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EXPLOITATION OF HETEROSIS FOR GRAIN YIELD AND YIELD COMPONENTS IN PEARL MILLET (*PENNISETUM GLAUCUM* L. R. BR.) USING DIVERSE MALE STERILE LINES

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ABSTRACT

Five cytoplasmic genic male sterile lines were crossed with ten diverse pollinators in line x tester design to study the nature and magnitude of heterosis for grain yield and its component traits in pearl millet. The experimental material comprising by five females, 10 males, their resulting 50 crosses and one standard check hybrid, GHB-1129 were evaluated in Randomized Block Design with three replications at Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar during *kharif* 2023. The extent of heterosis varied in each cross for all the characters studied. The high magnitude of heterosis in desired direction was observed for grain yield per plant, dry fodder yield per plant, ear head weight, number of effective tillers per plant and ear head length. While, moderate level heterosis in favourable direction was found for number of nodes on main stem, plant height, days to maturity and 1000-grains weight. The low amount economical heterosis was depicted through days to 50% flowering, length of protogyny and ear head diameter. Among 50 crosses studied, 40 and 10 crosses were narrated significant heterobeltiosis and standard heterosis in desired direction for grain yield per plant, respectively. The maximum positive heterosis of 99.64 and 21.24 per cent over better parent and standard check respectively, was recorded for grain yield per plant. Three promising crosses namely $JMSA_5$-20171 x J-2571, $JMSA_1$-20193 x J-2605 and $JMSA_5$-20226 x J-2562 had the high *per se* performance, considerable magnitude of heterobeltiosis as well as standard heterosis in favourable direction along with significant sca effects in desired direction for grain yield per plant and some other component traits.

***Key words*: Heterobeltiosis, Line x tester, Pearl millet, Standard heterosis.**

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] belongs to family *Poaceae* and genus *Pennisetum*. It is fourth important cereal food crop after rice, wheat and maize in India. Pearl millet is diploid (2n=14) in nature and commonly known as bajra, cattail millet and bulrush millet in different parts of the world, which is believed to be originated in West-Africa. Pearl millet is a cereal crop that thrives in the arid and semi-arid tropical regions of Asia and Africa. It is a short day C4 type warm weather crop and is the most drought tolerant warm season cereal grown in the harsh, arid and dry semi-arid tropical environments of south Asia and sub-Saharan Africa. It is more tolerant to high temperatures than any other cereals.

In India, it occupies an area of 70.08 lakh hectares with an average production of 95.31 lakh tones and productivity of 1360 kg/ha during the year 2023-24 (Anon., 2023a). The major pearl millet growing states are Rajasthan, Maharashtra, Uttar Pradesh, Gujarat and Haryana contributing 90% of total national production. It has a higher content of macronutrients and micronutrients such as iron, zinc, calcium, magnesium, copper, manganese, phosphorous, folic acid and riboflavin (Deshmukh *et al*., 2010). It is a good source of energy, carbohydrate, fat, ash, dietary fiber, α-amylase activity, quality protein, vitamin A and B, minerals, antioxidants such as ferulic acid and coumaric acids with better fat digestibility (Devos *et al.*, 2006; Velu, 2006). To bring millets into the mainstream for exploiting the nutritional rich properties and promoting their cultivation, Govt. of India has declared Year 2023 as the "International Year of Millets" by FAO Committee on Agriculture (COAG) forum.

The availability of cytoplasmic genetic male sterile lines in this crop is made feasible to exploit heterosis commercially and hybrid seed production on large scale. The exploitation of heterosis on commercial scale in pearl millet is regarded as one of the major breakthroughs in the improvement of its productivity. Heterosis breeding is an important one, among conventional breeding programme to identify the best hybrids which are promising.

Material and Methods

The material in present investigation involved five CGMS lines *viz*., JMSA$_5$-20171, JMSA$_1$-20193, JMSA$_5$-20226, JMSA$_1$-20227 and ICMA$_1$-99222, ten restorer pollinators like J-2539, J-2562, J-2565, J-2571, J-2576, J-2590, J-2596, J-2600, J-2603 and J-2605 and one standard check hybrid (GHB-1129) were received from Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar (Gujarat).

The complete set of 66 genotypes comprising 50 crosses, 15 parents and one standard check hybrid GHB-1129 were evaluated in a randomized block design with three replications at Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar during *kharif* 2023. Each plot with a spacing of 60 × 15 cm consisted of single row of 5.0 m length. All need based agronomic practices were followed during the crop growth period to raise a good crop. Observations were recorded on randomly selected five plants in each entry for 14 quantitative traits *viz*., days to 50% flowering, length of protogyny (days), number of nodes on main stem, number of effective tillers per plant, ear head length (cm), ear head diameter (cm), dry ear head weight (g), plant height (cm), days to maturity, 1000-grains weight (g), dry fodder yield per plant (g), grain yield per plant (g), harvest index (%) and threshing index (%) for each replication. The mean values were used for the analysis of variance for experimental design. The estimation of heterosis over better parent and standard check was carried-out as per the standard procedure.

Results and Discussion

Analysis of variance (Table 1) showed highly significant differences among the genotypes for all the traits under studied except for harvest index and threshing index. Thus, the results quantified the considerable amount of genetic diversity exist among genotypes for the different traits under study. Differences amongst the hybrids and parents were also found highly significant for all characters under studied except for harvest index and threshing index. The females *vs.* males' comparison were significant for all the characters except for days to 50% flowering, length of protogyny, ear head length, ear head weight, days to maturity and harvest index. This suggested that the contribution of females and males to crosses might be different due to differential performance of females and males for these characters.

Further heterosis analysis and combining ability analysis was not performed for harvest index and threshing index due to non-significant differences among genotypes, parents, crosses and parents *vs*. crosses for both these traits (Table 1).

Days to 50% flowering

As earliness is desirable character in case of pearl millet and days to 50% flowering is attributing character which influence on earliness. So, negative heterosis was considered desirable for this character. Among all 50 crosses, 35 and six crosses showed significant and desirable (negative) heterobeltiosis and standard heterosis (GHB-1129), respectively.

The range of heterobeltiosis for days to 50% flowering was -18.24% (ICMA$_1$-99222 x J-2562) to 10.74% (JMSA$_1$-20227 x J-2603). Out of 50 crosses studied, ICMA$_1$-99222 x J-2562 (-18.24%) exhibited the highest and desirable heterobeltiosis for days to 50% flowering followed by ICMA$_1$-99222 x J-2600 (-16.47%) and ICMA$_1$-99222 x J-2576 (-14.79%). The standard heterosis ranged from -7.95% (ICMA$_1$-99222 x J-2562) to 11.26% (JMSA$_5$-20171 x J-2603). Crosses ICMA$_1$-99222 x J-2562 (-7.95%) and ICMA$_1$-99222 x J-2571 (-7.95%) showed the highest significant and desirable standard heterosis for this trait followed by ICMA$_1$-99222 x J-2600 (-5.96%) and ICMA$_1$-99222 x J-2576 (-4.64%). The results obtained in present investigation for days to 50% flowering resemble to the findings reported by Jethva *et al*., (2012) and Bhadalia *et al*., (2013).

Length of protogyny

The short length of protogyny is desirable as it signifies synchrony between male and female parts. Therefore, negative value of heterosis is desirable for this trait. Among all 50 crosses, only one cross showed significant and desirable (negative) heterobeltiosis for this trait. For standard heterosis only two crosses manifested significant

Table 1: Analysis of variance for experimental design for different characters in pearl millet.

Source	df	Days to 50% flowering	Length of protogyny	No. of nodes on main stem	No. of effective tillers/plant	Ear head length	Ear head diameter	Ear head weight
Replications	2	0.02	0.05	0.12	0.03	0.47	0.003	7.51
Genotypes	64	29.98**	0.96**	2.23**	0.95**	28.92**	1.20**	963.57**
Parents (P)	14	22.55**	0.80**	1.15**	0.32**	17.92**	0.90**	243.40**
Females	4	53.27**	0.73*	1.44**	0.40**	14.36*	0.28**	272.77**
Males	9	11.19**	0.92**	0.87**	0.25*	21.49**	0.81**	254.34**
Females *vs* Males	1	1.88	0.01	2.50**	0.54*	0.13	4.14**	27.40
Crosses (C)	49	17.31**	0.98**	1.60**	1.04**	23.41**	1.20**	805.25**
P. *vs* C.	1	755.28**	2.18**	48.31**	5.22**	453.06**	5.27**	18803.93**
Error	128	1.28	0.30	0.21	0.11	5.00	0.06	38.99

Continue Table 1

Source	df	Plant height	Days to maturity	1000-grains weight	Dry fodder yield/plant	Grain yield/ plant	Harvest index	Threshing index
Replications	2	85.76	0.08	0.15	1.12	0.67	1.76	3.39
Genotypes	64	2196.56**	30.04**	8.37**	1529.14**	480.97**	2.86	20.48
Parents (P)	14	3598.19**	25.79**	4.67**	484.16**	136.60**	4.92	46.40
Females	4	629.25**	56.10**	3.51**	614.36**	159.09**	0.87	27.75
Males	9	686.41**	14.87**	5.30**	458.77**	134.91**	6.56	38.71
Females *vs* Males	1	41679.94**	2.84	3.73**	191.84*	61.92*	6.37	190.27*
Crosses (C)	49	740.60**	18.45**	9.57**	1139.89**	390.29**	2.01	12.74
P. *vs* C.	1	53915.72**	657.35**	0.99*	35232.32**	9745.41**	15.43	36.60
Error	128	141.04	2.04	0.23	46.05	14.93	8.00	30.66

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

and desirable heterosis for length of protogyny. Magnitude of heterobeltiosis for length of protogyny ranged from -30.00% ($JMSA_1$-20227 x J-2596) to 83.33% ($JMSA_5$-20226 x J-2590). The cross $JMSA_1$-20227 x J-2596 (-30.00%) recorded the highest and desirable heterobeltiosis followed by $JMSA_5$-20171 x J-2605 (-28.57%) and $JMSA_5$-20226 x J-2562 (-16.67%) for length of protogyny. The range of heterosis over standard check was -37.50% ($JMSA_5$-20171 x J-2605) to 37.50% ($ICMA_1$-99222 x J-2565). The crosses $JMSA_5$-20171 x J-2605 (-37.50%) and $JMSA_5$-20226 x J-2562 (-37.50%) recorded the highest and desirable standard heterosis followed by $JMSA_5$-20171 x J-2539 (-25.00%), $JMSA_5$-20171 x J-2596 (-25.00%), $JMSA_5$-20171 x J-2600 (-25.00%) and $JMSA_1$-20193 x J-2576 (-25.00%). Significant negative heterosis for this trait has also been reported by Nandaniya *et al*., (2016a), Acharya *et al*., (2017) and Ladumor *et al*., (2018a).

Numbers of nodes on main stem

Number of nodes is one of the components for expression of plant height. As plant height is a desirable character in pearl millet, the greater number of nodes was considered as desirable one. Out of 50 crosses studied, total 28 and six crosses exhibited significant and positive heterosis over better parent and standard check, respectively, for this character. The heterosis over better parent for number of nodes on main stem ranged from -4.03% ($JMSA_1$-20193 x J-2562) to 38.18% ($JMSA_5$-20226 x J-2600). The cross $JMSA_5$-20226 x J-2600 (38.18%) registered highly significant and desirable heterobeltiosis for number of nodes on main stem followed by $JMSA_5$-20171 x J-2605 (33.80%) and $JMSA_5$-20171 x J-2590 (28.16%). The range of standard heterosis for number of nodes on main stem was -17.19% ($ICMA_1$-99222 x J-2576) to 19.53% ($JMSA_5$-20171 x J-2562). The highest positive and significant standard heterosis was registered for cross $JMSA_5$-20171 x J-2562 (19.53%) followed by $JMSA_5$-20226 x J-2600 (18.75%) and $JMSA_1$-20227 x J-2562 (15.63%).

Numbers of effective tillers per plant

For number of effective tillers per plant, positive heterosis is considered as desirable for this character. Among 50 crosses studied, 10 crosses were found significant and positive heterosis over better parent for this trait. For heterosis over standard check, only eight crosses were showed significant and positive estimates for number of effective tillers per plant. The range of heterobeltiosis for number of effective tillers per plant

Table 2: Range of heterobeltiosis (H1) and standard heterosis (H2) as well as number of crosses with significant heterotic effects for various characters in pearl millet.

Sr. No.	Characters	Desir-able aspect	Rangeof heterosis		No. of crosses with significant heterosis			
			H1 (%)	H2 (%)	HB		SH	
					Positive	Negative	Positive	Negative
1	Days to 50%flowering	Early	-18.24 to 10.74	-7.95 to 11.26	5	35	19	6
2	Length of protogyny	Short	-30.00 to 83.33	-37.50 to 37.50	14	1	7	2
3	Number of nodes on main stem	More	-4.03 to 38.18	-17.19 to 19.53	28	0	6	13
4	Number of effective tillers per plant	More	-29.73 to 64.71	-38.10 to 35.71	10	2	8	19
5	Ear head length	More	-12.42 to 47.49	-26.39 to 32.26	17	0	6	4
6	Ear head diameter	More	-44.90 to 35.48	-48.33 to 21.53	12	12	10	23
7	Ear head weight	More	-8.10 to 99.42	-41.76 to 32.93	40	0	11	27
8	Plant height	High	-14.29 to 63.78	-17.58 to 15.58	23	1	2	13
9	Days to maturity	Early	-11.86 to 7.39	-5.56 to 7.69	7	30	20	5
10	1000 grains weight	High	-33.99 to 30.14	-38.41 to 24.76	9	28	7	36
11	Dry fodder yield per plant	High	-6.51 to 101.37	-40.70 to 35.00	42	0	12	27
12	Grain yield per plant	High	-7.33 to 99.64	-46.11 to 21.24	40	0	10	35

was -29.73% (JMSA$_5$-20226 x J-2565) to 64.71% (JMSA$_1$-20193 x J-2605). The top three crosses with significant and desirable heterobeltiosis for this trait were JMSA$_1$-20193 x J-2605 (64.71%), JMSA$_1$-20227 x J-2596 (59.38%) and JMSA$_5$-20226 x J-2562 (40.54%). The values of heterosis over standard check lied between -38.10% (JMSA$_1$-20193 x J-2600) to 35.71% (JMSA$_5$-20171 x J-2571). The top three crosses with significant and desirable standard heterosis for this trait were JMSA$_5$-20171 x J-2571 (35.71%), JMSA$_1$-20193 x J-2605 (33.33%) and JMSA$_5$-20171 x J-2539 (27.38%).

Ear head length (cm)

In the present investigation, out of 50 crosses studied, 17 and six crosses were found significant and in desirable direction for heterobeltiosis and standard heterosis, respectively, for ear head length. Heterobeltiosis values for ear head length were between -12.42% (JMSA$_5$-20226 x J-2590) to 47.39% (JMSA$_5$-20226 x J-2600). The cross JMSA$_5$-20226 x J-2600 (47.39%) was recognized as highly significant and desirable heterosis over better parent for ear head length followed by JMSA$_1$-20227 x J-2565 (41.58%) and ICMA$_1$-99222 x J-2596 (40.86%). The quantum of variation for standard heterosis ranged from -26.39% (ICMA$_1$-99222 x J-2590) to 32.26% (JMSA$_5$-20226 x J-2600). Among six significant and positive crosses for heterosis over standard check, the highest significant and desirable cross was JMSA$_5$-20226 x J-2600 (32.26%) followed by JMSA$_1$-20227 x J-2562 (25.81%), JMSA$_5$-20226 x J-2562 (22.58%) and JMSA$_1$-

Table 3: Comparative study of the six most standard heterotic crosses for grain yield per plant along with *per se* performance and their heterotic effects for component characters in pearl millet.

Heterotic crosses	Grain yield /plant (g)	Per cent heterosis for grain yield/plant over		Also, desirable significant standard heterosis for other traits
		Better parent	Standard check (GHB-1129)	
JMSA$_5$-20171 x J-2571	61.83	75.50**	21.24**	No. of effective tillers/plant, Ear head diameter, Ear head weight, 1000 grains weight, Dry fodder yield/plant
JMSA$_5$-20171 x J-2539	61.00	73.13**	19.61**	No. of effective tillers/plant, Ear head diameter, Ear head weight, 1000 grains weight, Dry fodder yield/plant
JMSA$_1$-20193 x J-2605	60.89	99.64**	19.39**	No. of effective tillers/plant, Ear head diameter, Ear head weight, 1000 grains weight, Dry fodder yield/plant
JMSA$_5$-20171 x J-2605	60.67	72.19**	18.95**	Length of protogyny, No. of nodes on main stem, No. of effective tillers/plant, Ear head diameter, Ear head weight, Dry fodder yield/plant
JMSA$_5$-20171 x J-2596	60.60	72.00**	18.82**	No. of effective tillers/plant, Ear head diameter, Ear head weight, Dry fodder yield/plant
JMSA$_5$-20226 x J-2562	60.33	87.47**	18.30**	Length of protogyny, No. of nodes on main stem, No. of effective tillers/plant, Ear head length, Ear head diameter, Ear head weight, Dry fodder yield/plant

20227 x J-2565 (20.82%). Significant positive heterosis for ear head length has also been reported by Krishnan *et al*., (2019) and Kharad *et al*., (2020).

Ear head diameter (cm)

For ear head diameter, positive heterosis is considered as desirable and the number of crosses showing significantly desirable heterobeltiosis and standard heterosis were 12 and 10, respectively. The heterosis over better parent for ear head diameter lay between -44.90% (JMSA$_5$-20226 x J-2590) to 35.48% (JMSA$_1$-20193 x J-2605). Out of all 50 crosses, the best three crosses with significant and desirable heterobeltiosis were JMSA$_1$-20193 x J-2605 (35.48%), JMSA$_1$-20227 x J-2596 (32.58%) and JMSA$_1$-20193 x J-2539 (31.52%). The estimates of standard heterosis ranged between -48.33% (JMSA$_5$-20226 x J-2590) to 21.53% (JMSA$_5$-20171 x J-2576). The cross JMSA$_5$-20171 x J-2576 (21.53%) manifested the maximum heterosis over standard check for ear head diameter followed by JMSA$_1$-20193 x J-2605 (20.57%) and JMSA$_5$-20171 x J-2571 (18.66%).

Table 4.1: Per cent heterobeltiosis (H_1) and standard heterosis (H_2) for days to 50% flowering, length of protogyny, number of nodes on main stem, number of effective tillers per plant and ear head length in pearl millet.

Sr. No.	Crosses	Days to 50% flowering		Length of protogyny		No. of nodes on main stem		No. of effective tillers/plant		Ear head length	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
1	JMSA$_5$-20171 x J-2539	-7.91**	7.95**	-14.29	-25.00	8.33	1.56	27.38**	27.38**	11.71	9.09
2	JMSA$_5$-20171 x J-2562	-4.05*	9.93**	33.33	0.00	23.39**	19.53**	4.76	4.76	15.94*	17.30*
3	JMSA$_5$-20171 x J-2565	-2.35	9.93**	14.29	0.00	23.89**	9.38*	-11.90	-11.90	21.99**	18.77*
4	JMSA$_5$-20171 x J-2571	-0.61	7.28**	0.00	-12.50	19.42**	-3.91	35.71**	35.71**	3.31	0.59
5	JMSA$_5$-20171 x J-2576	-10.65**	0.00	33.33	0.00	21.57**	-3.13	11.90	11.90	3.92	1.17
6	JMSA$_5$-20171 x J-2590	-2.50	3.31	0.00	-12.50	28.16**	3.12	14.29	14.29	4.82	2.05
7	JMSA$_5$-20171 x J-2596	-6.59**	3.31	-14.29	-25.00	24.76**	2.34	23.81*	23.81*	1.51	-1.17
8	JMSA$_5$-20171 x J-2600	-12.28**	-0.66	-14.29	-25.00	19.80**	-5.47	-11.90	-11.90	2.71	0.00
9	JMSA$_5$-20171 x J-2603	-5.62**	11.26**	14.29	0.00	25.00**	1.56	-16.67	-16.67	9.94	7.04
10	JMSA$_5$-20171 x J-2605	1.21	10.60**	-28.57	-37.50*	33.80**	12.89**	26.19**	26.19**	16.27*	13.20
11	JMSA$_1$-20193 x J-2539	-8.52**	6.62**	0.00	-12.50	3.33	-3.12	27.03*	11.90	-0.60	-2.93
12	JMSA$_1$-20193 x J-2562	-5.20**	8.61**	33.33	0.00	-4.03	-7.03	36.36**	7.14	1.16	2.35
13	JMSA$_1$-20193 x J-2565	-8.24**	3.31	37.50*	37.50*	11.50*	-1.56	0.00	-26.19**	23.02*	4.99
14	JMSA$_1$-20193 x J-2571	-6.75**	0.66	42.86*	25.00	16.50**	-6.25	3.23	-23.81*	12.89	-4.99
15	JMSA$_1$-20193 x J-2576	-7.69**	3.31	0.00	-25.00	9.80	-12.50**	15.15	-9.52	-1.29	-9.97
16	JMSA$_1$-20193 x J-2590	-5.00**	0.66	25.00	25.00	17.96**	-5.08	0.00	-26.19**	31.14**	4.99
17	JMSA$_1$-20193 x J-2596	-7.19**	2.65	12.50	12.50	17.14**	-3.91	-3.12	-26.19**	28.21**	2.64
18	JMSA$_1$-20193 x J-2600	-5.85**	6.62**	25.00	25.00	6.93	-15.63**	-16.13	-38.10**	9.52	-12.32
19	JMSA$_1$-20193 x J-2603	-5.11**	10.6**	0.00	0.00	17.31**	-4.69	21.88	-7.14	10.51	-10.56
20	JMSA$_1$-20193 x J-2605	-4.85**	3.97*	0.00	-12.50	10.19*	-7.03	64.71**	33.33**	9.09	-1.47
21	JMSA$_5$-20226 x J-2539	-7.34**	8.61**	33.33	0.00	-0.83	-7.03	18.92	4.76	8.41	5.87
22	JMSA$_5$-20226 x J-2562	-7.51**	5.96**	-16.67	-37.50*	14.52**	10.94*	40.54**	23.81*	21.16**	22.58**
23	JMSA$_5$-20226 x J-2565	-4.71**	7.28**	83.33**	37.50*	8.85	-3.91	-29.73**	-38.10**	-8.50	-17.89*
24	JMSA$_5$-20226 x J-2571	-5.52**	1.99	83.33**	37.50*	5.45	-9.38*	-21.62	-30.95**	3.59	-7.04
25	JMSA$_5$-20226 x J-2576	-8.28**	2.65	50.00*	12.50	-2.73	-16.41**	0.00	-11.90	18.97*	8.50
26	JMSA$_5$-20226 x J-2590	-3.13	2.65	83.33**	37.50*	15.45**	-0.78	-29.73**	-38.10**	-12.42	-21.41**
27	JMSA$_5$-20226 x J-2596	-7.78**	1.99	33.33	0.00	4.55	-10.16*	-5.41	-16.67	9.15	-2.05
28	JMSA$_5$-20226 x J-2600	-10.53**	1.32	66.67**	25.00	38.18**	18.75**	-21.62	-30.95**	47.39**	32.26**
29	JMSA$_5$-20226 x J-2603	-9.55**	6.62**	66.67**	25.00	7.27	-7.81	-2.70	-14.29	-0.98	-11.14
30	JMSA$_5$-20226 x J-2605	-3.64*	5.30**	16.67	-12.50	18.18**	1.56	37.84**	21.43*	12.99	2.05
31	JMSA$_1$-20227 x J-2539	2.68	1.32	42.86*	25.00	-0.83	-7.03	-18.92	-28.57**	0.90	-1.47
32	JMSA$_1$-20227 x J-2562	10.07**	8.61**	66.67**	25.00	19.35**	15.63**	-15.15	-33.33**	24.35**	25.81**
33	JMSA$_1$-20227 x J-2565	4.70*	3.31	22.22	37.50*	13.27**	0.00	10.71	-26.19**	41.58**	20.82**
34	JMSA$_1$-20227 x J-2571	2.68	1.32	42.86*	25.00	15.93**	2.34	10.00	-21.43*	34.84**	13.49
35	JMSA$_1$-20227 x J-2576	4.03*	2.65	66.67**	25.00	4.42	-7.81	-6.06	-26.19**	3.54	-5.57

Continue Table 4.1 ....

36	JMSA$_1$-20227 x J-2590	1.34	0.00	10.00	37.50*	12.39*	-0.78	0.00	-33.33**	14.73	-13.20
37	JMSA$_1$-20227 x J-2596	1.34	0.00	-30.00*	-12.50	10.62*	-2.34	59.38**	21.43*	33.72**	1.17
38	JMSA$_1$-20227 x J-2600	7.38**	5.96**	25.00	25.00	7.96	-4.69	17.24	-19.05	29.84**	-1.76
39	JMSA$_1$-20227 x J-2603	10.74**	9.27**	25.00	25.00	11.5*	-1.56	9.38	-16.67	21.01*	-2.05
40	JMSA$_1$-20227 x J-2605	0.67	-0.66	28.57	12.50	12.39*	-0.78	-14.71	-30.95**	-4.55	-13.78
41	ICMA$_1$-99222 x J-2539	-9.41**	1.99	0.00	-12.50	-1.67	-7.81	16.22	2.38	-2.70	-4.99
42	ICMA$_1$-99222 x J-2562	-18.24**	-7.95**	33.33	0.00	-3.23	-6.25	12.12	-11.90	-0.29	0.88
43	ICMA$_1$-99222 x J-2565	-12.94**	-1.99	37.50*	37.50*	2.65	-9.38*	-9.09	-28.57**	23.71*	5.57
44	ICMA$_1$-99222 x J-2571	-14.72**	-7.95**	42.86*	25.00	9.71	-11.72**	-6.06	-26.19**	10.80	-6.74
45	ICMA$_1$-99222 x J-2576	-14.79**	-4.64*	16.67	-12.50	3.92	-17.19**	12.12	-11.90	-10.61	-18.48*
46	ICMA$_1$-99222 x J-2590	-3.75*	1.99	25.000	25.00	11.65*	-10.16*	-15.15	-33.33**	-2.33	-26.39**
47	ICMA$_1$-99222 x J-2596	-13.17**	-3.97*	12.50	12.50	3.81	-14.84**	12.12	-11.90	40.86**	6.16
48	ICMA$_1$-99222 x J-2600	-16.47**	-5.96**	12.50	12.50	12.87*	-10.94*	3.03	-19.05	13.23	-14.66
49	ICMA$_1$-99222 x J-2603	-8.82**	2.65	0.00	0.00	9.62	-10.94*	9.09	-14.29	11.59	-9.68
50	ICMA$_1$-99222 x J-2605	-12.12**	-3.97*	28.57	12.50	0.00	-15.63**	8.82	-11.90	-4.22	-13.49
Mean		-5.25	3.13	24.17	7.75	12.00	-3.50	6.68	-10.26	11.91	-0.12
S. E. ±		0.92		0.44		0.37		0.27		1.83	
Number of crosses with desirable heterosis		**35**	**6**	**1**	**2**	**28**	**6**	**10**	**8**	**17**	**6**
*, ** Significant at 5% and 1% levels, respectively											

Ear head weight (g)

Out of 50 crosses studied, 40 and 11 crosses showed significantly in desirable direction heterobeltiosis and standard heterosis, respectively for ear head weight. The estimated heterosis over better parent varied from -8.10% (JMSA$_1$-20227 x J-2562) to 99.42% (JMSA$_5$-20226 x J-2605). Out of 50 crosses under studied, the best three crosses with significant and desirable heterobeltiosis were JMSA$_5$-20226 x J-2605 (99.42%), JMSA$_1$-20193 x J-2605 (98.82%) and JMSA$_1$-20227 x J-2596 (97.24%). Magnitude of standard heterosis varied from -41.76% (JMSA$_5$-20226 x J-2590) to 32.93% (JMSA$_5$-20171 x J-2571). Out of all 50 crosses under studied, the best three crosses with significant and desirable standard heterosis were JMSA$_5$-20171 x J-2571 (32.93%), JMSA$_5$-20171 x J-2596 (32.52%) and JMSA$_5$-20171 x J-2539 (32.43%). These findings confirmed the results of those reported by Suryawanshi *et al.*, (2021) and Galani *et al.*, (2022).

Plant height (cm)

For plant height, heterosis in positive direction is desirable due to long stem provide sufficient assimilates during grain development. In the present investigation, from all the 50 crosses, 23 showed significant and positive heterosis over better parent for plant height (Table 4.3). While, only two crosses showed significant and desirable heterosis over standard check for this trait.

The range of heterobeltiosis, for plant height was -14.29% (ICMA$_1$-99222 x J-2605) to 63.78% (JMSA$_5$-20226 x J-2600). Out of 50 crosses studied, the highest significant and desirable heterobeltiosis were exhibited by the cross JMSA$_5$-20226 x J-2600 (63.78%) followed by JMSA$_5$-20171 x J-2600 (42.08%) and JMSA$_1$-20227

Table 4.2: Per cent heterobeltiosis (H_1) and standard heterosis (H_2) for ear head diameter, ear head weight, plant height, days to maturity and 1000-grains weight in pearl millet.

Sr. No.	Crosses	Ear head diameter		Ear head weight		Plant height		Days to Maturity		1000-grains weight	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
1	JMSA$_5$-20171 x J-2539	8.11	14.83**	73.94**	32.43**	8.59	2.90	-6.13**	4.70**	17.80**	20.79**
2	JMSA$_5$-20171 x J-2562	-18.02**	-12.92*	51.19**	15.11*	20.40**	13.21**	-1.57	6.84**	3.10	5.71
3	JMSA$_5$-20171 x J-2565	-13.51*	-8.13	22.02*	-7.10	20.13**	4.34	-0.80	6.41**	-10.84**	-8.57*
4	JMSA$_5$-20171 x J-2571	11.71*	18.66**	74.60**	32.93**	13.26*	0.03	-0.41	4.70**	11.36**	14.19**
5	JMSA$_5$-20171 x J-2576	14.41**	21.53**	65.11**	25.70**	12.90*	-3.04	-7.57**	-0.85	12.07**	14.92**
6	JMSA$_5$-20171 x J-2590	-11.71*	-6.22	64.68**	25.38**	24.60**	1.90	0.00	1.71	15.48**	18.41**
7	JMSA$_5$-20171 x J-2596	9.01	15.79**	74.06**	32.52**	17.52**	2.30	-4.00**	2.56	-7.12*	-4.76
8	JMSA$_5$-20171 x J-2600	-32.43**	-28.23**	19.31	-9.16	42.08**	0.27	-7.60**	-1.28	-9.23*	-6.92

Continue Table 4.2 ....

9	JMSA$_5$-20171 x J-2603	-20.72**	-15.79**	0.97	-23.13**	17.61**	3.17	-3.85**	6.84**	-27.03**	-25.17**
10	JMSA$_5$-20171 x J-2605	7.21	13.88*	72.22**	31.12**	6.41	3.60	1.21	6.84**	0.15	2.70
11	JMSA$_1$-20193 x J-2539	31.52**	15.79**	76.13**	24.96**	7.39	1.77	-5.84**	3.42*	26.24**	24.76**
12	JMSA$_1$-20193 x J-2562	5.62	-10.05	51.88**	7.60	8.27	1.80	-2.76*	5.56**	13.98**	-0.63
13	JMSA$_1$-20193 x J-2565	-5.62	-19.62**	62.98**	-27.29**	17.33**	1.90	-4.38**	2.56	-13.02**	-26.41**
14	JMSA$_1$-20193 x J-2571	3.37	-11.96*	48.80**	-28.45**	13.00*	-0.20	-5.28**	-0.43	-9.01*	-23.02**
15	JMSA$_1$-20193 x J-2576	5.62	-10.05	37.48**	-7.10	10.76	-4.87	-5.98**	0.85	-3.90	-7.62*
16	JMSA$_1$-20193 x J-2590	-5.62	-19.62**	55.94**	-30.43**	23.09**	0.67	-3.36*	-1.71	-8.07	-22.22**
17	JMSA$_1$-20193 x J-2596	-1.12	-15.79**	17.88	-31.27**	16.40**	1.33	-4.80**	1.71	-10.13*	-23.97**
18	JMSA$_1$-20193 x J-2600	-32.58**	-42.58**	41.03*	-37.08**	31.44**	-7.24	-2.80*	3.85*	-22.21**	-34.19**
19	JMSA$_1$-20193 x J-2603	10.11	-6.22	92.39**	-5.84	10.69	-2.90	-1.95	7.69**	6.74	-9.52*
20	JMSA$_1$-20193 x J-2605	35.48**	20.57**	98.82**	30.82**	2.02	-0.67	-2.43	2.99*	20.36**	18.25**
21	JMSA$_5$-20226 x J-2539	-3.06	-9.09	52.38**	8.11	2.57	-2.80	-5.38**	5.13**	6.17	4.92
22	JMSA$_5$-20226 x J-2562	22.45**	14.83**	84.51**	30.72**	13.80**	7.01	-5.12**	2.99*	-3.20	-9.68**
23	JMSA$_5$-20226 x J-2565	-42.86**	-46.41**	14.31	-39.27**	0.81	-12.45*	-2.79*	4.27**	-29.81**	-34.51**
24	JMSA$_5$-20226 x J-2571	-40.82**	-44.50**	19.15	-36.71**	-6.46	-17.38**	-4.47**	0.43	-29.70**	-34.41**
25	JMSA$_5$-20226 x J-2576	6.12	-0.48	33.08**	-10.07	12.70*	-3.20	-5.98**	0.85	-12.65**	-16.03**
26	JMSA$_5$-20226 x J-2590	-44.90**	-48.33**	9.63	-41.76**	0.78	-17.58**	-0.84	0.85	-33.99**	-38.41**
27	JMSA$_5$-20226 x J-2596	-8.16	-13.88*	27.98*	-25.38**	9.05	-5.07	-5.60**	0.85	-12.45**	-18.32**
28	JMSA$_5$-20226 x J-2600	-24.49**	-29.19**	52.13**	-19.18*	63.78**	15.58**	-6.00**	0.43	-15.79**	-21.43**
29	JMSA$_5$-20226 x J-2603	-9.18	-14.83**	38.15**	-26.61**	1.83	-10.68*	-5.38**	5.13**	-18.00**	-23.49**
30	JMSA$_5$-20226 x J-2605	22.45**	14.83**	99.42**	31.21**	3.15	0.43	-0.81	4.70**	15.67**	13.65**
31	JMSA$_1$-20227 x J-2539	-10.87	-21.53**	-6.39	-33.59**	-7.50	-12.35*	3.04*	1.28	-20.98**	-21.90**
32	JMSA$_1$-20227 x J-2562	2.25	-12.92*	-8.10	-34.89**	-9.58	-14.98**	6.52**	4.70**	-10.05*	-21.59**
33	JMSA$_1$-20227 x J-2565	7.87	-8.13	72.97**	-30.92**	19.02**	3.37	3.48*	1.71	3.42	-22.35**
34	JMSA$_1$-20227 x J-2571	15.73*	-1.44	59.48**	-23.31**	15.98**	2.44	3.04*	1.28	2.75	-22.86**
35	JMSA$_1$-20227 x J-2576	14.61*	-2.39	2.09	-31.02**	12.08*	-3.74	3.48*	1.71	-29.56**	-32.29**
36	JMSA$_1$-20227 x J-2590	-39.33**	-48.33**	52.29**	-40.53**	1.26	-17.18**	2.17	0.43	-13.45**	-35.02**
37	JMSA$_1$-20227 x J-2596	32.58**	12.92*	97.24**	15.01	16.02**	1.00	2.61	0.85	30.14**	1.43
38	JMSA$_1$-20227 x J-2600	8.99	-7.18	70.75**	-31.57**	41.13**	-0.40	4.78**	2.99*	-8.32	-28.25**
39	JMSA$_1$-20227 x J-2603	14.61*	-2.39	67.64**	-17.95*	14.11*	0.10	7.39**	5.56**	-9.55*	-23.33**
40	JMSA$_1$-20227 x J-2605	11.83	-0.48	-1.89	-35.45**	3.02	0.30	0.00	-1.71	-28.92**	-30.16**
41	ICMA$_1$-99222 x J-2539	4.30	-7.18	35.70**	-3.73	-1.65	-6.81	-4.74**	2.99*	-7.16	-8.25*
42	ICMA$_1$-99222 x J-2562	-2.15	-12.92*	25.27*	-11.25	1.88	-4.20	-11.86**	-4.70**	-3.28	-15.68**
43	ICMA$_1$-99222 x J-2565	-7.53	-17.70**	46.64**	-30.92**	5.46	-8.41	-8.76**	-2.14	-14.52**	-26.92**
44	ICMA$_1$-99222 x J-2571	-6.45	-16.75**	45.97**	-29.81**	1.13	-10.68*	-10.16**	-5.56**	-12.66**	-25.33**
45	ICMA$_1$-99222 x J-2576	19.35**	6.22	28.17*	-13.39	0.91	-13.33**	-8.76**	-2.14	-10.34**	-13.81**
46	ICMA$_1$-99222 x J-2590	-19.35**	-28.23**	34.57*	-36.61**	2.86	-15.88**	-1.26	0.43	-26.29**	-36.98**
47	ICMA$_1$-99222 x J-2596	-7.53	-17.70**	32.25*	-22.89**	1.84	-11.34*	-9.20**	-2.99*	-5.16	-18.92**
48	ICMA$_1$-99222 x J-2600	-5.38	-15.79**	48.78**	-29.91**	19.20**	-15.88**	-9.60**	-3.42*	-12.92**	-25.56**
49	ICMA$_1$-99222 x J-2603	9.68	-2.39	60.80**	-21.30**	3.96	-8.81	-5.53**	2.14	-11.62**	-24.44**
50	ICMA$_1$-99222 x J-2605	18.28**	5.26	29.56*	-14.75	-14.29**	-16.55**	-8.10**	-2.99*	-18.58**	-20.00**
Mean		-1.20	-9.24	46.52	-11.12	11.05	-3.58	-3.08	1.82	-6.68	-14.06
S. E. ±		0.20		5.10		9.70		1.17		0.39	
Number of crosses with desirable heterosis		**12**	**10**	**40**	**11**	**23**	**2**	**30**	**5**	**9**	**7**
*, ** Significant at 5% and 1% levels, respectively											

x J-2600 (41.13%). The range of standard heterosis for plant height varied from -17.58% (JMSA$_5$-20226 x J-2590) to 15.58% (JMSA$_5$-20226 x J-2600). The highest significant and positive heterosis over standard check for plant height was registered by JMSA$_5$-20226 x J-2600 (15.58%) followed by JMSA$_5$-20171 x J-2562 (13.21%) and JMSA$_5$-20226 x J-2562 (7.01%).

Days to maturity

The negative heterosis for this character was considered desirable for earliness. Out of 50 crosses

Table 5: Per cent heterobeltiosis (H_1) and standard heterosis (H_2) for dry fodder yield per plant and grain yield per plant in pearl millet.

Sr. No.	Crosses	Dry fodder yield/plant		Grain yield/plant	
		H_1 (%)	H_2 (%)	H_1 (%)	H_2 (%)
1	$JMSA_5$-20171 x J-2539	75.49**	35.00**	73.13**	19.61**
2	$JMSA_5$-20171 x J-2562	57.17**	20.9**	49.42**	3.23
3	$JMSA_5$-20171 x J-2565	21.20*	-6.76	20.53*	-16.73**
4	$JMSA_5$-20171 x J-2571	74.85**	34.51**	75.50**	21.24**
5	$JMSA_5$-20171 x J-2576	64.73**	26.72**	61.40**	11.50
6	$JMSA_5$-20171 x J-2590	69.42**	30.33**	63.10**	12.68*
7	$JMSA_5$-20171 x J-2596	70.75**	31.35**	72.00**	18.82**
8	$JMSA_5$-20171 x J-2600	22.80*	-5.53	20.53*	-16.73**
9	$JMSA_5$-20171 x J-2603	6.02	-18.44**	4.82	-27.58**
10	$JMSA_5$-20171 x J-2605	73.42**	33.40**	72.19**	18.95**
11	$JMSA_1$-20193 x J-2539	79.23**	30.82**	75.57**	16.01**
12	$JMSA_1$-20193 x J-2562	46.83**	6.27	56.60**	-1.18
13	$JMSA_1$-20193 x J-2565	79.34**	-23.85**	64.51**	-35.59**
14	$JMSA_1$-20193 x J-2571	64.34**	-24.84**	54.15**	-34.51**
15	$JMSA_1$-20193 x J-2576	40.99**	-3.16	35.63**	-14.90*
16	$JMSA_1$-20193 x J-2590	86.00**	-21.02**	70.72**	-33.16**
17	$JMSA_1$-20193 x J-2596	27.94*	-23.24**	10.80	-34.82**
18	$JMSA_1$-20193 x J-2600	61.20**	-31.56**	48.00**	-42.06**
19	$JMSA_1$-20193 x J-2603	96.35**	-7.30	89.08**	-12.88*
20	$JMSA_1$-20193 x J-2605	98.17**	33.20**	99.64**	19.39**
21	$JMSA_5$-20226 x J-2539	49.58**	9.18	54.30**	1.96
22	$JMSA_5$-20226 x J-2562	81.20**	31.15**	87.47**	18.30**
23	$JMSA_5$-20226 x J-2565	20.36	-34.10**	16.73	-44.31**
24	$JMSA_5$-20226 x J-2571	19.31	-34.67**	22.81	-41.41**
25	$JMSA_5$-20226 x J-2576	30.07**	-10.66	29.15**	-18.97**
26	$JMSA_5$-20226 x J-2590	8.31	-40.70**	13.90	-45.65**
27	$JMSA_5$-20226 x J-2596	32.86**	-20.29**	18.10	-30.53**
28	$JMSA_5$-20226 x J-2600	56.44**	-14.34*	53.66**	-26.69**
29	$JMSA_5$-20226 x J-2603	33.83**	-26.72**	36.11**	-35.06**
30	$JMSA_5$-20226 x J-2605	92.80**	29.59**	97.27**	17.97**
31	$JMSA_1$-20227 x J-2539	-6.51	-31.76**	-7.33	-38.76**
32	$JMSA_1$-20227 x J-2562	-4.98	-31.23**	-2.74	-38.63**
33	$JMSA_1$-20227 x J-2565	80.88**	-27.87**	79.63**	-36.60**
34	$JMSA_1$-20227 x J-2571	73.66**	-20.57**	59.69**	-32.16**
35	$JMSA_1$-20227 x J-2576	4.24	-28.40**	2.21	-35.87**
36	$JMSA_1$-20227 x J-2590	85.83**	-36.02**	66.90**	-46.11**
37	$JMSA_1$-20227 x J-2596	101.37**	20.82**	99.11**	17.12**
38	$JMSA_1$-20227 x J-2600	96.85**	-25.61**	64.41**	-36.60**
39	$JMSA_1$-20227 x J-2603	83.51**	-13.36*	58.55**	-26.94**
40	$JMSA_1$-20227 x J-2605	2.38	-31.19**	1.91	-39.05**
41	$ICMA_1$-99222 x J-2539	31.44**	-4.06	35.91**	-10.20
42	$ICMA_1$-99222 x J-2562	25.03**	-9.51	28.33**	-19.02**
43	$ICMA_1$-99222 x J-2565	74.65**	-28.57**	60.00**	-37.25**
44	$ICMA_1$-99222 x J-2571	74.91**	-20.00**	58.98**	-32.46**
45	$ICMA_1$-99222 x J-2576	37.65**	-5.45	31.77**	-17.32**
46	$ICMA_1$-99222 x J-2590	56.21**	-36.11**	41.00**	-44.71**
47	$ICMA_1$-99222 x J-2596	28.89*	-22.66**	23.33*	-27.45**
48	$ICMA_1$-99222 x J-2600	95.99**	-19.84**	73.33**	-32.03**
49	$ICMA_1$-99222 x J-2603	73.61**	-18.03**	53.70**	-29.18**
50	$ICMA_1$-99222 x J-2605	29.82**	-12.75	31.15**	-21.57**
Mean		53.73	-7.94	48.13	-18.36
S. E. ±		5.54		3.15	
Number of crosses with desirable heterosis		**42**	**12**	**40**	**10**

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

Continue Table 5 ....

studied, 30 and five crosses showed significantly in desirable direction heterobeltiosis and standard heterosis, respectively for days to maturity. The range of heterobeltiosis for days to maturity was -11.86% (ICMA$_1$-99222 x J-2562) to 7.39% (JMSA$_1$-20227 x J-2603). The best three crosses for heterobeltiosis were ICMA$_1$-99222 x J-2562 (-11.86%), ICMA$_1$-99222 x J-2571 (-10.16%) and ICMA$_1$-99222 x J-2600 (-9.60%). The range of standard heterosis for days to maturity was between -5.56% (ICMA$_1$-99222 x J-2571) to 7.69% (JMSA$_1$-20193 x J-2603). For standard heterosis the best three crosses were ICMA$_1$-99222 x J-2571 (-5.56%), ICMA$_1$-99222 x J-2562 (-4.70%) and ICMA$_1$-99222 x J-2600 (-3.42%), which was registered significant and desirable heterosis.

1000-grains weight (g)

For test weight, positive heterosis is considered as desirable and out of 50 crosses studied, nine crosses displayed significant and positive heterosis over better parent and seven crosses registered significant and positive heterotic effects over standard check. Considering heterosis over better parent, the variation for 1000-grains weight was from -33.99% (JMSA$_5$-20226 x J-2590) to 30.14% (JMSA$_1$-20227 x J-2596). The best three heterobeltiotic crosses in desirable direction for this character were JMSA$_1$-20227 x J-2596 (30.14%), JMSA$_1$-20193 x J-2539 (26.24%) and JMSA$_1$-20193 x J-2605 (20.36%). Estimations of standard heterosis for 1000-grains weight was ranged from -38.41% (JMSA$_5$-20226 x J-2590) to 24.76% (JMSA$_1$-20193 x J-2539). Out of 50 crosses, the best three heterotic crosses for 1000-grains weight were JMSA$_1$-20193 x J-2539 (24.76%), JMSA$_5$-20171 x J-2539 (20.79%) and JMSA$_5$-20171 x J-2590 (18.41%).

Dry fodder yield per plant (g)

Fodder is an important component of pearl millet especially for dual purpose crop. Among the 50 crosses studied, 42 and 12 crosses showed significant positive heterosis over better parent and standard check, respectively, for dry fodder yield per plant. For dry fodder yield per plant, the estimates of heterobeltiosis ranged from -6.51% (JMSA$_1$-20227 x J-2539) to 101.37% (JMSA$_1$-20227 x J-2596). The cross JMSA$_1$-20227 x J-2596 (101.37%) was noticed the highest positive and significant heterobeltiosis for dry fodder yield per plant followed by JMSA$_1$-20193 x J-2605 (98.17%) and JMSA$_1$-20227 x J-2600 (96.85%). The range of heterosis over standard check for dry fodder yield per plant expressed from -40.70% (JMSA$_5$-20226 x J-2590) to 35.00% (JMSA$_5$-20171 x J-2539). The cross JMSA$_5$-20171 x J-2539 (35.00%) manifested the highest positive and significant standard heterosis for this character followed by JMSA$_5$-20171 x J-2571 (34.51%) and JMSA$_5$-20171 x J-2605 (33.40%).

Grain yield per plant (g)

In the present investigation, out of 50 crosses studied, 40 and 10 crosses were found significant and in desirable direction for heterobeltiosis and standard heterosis, respectively for grain yield per plant. The range of heterosis over better parent for grain yield per plant was -7.33% (JMSA$_1$-20227 x J-2539) to 99.64% (JMSA$_1$-20193 x J-2605). The best three heterobeltiotic crosses for grain yield per plant were JMSA$_1$-20193 x J-2605 (99.64%), JMSA$_1$-20227 x J-2596 (99.11%) and JMSA$_5$-20226 x J-2605 (97.27%). The minimum and the maximum values of heterosis over standard check was -46.11% (JMSA$_1$-20227 x J-2590) and 21.24% (JMSA$_5$-20171 x J-2571), respectively, for grain yield per plant. The highest positive and significant standard heterosis showed by the cross JMSA$_5$-20171 x J-2571 (21.24%) for grain yield per plant followed by JMSA$_5$-20171 x J-2539 (19.61%) and JMSA$_1$-20193 x J-2605 (19.39%). Similar cumulative heterotic effects of two or more yield components on grain yield of pearl millet was also reported earlier by Davda *et al*., (2012), Aswini *et al*., (2021), Suryawanshi *et al*., (2021), Galani *et al*., (2022), Sharma *et al*., (2023a) and Patel *et al*., (2024).

Conclusion

From the present findings, it can be concluded that substantial amount of variation was present in the material for grain yield and its component traits. The heterobeltiosis for grain yield per plant was ranged from -7.33 to 99.64%, while, the standard heterosis was laid between -46.11 to 21.24%. The best three promising crosses namely JMSA$_5$-20171 x J-2571, JMSA$_1$-20193 x J-2605 and JMSA$_5$-20226 x J-2562 had the high *per se* performance, considerable magnitude of heterobeltiosis as well as standard heterosis in favourable direction along with significant sca effects in desired direction for grain yield per plant and some other component traits. Therefore, these three best crosses could be further evaluated over years and locations to exploit for commercial cultivation through heterosis breeding or utilized in future breeding programme to obtain desirable transgressive segregants for the development of superior inbreds or genotypes.

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References

Acharya, Z.R. (2017). Study on heterosis and combining ability analysis using male sterile lines in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Unpublished M.Sc. (Agri.) thesis submitted to Junagadh Agricultural University, Junagadh.

Anonymous (2023a). Second advance estimates data of area, production and yield of food grains of India for the year 2023-24, Directorate Economic and Statistics, Department of Agriculture and Farmers Welfare, Government of India, https://eands.dacnet.nic.in> accessed on 12 June, 2024.

Aswini, M.S., Ganesan K.N., Ezhilarasi T. and Sivakumar S.D. (2021). Combining ability and heterosis studies in fodder pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Electronic Journal of Plant Breeding*, **12(3)**, 1011-1021.

Bhadalia, A.S., Dhedhi K.K. and Joshi H.J. (2013). Heterosis study in diallel crosses of pearl millet.*Journal of Agriculture Research and Technology*, **38(3)**, 360-365.

Davda, B.K., Dhedhi K.K. and Dangaria C.J. (2012). Evaluation of heterosis in pearl millet under rainfed condition. *International Journal of Plant Sciences*, (Muzaffarnagar), **7(1)**, 74-78.

Deshmukh, D.S., Pawar B.R., Yeware P.P. and Landge V.U. (2010). Consumer's preference for pearl millet products. *Agriculture Update*, **5(1-2)**, 122-124.

Devos, K.M., Hanna W.W. and Ozias-Akins P. (2006). Pearl millet. Cereals and Millets, 303-323.

Galani, S.N., Madariya R.B., Parmar S.K. and Sorathiya J.S. (2022). Study of heterosis in F_1 and F_2 generations of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *The Pharma Innovation Journal*, **11(9)**, 1621-1622.

Jethva, A.S., Raval L., Madariya R.B., Mehta D.R. and Mandavia C. (2012). Heterosis for grain yield and its related characters in pearl millet. *Electronic Journal of Plant Breeding*, **3(3)**, 848-852.

Kharad, D.A., Patil D.K., Shaikh A.B., Kardile P.B. and Pawar Y. (2020). Performance of different characters of parents and hybrids, analysis of variance and heterosis studies in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Journal of Pharmacognosy and Phytochemistry*, **9(5S)**, 501-505.

Krishnan, M.R., Patel M.S. and Gami R.A. (2019). Heterosis analysis in pearl millet hybrids [*Pennisetum glaucum* (L.) R. Br.]. *Indian Journal of Agricultural Research*, **53(5)**, 572-577.

Ladumor, V.L., Mungra K.D. and Parmar S.K. (2018a). Heterosis for grain yield components in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *BioScience Trends*, **11(27)**, 3473-3477.

Nandaniya, K.U., Mungra K.D. and Sorathiya J.S. (2016). Estimation of heterosis in pearl millet [*Pennisetum glaucum* (L.)] for yield and quality traits. *Electronic Journal of Plant Breeding*, **7(3)**, 758-760.

Patel, Y.N., Patel M.S., Patel J.M., Patel N.B., Patel A.M. and Gajjar K.D. (2024). Identification of heterotic effect and combining ability in the hybrids of male sterile and restorer pearl millet [*Pennisetum glaucum* (L.) R. Br.] Lines. *International Journal of Advanced Biochemistry Research*, **8(5)**, 302-309.

Sharma, S.K., Solanki K.L. and Gupta P.C. (2023a). Heterosis for grain yield and its components in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Annals of Arid Zone*, **62(2)**, 141-145.

Suryawanshi, M.B., Deore G.N., Gavali R.K., Shinde G.C., Karvar S.H., Langi A.M. and Banik M. (2021). Heterosis analysis for grain yield components in pearl millet [*Pennisetum glaucum* (L.) R. Br.)]. *Journal of Pharmacognosy and Phytochemistry*, **10(1)**, 1878-1881.

Velu, G. (2006). Genetic variability, stability and inheritance of grain iron and zinc content in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Ph. D. Thesis, Tamil Nadu Agricultural University, Coimbatore, India.