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RESEARCH PAPER

Combining ability analysis for grain yield and yield components using diverse lines in pearl millet [*Pennisetum glaucum* (L.) R. Br]

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Abstract: Thirty minicores were crossed with three diverse CMS sources (ICMA 94555, ICMA 04777 and ICMA 02555) in a line × tester fashion to elucidate the information on the combining ability for seed yield and its component traits. A total of ninety crosses were evaluated for nine different quantitative traits. Among the three lines used in the study, ICMA 94555 and ICMA 02555 exhibited significant GCA effects for most of the characters studied and were found to be the good combiners. Likewise, among testers IP 21452, IP 9645, IP 14522 and IP 8863 were found to be good general combiners for most of the traits under observation. The estimates of variance components revealed predominance of non-additive gene action for most of the characters studied.

Key words: Combiners, Combining ability, Non additive gene action, Pearl millet

Introduction

Pearl millet [(*Pennisetum glaucum* (L.) R. BR)] is an important cereal crop of India. To develop pearl millet hybrids with improved yield potential, the choice of parents through careful and critical evaluation is of prime importance in order to improve productivity and total production. The seed yield and yield attributing characters show polygenic inheritance and thus, are susceptible to environmental fluctuations. Therefore, selection of parents for hybridization is a complex problem.

According to the concept of combining ability, the general combining ability is the average performance of a strain in a series of cross combinations, estimated from the performance of F_1 from the crosses, whereas specific combining ability is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance of lines involved. General combining ability and specific combining ability reveals additive and non-additive gene actions, respectively. This helps the breeders to assess the parents for adoption in heterosis breeding programme. Therefore, it is essential to study combining ability to select superior combination of parents and to attain maximum success in the breeding programme.

The choice of the parents is governed by *per se* performance of the parents and behavior of the parents in respective hybrid combinations. Some idea on the usefulness of parents may be obtained from their individual performance particularly in respect of yield components (Gilbert, 1958). The mode of gene action depends upon the genetic structure and extent of divergence between the parents involved. Therefore, it is necessary to estimate the genetic potentialities of parents in hybrid combinations through systematic studies with regard to general combining ability and specific combining ability. A wide range of variability and cytoplasmic male sterility sources are available in pearl millet. In the present study, A5 cytoplasm based lines and restorers were used to generate experimental hybrids to identify the good combiners for further utilization in hybridization programmes.

Many biometrical procedures have been developed to obtain information on combining ability; Line × Tester analysis (Kempthorne, 1957) is one among them, which is widely used to study combining ability of the parents to be chosen for heterosis breeding. With a view to identify the lines with good combining ability and to identify the good specific crosses for further exploitation, the present investigation was undertaken.

Material and methods

The present study was carried out during *kharif* 2019 at Regional Agricultural Research Station, Vijayapura (Karnataka) India, located in the northern dry zone of Karnataka at an altitude of 593 m from mean sea level. Crossing programme was done in summer 2019 and evaluation of parents and F_1's along with checks (GHB558, 86M38 and Kaveri Super Boss) was taken up in *kharif* 2019. All the experimental hybrids produced were sown along with their parents and three checks including two national checks (GHB558 and 86M38) and one commercial check *i.e.,* Kaveri Super Boss in a Randomized Block Design (RBD) with three replications. Each hybrid was accommodated in 2 rows of 3 meter row length with a row spacing of 45 cm and plant to plant spacing of 15 cm.

The research material for the present study consisted of three diverse cytoplasmic male sterile lines *viz.*, ICMA 94555, ICMA 04777 and ICMA 02555 and thirty minicores *viz.*, IP 11546, IP 3706, IP 17465, IP 21452, IP 1917, IP 5711, IP 9645, IP 6340, IP 13991, IP 15119, IP 16863, IP 20576, IP 21283, IP 13261, IP 20274, IP 18657, IP 10665, IP 10925, IP 19448, IP 14522, IP 11010, IP 2704, IP 14537, IP 16863, IP 10437, IP 20611, IP 20409, IP 8863, IP 6057, IP 6482 received from ICRISAT Hyderabad.

From each entry/replication, five random, competitive plants were tagged and numbered in the middle of the row to observe yield and other quantitative characters. Mean of the plants was computed and taken for analysis. The following observations were recorded: *viz.,* days to 50 per cent flowering, plant height (cm), number of productive tillers per plant, panicle length (cm), panicle girth (cm), panicle weight (g $plot^{-1}$) , grain yield (kg ha^{-1}), dry fodder yield (kg ha^{-1}), and thousand seed weight (g). The data were analyzed by L × T design.

Results and discussion

The analysis of variance for combining ability of parents and crosses for different yield component traits in line ′ tester design (Table 1) indicated the significant variation for all the traits indicating the existence of genetic diversity in the parental material and varying performance of the cross combinations. The level of contribution by the lines was more for the characters such as days to 50 per cent flowering, panicle weight, grain yield, dry fodder yield. On the other hand, testers contributed more for the characters such as panicle girth, dry fodder yield per hectare, grain yield per hectare and thousand seed weight. Whereas contribution of line × tester interaction was highest for all the traits indicating that the testers were highly divergent from lines. The SCA variance was higher than GCA variance for all the traits studied indicating predominance of non-additive type of gene action and same has been reported by Sushir *et al*., 2005; Bhanderi *et al*., 2007; Lakshmana, 2008; Vetriventhan *et al.,* 2008a and Vagadiya *et al*., 2010.

The general combining ability effects (Table 2) indicated that ICMA 09555 was good general combiner as evident from its significant GCA effect in desirable direction for as many as four characters *viz*., days to 50 per cent flowering, panicle weight (g $plot^{-1}$), grain yield (kg ha^{-1}) and dry fodder yield (kg ha^{-1}). The next best general combiner was ICMA 02555 for panicle weight (g $plot^{-1}$), grain yield (kg ha^{-1}) and dry fodder yield (kg ha^{-1}).

Among the testers (Table 3), out of thirty testers, eighteen of them were found in the high category *viz.,* IP 3706, IP 17465, IP 21452, IP 1917, IP 5711, IP 9645, IP 15119, IP 20576, IP 13261, IP 10925, IP 14522, IP 2704, IP 14537, IP 6193, IP 10437, IP 20409, IP 8863 and IP 6057.IP 9645 had better general combining ability for days to 50 % flowering, panicle weight per plot, grain yield per hectare, dry fodder yield per hectare and thousand seed weight. IP 14522 had better general combining ability for number of productive tillers per plant, panicle length, panicle girth, panicle weight per plot, grain yield per hectare and dry fodder yield per hectare. Whereas IP 8863 showed good combining ability for days to 50 % flowering, panicle girth, panicle weight per plot, grain yield per hectare and dry fodder yield per hectare.

Similar observations have been made by Karad and Harer, 2005; Lakshmana, 2008 ; Vetriventhan*et al.*, 2008a; Singh and Sharma, 2014; Bhadalia *et al*., 2014; Bhardwaj *et al.,* 2015; Mungra *et al*., 2015; Athoni *et al.,* 2016; Patel *et al*., 2016;

Table 1. Analysis of variance (Mean sum of squares) with respect to morphological characters in pearl millet

Source	Df	Days to 50 per cent flowering	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g $plot^{-1}$)	Grain yield (kg ha^{-1})	Dry fodder (kg ha^{-1})	Thousand seed weight (g)
Replication	2	2.93	11.30	0.04	2.96	0.05	1.70	51799	1011682	2.14
Crosses/Hybrids	89	30.91**	264.12**	0.12**	9.98**	0.14**	44.32**	1234514**	3323361**	3.03**
Line	2	45.77**	1132.44**	0.04	6.77	0.27*	30.80**	70642	3338440**	0.48
Tester	29	45.64**	199.67	0.08	10.50**	0.10	23.48**	476347**	6889244**	2.4**
L × T	58	30.01**	352.13**	0.11**	9.74**	0.14**	42.97**	1154859**	2652757**	3.17**
Error	244	1.96	155.99	0.07	4.27	0.07	4.87	85123	525123	0.76
Contribution of line %		15.87	0.34	3.03	2.08	0.01	5.35	9	15	2.86
Contribution of tester %		20.86	12.77	33.76	34.26	34.51	31.46	30	33	28.32
Contribution of L × T %		63.26	86.88	63.20	63.65	65.47	63.18	61	52	68.81
GCA variance		1.79**	5.66	0.001*	0.003	0.001	0.63*	40179**	199188**	0.001
SCA variance		9.34**	65.38**	0.015**	1.83**	0.03**	12.69**	356579**	709211**	0.80**
GCA/SCA		0.19	0.09	0.07	0.002	0.03	0.05	0.11	0.28	0.001

Table 2. Estimates of general combining ability (GCA) effects of lines for morphological characters in pearl millet

Parents (Lines)	Days to 50 per cent flowering	Plant height (cm)	No. of productive tillersper plant	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g $plot^{-1}$)	Grain yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})	Thousand seed weight (g)
ICMA 94555	-1.75 **	0.59	-0.04	-0.30	0.002	0.65**	177**	199**	0.12
ICMA 04777	0.51 **	0.14	0.01	-0.03	0	-1.25**	-273**	-558**	0.11
ICMA 02555	1.24 **	-0.73	0.04	0.33	-0.002	0.6*	96 **	359**	-0.23 *
S.E (g_i)	0.15	1.32	0.03	0.22	0.03	0.23	31.75	76.39	0.09
S.E (g_i-g_j)	0.21	1.86	0.04	0.31	0.04	0.33	43.49	108.03	0.13
C.D. at 5%	0.29	2.60	0.06	0.43	0.05	0.46	60.69	150.74	0.18
C.D. at 1%	0.38	3.43	0.07	0.57	0.07	0.61	80.08	198.89	0.24

Note: *Significance at 5% probability, **significance at 1% probability

Table 3. Estimates of general combining ability (GCA) effects of testers for morphological characters in pearl millet

Parents (Testers)	Days to 50 per cent flowering	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g plot^{-1})	Grain yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})	Thousand seed weight (g)
IP 11546	0.26	0.84	-0.15	0.74	0.01	-3.31**	-379**	-492*	-0.92 **
IP 3706	-2.63 **	2.62	0.12	1.37 *	0.05	0.85	138	207	-0.35
IP 17465	0.26	0.95	-0.04	1.37 *	-0.16	-0.04	-112	-369	0.00
IP 21452	-1.52 **	-3.05	0.12	-0.07	0.19 *	1.98**	419**	207	0.01
IP 1917	-0.52	7.17	-0.04	1.27	-0.18 *	-1.00	201*	207	0.36
IP 5711	-0.40	3.62	0.12	-0.06	0.23 **	-1.41	-158	-287	-0.50
IP 9645	-2.07 **	-4.83	0.12	0.95	-0.11	3.76**	555**	578*	0.72 *
IP 6340	1.04 *	-1.16	0.12	-1.06	0.01	-1.80*	-576**	-863**	0.41
IP 13991	0.26	-2.60	-0.19 *	-1.77 *	-0.12	-0.24	64	454	0.03
IP 15119	2.26 **	1.95	0.16	-0.34	-0.08	0.89	271**	742**	1.24 **
IP 16863	0.82	-0.49	-0.06	-1.28	-0.02	-3.61**	-390**	-698**	0.10
IP 20576	-2.07 **	-4.72	0.14	-1.19	-0.01	2.21**	133	536*	-0.18
IP 21283	-1.10 *	-1.60	-0.13	0.12	0.04	-1.20	-126	-904**	0.53
IP 13261	-0.63	1.29	-0.04	-0.71	-0.09	2.01**	47	-122	-0.10
IP 20274	-2.18 **	3.51	-0.23 **	1.02	0.02	-0.48	-318**	-1274**	0.13
IP 18657	-0.52	2.84	0.01	0.63	0.13	-0.82	-90	-81	0.20
IP 10665	-0.29	2.51	-0.15	1.15	-0.14	-2.30**	-489**	-739**	0.21
IP 10925	1.60 **	-4.72	0.11	0.42	0.06	2.38**	418.22 **	907**	-0.29
IP 19448	-1.52 **	4.29	-0.12	0.02	-0.15	-3.08**	-674.04 **	-863**	-0.15
IP 14522	1.15 *	4.17	0.20 *	1.40 *	0.29 **	4.41**	736.95 **	1030**	0.38
IP 11010	3.94 **	-6.94	-0.06	-1.52 *	-0.21 *	0.39	178.50	290	0.39
IP 2704	0.26	-0.16	0.12	-0.84	-0.01	2.18**	132.00	125	-1.80 **
IP 14537	1.60 **	0.06	-0.15	-1.40 *	-0.10	-0.50	-28.90	1	0.01
IP 6193	1.15 *	1.73	-0.06	-1.53 *	-0.01	-1.32	-155.20	166	-0.45
IP 10437	1.37 **	-2.49	-0.02	-1.01	-0.04	0.20	29.80	-287	-0.31
IP 20611	-0.63	-5.72	0.10	-1.37 *	-0.12	-3.34**	-542.42 **	-739**	-0.11
IP 20409	0.37	1.40	-0.08	0.48	0.09	-0.29	153.60	495*	-0.40
IP 8863	-1.52 **	-3.05	0.03	0.64	0.19 *	3.67**	610.42 **	742**	0.24
IP 6057	1.26 **	1.62	0.03	1.37 *	0.13	1.54*	42.80	660**	0.09
IP 6482	-0.07	0.95	0.01	1.18	0.09	-1.75*	-92.50	372	0.48
S.E (g_i)	0.47	4.16	0.09	0.69	0.09	0.74	97.25	242	0.29
S.E (g_i-g_j)	0.66	5.89	0.13	0.98	0.12	1.04	137.54	342	0.41
C.D. at 5%	0.92	8.22	0.18	1.36	0.17	1.45	191.92	477	0.57
C.D. at 1%	1.22	10.84	0.23	1.79	0.23	1.92	253.22	629	0.76

Jeeterwal *et al.,* 2017; and Badurkar *et al.,* 2018. The lines and testers exhibiting highly significant positive GCA effect for grain yield per hectare and other yield components can be involved in crossing programme to develop superior hybrids or to derive superior recombinants which could be used to develop parental lines.

The SCA effects (Table 4) showed that, three of the hybrids recorded higher SCA effects for all the traits. The cross, ICMA 94555 × IP 17465 registered maximum SCA effect for grain yield per hectare. The other crosses *viz.,* ICMA 94555 × IP 5711 and ICMA 04777 × IP 21452 also exhibited highly substantial SCA effect for grain yield per hectare. The crosses *viz.,*ICMA 94555 × IP 17465, ICMA 04777 × IP 9645 and ICMA 02555 × IP 3706 exhibited highly substantial SCA effect for dry fodder yield per hectare.

Twenty five hybrids recorded higher significant positive SCA effects for grain yield. The hybrids which were considered superior for this trait were ICMA 94555 × IP 17465 (1125.73), ICMA 94555 × IP 5711 (979.94), ICMA 04777 × IP 21452 (874.42), ICMA 02555 × IP 2704 (817.38), ICMA 02555 × IP 3706 (671.68) and ICMA 04777 × IP 9645 (655.96). The extent of SCA effects for dry fodder yield was positive and significant for twenty four hybrids. The superior crosses exhibiting high SCA effect for this trait were; ICMA 94555 × IP 17465 (1858.86), ICMA 04777 × IP 9645 (1422.62) and ICMA 02555 × IP 3706 (1245.64).

The crosses with significant SCA for grain yield per hectare also exhibited high specific combining ability for other yield components indicating that improvement in grain yield per hectare could be achieved by improving other yield components like panicle length, panicle girth, number of productive tillers per plant and thousand seed weight. It was also observed that, crosses which showed significant SCA effect for grain yield per hectare, also exhibited significant heterosis.

The present study and earlier reports of Karad and Harer (2005), Dhuppe *et al.* (2006), Bhanderi *et al.* (2007), Lakshmana (2008), Vetriventhan *et al.* (2008a), Vagadiya *et al.* (2010), Badurkar *et al*. (2018) and Patel *et al*. (2016) clearly indicated

Table 4. Estimates of specific combining ability (SCA) effects for morphological characters in pearl millet

Crosses	Days to 50 per cent flowering	Plant height (cm)	No. of productive tillers per plant	Panicle length (cm)	Panicle girth (cm)	Panicle weight (g plot^{-1})	Grain yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})	Thousand seed weight (g)
ICMA 94555 × IP 11546	-2.03 *	-2.47	0.09	-0.81	0.02	-1.93	-451.63 **	747.67	-1.28 *
ICMA 94555 × IP 3706	-1.14	-4.25	-0.04	-1.18	-0.12	0.15	53.47	171.48	-0.65
ICMA 94555 × IP 17465	1.98 *	-6.25	0.18	0.79	0.39*	7.20 **	1125.73 **	1858.86 **	0.70
ICMA 94555 × IP 21452	4.08 **	13.08	-0.18	0.00	-0.17	-4.28 **	-991.29 **	-1063.18 *	-0.95
ICMA 94555 × IP 1917	0.75	18.53 *	0.05	2.63 *	0.34 *	4.70 **	243.78	1159.21 **	-0.96
ICMA 94555 × IP 5711	2.64 **	-5.60	0.09	1.66	0.00	3.84 **	979.94 **	788.82	1.03 *
ICMA 94555 × IP 9645	0.30	10.53	-0.18	0.91	-0.46 **	-6.86 **	-1021.59 **	-1433.58 **	0.71
ICMA 94555 × IP 6340	2.19 **	-20.81 **	0.02	-1.14	0.02	-1.87	-189.53	-116.61	-0.28
ICMA 94555 × IP 13991	-2.36 **	-11.03	-0.07	0.06	0.01	2.91 *	285.44	788.82	-0.26
ICMA 94555 × IP 15119	-1.03	14.75 *	-0.15	0.94	0.08	-2.10	-497.14 **	-240.07	0.29
ICMA 94555 × IP 16863	-1.59	-5.81	-0.20	-2.38 *	-0.19	-2.56 *	-502.67 **	-528.16	-0.93
ICMA 94555 × IP 20576	-0.70	11.75	0.07	0.73	0.06	6.28 **	777.11 **	1076.91 *	0.21
ICMA 94555 × IP 21283	4.30 **	4.64	-0.13	-0.79	-0.18	-1.67	-493.70 **	-1063.18 *	-0.19
ICMA 94555 × IP 13261	1.86 *	-5.59	-0.09	-3.36 **	-0.01	3.38 **	375.40 *	130.33	0.56
ICMA 94555 × IP 20274	4.41 **	-1.47	-0.15	-1.09	-0.06	-3.19 *	-571.81 **	-816.25	0.91
ICMA 94555 × IP 18657	-1.92 *	-4.47	-0.13	-0.80	0.00	-1.15	271.28	459.57	0.20
ICMA 94555 × IP 10665	-3.47 **	-9.81	-0.11	-0.65	0.26	0.13	-377.04 *	-487.01	-0.68
ICMA 94555 × IP 10925	0.97	13.42	-0.03	0.88	0.06	6.22 **	473.53 **	583.04	0.22
ICMA 94555 × IP 19448	-3.92 **	11.42	-0.08	0.18	0.38*	-1.20	-317.20	500.73	0.05
ICMA 94555 × IP 14522	1.42	-1.82	0.14	0.77	0.03	1.18	265.69	583.04	1.15 *
ICMA 94555 × IP 11010	-1.36	2.65	0.14	2.91*	-0.35 *	3.64 **	288.74	-34.30	-0.06
ICMA 94555 × IP 2704	2.65 **	-21.47 **	0.02	-0.71	0.10	-3.59 **	-393.76 *	-857.40 *	1.46 **
ICMA 94555 × IP 14537	0.98	0.30	0.02	0.78	-0.05	-0.07	163.78	6.87	0.93
ICMA 94555 × IP 6193	0.08	15.00 *	0.14	2.86 *	0.13	-3.18 *	640.72 **	583.04	-0.51
ICMA 94555 × IP 10437	1.19	-6.47	0.02	-2.03	-0.24	-3.81 **	-576.01 **	-1433.59 **	0.01
ICMA 94555 × IP 20611	-2.82 **	0.42	0.18	-0.03	-0.02	-0.16	360.68 *	-363.54	-0.76
ICMA 94555 × IP 20409	1.19	5.30	-0.18	-0.12	-0.07	-1.76	-495.42 **	-980.88 *	-1.10 *
ICMA 94555 × IP 8863	-3.59 **	-8.25	-0.22	-1.04	-0.17	-4.87 **	-611.15 **	-733.95	-0.44
ICMA 94555 × IP 6057	-5.03 **	-5.93	0.51 **	0.29	0.10	3.64 **	783.03 **	829.98 *	0.55
ICMA 94555 × IP 6482	-0.03	-0.25	0.27	-0.25	0.13	0.98	401.67 *	-116.61	0.10
ICMA 04777 × IP 11546	-1.63 *	-3.71	-0.16	-0.08	0.12	0.21	-202.44	-840.95 *	3.26 **
ICMA 04777 × IP 3706	2.95 **	6.87	-0.23	0.42	-0.16	-3.95 **	-725.14 **	-1417.12 **	0.27
ICMA 04777 × IP 17465	2.38 **	4.19	-0.07	1.22	0.02	-2.99 *	-385.85 *	-594.01	-0.29
ICMA 04777 × IP 21452	1.49	2.19	0.24	2.20	0.13	6.86 **	874.42 **	805.28	0.47
ICMA 04777 × IP 1917	1.16	0.65	-0.01	-0.08	-0.38 *	-1.44	-531.12 **	-1664.05 **	0.99
ICMA 04777 × IP 5711	-3.63 **	-15.14 *	-0.03	-2.41 *	0.00	-1.63	-272.83	64.48	0.74
ICMA 04777 × IP 9645	-2.97 **	-4.71	0.10	0.11	0.33 *	3.07 *	655.96 **	1422.62 **	-0.28
ICMA 04777 × IP 6340	-0.73	10.65	-0.03	2.12	0.12	1.13	167.33	517.19	-0.47
ICMA 04777 × IP 13991	1.05	10.42	0.22	-1.55	-0.16	-1.99	-349.71 *	-58.99	0.42
ICMA 04777 × IP 15119	0.38	-4.14	0.06	-2.56 *	-0.26	-1.76	-158.32	270.26	-0.20
ICMA 04777 × IP 16863	1.49	5.65	-0.12	1.08	0.04	1.11	-166.55	-264.77	-0.31
ICMA 04777 × IP 20576	3.38 **	-6.47	-0.19	-2.54 *	-0.10	-3.04 *	-341.31 *	-141.30	-1.55 **
ICMA 04777 × IP 21283	0.38	-1.25	0.22	0.28	0.09	-0.17	105.18	805.28	0.55
ICMA 04777 × IP 13261	-2.39 **	-4.14	0.13	1.23	-0.11	-2.22	-259.48	-223.61	-0.12
ICMA 04777 × IP 20274	-1.85 *	-6.36	-0.07	-0.02	0.11	-1.43	-105.80	-182.46	-1.24 *

Table 4 contd...

ICMA 04777 × IP 18657	1.83 *	6.30	-0.05	-0.33	-0.10	-1.45	-233.23	105.63	-0.49
ICMA 04777 × IP 10665	0.61	8.30	0.04	1.34	0.17	1.50	643.62 **	1011.05 *	0.40
ICMA 04777 × IP 10925	0.05	-1.82	0.12	1.71	-0.03	-3.69 **	-111.97	105.63	0.53
ICMA 04777 × IP 19448	6.15 **	-3.14	0.07	1.48	-0.42 **	1.47	439.46 **	764.12	-1.80 **
ICMA 04777 × IP 14522	-2.17 **	-10.03	0.02	-0.58	0.03	4.38 **	545.99 **	105.63	-0.80
ICMA 04777 × IP 11010	-4.62 **	-1.25	-0.12	-0.76	0.34 *	0.31	755.73 **	599.50	0.09
ICMA 04777 × IP 2704	1.38	14.98 *	-0.10	1.90	0.13	-2.59 *	-423.63 *	-347.08	-0.36
ICMA 04777 × IP 14537	0.05	-3.93	0.10	-1.80	-0.08	-0.01	50.93	-100.15	0.00
ICMA 04777 × IP 6193	0.49	-3.60	0.28	-0.15	-0.13	3.92 **	-163.34	-141.30	0.57
ICMA 04777 × IP 10437	-3.39 **	5.64	-0.10	1.47	0.07	1.96	-21.84	681.81	-0.01
ICMA 04777 × IP 20611	-1.40	-2.14	-0.14	-2.36 *	0.11	1.17	47.31	270.26	0.52
ICMA 04777 × IP 20409	-2.39 **	-1.92	0.37*	-0.09	0.03	1.98	439.30 **	270.26	0.21
ICMA 04777 × IP 8863	0.16	-2.81	0.06	-0.55	0.03	1.74	144.53	393.72	-0.66
ICMA 04777 × IP 6057	3.38 **	-7.47	-0.27	-0.38	0.10	-4.00 **	-505.53 **	-1869.84 **	-1.05 *
ICMA 04777 × IP 6482	-1.62 *	8.19	-0.31 *	-0.32	-0.07	1.54	88.30	-347.08	0.63
ICMA 02555 × IP 11546	3.65 **	6.17	0.07	0.89	-0.14	1.72	654.06 **	93.29	-1.98 **
ICMA 02555 × IP 3706	-1.80 *	-2.61	0.27	0.75	0.28	3.80 **	671.68 **	1245.64 **	0.38
ICMA 02555 × IP 17465	-4.35 **	2.06	-0.11	-2.01	-0.40 **	-4.21 **	-739.88 **	-1264.85 **	-0.41
ICMA 02555 × IP 21452	-5.58 **	-15.27 *	-0.06	-2.20	0.04	-2.57 *	116.87	257.91	0.48
ICMA 02555 × IP 1917	-1.91 *	-19.16 **	-0.04	-2.55 *	0.05	-3.26 *	287.35	504.84	-0.03
ICMA 02555 × IP 5711	0.98	20.73 **	-0.06	0.75	0.00	-2.21	-707.12 **	-853.29 *	-1.77 **
ICMA 02555 × IP 9645	2.65 **	-5.83	0.07	-1.03	0.14	3.79 **	365.63 *	10.98	-0.43
ICMA 02555 × IP 6340	-1.46	10.17	0.01	-0.98	-0.14	0.74	22.20	-400.58	0.75
ICMA 02555 × IP 13991	1.32	0.62	-0.15	1.49	0.15	-0.91	64.27	-729.83	-0.16
ICMA 02555 × IP 15119	0.65	-10.61	0.10	1.63	0.18	3.86 **	655.46 **	-30.18	-0.08
ICMA 02555 × IP 16863	0.09	0.17	0.32 *	1.31	0.15	1.46	669.21 **	792.93	1.23 *
ICMA 02555 × IP 20576	-2.69 **	-5.27	0.12	1.82	0.04	-3.23 *	-435.81 *	-935.60 *	1.34 **

that the grain yield per hectare is predominantly under the control of non-additive gene action.

Conclusion

The crosses showing SCA effect for grain yield per hectare were observed in the present study. It indicates that the crosses with high SCA effect are generally heterotic in nature. The information on combining ability and heterosis considered together would be more meaningful. If the heterotic hybrids involve parents with high GCA effect, it implies that the parental contribution to heterosis is mainly through additive gene effect. The present study indicates that highly heterotic hybrids could be obtained from parents with any combination of GCA *i.e.,* High × High, High × Low, Low × High and Low × Low which further substantiate the operation of non-additive gene action for the characters studied. However, the frequency of heterotic hybrids was comparatively more in High × Low or Low × High type of crosses. It was concluded that almost all the characters studied were governed by non-additive gene action, besides using diverse CMS sources are equally efficient in expressing their fullest potential of yield and yield contributing characters. These sources can be safely used in breeding to broaden the genetic base of CMS source to safeguard pearl millet crop from any eventuality of biotic and abiotic threats in future.

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