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Heterosis Studies for Grain Yield and its Contributing Traits in Pearl millet (*Pennisetum glaucum* (L.) R. Br.) under Different Sowing Conditions

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ABSTRACT

In the present study, 20 diverse male parents (tester) and 5 female parents (male sterile lines) were used to develop 100 crosses in line x tester design. The magnitude of heterosis over mid parent value (H), better parent (HB) and hybrid check (SH) for grain yield per plant ranged from -40.92% to 37.22%, -46.92% to 34.05% and -29% to 49.13%, respectively in data pooled over three environments, while it were ranged from -54.37% to 57.29%, -58.77% to 48.60% and -41.97% to 64.53%, respectively for dry fodder yield per plant. Out of hundred crosses, ten and eleven crosses in pooled data showed significant positive heterosis over hybrid check (SH) for grain yield per plant and dry fodder yield per plant, respectively. Out of these crosses, ICMA-843-22 x RIB-3135-18 (22.37) and ICMA-94111 x RIB- 3135-18 (19.99) found best cross on *per se* performance for grain yield and also showed significant positive heterosis over standard check (RHB-177) on pooled basis for grain yield (49.13 and 33.27), dry fodder yield per plant (46.42 and 23.39) and earliness of 50% flowering (-10.29 and -9.29), respectively, thus those crosses could be tested in multi-location programme to identify commercial hybrid.

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a nutritious, highly cross-pollinated C_4 monocot species belonging to the family *Poaceae* with protogynous condition and resilient crop in the face of climate change (Anuradha *et al.*, 2017; Sangwan *et al.*, 2019). It is mainly cultivated as a staple food crop in all around the world especially in dry and semi-dry regions of Asia, Africa and Latin America with more than 30 million hectares (Yadav and Rai, 2013). India is the largest producer of pearl millet, with about 9.1 million metric tons of grains produced from an area of 7.4 million ha (AICPMIP, 2019) with an average productivity of 1,000 kg ha^{-1} (Yadav and Rai, 2013).

It is a crop of area characterized with low and erratic rainfall (200-600 mm), high temperature, high salinity or low pH and impoverished infertile soils. Because of its tolerance to harsh growing conditions, it can be grown in areas where other cereal crops, such as wheat, maize and rice would not survive (Sangwan *et al.,* 2019). Besides, it has also a good stover value (used as animal fodder) mainly in north western India, especially in Rajasthan (Yadav and Rai, 2013).

Pearl Millet is grown most widely in India including highly stress prone areas of western Rajasthan. Among the major growing countries India is although having the largest acreage and production but its productivity is the lowest. In the last decades, efforts have been made in India to increase the productivity of pearl millet. This has been possible primarily through the development of hybrid varieties which have yield potential as high as 4000 kg ha. In spite of the proven superiority of hybrids, their impact on production in the country is by no means dramatic, this mainly because they have not been widely adopted in the principal pearl millet growing areas such as Rajasthan, where hybrid coverage is less. Tendency of farmers to use their own seed saved from the last season's crop, vast fluctuations in yield due to ecological hazards discouraging the farmers to buy costlier hybrid seed, failure of crop establishment particularly in the rainfed arid and semi-arid zones, where the crop is mainly grown, facing the difficulties in seed availability, of some of the factors coming in the way of large scale adoption of hybrids.

Pearl millet is a heterozygous and heterogeneous in nature. Due to its high degree (more than 85 %) of natural out crossing nature (Burton, 1974), it allows to develop both open-pollinated varieties (OPVs) and single cross hybrids by using partial and fully exploitation of heterosis (Govindaraj *et al.*, 2019). The success of heterosis breeding program in pearl millet is mainly dependent on the development of sustainable cytoplasmic genetic male sterility (CGMS) to develop diverse desirable parents (A/B and R-lines) with wider adaption (including adverse conditions) and greater diversity among them (Satyavathi *et al.*, 2013). Thus, wide genetic variability would be useful to attempt crossing program for these nutritional traits and detect heterotic individuals.

Continued improvement in the yield potential of varieties and hybrids of crop plants depends on selection of parents in hybridization programme. Advancement and diversification of hybrids in pearl millet is a continuous process (Pethani and Kapoor, 1985). The scope for exploitation of hybrid vigour depends on the direction and magnitude of heterosis in the crosses of newly developed parents.

Materials and Methods

The experimental material for the present study *i.e.* 100 single cross hybrids (F_1`s) generated by crossing 20 genetically diverse inbred lines (male parents) with 5 male sterile lines (female parents) in Line x Tester mating design during *Summer*, 2018 at RARI, Durgapura and further, the parents along with their 100 F_1's and two hybrid checks namely, HHB-67 and RHB-177 were evaluated in randomized block design with three replications with three different dates of sowing *viz.*, early sowing (E_1 – 15th June), normal sowing (E_2 – 1st July) and late sowing (E_3 – 16th July) at RARI, Durgapura, Jaipur, Rajasthan, India during *Kharif*, 2018. In each environment, plot of parents and F_1's consisted of two rows of 5 meter length with the spacing of 50 cm between rows and 15 cm between plants. Normal and uniform cultural operations were followed during the crop season to raise a good crop. To offset the competition effect of hybrids, the inbreds and hybrids were separately blocked within each replication (Arunachalam, 1974). Non-experimental rows planted all around the experiment to safe guard stay animals and birds away. Recommended agronomic practices work followed for raising the crop. Ten competitive plants in parents and F_1's were selected randomly were tagged before flowering in each plot of every replication for recording observations for all the characters *viz*., plant height, number of effective tillers per plant, ear length and girth, flag leaf area, dry fodder yield per plant, grain yield per plant, Grain density (no. of grains/ cm squares), 1000-grain weight and harvest index and averaged to obtain the plot mean except, days to 50 % flowering and days to maturity, which were data recorded on plot basis. The mean value of each plot was used for statistical analysis. Analysis of variance for all the characters was done as described by Panse and Sukhatme, (1985) separately for individual as well as for pooled over environments to determine the significance of differences between genotypes, environments and genotype x environment interaction effects. The percentages of heterosis in F_1 over the mid-parent (MP) and better parent (BP) were calculated using standard formulae.

For each cross combination, relative mid-parent heterosis (H) and better-parent heterosis (HB) were calculated as $H = 100\times(F_1 - MP)/MP$ and $HB = 100\times(F_1 - BP)/BP$ respectively. The significance of the heterosis value was identified by the t-test using the error variance of the experiment for all the characters in individual as well as pooled over environments. The significant superiority of hybrid mean was tested by comparing it with the mean performance of the check hybrid HHB-67 and RHB-177, referred as standard heterosis (SH). The mean performance of hybrids one $CD_{0.05}$ above the best control hybrid was used as a criterion to test their significance.

Results and Discussion

The pooled analysis of variance over different sowing dates revealed highly significant differences among parents and F_1's for all the characters studied, indicating the material may therefore, be considered as diverse enough for the study planned. Significant differences among sowing dates were also observed, indicating the differential influence of environment on the character expression. The genotype x environment interaction was found significant for all characters, indicating existence of non-linear response of genotype to the varying environments.

The possibility of commercial exploitation of hybrid vigor depends on the magnitude of heterosis and feasibility of hybrid seed production. Pearl millet is a cross-pollinated crop and a mechanism of cytoplasmic genetic male sterility is available to produce hybrid seed on a commercial scale. Therefore, the heterosis *per se* is of economic importance in this crop.

In some cases, crosses with high mid-parent and better-parent heterosis may be found to be inferior to the existing commercial check hybrids. This is attributed to the poor yielding ability of the parents involved in the crosses. In such cases, mid-parent and better-parent heterosis do not hold any economic promise. The check hybrid RHB 177 was considered as the best check to estimate standard heterosis for grain yield as well as for other characters. Therefore, it leads to suggest that the heterosis over the check hybrid (standard heterosis or economic heterosis) should be considered as the most reliable guide for the commercial exploitation of heterosis.

The magnitude of heterosis over mid parent value (H), better parent (HB) and hybrid check (SH) for grain yield per plant ranged from -40.92% (ICMA-04999 x RIB-15185) to

37.22% (ICMA-94111 x RIB-3135-18), -46.92% (ICMA-04999 x RIB-15185) to 34.05% (ICMA-94111 x RIB-3135-18) and -29% (ICMA-04999 x RIB-15185) to 49.13% (ICMA-843-22 x RIB-3135-18), respectively on pooled basis (Table 2). Out of hundred crosses, seventeen, nine and ten crosses in pooled data showed significant positive heterosis over mid parent value (H), better parent (HB) and hybrid check (SH), respectively for grain yield per plant. Out of ten crosses, ICMA-843-22 x RIB-3135-18, ICMA-93333 x RIB-15270, ICMA-93333 x RIB-15259 were best crosses showed significant positive heterosis over standard check (RHB-177) on pooled basis for grain yield per plant.

The magnitude of heterosis over mid parent value (H), better parent (HB) and hybrid check (SH) for dry fodder yield per plant ranged from -54.37% (ICMA-93333 x RIB-15159) to 57.29% (ICMA-94111 x RIB-494), -58.77% (ICMA-93333 x RIB-15159) to 48.60% (ICMA-94111 x RIB-494) and -41.97% (ICMA-04999 x RIB-15185) to 64.53% (ICMA-843-22 x RIB-192), respectively in data pooled over three environments (Table 2 & 3). Out of hundred crosses, thirteen, seven, eleven crosses in pooled data showed significant positive heterosis over mid parent value (H), better parent value (HB) and standard check (SH), respectively. Out of eleven, ICMA-843-22 x RIB-192, ICMA-843-22 x RIB-3135-18 and ICMA-94111 x RIB-494 were best among the eleven crosses showed significant positive heterosis over standard check (RHB-177) on pooled basis (Table 3).

The results of the present investigation revealed that the relative heterotic expression was fairly high for flag leaf area (20.18 to 108.64), grain density (11.03 to 83.90), plant height (17.20 to 75.10), 1000-grain weight (13.91 to 74.17), harvest index (-29.36 to 66.08), ear girth (17.52 to 65.51), dry fodder yield (-54.37 to 57.29), number of effective tillers per plant (-66.98 to 55.64), ear length (-21.53 to 45.09), grain yield per plant (-40.92 to 37.22), days to 50% flowering (-18.86 to 4.50) and days to maturity (-10.39 to 1.43) on pooled basis (Table 2).

Maximum desirable heterobeltiosis was 95.59% for flag leaf area, 82.79% for grain density, 70.37% for plant height, 68.24% for 1000-grain weight, 63.20% for harvest index, 53.29% for ear girth, 48.60% for dry fodder yield per plant, 44.57% for ear length, 42.67% for number of effective tillers per plant, 34.05% for grain yield per plant, -18.86% for days to 50% flowering and -10.52% for days to maturity on pooled basis.

The results are in conformity with the observations of several workers. High estimates of relative heterosis and heterobeltiosis have been reported earlier for plant height (Vetriventhan *et al.,* 2008; Nandaniya *et al.,* 2016); days to 50 % flowering (Vetriventhan *et al.,* 2008; Patel *et al.,* 2016; Badhe *et al.,* 2018); ear length (Vagadiya *et al.,* 2010; Jethva *et al.,* 2012); ear girth (Nandaniya *et al.,* 2016); flag leaf area (Jethva *et al.,* 2012); dry fodder yield (Jethva *et al.,* 2012; Patel *et al.,* 2016; Badhe *et al.,* 2018); grain yield (Jethva *et al.,* 2012; Nandaniya *et al.,* 2016; Patel *et al.,* 2016; Badhe *et al.,* 2018); 1000-grain weight (Jethva *et al.,* 2012); and harvest index (Jethva *et al.,* 2012; Nandaniya *et al.,* 2016).

Moderate relative heterosis and heterobeltiosis were observed for plant height (Vetriventhan *et al.,* 2008); ear length (Vetriventhan *et al.,* 2008; Badhe *et al.,* 2018); number of effective tillers per plant (Badhe *et al.,* 2018); 1000-grain weight (Nandaniya *et al.,* 2016) and grain yield (Dhuppe *et al.,* 2005; Vetriventhan *et al.,* 2008; Jethva *et al.,* 2012).

Table.1 ANOVA for grain yield and its components based on data pooled over environments

Source of variation	Mean squares												
	d.f.	Days to 50% flowering	Days to maturity	Plant height	No. of effective tillers / plant	Ear length	Ear-Girth	Flag leaf Area	Dry Fodder yield / plant	Grain yield / plant	Grain Density	1000-grain weigh	Harvest index
Env.	2	6119.51**	5230.84**	160448.75**	5.3**	985.77**	35.55**	92755.19**	84640.83**	11513.72**	3646.07**	1159.53**	12528.52**
Replication(r)	6	3.75	3.45	94.33	0.20*	3.44	0.03	35.41	27.75	14.18	14.21	0.75	14.99
Genotype (G)	124	39.20**	34.72**	5262.99**	2.64**	52.22**	0.60**	2268.61**	665.27**	45.31**	232.46**	15.88**	204.12**
Parents (P)	24	67.48**	71.08**	1155.00**	5.89**	118.28**	0.08**	646.06**	1156.84**	31.54**	144.15**	2.45*	252.44**
Hybrids (H)	99	13.58**	11.17**	426.49**	0.62**	20.82**	0.09**	1145.87**	506.72**	48.91**	76.98**	5.30**	179.22**
P vs H	1	1947.49**	1540.33**	592341.85**	128.95**	1638.48**	64.71**	154606.56**	4881.40**	12.30**	18056.35**	1407.11**	1559.35**
G x E	252	13.26**	10.88**	278.73**	0.42**	7.37**	0.05**	677.66**	232.40**	26.39**	38.42**	3.31**	85.03**
Error	756	3.99	3.57	179.80	0.09	3.47	0.02	233.38	25.86	6.05	15.60	1.47	18.71

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

Table.2 Range of heterosis and number of desirable crosses for grain yield and its contributing characters based on pooled over environments

Characters	Range of heterosis (%)			Number of crosses showing desirable significant heterosis		
	H	HB	SH	H	HB	SH
Days to 50% flowering	(-)18.86 — 4.50	(-)18.86 — 4.33	(-)10.29 — (-)7.28	70	76	5
Days to maturity	(-)10.39 — 1.43	(-)10.52 — 2.41	(-)4.49 — 3.15	67	74	1
Plant height	17.20 — 75.10	7.77 — 70.37	14.00 — 22.23	100	87	29
No. of effective tillers / plant	(-)66.98 — 55.64	(-)71.81 — 42.67	(-)38.27 — (-)32.72	3	2	0
Ear length	(-)21.53 — 45.09	(-)35.05 — 44.57	(-)30.91 — 17.01	51	7	1
Ear girth	17.52 — 65.51	2.04 — 53.29	10.19 — 20.95	100	100	27
Flag leaf Area	20.18 — 108.64	18.17 — 95.59	(-)29.99 — (-)23.53	87	76	0
Dry Fodder yield / plant	(-)54.37 — 57.29	(-)58.77 — 48.60	(-)41.97 — 64.53	13	6	12
Grain yield / plant	(-)40.92 — 37.22	(-)46.92 — 34.05	(-)29.00 — 49.13	17	9	10
Grain Density	11.03 — 83.90	(-)27.52 — 82.71	(-)26.18 — (-)20.89	82	60	0
1000-grain weight	13.91 — 72.17	14.34 — 68.24	24.28 — 43.09	97	92	38
Harvest index	(-)29.36 — 66.08	(-)44.11 — 63.20	(-)34.31 — 37.56	53	32	15

Table.3 Estimates of heterosis (H), heterobeltiosis (HB), and standard heterosis (SH) for dry fodder yield per plant and grain yield per plant data pooled over three environments

SN	Crosses	Grain yield /plant (g)				Dry fodder yield/plant (g)			
		Mean	H	HB	SH	Mean	H	HB	SH
1	ICMA 93333 X RIB-192	15.6	-11.92*	-22.76**	4.00	33.43	-5.74	-30.45**	-7.14
2	ICMA 93333 X RIB-494	15.46	-7.28	-23.43**	3.07	28.02	-28.01**	-41.71**	-22.17
3	ICMA 93333 X RIB-3135-18	16.85	-4.01	-16.55**	12.33	32.78	-19.02**	31.80**	-8.94
4	ICMA 93333 X RIB-135071	12.48	-26.93**	-38.17**	-16.8	25.88	-36.90**	-46.15**	-28.11*
5	ICMA 93333 X MIR-525-2	18.53	4.39	-8.22	23.53	36.47	-11.79*	-24.13**	1.31
6	ICMA 93333 X RIB-155076	16.05	-7.29	-20.48**	7.00	27.52	-34.95**	-42.74**	-23.56*
7	ICMA 93333 X RIB-155137	16.74	-5.67	-17.06**	11.60	29.32	-35.82**	-38.99**	-18.56
8	ICMA 93333 X RIB-155147	15.69	-9.08	-22.26**	4.60	29.98	-23.59**	-37.63**	-16.72
9	ICMA 93333 X J-2290	13.88	-24.42**	-30.23**	-6.07	27.67	-27.65**	-33.70**	-11.47
10	ICMA 93333 X J-2340	15.32	0.30	-5.30	27.47*	24.56	-13.40*	-28.57**	-4.64
11	ICMA 93333 X H-77/833-2	17.75	-11.50*	-16.57**	12.33	32.51	-38.27**	-47.11**	-29.36*
12	ICMA 93333 X RIB-15153	12.96	-19.48**	-31.24**	-7.47	23.25	-41.62**	-42.43**	-23.14*
13	ICMA 93333 X RIB-15159	17.02	-14.70**	-24.12**	2.13	34.7	-54.37**	-58.77**	-31.78**
14	ICMA 93333 X RIB-15181	15.43	-2.34	-12.05*	18.33	30.47	-44.33**	-52.69**	-9.69
15	ICMA 93333 X RIB-15185	13.17	-35.19**	-35.78**	-13.60	37.11	-44.85**	-51.63**	-35.42**
16	ICMA 93333 X RIB-15197	14.09	-11.99*	-15.68**	13.47	31.87	-23.56**	-27.81**	-3.61
17	ICMA 93333 X RIB-15217	19.12	-15.54**	-23.58**	2.87	34.33	-25.12**	-36.62**	-15.36
18	ICMA 93333 X RIB-15243	16.85	-23.32**	-34.76**	-12.20	25.43	-3.47	-22.79	3.08
19	ICMA 93333 X RIB-15259	19.27	7.97	-4.54	28.47*	32.33	-19.79**	-32.73**	-10.19
20	ICMA 93333 X RIB-15270	20.77	11.85*	2.89	38.47**	37.68	-9.05	-21.62**	4.67
21	ICMA-843-22 x RIB-192	19.05	12.82*	2.71	27.00*	59.23	32.31**	-11.16**	64.53**
22	ICMA-843-22 x RIB-494	16.9	6.63	-8.86	12.67	39.29	-18.53**	-41.07**	9.14
23	ICMA-843-22 x RIB-3135-18	22.37	33.72**	20.62**	49.13**	52.71	5.89	-20.93**	46.42**
24	ICMA-843-22 x RIB-135071	14.99	-7.81	-19.16**	-0.07	38.57	-23.34**	-42.14**	7.14
25	ICMA-843-22 x MIR-525-2	18.28	7.97	-1.44	21.87	48.18	-4.87	-27.73**	33.83**
26	ICMA-843-22 x RIB-155076	14.57	-11.69	-21.45**	-2.87	39.05	-24.34**	-41.43**	8.47
27	ICMA-843-22 x RIB-155137	14.12	-16.60	-23.87**	-5.87	29.9	-45.63**	-55.16**	-16.94
28	ICMA-843-22 x RIB-155147	13.85	-15.78*	-25.34**	-7.67	28.21	-41.87**	-57.68**	-21.64
29	ICMA-843-22 x J-2290	12.76	-19.39**	-22.55**	-4.27	30.38	-38.76**	-51.00**	-9.25
30	ICMA-843-22 x J-2340	15.12	-11.59*	-1305*	7.47	32.95	-6.56	-31.40**	27.03*
31	ICMA-843-22 x H-77/833-2	14.38	-14.04*	-15.58*	4.33	33.56	-17.72**	-37.69**	15.39
32	ICMA-843-22 x RIB-15153	11.82	-22.27	-31.19**	-14.93	42.92	-46.43**	-54.43**	-15.61
33	ICMA-843-22 x RIB-15159	14.54	-11.8*	-18.48**	0.80	41.84	-47.79**	-50.58**	-8.47
34	ICMA-843-22 x RIB-15181	12.62	17.13**	-22.43**	-4.13	45.8	-50.42**	-51.16**	-6.78
35	ICMA-843-22 x RIB-15185	14.91	-38.37**	-40.35**	-21.2	31.91	-16.60**	-35.62**	19.22
36	ICMA-843-22 x RIB-15197	14.36	-21.51**	-21.62**	-3.07	32.67	-23.50**	-37.23**	16.22
37	ICMA-843-22 x RIB-15217	16.12	-27.64**	-31.94**	-15.87	45.73	-8.39*	-31.30**	27.22*
38	ICMA-843-22 x RIB-15243	15.65	-8.85	-19.60**	-0.6	41.54	-33.16**	-52.13**	-11.36
39	ICMA-843-22 x RIB-15259	15.53	-8.80	-16.26**	3.53	34.08	-31.30**	-48.88**	-5.33
40	ICMA-843-22 x RIB-15270	17.73	-0.14	-4.42	18.20	45.25	-10.80**	-32.13**	25.69*
41	ICMA-97111 x RIB-192	14.74	-0.38	-9.41	-1.73	42.31	38.47**	10.62	17.53
42	ICMA-97111 x RIB-494	16.13	9.63	-0.89	7.53	36.38	6.96	-4.89	1.06
43	ICMA-97111 x RIB-3135-18	18.65	19.64**	14.62*	24.33	39.78	11.82*	3.99	10.5

44	ICMA-97111 x RIB-135071	17.42	15.17*	7.04	16.13	25.92	-28.22**	-32.24**	-28.00*
45	ICMA-97111 x MIR-525-2	13.75	-12.94*	-15.53*	-8.33	30.87	-15.28**	-19.30**	-14.25
46	ICMA-97111 x RIB-155076	14.36	-6.50	-11.77	-4.27	32.78	-12.37*	-14.31*	-8.94
47	ICMA-97111 x RIB-155137	15.24	-3.48	-6.35	1.60	24.38	-40.21**	-43.70**	-32.28**
48	ICMA-97111 x RIB-155147	15.39	0.56	-5.45	2.60	33.93	-1.16	-11.31	-5.75
49	ICMA-97111 x J-2290	13	-22.05**	-23.90**	-13.33	35.11	-10.32	-12.31*	-2.47
50	ICMA-97111 x J-2340	15.67	-8.4	-12.63	4.47	39.84	14.69*	4.14	10.67
51	ICMA-97111 x H-77/833-2	15.73	-7.87	-12.00	4.87	45.91	26.55**	20.00**	27.53*
52	ICMA-97111 x RIB-15153	16.37	7.12	0.57	9.13	32.04	-24.62**	-31.47**	-11.00
53	ICMA-97111 x RIB-15159	13.68	-14.54*	-15.97*	-8.80	28.96	-40.79**	-51.38**	-19.56
54	ICMA-97111 x RIB-15181	18.08	11.41	11.05	20.53	32.46	-39.32**	-52.77**	-9.83
55	ICMA-97111 x RIB-15185	15.12	-16.25**	-23.74**	0.80	21.21	-43.08**	-44.57**	-41.08**
56	ICMA-97111 x RIB-15197	14.03	-19.32**	-24.16**	-6.47	38.29	-5.44	-10.38	6.36
57	ICMA-97111 x RIB-15217	16.79	2.94	2.73	11.93	40.15	12.18*	4.93	11.53
58	ICMA-97111 x RIB-15243	14.95	-1.82	-8.18	-0.33	44.5	32.70**	16.34**	23.61*
59	ICMA-97111 x RIB-15259	14.29	-10.09	-12.21	-4.73	37.87	6.97	-1.00	5.19
60	ICMA-97111 x RIB-15270	16.97	2.15	0.10	13.13	40	9.50	4.57	11.11
61	ICMA-04999 x RIB-192	17.41	10.71	7.30	16.07	36.19	9.54	-16.24**	0.53
62	ICMA-04999 x RIB-494	14.23	-3.15	-12.31	-5.13	30.45	-16.56**	-29.52**	-15.42
63	ICMA-04999 x RIB-3135-18	15.53	-0.21	-4.24	3.53	34.06	-10.49	-21.17**	-5.39
64	ICMA-04999 x RIB-135071	11.6	-23.22**	-28.53**	-22.67	30.95	-19.78**	-28.36**	-14.03
65	ICMA-04999 x MIR-525-2	15.87	0.66	-2.16	5.80	26.5	-31.88**	-38.65**	-26.39*
66	ICMA-04999 x RIB-155076	16.51	7.67	1.77	10.07	28.26	-29.13**	-34.58**	-21.5
67	ICMA-04999 x RIB-155137	14.37	-8.88	-11.44	-4.20	24.83	-42.58**	-42.66**	-31.03**
68	ICMA-04999 x RIB-155147	12.55	-17.84**	-22.62**	-16.33	20.89	-43.23**	-51.64**	-41.97**
69	ICMA-04999 x J-2290	15.67	-5.90	-8.28	4.47	23.45	-43.66**	-45.73**	-34.86**
70	ICMA-04999 x J-2340	17.05	-0.18	-4.94	13.67	24.99	-32.85**	-42.16**	-30.58**
71	ICMA-04999 x H-77/833-2	12.21	-28.37**	-31.68**	-18.60	25.71	-33.66**	-40.49**	-28.58*
72	ICMA-04999 x RIB-15153	15.56	1.96	-4.12	3.73	32.82	-27.03**	-29.80**	-8.83
73	ICMA-04999 x RIB-15159	11.46	-28.28**	-29.36**	-23.60	25	-51.35**	-58.03**	-30.56**
74	ICMA-04999 x RIB-15181	11.65	-28.10**	-28.21**	-22.33	29.2	-47.81**	-57.50**	-18.89
75	ICMA-04999 x RIB-15185	10.65	-40.92**	-46.29**	-29.00*	24.44	-38.47**	-43.42**	-32.11**
76	ICMA-04999 x RIB-15197	14.06	-19.00**	-23.97**	-6.27	31.4	-26.92**	-27.32**	-12.78
77	ICMA-04999 x RIB-15217	14.14	-13.15*	-13.47	-5.73	25.59	-33.12**	-40.77**	-28.92*
78	ICMA-04999 x RIB-15243	14.93	-1.72	-7.95	-0.47	28.78	-20.09**	-33.38**	-20.06
79	ICMA-04999 x RIB-15259	15.1	-4.82	-6.90	0.67	22.1	-41.66**	-48.85**	-38.61**
80	ICMA-04999 x RIB-15270	14.44	-12.99*	-14.87*	-3.73	25.71	-34.06**	-40.49**	-28.58*
81	ICMA-94111 x RIB-192	18.33	24.51**	20.42**	22.2	42.79	51.88**	27.81**	18.86
82	ICMA-94111 x RIB-494	16.27	18.86*	14.4	8.47	49.75	57.29**	48.60**	38.19**
83	ICMA-94111 x RIB-3135-18	19.99	37.22**	34.05**	33.27*	44.42	33.84**	32.69**	23.39*
84	ICMA-94111 x RIB-135071	19.03	34.95**	33.79**	26.87*	35.76	6.05	5.29	-0.67
85	ICMA-94111 x MIR-525-2	17.12	15.93*	11.81	14.13	39.42	15.75*	13.84*	9.50
86	ICMA-94111 x RIB-155076	18.5	29.06**	28.07**	23.33	37.83	8.03	3.48	5.08
87	ICMA-94111 x RIB-155137	16.47	11.56	7.59	9.80	45.5	18.51**	5.06	26.39*
88	ICMA-94111 x RIB-155147	14.19	-0.59	-0.98	-5.40	37.82	18.40**	12.96	5.06
89	ICMA-94111 x J-2290	12.91	-17.54**	-24.45**	-13.93	28.35	-22.86**	-29.18**	-21.25
90	ICMA-94111 x J-2340	17.97	11.78	0.22	19.80	35.03	8.29	4.64	-2.69
91	ICMA-94111 x H-77/833-2	19.58	22.01**	9.53	30.53*	30.28	-10.65	-11.72	-15.89

92	ICMA-94111 x RIB-15153	15.41	8.13	7.88	2.73	32.29	-19.50**	-32.92**	-10.31
93	ICMA-94111 x RIB-15159	19.64	31.14**	24.84**	30.93*	44.48	-4.39	-25.32**	23.56*
94	ICMA-94111 x RIB-15181	15.56	2.39	-3.79	3.73	37.83	-25.95**	-44.94**	5.08
95	ICMA-94111 x RIB-15185	17.65	3.67	-10.98	17.67	28.79	-17.43**	-20.60**	-20.03
96	ICMA-94111 x RIB-15197	19.22	17.49**	3.92	28.13*	31.44	-17.47**	-26.40**	-12.67
97	ICMA-94111 x RIB-15217	18.74	22.62**	14.66*	24.93	25.4	-23.94**	-24.13**	-29.44*
98	ICMA-94111 x RIB-15243	16.89	19.01**	18.78*	12.60	31.42	0.88	-6.14	-12.72
99	ICMA-94111 x RIB-15259	15.49	4.16	-0.16	3.27	31.94	-3.28	-4.61	-11.28
100	ICMA-94111 x RIB-15270	16.6	6.51	-2.07	10.67	36.63	7.33	5.33	1.75
	S.E.D	15.89	1.00	1.16		35.15	2.07	2.39	
	CD 5%	1.14	1.97	2.27		5.62	4.07	4.7	
	CD 1%	3.17	2.59	2.99		15.6	5.36	6.19	

Among the characters, maximum number of crosses with significant desirable standard heterosis was found in plant height, ear girth, test weight, harvest index, dry fodder yield per plant and grain yield per plant. When crosses were compared individually for each character, highest desirable heterotic expression (over superior check hybrid) was for dry fodder yield per plant (64.53) in cross ICMA- 843-22 x RIB-192 followed by grain yield per plant (49.13) in cross ICMA-843-22 x RIB-3135-18; 1000-grain weight (43.09) in cross ICMA-94111 x RIB-494; harvest index (37.56) in cross ICMA-94111 x RIB-15217; plant height (22.23) in cross ICMA-93333 x RIB- 15243; ear girth (20.95) in cross ICMA-93333 x RIB- 15185. Earliness is the desirable character, and therefore, in the present study the cross ICMA-94111 x RIB-3135-18 is early in maturity and the crosses ICMA- 843-22 x RIB-3135-18, ICMA- 843-22 x RIB-155137 and ICMA- 9711 x RIB-3135-18 were considered very desirable as it showed standard heterosis for earliness in flowering.

High estimation of standard heterosis has been reported plant height (Vetriventhan *et al.*, 2008; Patel *et al.*, 2016; Salagarkar and Wali, 2016; Badhe *et al.*, 2018); number of effective tillers and 1000-grain weight (Jethva *et al.*, 2012); harvest index (Kumar *et al.*, 2017); dry fodder yield (Jethva *et al.*, 2012; Badhe *et al.*, 2018); and grain yield (Jethva *et al.*, 2012; Kumar *et al.*, 2017; Badhe *et al.*, 2018; Kumawat *et al.*, 2019). In the pooled analysis, 10 crosses showed significant positive standard heterosis for grain yield per plant (Table 3.). These 10 crosses viz., ICMA-843-22 x RIB-3135-18, ICMA-93333 x RIB-15270, ICMA-94111 x RIB- 3135-18, ICMA-94111 x RIB-15159, ICMA-94111 x H-77/833-2, ICMA-93333 x RIB-15259, ICMA-94111 x RIB-15197, ICMA-93333 x J-2340, ICMA-843-22 x RIB-192 and ICMA-94111 x RIB-135071 have high *per se* performance. Above crosses were also found to be superior in there *per se* performance for various contributing traits. Out of these crosses in *per se* performance for grain yield per plant, cross ICMA-843-22 x RIB-3135-18 and ICMA-94111 x RIB- 3135-18 having high positive standard heterosis for grain yield per plant as well as dry fodder yield per plant and earliness of 50% flowering while cross ICMA 93333 x RIB-15270 having high positive standard heterosis for grain yield per plant only, thus these crosses could be tested in multi-location to identify commercial hybrid.

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