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Research Article

Heterosis and combining ability in diverse A and R lines of pearl millet tested in Western Rajasthan

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Abstract
The present study was conducted to estimate the combining ability and heterosis in pearl millet hybrids. Forty five pearl millet hybrids were developed using three male sterile lines (A line) with fifteen restore lines (R line) through the Line x Tester mating approach and were evaluated during *kharif,* 2018. Analysis of variance revealed that the mean square of treatments showed significance for all the traits. For days to 50 % flowering and days to maturity, lines *viz*., ICMA 93333, ICMA 97111, BIB 186, BIB 193 and BIB 281 had negative *gca* effect so these lines can be used as parents for hybrid development under harsh environmental conditions. Based on *sca* effect, heterosis and *per se* performance, crosses ICMA 97111 x BIB 208, ICMA 93333 x BIB 186 and ICMA 88004 x BIB 283 were identified as potential crosses for commercial exploitation of heterosis in pearl millet.

Keywords: Pearl millet, male sterile lines, Line x Tester, Combining ability and heterosis

INTRODUCTION

Among all the millet species, Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the most widely grown for grain and fodder purpose in the arid and subtropical regions of the world and some part of temperate regions also. It is an important *kharif* crop particularly in rainfed areas. It belongs to the family *Poaceae*, which is originated in Africa. It is an annual, C_4 and diploid with 12 basic chromosomes. The flowering pattern in it is protogyneous which assures a high degree of cross-pollination. It can be grown in a wide range of soils but does not prefers acidic and water logging soils. Pearl millet can grow in a wide range of ecological conditions like drought stress and high temperature (Acharya *et al*., 2017). In Asia, pearl millet is the most important cereal crop, which is grown widely in India, Pakistan, Syria, Myanmar and Saudi Arabian arid and semi-arid regions. It contains carbohydrates (60-78%), proteins (11.5%), lipids (5%) with micronutrients like iron (2.80%), vitamins and mineral components along with some anti-nutritional factors. India is a major pearl millet producing country with 43.3 per cent of the world area and 42 per cent of world production (Reifschneider and Hussain, 2004). It is grown most extensively as a grain, forage uses and fuel for cooking, particularly in dryland areas.

A major revolution in productivity and over-all production of pearl millet was detected when the release of hybrids in the sixties. To overcome the problem of volatility in productivity and production, it will be wise to advance a wide range of hybrids and varieties. For improving the grain yield potential of pearl millet varieties/hybrids selection of desirable parents, which have good general combiners are a prerequisite (Kumar *et al*., 2020). First time in the year 1942, Sprague and Tatum elaborated on the concept of general combining ability (GCA) and specific combining ability (SCA) and defined it as the relative ability of a biotype to transmit a desirable performance to its crosses. The most common approach used to measure the general and specific combining ability is Top cross method (Jenkins and Brunson, 1932), Polycross (Tysdal *et al*., 1942), Diallel mating design or their modifications (Griffing, 1956; Kempthorne and Curnow, 1961; Rawlings and Cockrham, 1962), Line x Tester method (Kempthorne, 1957).

Heterosis refers to an increase of F_1 in fitness and vigor over the parental values, which was first time reported by Koelreuter (1766) and a term coined by Shull (1914). Efficient exploitation of heterosis is important for successful hybrid breeding in pearl millet. The general expectation of pearl millet growing farmers is the yield superiority over the local varieties so that can generate more income. Therefore, there is a compulsory need for the breeder to evaluate the newly developed hybrids/varieties with standard checks for yield or any other desirable characters (Sumathi and Revathi, 2017). Keeping these points in view, the present investigation was conducted to select good parents with potential heterotic gene pools, which were developed through Line x Tester mating design.

MATERIALS AND METHODS

The study was conducted at Agricultural Research Station, SKRAU, Bikaner, during *kharif*, 2018, which falls under Agro-Climate Zone IC of Rajasthan where average rainfall is about 260 mm, mostly received during July-September. The experimental material for the study consisted of 45 hybrids developed by three male sterile lines (A line) and the fifteen restorers lines(R line) through Line x Tester approach and three check hybrids (**Table 1**). The experimental material was laid out in a Randomized Block Design with three replications during *kharif,* 2018 with 60 cm x 15 cm plant geometry. Genotypes were grown in a single row with 20 plants with a plot size of 3 m^2. Normal and uniform cultural operations were followed during the crop season to raise a good crop.

The observations were recorded on an individual plant basis on 10 randomly selected plants from each replication for ten traits *viz.,* plant height, the number of effective tillers per plant, ear head diameter, ear head length, test weight, biological yield per plant, harvest index and seed yield per plan, while two characters namely days to 50 % flowering and days to maturity were recorded on a whole plot basis. Analysis of variance for all the treatments was carried out by Panse and Sukhtame (1967) and combining ability analysis and the testing of significance of different genotypes was based on the procedure given by Kempthorne (1957). Economic Heterosis/Standard Heterosis was calculated on the check hybrid HHB 67 as per the procedure suggested by Briggle (1963). Heterosis in a positive direction was considered desirable for all the characters except traits like days to 50 % flowering and days to maturity.

RESULTS AND DISCUSSION

Analysis of variance exhibited significant differences among the hybrids for all the characters indicating the presence of good amount of variability among the hybrids for all the characters (**Table 2**). Analysis of variance for combining ability indicated that the variance due to *sca* was higher than *gca* for all the traits (**Table 2**). Results were in accordance with Yadav *et al.* (2005) and Solanki *et al.* (2017).

Table 1. Experimental materials and their sources used for present study

Genotypes	Source	Genotypes	Source
ICMA 88004	ICRISAT, Hyderabad	BIB 281	SKRAU, Bikaner
ICMA 93333	ICRISAT, Hyderabad	BIB 283	SKRAU, Bikaner
ICMA 97111	ICRISAT, Hyderabad	BIB 339	SKRAU, Bikaner
BIB 180	SKRAU, Bikaner	BIB 228	SKRAU, Bikaner
BIB 183	SKRAU, Bikaner	BIB 241	SKRAU, Bikaner
BIB 186	SKRAU, Bikaner	BIB 248	SKRAU, Bikaner
BIB 193	SKRAU, Bikaner	BIB 276	SKRAU, Bikaner
BIB 196	SKRAU, Bikaner	**Checks**	
BIB 207	SKRAU, Bikaner	HHB-67 (improved)	CCS HAU, Hisar
BIB 208	SKRAU, Bikaner	RHB-177	SKRAU, Bikaner
BIB 212	SKRAU, Bikaner	MPMH-17	AU, Jodhpur

ICMA series were male sterile line, BIB series were restorer line and rest are hybrids which were used as checks

Table 2. Analysis of variance for combining ability for different traits of pearl millet

Characters	df	DOF	DM	PH	NTP	EHL	EHD	TW	HI	BYP	SYP
Replications	2	0.78	4.71	23.09	0.05	27.12	0.035	1.03	19.48	9.36	0.49
Treatments	47	28.40**	25.01**	528.20**	0.29**	23.30*	0.10**	2.57**	90.48**	445.26**	32.03**
Crosses	44	26.35**	22.70**	519.57**	0.31**	24.75*	0.07**	2.46**	91.74**	465.91**	34.14**
Lines	2	75.38*	120.87**	244	0.07	25.26	0.045	6.45*	138.6	850.1	10.97
Testers	14	41.98*	24.59	1255.19**	0.19	34.07	0.13**	4.03**	105.81	424.77	18.21
Line x tester	28	15.04**	14.74**	171.44**	0.38**	20.06	0.04	1.39**	81.36**	459.04**	43.76**
Error	94	2.68	2.83	72.31	0.09	13.63	0.02	0.53	31.02	42.32	3.77

* Level of significance at 5%, ** level of significance at 1%

For the traits days to 50 % flowering, plant height and days to maturity, out of three female lines, one line ICMA 93333 was considered as a good general combiner and three testers *viz.,* BIB 193, BIB 186 and BIB 281 were good general combiner for days to maturity and days to 50% flowering but for PH BIB 180, BIB 212 and BIB 241 showed significant positive *gca* effect (**Table 3**). These results were comparable with the findings of Kumar *et al*. (2017) and Krishnan *et al*. (2017) who reported the additive gene action for days to maturity and days to 50% flowering. However, Patel *et al*. (2018) found that some lines are poor combiner for these traits. For the traits, the number of effective tillers per plant, ear head length, ear head diameter and seed yield per plant none of the female lines showed significant effects but in case of male lines BIB 183, BIB 186 and BIB 207 for NTP (Solanki *et al*., 2017; Kumar *et al*., 2017); BIB 283 for ear head length (Patel *et al*., 2018); BIB 193, BIB 207 and BIB

Table 3. Estimates of *gca* effects of parents for ten traits of pearl millet

Parents	DOF	DM	PH	NTP	EHL	EHD	TW	HI	BYP	SYP
Lines										
ICMA 88004	0.36	1.71**	0.20	-0.03	-0.65	0.01	-0.10	0.92	-3.54**	-0.57
ICMA 93333	-1.44**	-0.16	2.22	0.04	0.82	-0.04	-0.32**	-2.02*	4.85**	0.33
ICMA 97111	1.07**	-1.56**	-2.42*	-0.01	-0.17	0.02	0.42**	1.10	-1.31	0.23
SE±	0.58	0.77	0.91	1.03	0.65	0.69	0.55	0.50	0.86	0.66
Testers										
BIB 180	-0.93	0.78	15.07**	-0.09	2.40	-0.25**	-0.76	-4.11*	-5.34*	-2.97**
BIB 183	-0.03	1.56**	2.40	0.20*	-0.50	0.01	0.10**	-0.85	1.47	0.24
BIB 186v	-2.48**	-1.67**	-8.60	0.29**	-1.37	-0.02	-0.25	-4.46*	12.52**	0.86
BIB 193	-4.04**	-2.67**	-15.93**	-0.11	-0.90	0.18**	1.06**	-0.28	-1.70	-0.18
BIB 196	-0.59	0.22	-3.38	-0.09	-0.04	0.07	0.45	4.52*	-5.39*	0.36
BIB 207	-0.37	0.78	-12.49**	0.20*	-1.09	0.16**	0.32	1.07	-6.72**	-1.19
BIB 208	-1.59**	-0.78	-12.71**	0.17	1.50	0.07	0.29	6.31**	-7.00**	0.62
BIB 212	1.96**	0.89	7.84**	0.05	-0.62	0.17**	-0.36	-1.83	0.60	-0.68
BIB 228	3.63**	2.22**	15.06**	-0.02	0.80	-0.05	-0.61*	-3.59	9.55**	1.06
BIB 241	3.63**	2.56**	18.51**	0.09	-0.10	-0.05	-0.82**	-4.01*	13.51**	1.73**
BIB 248	-0.15	-0.67	-7.04*	-0.11	-1.16	-0.06	0.42	0.04	-2.62	-0.57
BIB 276	0.74	-0.22	-2.60	-0.04	-1.36	-0.15**	-1.00**	-0.99	-1.35	-0.64
BIB 281	-2.26**	-3.33**	-10.27**	0.07	-0.98	0.06	-0.56*	2.05	0.34	0.90
BIB 283	1.30*	-0.11	16.29**	-0.09	5.58**	-0.10	0.17	5.22**	0.13	2.51**
BIB 339	1.18*	0.44	-2.16	-0.20*	-2.15	-0.009	0.65*	0.92	-8.00**	-2.07**
SE±	1.53	2.03	2.40	2.73	1.73	1.83	1.45	1.32	2.28	1.75

* Level of significance at 5%, ** level of significance at 1%

DOF days to 50 % flowering, DM days to maturity, PH plant height, NTP number of effective tillers per plant, EHL ear head length, EHD ear head diameter, TW test weight, HI harvest index, BYP biological yield per plant, SYP seed yield per plant

212 for ear head diameter (Patel *et al*.,2018) and BIB 241 and BIB 283 for seed yield per plant (Kumar *et al*., 2017) showed positive significant *gca* effects and hence, can be used as a good combiner (**Table 3**).

In present study for significant *sca* effect (**Table 4**) in desirable direction (positive for all the traits except days to 50 % flowering, days to maturity and plant height) was reported such as seven crosses for days

Table 4. Estimates of *sca* effects for different characters of pearl millet

Crosses	DOF	DM	PH	NTP	EHL	EHD	TW	HI	BYP	SYP
ICMA 88004 x BIB 180	0.19	-1.60	5.36	0.23	-2.10	0.16	0.46	0.52	6.73	2.09
ICMA 88004 x BIB 183	0.30	-1.38	-4.31	0.61**	-1.70	-0.07	-0.39	3.29	5.89	3.21**
ICMA 88004 x BIB 186	0.74	-0.16	-8.98	-0.54**	-1.40	-0.08	-0.56	0.29	-15.17**	-2.10**
ICMA 88004 x BIB 193	0.97	-0.49	-2.98	-0.08	0.37	0.16	0.53	-3.00	-3.15	-2.16
ICMA 88004 x BIB 196	0.52	-1.71	-4.2	-0.03	0.17	-0.03	-0.35	5.95	0.70	2.11
ICMA 88004 x BIB 207	0.30	-1.27	-6.09	-0.06	-0.61	-0.09	-0.02	-3.86	-3.30	-2.69*
ICMA 88004 x BIB 208	1.86	0.96	-11.20*	-0.01	-1.70	-0.03	-0.62	-11.92**	-4.38	-5.40**
ICMA 88004 x BIB 212	-0.03	0.96	-7.09	-0.1	-1.97	0.07	-0.17	-2.55	-12.48**	-4.20**
ICMA 88004 x BIB 228	0.64	2.29*	4.69	0.17	1.00	-0.14	0	0.66	11.79**	3.55**
ICMA 88004 x BIB 241	-0.70	0.29	5.58	0.19	-0.03	-0.08	0.4	-1.78	9.77*	1.60
ICMA 88004 x BIB 248	-1.59	0.51	1.13	-0.14	-0.47	0.00	-0.1	2.34	0.02	0.76
ICMA 88004 x BIB 276	2.53**	3.40**	15.02**	-0.01	-0.14	-0.08	0.11	-6.52	5.37	-1.30
ICMA 88004 x BIB 281	0.86	1.84	3.02	-0.13	0.15	0.01	-0.32	7.98*	-8.93*	-0.11
ICMA 88004 x BIB 283	-4.70**	-3.38**	5.8	-0.17	8.96**	0.10	1.32**	6.89*	4.54	4.43**
ICMA 88004 x BIB 339	-1.10*	-0.27	4.24	0.08	0.45	0.11	-0.31	1.71	2.61	1.08
ICMA 93333 x BIB180	-0.34	-2.07*	-3.67	-0.04	2.67	-0.03	-0.01	-1.11	2.70	0.25
ICMA 93333 x BIB183	1.1.	-0.51	-0.67	-0.33	2.17	0.11	1.11*	-1.05	-0.06	-0.52
ICMA 93333 x BIB186	-1.79	-2.62**	12.33*	0.98**	0.4.	-0.03	0.34	-0.35	37.67**	8.09**
ICMA 93333 x BIB193	0.44	-0.96	3.67	0.25	0.44	-0.03	0.27	4.23	12.11*	5.49**
ICMA 93333 x BIB196	3.33**	2.49*	-0.22	-0.18	0.00	-0.02	-0.21	-1.89	-5.11	-1.80
ICMA 93333 x BIB207	1.77	0.60	-1.78	0.27	0.22	0.00	-0.11	-1.69	-4.27	-1.65
ICMA 93333 x BIB208	0.66	-0.18	-0.22	-0.15	-2.11	0.01	0.14	1.56	-2.67	-0.11
ICMA 93333 x BIB212	-2.23*	-1.18	-0.11	-0.51**	-0.18	-0.15	0.05	2.80	-4.47	0.56
ICMA 93333 x BIB228	-0.56	0.82	1.33	0.09	0.40	0.14	-0.58	0.43	-4.20	-1.12
ICMA 93333 x BIB241	-1.23	-0.18	3.56	-0.02	1.17	0.002	-0.11	1.10	-3.93	-0.55
ICMA 93333 x BIB248	0.21	0.71	3.44	-0.09	0.00	-0.09	0.16	-0.14	3.14	1.04
ICMA 93333 x BIB276	-3.67**	-2.40*	-7.00	-0.02	0.26	-0.03	0.08	6.96*	-10.04**	0.16
ICMA 93333 x BIB281	-1.34	-0.29	-7.33	-0.2	-1.45	0.02	0.87*	-6.62*	-3.73	-3.47**
ICMA 93333 x BIB283	3.10**	4.49**	0.44	0.09	-4.04	0.11	-0.94*	- 6.88*	-8.54*	-5.27**
ICMA 93333 x BIB339	0.55	1.27	-3.78	-0.13	0.18	-0.009	-1.05*	2.65	-8.59*	-1.08
ICMA 97111 x BIB180	0.15	3.67**	-1.69	-0.19	-0.57	-0.12	-0.45	0.59	-9.43*	-2.35*
ICMA 97111 x BIB183	-1.41	1.89	4.98	-0.28	-0.47	-0.05	-0.72	-2.25	-5.83	-2.69*
ICMA 97111 x BIB186	1.04	2.78**	-3.36	-0.43*	1.03	0.11	0.22	0.05	-22.49**	-5.09**
ICMA 97111 x BIB193	-1.41	1.44	-0.69	-0.17	-0.81	-0.12	-0.8	-1.23	-8.95*	-3.33**
ICMA 97111 x BIB196	-3.85**	-0.78	4.42	0.21	-0.17	0.05	0.55	-4.05	4.40	-0.31
ICMA 97111 x BIB207	-2.07*	0.67	7.87	-0.21	0.38	0.10	0.13	5.56	7.57*	4.35**
ICMA 97111 x BIB208	-2.52*	-0.78	11.42*	0.17	3.89	0.02	0.48	10.36**	7.06	5.51**
ICMA 97111 x BIB212	2.26*	0.22	7.20	0.61**	2.15	0.087	0.11	-0.25	16.95**	3.63**
ICMA 97111 x BIB228	-0.07	-3.11**	-6.02	-0.26	-1.41	0.009	0.58	-1.09	-7.58*	-2.43*
ICMA 97111 x BIB241	1.93*	-0.11	-9.13	-0.17	-0.14	0.08	-0.28	0.68	-5.83	-1.05
ICMA 97111 x BIB248	1.37	-1.22	-4.58	0.23	0.48	0.09	-0.06	-2.19	-3.16	-1.80
ICMA 97111 x BIB276	1.15	-1.00	-8.02	0.03	-0.12	0.11	-0.19	-0.44	4.67	1.14
ICMA 97111 x BIB281	0.48	-1.56	4.31	0.32	1.30	-0.04	-0.55	-1.36	12.66**	3.58**
ICMA 97111 x BIB283	1.59	-1.11	-6.24	0.08	-4.92*	-0.21*	-0.38	-0.01	4.01	0.84
ICMA 97111 x BIB339	1.37	-1.00	-0.47	0.05	-0.63	-0.10	1.36**	-4.36	5.98	0.01
SE±	2.16	2.86	3.39	3.86	2.45	2.59	2.05	1.86	3.22	2.48

* Level of significance at 5%, ** level of significance at 1%

DOF days to 50 % flowering, DM days to maturity, PH plant height, NTP number of effective tillers per plant, EHL ear head length, EHD ear head diameter, TW test weight, HI harvest index, BYP biological yield per plant, SYP seed yield per plant

Table 5. Estimates of Standard Heterosis (SH) over HHB 67 for all the traits of Pearl millet hybrids (in Per cent)

Crosses	DOF	DM	PH	NTP	EHL	EHD	TW	HI	BYP	SYP
ICMA 88004 x BIB 180	-5.88	5.63	6.45	21.43	-4.67	-8.00	-18.00	-12.17	-2.97	-14.62
ICMA 88004 x BIB 183	-3.92	7.04*	-8.39	71.43*	-16.36	-8.00	-9.00	8.25	11.09	19.97
ICMA 88004 x BIB 186	-7.84	4.23	-18.06*	-7.14	-18.69	-8.00	-23.0*	-14.13	-12.48	-24.68
ICMA 88004 x BIB 193	-9.80*	2.82	-19.35*	0.00	-8.41	8.00	1.00	-11.12	-17.68	-26.36
ICMA 88004 x BIB 196	-3.92	5.63	-11.61	7.14	-5.14	-4.00	-14.00	35.35	-17.26	12.22
ICMA 88004 x BIB 207	-3.92	7.04*	-18.71*	21.43	-14.02	0.00	-12.00	-9.43	-29.83	-38.66
ICMA 88004 x BIB 208	-3.92	7.04*	-22.58**	0.00	-7.01	-4.00	-18.00	-18.99	-33.05	-45.77*
ICMA 88004 x BIB 212	0.00	9.86**	-6.45	7.14	-18.22	4.00	-20.00	-14.84	-34.2	-46.49*
ICMA 88004 x BIB 228	3.92	14.08**	5.81	21.43	2.34	-12.00	-21.0*	-9.9	44.02*	29.31
ICMA 88004 x BIB 241	1.96	11.27**	8.39	35.71	-11.21	-8.00	-19.00	-19.57	48.59*	19.09
ICMA 88004 x BIB 248	-7.84	7.04*	-10.97	-7.14	-13.55	-8.00	-11.00	8.01	-12.36	-6.07
ICMA 88004 x BIB 276	1.96	11.27**	1.29	7.14	-13.08	-12.00	-24.0*	-25.41	3.23	-23.08
ICMA 88004 x BIB 281	-5.88	5.63	-11.61	7.14	-9.81	0.00	-23.0*	33.9	-26.48	-1.28
ICMA 88004 x BIB 283	-9.80*	2.82	7.10	-7.14	62.15*	-4.00	0.00	40.89	4.76	47.84*
ICMA 88004 x BIB 339	-5.88	7.04*	-5.81	7.14	-14.02	0.00	-11.00	8.85	-18.93	-15.5
ICMA 93333 x BIB180	-9.80*	2.82	1.94	7.14	24.77	-1.01	-25.0*	-27.64	7.3	-22.04
ICMA 93333 x BIB183	-5.88	5.63	-4.52	7.14	8.88	0.00	4.00	-16.39	16.85	-2.56
ICMA 93333 x BIB186	-15.69**	-1.41	-3.23	107.14**	-3.74	-8.00	-16.00	-26.23	131.66**	71.09**
ICMA 93333 x BIB193	-13.73**	0.00	-13.55	28.57	-1.40	0.00	-4.00	3.38	38.02	42.01
ICMA 93333 x BIB196	-1.96	8.45*	-7.74	0.00	0.93	-4.00	-14.00	-1.12	-11.21	-11.98
ICMA 93333 x BIB207	-3.92	7.04*	-14.84	50.00	-3.27	0.00	-15.00	-12.10	-12.34	-23.16
ICMA 93333 x BIB208	-9.80*	2.82	-14.19	-7.14	-2.34	-4.00	-13.00	16.63	-9.25	3.67
ICMA 93333 x BIB212	-7.84	4.23	-0.65	-14.29	-2.8	-4.00	-20.00	-6.69	4.43	-1.36
ICMA 93333 x BIB228	-1.96	8.45*	5.16	21.43	6.54	-4.00	-29.0**	-20.65	26.11	-0.88
ICMA 93333 x BIB241	-1.96	8.45*	8.39	21.43	6.07	-8.00	-26.0*	-19.80	36.06	9.03
ICMA 93333 x BIB248	-7.84	4.23	-7.74	7.14	-4.67	-12.00	-11.00	-10.31	14.74	3.35
ICMA 93333 x BIB276	-13.73**	1.41	-11.61	14.29	-4.21	-12.00	-26.0*	10.21	-13.30	-4.23
ICMA 93333 x BIB281	-13.73**	0.00	-16.77*	7.14	-10.28	-4.00	-14.00	-25.41	5.53	-21.01
ICMA 93333 x BIB283	1.96	11.27**	5.16	21.43	7.94	-4.00	-25.0*	-15.58	-6.29	-22.52
ICMA 93333 x BIB339	-3.92	7.04*	-9.68	-7.14	-8.41	-8.00	-21.0*	2.10	-25.54	-25.64
ICMA 97111 x BIB180	-3.92	8.45*	0.00	-7.14	4.67	-20.0*	-22.0*	-11.29	-35.76	-43.61*
ICMA 97111 x BIB183	-5.88	7.04*	-3.87	7.14	-8.41	-4.00	-7.00	-9.87	-11.23	-20.77
ICMA 97111 x BIB186	-5.88	4.23	-16.13*	7.14	-5.14	0.00	-10.00	-14.30	-24.46	-34.98
ICMA 97111 x BIB193	-13.73**	1.41	-19.35*	-7.14	-11.68	0.00	-7.00	-4.53	-26.06	-29.31
ICMA 97111 x BIB196	-11.76*	1.41	-7.74	21.43	-4.67	0.00	1.00	2.20	-3.30	-0.80
ICMA 97111 x BIB207	-7.84	4.23	-11.61	14.29	-7.01	8.00	-5.00	22.98	1.04	23.96
ICMA 97111 x BIB208	-9.80*	0.00	-9.68	14.29	21.5	0.00	-2.00	56.94*	-0.85	47.76*
ICMA 97111 x BIB212	5.88	4.23	1.29	64.29*	3.27	8.00	-12.00	-6.45	40.32	22.44
ICMA 97111 x BIB228	3.92	1.41	-2.58	-7.14	-6.54	-4.00	-10.00	-15.21	3.65	-12.14
ICMA 97111 x BIB241	7.84	5.63	-2.58	7.14	-4.67	-4.00	-21.00*	-10.65	17.09	4.31
ICMA 97111 x BIB248	0.00	0.00	-16.13*	21.43	-7.01	-4.00	-6.00	-6.66	-14.6	-20.13
ICMA 97111 x BIB276	1.96	1.41	-15.48*	14.29	-10.75	-4.00	-21.00*	-4.26	6.83	2.88
ICMA 97111 x BIB281	-5.88	-4.23	-12.26	42.86	-2.34	-4.00	-21.00*	2.94	29.61	34.66
ICMA 97111 x BIB283	3.92	1.41	-1.94	14.29	-0.47	-16.00	-12.00	18.18	8.76	25.56
ICMA 97111 x BIB339	1.96	1.41	-10.32	7.14	-16.82	-8.00	11.00	-11.05	-5.72	-17.73
SE±	1.81	1.80	6.94	0.35	2.95	1.55	0.70	3.32	10.80	3.70

* Level of significance at 5%, ** level of significance at 1%
DOF days to 50 % flowering, DM days to maturity, PH plant height, NTP number of effective tillers per plant, EHL ear head length, EHD ear head diameter, TW test weight, HI harvest index, BYP biological yield per plant, SYP seed yield per plant

to flowering (Sushir *et al.,* 2005; Kumar *et al.,*2017), five crosses for days to maturity (Sushir *et al.,* 2005; Bhanderi *et al.,* 2007), one (Kanfany *et al.,* 2018) and three crosses (Rathore *et al.,*2004; Kumar *et al*., 2017) for plant height with negative and positive *sca* effect, respectively, three (Kanfany *et al.,* 2018) and three crosses (Rathore *et al.,* 2004; Kumar *et al*., 2017 and Kanfany *et al.,* 2018) for the number of tillers with negative and positive *sca* effect, respectively, one cross for ear head length (Krishnan *et al.,* 2017), four crosses for test weight (Kumar *et al*., 2017 and Krishnan *et al*., 2017) and harvest index (Kumar *et al*., 2017), seven crosses for biological yield (Krishnan *et al*., 2017) and nine crosses for seed yield (Sushir *et al.,* 2005; Kumar *et al*., 2017; Kanfany *et al.,* 2018).

Among all three check hybrids, HHB 67 showed better *per se* performance. Therefore, in the present study, standard heterosis was estimated for various characters over best check hybrid HHB 67 (**Table 5**). In the present study, a significant heterosis effect in the desirable direction (positive for all the traits except Days to 50 % flowering, days to maturity and plant height) was reported such as eleven crosses for days to 50 % flowering (Sheoran and Govila,1996; Karad and Harer, 2005 and Yadav,2006) and nine crosses (Rathore *et al.,* 2004; Kumar *et al*., 2017) for plant height (Kanfany *et al.,* 2018), three (Kanfany *et al.,*2018) and three crosses for the number of tillers (Chittora and Patel, 2017) and Bhasker *et al.,*2017), one cross for ear head length (Krishnan *et al.,* 2017), one cross for ear head length (Salagarkar *et al.,*2016 and Bhasker *et al.,*2017) and harvest index (Singh *et al*.,2015); Nandaniya *et al.,*2016) and Chittora and Patel (2017), three crosses for biological yield (Singh *et al*.,2015 and Kanfany *et al.,* 2018) and seed yield (Chittora and Patel, 2017; Bhasker *et al.,* 2017; Kanfany *et al.,* 2018).

Based on heterosis and combining ability effects, the selection of the parents can be done for hybridization. Likewise, the crosses can also be selected both for the handling of segregating generation with an aim to obtain transgressive segregants or for commercial exploitation of heterosis. Based on the above criteria, ICMA 97111 x BIB 208, ICMA 93333 x BIB 186 and ICMA 88004 x BIB 283 were identified as potential crosses for commercial exploitation of heterosis in pearl millet as these crosses exhibited the highest magnitude of standard heterosis and *sca* effects with good *per se* performance under drought/ low rainfall stress condition. These hybrids can be recommended for widespread cultivation in arid and semi-arid regions after evaluation in multi-location trials for increasing pearl millet production and productivity.

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