00 to 19.63	9

Table.4 Top five best heterotic crosses for various characters

Characters	*Per se* performance of hybrids	HB	SH
Days to 50 % flowering	JMSA-101 x AIB-20 JMSA-9904 x AIB-17 ICMA-99555 x AIB-6 JMSA-9904 x AIB-15 JMSA-101 x AIB-28	JMSA-101 x AIB-20 JMSA-9904 x AIB-17 ICMA-99555 x AIB-6 JMSA-9904 x AIB-15 ICMA-99555 x AIB-15	JMSA-101 x AIB-20 JMSA-9904 x AIB-17 ICMA-99555 x AIB-6 JMSA-9904 x AIB-15 JMSA-101 x AIB-28
Days to physiological maturity of grains	JMSA-9904 x AIB-15 JMSA-101 x AIB-20 ICMA-92777 x AIB-6 ICMA-96333 x AIB-6 ICMA-99555 x AIB-17	ICMA-96555 x AIB-6 JMSA-9904 x AIB-15 JMSA-101 x AIB-20 ICMA-92777 x AIB-6 ICMA-96333 x AIB-6	JMSA-101 x AIB-20 JMSA-9904 x AIB-15 ICMA-92777 x AIB-6 ICMA-96333 x AIB-6 ICMA-99555 x AIB-17
Plant height	JMSA-9904 x AIB-6 ICMA-96333 x AIB-28 JMSA-9904 x AIB-20 JMSA-9904 x AIB-28 ICMA-96333 x AIB-6	JMSA-101 x AIB-15 JMSA-9904 x AIB-20 JMSA-9904 x AIB-28 JMSA-101 x AIB-28 JMSA-101 x AIB-28	JMSA-9904 x AIB-6 ICMA-96333 x AIB-28 JMSA-9904 x AIB-20 JMSA-9904 x AIB-28 ICMA-96333 x AIB-6
Number of total tillers per plant	JMSA-9904 x AIB-20 ICMA-08111 x AIB-14 JMSA-9904 x AIB-15 JMSA-101 x AIB-14 ICMA-92777 x AIB-6	JMSA-9904 x AIB-15 ICMA-92777 x AIB-6 JMSA-101 x AIB-14 JMSA-9904 x AIB-6 ICMA-92777 x AIB-14	JMSA9904 x AIB-20 JMSA-9904 x AIB-15 ICMA-92777 x AIB-6 JMSA-101 x AIB-14 ICMA-92777 x AIB-6
Number of effective tillers per plant	JMSA-9904 x AIB-15 JMSA-101 x AIB-20 ICMA-96333 x AIB-28 JMSA-101 x AIB-14 ICMA-92777 x AIB-28	JMSA-9904 x AIB-17 ICMA-96333 xAIB-17 ICMA-08111 x AIB-17 ICMA-92777 x AIB-17 JMSA-9904 x AIB-14	JMSA 9904 x AIB-15 JMSA-101 x AIB-20 ICMA-96333x AIB-28 JMSA-101 x AIB-14 ICMA-92777 x AIB-28

Average internode length	ICMA-96333 x AIB-28 ICMA-96333 x AIB-30 JMSA-9904 x AIB-20 ICMA-92777 x AIB-14 ICMA-99555 x AIB-28	JMSA-101 x AIB-10 ICMA-92777 x AIB-10 ICMA-92777 x AIB-17 ICMA-92777 x AIB-15 JMSA-101 x AIB-20	ICMA-96333 x AIB-28 ICMA-96333 x AIB-30 JMSA-9904 x AIB-20 ICMA-92777 x AIB-14 ICMA-99555 x AIB-28
Earhead length	JMSA-101 x AIB-28 JMSA-101 x AIB-20 JMSA-101x AIB-30 ICMA-08111 x AIB-17 JMSA-101 x AIB-6	ICMA-08111x AIB-17 ICMA-92777 x AIB-14 ICMA-96333 x AIB-14 JMSA-9904 x AIB-15 ICMA-08111x AIB-6	JMSA-101 x AIB-28 JMSA-101 x AIB-20 JMSA-101x AIB-30 ICMA-08111x AIB-17 JMSA-101 x AIB-6
Earhead girth	JMSA-9904 x AIB-15 ICMA-92777 x AIB-14 JMSA-9904 x AIB-30 ICMA-92777 x AIB-30 ICMA-08111 x AIB-6	ICMA-08111 x AIB-6 ICMA-92777 x AIB-14 ICMA-96333 x AIB-6 ICMA-92777 x AIB-17 ICMA-92777 x AIB-30	JMSA-9904 x AIB-15 ICMA-92777 x AIB-14 JMSA-9904 x AIB-30 ICMA-92777 x AIB-30 ICMA-08111 x AIB-6
Ear heads weight per plant	JMSA-101 x AIB-6 ICMA-99555 x AIB-30 ICMA-08111 x AIB-17 JMSA-9904 x AIB-15 JMSA-101 x AIB-28	ICMA-08111 x AIB-17 JMSA-9904 x AIB-15 JMSA-101 x AIB-28 JMSA-101 x AIB-6 ICMA-96333 x AIB-15	JMSA-101 x AIB-6 ICMA-99555 x AIB-30 ICMA-08111 x AIB-17 JMSA-9904 x AIB-15 JMSA-101 x AIB-28
Grain yield per plant	JMSA-9904 x AIB-15 JMSA-9904x AIB-30 ICMA-99555 x AIB-30 JMSA-101 x AIB-28 ICMA-08111 x AIB-17	JMSA-9904 x AIB-30 ICMA-99555 x AIB-30 JMSA-101 x AIB-28 JMSA-101 x AIB-30 ICMA-92777 x AIB-30	JMSA-9904 x AIB-15 JMSA-9904x AIB-30 ICMA-99555 x AIB-30 JMSA-101 x AIB-28 ICMA-08111 x AIB-17
Dry fodder yield per plant	ICMA-96333 x AIB-20 JMSA-9904 xAIB-15 ICMA-963333 x AIB-15 ICMA-08111 x AIB-17 JMSA-101 x AIB-28	JMSA-9904 x AIB-14 JMSA-101 x AIB-14 ICMA-96333 x AIB-14 JMSA-9904 x AIB-15 ICMA-08111 x AIB-17	ICMA-96333 x AIB-20 JMSA-9904 xAIB-15 ICMA-963333 x AIB-15 ICMA-08111 x AIB-17 JMSA-101 x AIB-28
Test weight	ICMA-08111 x AIB-17 ICMA-92777x AIB-17 ICMA-08111 x AIB-15 ICMA-92777x AIB-6 ICMA-92777x AIB-30	ICMA-92777 x AIB-30 ICMA-08111 x AIB-30 ICMA-96333 x AIB-14 JMSA-9904 x AIB-15 ICMA-08111 x AIB-14	ICMA-08111 x AIB-17 ICMA-92777x AIB-17 ICMA-08111 x AIB-15 ICMA-92777x AIB-6 ICMA-92777x AIB-30
Panicle harvest index	JMSA-9904 x AIB-15 JMSA-101 x AIB-14 JMSA-9904 x AIB-30 ICMA-99555 x AIB-14 ICMA-0811 x AIB-15	ICMA-92777 x AIB-30 ICMA-08111 x AIB-30 JMSA-101 x AIB-30 JMSA-9904 x AIB-30 ICMA-96333 x AIB-30	JMSA-9904 x AIB-15 JMSA-101 x AIB-14 JMSA-9904 x AIB-30 ICMA-99555 x AIB-14 ICMA-0811xAIB-15
Total protein content	JMSA-101 x AIB-10 JMSA-101 x AIB-20 JMSA-101 x AIB-15 ICMA-92777 x AIB-20 ICMA-96333 x AIB-20	ICMA-92777 x AIB-30 ICMA-92777 x AIB-10 JMSA-101 x AIB-30 ICMA-08111 x AIB-6 ICMA-08111 x AIB-15	JMSA-101 x AIB-10 JMSA-101 x AIB-20 JMSA-101 x AIB-15 ICMA-92777 x AIB-20 ICMA-96333 x AIB-20

The estimates of SH ranged from -56.41 (JMSA-101 x AIB-15) to 6.92 (JMSA-9904 x AIB-15) per cent. The results are in accordance with the findings of (Dangaria *et al*., 2009) for HB. The estimates of heterobeltiosis for protein content ranged from -22.23 (ICMA-08111x AIB-28) to 33.83 (ICMA-92777 x AIB-30) per cent. Total 28 F_1S had significant estimates; of which, only 9 F_1S depicted positive effect. The estimates of standard heterosis over check hybrid GHB-558 varied from -14.00 (JMSA-9904 x AIB-28) to 19.63 (JMSA-101 x AIB-10) per cent. Out of 48 F_1S, total 18 F_1S exhibited significant estimates, of which 9 F_1S had negative heterotic effect.

In conclusion, the heterosis calculated over better parent and standard check revealed superiority of some cross combinations .For grain yield, the cross JMSA-9904 x AIB-15 (14.11 %) showed highest significant and positive heterosis over standard check.The other F_1S with significant and positive SH were JMSA-9904 x AIB-30 (13.75%) and ICMA-99555 x AIB-30 (11.17%). Crosse, JMSA-9904 x AIB-30 (93.78%) exerted the highest heterobeltiosis followed by ICMA-99555 x AIB-30 (88.16%), and JMSA-101 x AIB-28 (75.65%). A perusal of heterosis indicated that hybrids JMSA-9904 x AIB-15, JMSA-9904 x AIB-30 and ICMA-99555 x AIB-30 were found promising for further evaluation. Heterosis is also useful to decide the direction of future breeding programme and to identify the cross combinations which are promising in conventional breeding programme. While interpreting the results, positive effects were considered as favourable effects for all the characters excepts days to flowering, days to maturity and plant height for which negative effects were considered favourable.

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