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Lipendr Kumar Saini
M.Sc. Scholar, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

KantiLal Solanki
Ph. D, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

PC Gupta
Professor, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

Harkesh Saini
M.Sc. Scholar, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

Akash Gaurav Singh
M.Sc. Scholar, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

Correspondence
Lipendr Kumar Saini
M.Sc. Scholar, Department of Plant Breeding and Genetics, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan, India

Combining ability studies for grain yield and component traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

Lipendr Kumar Saini, KantiLal Solanki, PC Gupta, Harkesh Saini and Akash Gaurav Singh

Abstract
The experiment was conducted with 56 hybrids which were generated through L × T mating design using 8 lines and 7 testers as parental material along with 2 standard check hybrids and evaluated in RBD with 3 replications during kharif 2016 season at ARS, Bikaner to study combining ability along with inheritance of grain yield and component characters of pearl millet to identify suitable parents and desirable hybrid combinations. Analysis of variance exhibited significant differences among the hybrids for all the characters. Mean sum of squares due to lines were significant for all the characters. While the mean sum of squares due to testers was significant for all the characters except no. of effective tillers and biological yield per plant which signifies that testers were diverse for these characters. The interaction effects were found to be significant for all the traits except grain yield/ plant, biological yield/plant and harvest index. It is concluded from the present investigation that the crosses JMSA 20042 × BIB 19 followed by ICMA 97111 × BIB 16, ICMA 93333 × BIB 31 and ICMA 843-22A × BIB 4 were identified as potential crosses for commercial exploitation of heterosis in pearl millet as these crosses exhibited highest magnitude of standard heterosis and *sca* effects. Thus, these hybrids can be commercially exploited through heterosis breeding programme after testing in multi locational trial for wide spread cultivation in arid part of western Rajasthan for increasing production and productivity of pearl millet.

Keywords: *Pennisetum glaucum, Combining ability*, L × T mating design, GCA, SCA

Introduction
Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is world's sixth important cereal crop after wheat, rice, maize, barley and sorghum in area and production. It is India's fourth important cereal crop after rice, wheat and sorghum.Pearl millet is an allogamous crop with wind borne pollination mechanism, which fulfils one of the essential requirements for hybrid seed development. It is classified under the family *Gramineae* (*Poaceae*) sub family *Peniceidae* and genus *Pennisetum* having chromosome number 2n=2x=14. It is believed to be originated in West Africa and from there it was introduced to India.

Pearl millet is of great importance in the arid and semi-arid tropics, where it is a staple food for millions of people and also form an important fodder crop for livestock population in arid and semi-arid regions of India. The crop is generally grown in area where environmental conditions, especially rainfall, temperature and soil fertility, are too harsh to grow other cereal crops. The improvement in pearl millet crop in India started as early as in 1920, but the real breakthrough was made when the first and the most widely used cytoplasmic genetic male sterile line Tift 23A was utilized [3], which permitted development of hybrids in India. Subsequently, availability of several cytoplasmic genetic male sterility sources has facilitated development and release of number of high yielding hybrids with increased drought tolerance and resistance to biotic stress [4].

India is the largest producer of pearl millet with an annual production of 8.06 million tonnes from an area of 7.12 million hectare with productivity of 1132 kg/ha. Pearl millet is mainly grown in the states of Rajasthan, Uttar Pradesh, Gujarat, Maharashtra, Haryana, Karnataka, Tamil Nadu, Madhya Pradesh, and Andhra Pradesh [2].

Rajasthan occupies first position in area and production of pearl millet in India. In Rajasthan, it is cultivated on 40.76 lakh hectare area with the production of 44.56 lakh tonnes and productivity of 1093 kg/ha. Major pearl millet producing districts of Rajasthan are Barmer, Jodhpur, Nagaur, Churu, Jalore, Jaipur, Sikar, Jhunjhunu, Alwar and Bikaner, Bharatpur, Karoli, Dausa, Dholpur, Sawai Madhopur, Jaisalmer [1].

It is well known fact that high yielding parent or line may or may not combine well, when used in hybridization. Therefore, a study on general combining ability and specific combining ability effects for quantitative traits of parents is essential. Since, general combining ability (*gca*) estimate the average performance of a line in crosses, it reflects the breeding value of the line. Such studies also elucidate the nature and magnitude of gene actions involved in the inheritance of grain yield and its components, which will decide the breeding programme to be followed in segregating generations. Good combining ability of improved inbreds is essential because inbreds are used to produce hybrids and synthetics. Both GCA and SCA are important, depending on the use of the inbred and traits of interest. Many biometrical procedures have been developed to obtain information on combining ability, a Line × Tester analysis is one among them which is widely used to study combining ability of the parents to be chosen for heterosis breeding. It also provides a guideline to determine the value of source populations and appropriate procedures to use in crop improvement programme. This design is useful in evaluation of large number of germplasm lines at a time in terms of combining ability variances and effects [9]. This knowledge in fact helps in exploiting heterosis for commercial purpose.

In pearl millet selection of parents, for hybridization is an important aspect for crop improvement programme. Selection of parents based on their *per se* performance and combining ability is a pre- requisite for development of new inbreds as parents. As such study indented to determine combining ability, which not only provides information regarding choice of parents, but it also simultaneously illustrates the nature and magnitude of gene effects.

Material and methods

Details of Parental line

S. No.	Female lines	Source	S. No.	Testers	Source
1.	RMS 6A	RARI, Durgapuara	1.	BIB 1	AICRP on Pearl millet, Bikaner
2.	RMS 7A	RARI, Durgapuara	2.	BIB 4	AICRP on Pearl millet, Bikaner
3.	RMS 21A	RARI, Durgapuara	3.	BIB 16	AICRP on Pearl millet, Bikaner
4.	ICMA 843-22	ICRISAT, Hyderabad	4.	BIB 19	AICRP on Pearl millet, Bikaner
5.	ICMA 93333	ICRISAT, Hyderabad	5.	BIB 24	AICRP on Pearl millet, Bikaner
6.	ICMA 97111	ICRISAT, Hyderabad	6.	BIB 31	AICRP on Pearl millet, Bikaner
7.	ICMA 06999	ICRISAT, Hyderabad	7.	BIB 41	AICRP on Pearl millet, Bikaner
8.	JMSA 20042	Jamnagar, Gujrat			
	Checks	**Source**		**Checks**	**Source**
1.	HHB67-imp.	AICPIP, CCSHAU, Hisar	2.	RHB177	AICPIP, SKRAU, Jaipur

Field Layout

The resultant 56 cross combinations along with 2 standard check, were grown in arandomized block design with three replications during *Kharif* 2016 at Agricultural Research Station, Bikaner (Rajasthan), India. Each entry was planted in a 4 meter long row with inter and intra row spacing of 60 × 15 cm. Two row of each entry was planted in each replication. Recommended agronomic practices and plant protection measures were adopted to raise healthy crop.

Data Analysis

The observations were recorded on individual plant basis on 5 randomly selected plants for each entry, in each replication for characters viz., plant height, number of effective tillers per plant, ear head diameter, ear length, 1000 seed weight, biological yield per plant, harvest index (%), and grain yield per plant while two characters namely days to 50 per cent flowering and days to maturity were recorded on whole plot basis.

Statistical Analysis

The mean values of the characters measured in 56 genotypes in each replication were analyzed for analysis of variance, estimation of standard error and critical difference by adopting the method suggested by Panse and Sukhatme [10]. The combining ability analysis was carried out using line x tester mating design as per the procedure suggested by Kempthorne [7].

Result and Discussion

The analysis of variance for combining ability (Table.1) revealed that mean square due to crosses were highly significant for grain yield and its components except biological yield/plant and harvest index which indicated that there were significant differences in hybrids for all the characters. Thus, it revealed the presence of significant variability in the material studied. When the effects of crosses was partitioned in to lines, testers and line x tester effects, the lines recorded significant differences for all characters studied. Mean sum of squares due to testers were significant for all the characters except no. of effective tillers and biological yield per plant which signifies that testers were diverse for these characters. The interaction effects (lines x testers) were found to be significant for all the traits except grain yield/ plant, biological yield/plant and harvest index. The above results suggested that the parents used in this study were diverse and significant difference exists between them and also resulted in creation of substantial genetic variability in the crosses. Such variations in parents have also been reported earlier by Rathore [14] *et al*. and Patel [12] *et al.* However, mean squares due to testers were larger than those due to lines for all the characters except plant height indicating more diversity among the testers for these characters.

Analysis of variance for combining ability indicated that the variance due to *sca* was higher than *gca* for characters like days to maturity, no. of effective tillers/plant, biological yield/plant, harvest index and grain yield/plant (Table 1).

Whereas, the ratio of σ2 *gca* / σ2 *sca* was higher than unity for the character ear head diameter, followed by ear head length, plant height, test weight, and days to 50 % flowering predicted that additive components played greater role in the inheritance of these traits. The ratio of σ2 *gca* / σ2 *sca* was less than unity for the characters days to maturity, no. of effective tillers/plant, grain yield/ plant, biological yield/plant and harvest index indicating preponderance of non-additive gene action (dominance and epistasis).It indicated that non additive components played greater role in the inheritance of these traits.

This showed the possibility of improvement of these traits through heterosis breeding. The presence of predominantly large amount of non-additive gene action would be necessitating the maintenance of heterozygosity in the population. Breeding method such as biparental mating followed by reciprocal recurrent selection may increase frequency of genetic recombination and hasten the rate of genetic improvement. The present findings are akin to those reported by Yadav [16] *et al.* Analysis also revealed higher magnitude of mean sum of squares for SCA than GCA for all characters, indicated the preponderance of non-additive gene action to control these characters [9] and therefore, heterosis breeding will be rewarding.

General Combining Ability effects

In a crop improvement programme, much of the success depends upon isolation of valuable genes combinations as determined in the form of lines with a good combining ability. The combining ability analysis is a powerful tool to discriminate good as well as poor combiners and to choose appropriate parental material in breeding programme. The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and Tatum [15]. The general combining ability is an average performance of a line in hybrid combinations, and can be recognized as a measure of additive gene action and specific combining ability is the deviation in a performance of a hybrid from expected value on the basis of general combining ability effect of lines involved, and can be regarded as a measure of non-additive gene action. The predominance of non- additive action in the expression of several of the yield component characters suggest that it can be commercially exploited through the production of hybrids. However, for the development of high yielding varieties general combining ability was more important [14].

The estimates of GCA effects for ten characters are presented in Table 2. In the present investigation, among the female parents RMS 6A and ICMA 93333 were the best general combiner for grain yield per plant. The female parents RMS 6A also had significantly desirable *gca* effects for no. of effective tiller per plant, test weight and biological yield per plant and desirable negative significant GCA effect for days to 50% flowering and days to maturity. Line ICMA 93333 exhibited desirable and significant *gca* for plant height, ear head length, ear head diameter, biological yield per plant and harvest index also.

Amongst the testers, positive and highly significant *gca* effects for grain yield per plant were exhibited by BIB 4 and BIB 16. Tester BIB 4 also had significant *gca* effects for ear head length, ear head diameter and harvest index and desirable negative significant GCA effect for days to 50% flowering and days to maturity. BIB 16 also exhibited positive and significant *gca* effect for plant height, no. of effective tiller per plant, ear head length and harvest index harvest index and desirable negative significant GCA effect for days to 50% flowering and days to maturity. Significant positive *gca* effects for yield and its components were observed by Karad and Harer [6], and Lakshmana [8] *et al*. The data on GCA effects indicated that the effects varied significantly for different characters and in different parents. High general combining ability effects mostly contribute either additive gene effect or additive x additive interaction effect or both and represent fixable portion of genetic variation. Hence the parents viz., RMS 6A and ICMA 93333, BIB 4 and BIB 16 offer the best possibilities of exploitation for the development of improved lines with enhanced yielding ability in pearl millet. These genotypes can be exploited through hybridization. Further, the lines showing good general combining ability for particular components may be utilized in component breeding programme for improving specific trait of interest.

Specific Combining Ability effects

Sprague and Tatum [15] reported that the SCA effect is due to non-additive genetic proportion. It is an important parameter for judging and selecting superior cross combinations, which might be exploited through heterosis breeding programme. The crosses which showed highest significant positive SCA effects for grain yield per plant presented in Table 3. Amongst the crosses, sixteen cross combinations exhibited significant positive sca effects for grain yield per plant. The combination JMSA 20042 × BIB 19 was the best specific combination for grain yield per plant. It was followed by combination ICMA 93333 × BIB 31, ICMA 97111 × BIB 16, ICMA 97111× BIB 1, and RMS 7A × BIB 4 showed the best performance with significantly positive *sca* effect for grain yield. The genotypes with high *gca* effects for many characters did not always produce combinations with high *sca* effects. These crosses were derived from the parents having high x low, low x low and high x high *gca* effects for grain yield per plant. Navale and Harinarayana [9] reported that the high *sca* effects involved combinations with good x good, good x medium and poor x medium combining parents indicating presence of higher order interactions for grain yield and other characters. While Garten [5] *et al.,* and Pethani [13] *et al.,* observed that use of at least one good general combining parent in a cross is essential for improving grain yield. The results are comparable with the results, Lakshmana [8] *et al.*, Rathore [14] *et al*. and Karad and Harer [6] who reported non additive gene action for grain yield per plant.

The top three crosses had at least one parent as good general combiners for grain yield. The crosses which show higher *sca* effects for different characters does not had G x G combination of parents in other way it good general combiners when crossed may not always produce the best hybrid. Marked negative effects in crosses between good x good were noteworthy, which could be attributed to the lack of complementation between favourable alleles of the parents involved. Marked positive *sca* effects in crosses between good x poor and poor x poor could be ascribed to better complementation between favourable alleles of parents involved. These findings are in agreement with the earlier findings of Pethani [13] *et al*., Lakshmana [8] *et al.* and Parmar [11] *et al*. Therefore, while selecting the parents for hybridization programme due weightage given to average or poor combiners. While those crosses having both good general combiner parents need to be advanced for desired transgressive segregants and/or to develop new CGMS lines and restorers in addition to exploitation of heterosis, as their heterotic effects could be because of pseudo- additive interalleliec interaction. Therefore, while selecting the parents for hybridization programme due weightage given to average or poor combiners. Those crosses having both good general combiner parents need to be advanced for desired transgressive segregants and/or to develop new CGMS lines and restorers in addition to exploitation of heterosis, as their heterotic effects could be because of pseudo- additive interalleliec interaction. Whereas, crosses those having at least one parent as average or poor general combiner could be exploited for heterosis breeding as their seed parents are CGMS lines. The CGMS lines having desired gene effects for various attributes could be inter mated with uses of their maintainer lines, and desirable CGMS recombinants could be identified from the segregating populations.

From the present findings it can be concluded that for the all characters displayed higher *sca* effect than *gca* effect indicated that there was substantial role played by dominance gene action. Such characters could be improve through heterosis breeding or through segregants in the segregating generations, which the breeder can handle through pedigree method for developing high yielding types in pearl millet. The most of the crosses exhibiting high *sca* effect involved either good x poor, poor x poor or good x good general combiners, for majority of the characters studied. The results suggested the presence of additive x dominance, dominance x dominance and additive x additive type of gene interactions. When epistasis is present, the recurrent selection followed by pedigree or biparental mating or diallel selective mating systems may prove to be effective in improvement of grain yield and its attributes in pearl millet.

Table 1: Analysis of variance for combining ability and variance components for different characters in pearl millet

Source	d.f.	Days to50% flowering	Days to maturity	Plant height(cm)	No. of effective tillers/ plant	Ear head length (cm)	Ear head diameter (cm)	Test weight (g)	Biological yield/plant (g)	Harvest index	Grain yield/ plant (g)
Replication	2	0.74	1.95	73.74	0.11	0.71	0.02	0.57*	3205.49	18.23	58.88
Crosses	55	11.95**	6.85**	788.74**	0.52**	22.01**	0.24**	7.02**	2011.01	269.09	90.99*
Lines	7	13.56*	10.59**	3421.46**	1.45**	110.16**	0.23**	35.99**	6431.86*	620.24**	234.67**
Tester	6	62.57**	26.89**	2281.63**	0.43	45.36**	1.67**	9.10**	3667.48	985.53**	198.25**
L × Tester	42	4.46**	3.36**	136.69**	0.38**	3.98**	0.03**	1.89**	1037.56	108.21	51.72
Error	110	1.24	0.83	27.32	0.04	1.06	0.01	0.17	242.66	36.55	13.37
Variance Component											
$\sigma^2 gca$		1.49	0.68	120.66	0.03	3.28	0.04	0.92	14.15	2.33	0.57
$\sigma^2 sca$		1.07	0.84	36.45	0.11	0.97	0.01	0.57	1085.78	166.56	46.52
$\sigma^2 gca / \sigma^2 sca$		1.39	0.81	3.31	0.23	3.38	5.63	1.61	0.01	0.01	0.01
Proportional contribution for variation of lines, testers and lines × testers											
Lines		14.43	19.68	55.2	35.58	63.71	12.44	65.24	40.71	29.34	32.82
Testers		57.09	42.82	31.55	9.13	22.48	76.73	14.13	19.89	39.95	23.77
Lines × Testers		28.46	37.49	13.23	55.27	13.8	10.82	20.61	39.4	30.71	43.41

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

Table 2: Estimates of general combining ability effects for different characters of pearl millet

Parents	Days to50%flowering	Days to maturity	Plant height(cm)	No. of effective tillers/plant	Ear head length(cm)	Ear head diameter(cm)	Test weight(g)	Biological yield per plant (g)	Harvest index	Grain yield/ plant (g)
Female lines										
RMS 6A	-1.27**	-0.53**	0.69	0.19**	-0.58*	-0.06*	0.73**	23.28 **	-3.25 *	4.42 **
RMS 7A	0.35	-0.01	-2.07	-0.37**	-1.68**	0.02	1.16**	18.45 **	-7.41 **	-0.63
RMS 21A	-0.18	-0.67**	16.60**	0.03	4.20**	-0.15**	-2.34**	-17.75 **	-4.62 **	-5.96 **
ICMA 843-22A	0.87**	1.19**	-7.45**	-0.22**	-1.61**	-0.05*	-0.05	-17.19 **	6.74 **	-1.26
ICMA 93333	0.35	-0.34	18.60**	-0.11*	1.79**	0.17**	-1.14**	11.33 **	3.22 *	4.04 **
ICMA 97111	-1.08**	-0.67**	-3.36**	-0.11*	0.23	0.12**	0.31**	-13.51 **	6.06 **	0.85
ICMA 06999	0.16	0.14	-1.93	0.11*	0.74**	0.01	-0.41**	-15.13 **	3.32 *	-1.98 *
JMSA 20042	0.82**	0.90**	-21.07**	0.47**	-3.08**	-0.06*	1.75**	10.53 **	-4.05 **	0.52
S.E.(Gi)	0.24	0.19	1.14	0.04	0.22	0.02	0.08	3.39	1.31	0.79
S.E. (Gi-Gj)	0.34	0.28	1.61	0.06	0.31	0.03	0.12	4.80	1.86	1.12
CD (5%)	0.48	0.39	2.26	0.09	0.44	0.04	0.17	9.42	3.65	2.21
CD (1%)	0.63	0.51	2.98	0.12	0.59	0.06	0.23	12.40	4.81	2.91
Male lines										
BIB 1	3.21**	1.96**	-8.33**	-0.01	-2.25**	0.13**	0.60**	-2.05	-0.74	-1.18
BIB 4	-1.46**	-0.42*	-8.99**	0.05	0.47*	0.13**	-0.02	-5.66	5.38 **	2.40 **
BIB 16	-1.21**	-0.75**	5.59**	0.19**	0.53*	-0.44**	-0.16	-3.34	7.69 **	4.08 **
BIB 19	-1.04**	-0.79**	11.76**	-0.05	2.32**	-0.09**	-0.72**	0.95	-0.50	0.59
BIB 24	-0.46*	-0.75**	12.80**	-0.05	-0.26	-0.22**	0.92**	24.12 **	-12.50 **	-3.26 **
BIB 31	0.54*	-0.21	-7.95**	-0.23**	-0.50*	0.16**	-0.72**	-16.72 **	-0.44	-3.70 **
BIB 41	0.42	0.96**	-4.87**	0.11*	-0.32	0.33**	0.11	2.71	1.11	1.06
S.E. (Gi)	0.22	0.18	1.06	0.04	0.21	0.02	0.08	3.17	1.23	0.74
S.E. (Gi-Gj)	0.32	0.26	1.50	0.06	0.29	0.03	0.11	4.49	1.74	1.05
CD (5%)	0.44	0.36	2.11	0.08	0.41	0.04	0.16	8.81	4.50	2.06
CD (1%)	0.59	0.48	2.79	0.11	0.55	0.05	0.21	11.60	4.50	2.72

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

Table 3: Estimates of specific combining ability effects for different characters of pearl millet

S. No.	Genotypes	Days to 50% flowering	Days to Maturity	Plant height (cm)	No. of effective tillers per plant	Ear head length (cm)	Ear head diameter (cm)	Test weight (g)	Biological yield per plant (g)	Harvest Index (%)	Grain yield per plant (g)
1	RMS 6A × BIB 1	-2.35**	-2.05**	2.52	0.82**	0.36	0.02	1.00**	43.23 **	-6.28	3.58
2	RMS 6A × BIB 4	2.31**	0.99	-6.15*	-0.54**	-0.75	0.06	-0.16	-7.08	-3.38	-3.26
3	RMS 6A × BIB 16	0.39	0.66	-5.73	-0.28*	-0.62	0.06	0.53*	-0.26	-9.92 **	-5.65 **
4	RMS 6A × BIB 19	0.56	-0.30	10.10**	-0.34**	0.39	0.05	-0.62*	-10.21	4.21	-0.24
5	RMS 6A × BIB 24	-0.02	-0.35	1.39	-0.05	0.67	-0.18**	-1.02**	-30.97 **	10.76 **	0.84
6	RMS 6A × BIB 31	-0.68	0.11	0.81	0.19	0.61	0.10	-0.33	-0.96	4.93	2.37
7	RMS 6A × BIB 41	-0.22	0.95	-2.94	0.20	-0.67	-0.10	0.60*	6.24	-0.32	2.36
8	RMS 7A × BIB 1	-0.30	-0.58	12.95**	-0.02	0.56	-0.02	0.89**	28.92 **	-1.59	4.72 *
9	RMS 7A × BIB 4	-0.64	0.80	-1.39	0.02	-1.75**	-0.02	-0.44	-5.65	6.65	4.50 *
10	RMS 7A × BIB 16	-0.55	0.13	1.36	-0.22	0.28	0.00	-0.07	-10.13	-6.29	-4.46 *
11	RMS 7A × BIB 19	0.28	-0.83	-13.80**	-0.17	1.19*	-0.11	-0.64**	-16.75	1.20	-1.78
12	RMS 7A × BIB 24	0.70	1.13*	-1.18	-0.08	0.47	-0.10	-0.90**	14.71	-0.89	-3.26
13	RMS 7A × BIB 31	0.03	-0.41	2.24	0.10	-0.39	0.06	-0.31	-17.29	2.12	-1.14
14	RMS 7A × BIB 41	0.49	-0.24	-0.18	0.36**	-0.37	0.18**	1.47**	6.18	-1.20	1.42
15	RMS 21A × BIB 1	0.45	-0.24	-4.05	-0.22	0.07	0.04	-1.43**	-10.10	-4.31	-2.44
16	RMS 21A × BIB 4	0.22	1.46**	-0.05	0.02	-0.64	-0.12	0.02	-1.95	-2.69	-2.87
17	RMS 21A × BIB 16	0.64	0.80	-3.64	-0.12	-0.20	-0.02	-0.95**	-4.56	3.69	-2.02
18	RMS 21A × BIB 19	-0.20	-0.16	2.20	0.03	-0.29	0.08	0.14	0.70	2.40	1.17
19	RMS 21A × BIB 24	-0.11	0.80	4.49	-0.18	0.59	0.02	1.43**	-4.18	8.57 *	3.64
20	RMS 21A × BIB 31	0.55	-0.74	3.57	0.20	-0.98	0.03	0.19	12.04	-8.60 *	-0.54
21	RMS 21A × BIB 41	-0.66	-1.91**	-2.51	0.26*	1.45*	-0.04	0.61*	8.05	0.93	3.05
22	ICMA 843-22A × BIB 1	-1.49*	0.23	8.66**	0.23	0.99	-0.04	0.70**	-1.45	5.01	2.38
23	ICMA 843-22A × BIB 4	-0.83	-0.39	-2.67	-0.13	1.38*	-0.02	0.25	10.98	3.44	4.28 *
24	ICMA 843-22A × BIB 16	0.26	-0.06	-3.26	-0.07	-0.29	-0.02	0.19	10.03	1.82	3.38
25	ICMA 843-22A × BIB 19	0.09	-0.02	3.91	0.17	0.22	0.21**	0.67**	1.69	-2.95	-0.76
26	ICMA 843-22A × BIB 24	0.51	-0.06	1.20	0.06	-0.50	-0.04	0.51*	4.90	-7.02 *	0.29
27	ICMA 843-22A × BIB 31	1.17	0.40	-8.38**	-0.15	-1.36*	-0.11	-1.03**	-6.29	-5.46	-4.75 *
28	ICMA 843-22A × BIB 41	0.30	-0.10	0.54	-0.10	-0.44	0.01	-1.29**	-19.86 *	5.15	-4.82 *
29	ICMA 93333 × BIB 1	4.03**	1.76**	-12.72**	-0.38**	-1.51*	-0.27**	-1.13**	-37.26 **	0.58	-8.25 **
30	ICMA 93333 × BIB 4	-0.30	-0.87	-2.05	-0.14	-0.93	0.12	-0.29	-14.08	1.48	-1.86
31	ICMA 93333 × BIB 16	0.11	0.46	1.70	-0.28*	0.41	0.03	-0.22	-4.89	-2.52	-0.47
32	ICMA 93333 × BIB 19	-0.72	-0.51	11.20**	-0.14	1.02	-0.10	0.01	-7.96	-3.23	-2.29
33	ICMA 93333 × BIB 24	0.36	0.46	5.16	-0.10	-2.10**	0.04	1.03**	36.24 **	-3.71	4.04
34	ICMA 93333 × BIB 31	-2.30**	-1.08*	-0.43	0.24	2.64**	-0.01	1.07**	0.79	13.40 **	6.53 **
35	ICMA 93333 × BIB 41	-1.18	-1.24*	-2.85	0.80	0.46	0.20**	-0.47*	27.17 **	-6.00	2.30
36	ICMA 97111 × BIB 1	-0.54	1.76**	-3.44	-0.08**	-0.26	0.04	-0.51*	3.90	9.30 **	5.00 *
37	ICMA 97111 × BIB 4	0.79	-0.54	1.90	0.06	-0.07	-0.03	-0.01	12.66	0.43	2.70
38	ICMA 97111 × BIB 16	0.54	-0.20	3.32	0.22	0.67	-0.05	0.88**	11.55	4.54	5.57 **
39	ICMA 97111 × BIB 19	0.71	-0.16	-12.19**	0.11	-2.72**	-0.12	0.26	-13.65	2.25	-4.37 *
40	ICMA 97111 × BIB 24	0.13	-0.20	0.11	-0.05	-0.04	0.14*	-0.05	-18.74 *	-1.76	-2.55
41	ICMA 97111 × BIB 31	-0.88	-0.74	10.52**	-0.06	1.60**	0.04	0.84**	8.64	-7.32 *	-1.56
42	ICMA 97111 × BIB 41	-0.75	0.09	-0.23	-0.20	0.82	-0.02	-1.41**	-4.36	-7.45 *	-4.79 *
43	ICMA 06999 × BIB 1	-0.78	0.28	-7.86*	-0.40**	-1.27*	0.07	0.49*	4.98	-1.06	1.90
44	ICMA 06999 × BIB 4	-0.78	-0.35	5.80	0.44**	1.72**	0.00	0.26	0.08	0.34	-1.50
45	ICMA 06999 × BIB 16	-0.36	-1.01	1.89	0.00	-0.44	0.00	-0.03	-0.36	5.76	0.88
46	ICMA 06999 × BIB 19	-0.53	-0.97	4.39	0.24	0.47	0.02	-0.15	-4.04	-3.44	-1.24
47	ICMA 06999 × BIB 24	-0.78	-1.01	1.68	0.53**	0.74	0.02	-0.17	3.63	-3.78	1.03
48	ICMA 06999 × BIB 31	0.89	1.11*	-5.57	-0.28*	-0.52	0.03	-0.29	3.33	4.78	1.43
49	ICMA 06999 × BIB 41	2.35**	1.95**	-0.32	-0.53**	-0.69	-0.15*	-0.11	-7.61	-2.60	-2.50
50	JMSA 20042 × BIB 1	1.89**	-1.15*	3.95	0.04	1.06	0.14*	-0.02	-32.23 **	-1.65	-6.89 **
51	JMSA 20042 × BIB 4	-0.78	-1.11*	4.61	0.28*	1.04	0.00	0.37	5.05	-6.27	-1.98
52	JMSA 20042 × BIB 16	-1.03	-0.77	4.36	0.74**	0.18	-0.01	-0.34	-1.37	2.93	2.75
53	JMSA 20042 × BIB 19	-0.20	1.94**	-5.80	0.11	-0.28	-0.02	0.34	50.23 **	-0.45	9.51 **
54	JMSA 20042 × BIB 24	-0.78	-0.77	-12.85**	-0.13	0.17	0.11	-0.82**	-5.58	-2.18	-4.03
55	JMSA 20042 × BIB 31	1.22	1.35*	-2.76	-0.24*	-1.59**	-0.15*	-0.15	-0.26	-3.85	-2.34
56	JMSA 20042 × BIB 41	-0.32	0.52	8.49**	-0.79**	-0.57	-0.07	0.60*	-15.83	11.48 **	2.98
	SE	0.64	0.52	3.01	0.12	0.59	0.06	0.23	8.99	3.49	2..11
	CD at 5%	1.27	1.03	5.98	0.24	1.18	0.12	0.47	24.92	9.67	5.85
	CD at 1%	1.68	1.37	7.91	0.31	1.56	0.16	0.62	32.81	12.73	7.70

Conclusion

It is concluded from present investigations that the female parents, RMS 6A and ICMA 93333 were the best general combiner for almost all the characters. Amongst male parents, BIB 4 and BIB 16 were good general combiner for most of the characters. While, cross JMSA 20042 × BIB 19 followed by ICMA 93333 × BIB 31, ICMA 97111 × BIB 16, ICMA 97111× BIB 1, and RMS 7A × BIB 4 were identified as potential crosses for commercial exploitation of heterosis in pearl millet as these crosses exhibited highest magnitude of standard heterosis and SCA effects. These hybrids can be recommended for wide spread cultivation in arid part of western Rajasthan after evaluation in multi-locational trails for increasing pearl millet production and productivity.

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