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General Combining Ability Effects of New CMS Lines and Advanced Breeding Restorers and Identification of Best Specific Combiners to Exploit Heterosis in Rice (*Oryza sativa* L.)

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Abstract

In an effort to generate information on effects due to combining ability in respect of yield and yield attributes, an investigation was carried out on 160 rice hybrids produced through line x tester mating design using 8 new CMS lines and 20 advanced breeding restorers used as testers. Analysis of variance revealed that the mean sum of squares due to the lines was significant for all characters except for panicles per plant, panicle length, panicle weight and 1000 grain weight. Among the testers, most of the characters except for panicle weight differed significantly. Estimation of general combining ability (GCA) effects of lines and testers indicated that, no single line or tester was found to be a good general combiner for all the characters studied. However, the lines 5A, 6A and 7A exhibited significant GCA effects in the desired direction for panicles per plant, plant height and spikelets per plant and were considered as good general combiners among lines. The testers, R3 (plant height, panicles per plant, spikelets per panicle and grain yield per plant) R4 (spikelets per panicle, spikelet fertility and grain yield per plant), R11 (plant height and grain yield per plant), R13 (plant height, spikelets per panicle and grain yield per plant), R15 (spikelets per panicle, spikelet fertility and grain yield per plant), R17 (plant height, spikelets per panicle and grain yield per plant) and R19 (plant height, spikelets per panicle and grain yield per plant) were considered as the good general combiners since they had highly significant GCA effects for respective characters. High significant L x T interaction towards total variance emphasizes importance of non-additive gene action in exploitation of heterosis. Ten best specific combiners were selected based on their *per se* performance. These hybrids also showed high significant SCA variances and can be future potential hybrids.

Keywords: General combining ability, line x tester analysis, *Oryza sativa* L., specific combining ability

Rice is the principal food crop of India and south-east Asia. India is the second largest producer and consumer of rice in the world. More than half of the world's population relies on rice as the major daily source of calories. Exploiting heterosis is one of the methods used to increase rice yield that has stagnated in recent years. The success of the hybridization is largely dependent on the correct selection of parents. Estimates of genetic variation and combining ability are useful in determining the breeding value of some populations and the appropriate procedures to use in a breeding programme. The general combining ability (GCA) effects are important indicators of the value of genotypes in hybrid combinations. Differences in general combining ability effects have been attributedto additive, additive x additive and higher-order additive interactions, whereas differences in specific combining ability (SCA) have been attributed to non-additive genetic variance.

The high GCA effect for a particular trait of a parent indicates the additive gene effect for the trait governed by the genes in the parent concerned. The combining ability of parents gives useful information on the choice of parents in terms of expected performance of their progenies. The GCA effect is considered as the inherent genetic value of the parent for a trait which is due to additive gene effect and it is fixable.

Line x Tester analysis is a powerful tool to discriminate the good as well as poor combiners for choosing appropriate parental material in successful hybrid breeding program. However, the success of hybrid rice program depends upon the magnitude of heterosis which also helps in the identification of potential cross combinations to be used in the conventional breeding program to create wide array of variability in the segregating generations.

Therefore, the present investigation has been conducted to determine the general combining ability for yield and its components using line x tester mating design in order to find out the best combiners in respect of their combining ability effects among the newly evolved CMS lines and advance breeding testers.

MATERIAL AND METHODS

Experimental material comprised of 160 hybrids obtained from eight newly evolved CMS lines (1A to 8A) and twenty new advanced breeding linesas restorer testers (R1 to R20). Standard hybrid checks MC 13, DRH 836 and KRH 4 and varietal checks *viz.*,Surya, Meenakshi, MB Sona were included.

Experimental design and trial management : In summer 2017, 160 F_1 hybrids and standard checks were planted along with 8 lines and 20 Advance breeding restorer testers at plot no. 6, C-block, V. C. Farm, Mandya. The experiment was planted in an Augmented design (Federer, 1956) and the experimental plot was divided into four blocks. Check entries were replicated in each block and test entries were not replicated. Twenty one days old seedlings were transplanted in the field. Single seedling per hill was transplanted. A standard spacing of 20 x 15 cm was adopted for planting and 26 plants were maintained in a single row. Recommended package of practices suitable for southern Karnataka were followed.

Data collection and analysis : Observations were recorded on five randomly selected plants for ten yield attributing quantitative traits *viz.*, days to 50 per cent flowering, plant height, tillers per plant, panicles per plant, panicle length, panicle weight, spikelets per plant, spikelet fertility (%), 1000 grain weight and seed yield per plant. Combining ability analysis was carried out by the method suggested by Kempthorne (1957).

General combining ability effects were calculated using the expression :

$$g_i = (X_i../tr)-(X.../ltr)$$

Specific combining ability effects were calculated using the expression :

$$s_i=(X_{ij}/r)-(X_i.../tr)-(X._j./lr)+(X.../ltr)$$

l = number of lines

t = number of treatments

r = number of replications

RESULTS AND DISCUSSION

Analysis of variance : The ANOVA for combining ability of the line x tester set revealed that the variances due to lines as well as testers were significant for all the characters, indicating the presence of considerable variation among parents used in this study in terms of general combining ability (Table I). Nadali (2010) also observed higher estimates of GCA variances due to testers in rice. The significant differences were also recorded for parent's *vs* hybrids indicating presence of heterosis for days to 50 per cent flowering, plant height, spikelets per panicle, spikelet fertility and yield per plant. The significance of line x tester for all the characters except panicle weight, provided a direct test, indicating that non-additive variances were important for majority of the characters. The significant mean sum of square due to lines and testers indicated prevalence of additive variance for the yield and its components.

General combining ability effects : The estimates of general combining ability (GCA) effects due to 8 lines and 20 testers for different characters are presented in Table II and Table III, respectively and pictorially represented in Fig. 1 and Fig. 2. These are discussed briefly hereunder.

None of the lines exhibited significant GCA effect in desirable direction for days to 50 per cent flowering. However, line 1A showed highest GCA effect (0.85) in desirable direction. On the other hand, the tester R6 produced positive and significant GCA effect (4.0) in desirable direction among testers. The line 6A registered highest negative and significant GCA effect (-4.18) for plant height followed by line

TABLE I

Analysis of variance for Line X Tester and combining ability

Source	Mean Sum of Squares										
	df	DFF	PH	TPP	PPP	PL	PW	SPP	SF	TGWT	YPP
Treatments	187	9.27 **	300.89 **	24.98 **	134.25 **	8.37 **	0.52	2241.4 **	51.6 **	5.18 **	149.54 **
Parents	27	10.21 **	1011.17 **	35.68 **	11.47 **	14.03 **	0.46	2005.69 **	36.89 **	3.82 **	43.38 **
Lines	7	8.83 **	7.82 **	5.69 *	2.28	0.56	0.06	26577.34 **	30.96 **	0.46	6.71 **
Tester	19	3.2 **	97.03 **	8.83 **	7.01 **	3.08 **	0.36	921.27 **	35.08 **	2.51 *	17.7 **
Line vs Tester	1	153.03	25403.17 **	755.71 *	160.51	316.41 *	5.07	17908.01 **	112.8	52.16	788.02 *
Parents vs Hybrids	1	445.01 *	1248.28 *	22.74	52.07	124.16	2.35	25268.5 **	307.63 *	46.99	2535.08 *
Hybrids	159	6.37 **	174.32 **	23.17 **	155.61 **	6.69 **	0.52	2136.61 **	52.49 **	5.14 **	152.57 **
Line effect	7	4.67 *	176.44 **	12.47 **	114.87 **	9.55 **	0.23	1554.05 **	59.82 **	6.24 **	127.82 **
Tester effect	9	14.71 **	772.22 **	26.76 **	121.13 **	9.97 **	0.95	3399.24 **	80.68 **	12.48 **	310.14 **
L X T effect	133	5.27 **	88.79 **	23.22 **	162.68 **	6.07 **	0.48	1986.89 **	48.08 **	4.04 **	131.14 **
Total	187	9.27 **	300.89 **	24.98 **	134.25 **	8.37 **	0.52	2241.4 **	51.60 **	5.18 **	149.54 **
Error	21	0.001	0.736	0.148	0.241	0.374	0.01	97.256	1.094	4.707	0.907

*and ** significant at 5% and 1% level, respectively.

DFF=days to 50% flowering, PH=plant height, TPP= tillers per plant, PPP= panicles per plant, PL= panicle length, PW= panicle weight, SPP =spikelets per panicle, SF=spikelet fertility, TGWT= 1000 grain weight, YPP=yield per plant.

TABLE II

General Combining Ability effects due to eight lines of rice

Line	DFF	PH	TPP	PPP	PL	PW	SPP	SF	TGWT	YPP
1A	0.85	2.24	-0.239	-1.113	0.648	-0.120	-17.969 **	-0.612	-0.356	-3.809 *
2A	0.36	0.92	1.756	0.693	-0.157	0.058	3.731 *	-1.617	-0.166	-1.938
3A	-0.15	2.09	0.336	-0.502	0.433	0.102	11.931 **	0.34	0.397	1.435
4A	-0.85	2.02	-0.249	-1.113	1.011	0.184	-0.669	-1.339	1.077	1.158
5A	-0.05	-2.90	-0.734	5.658 *	-0.004	-0.034	-4.269 *	1.954	-0.245	1.898
6A	-0.2	-4.18 *	-0.319	-1.218	-0.429	-0.121	2.981	2.355	0.273	2.075
7A	0.05	-3.37	0.081	-0.648	0.153	-0.015	5.881 *	1.203	-0.268	2.314
8A	0.35	3.17	-0.634	-1.758	-1.057	-0.055	-1.619	-2.289	-0.713	-3.133
SE	0.11	4.19	0.32	2.88	0.22	0.006	38.57	1.44	0.14	3.11

*and ** significant at 5% and 1% level, respectively.

DFF=days to 50% flowering, PH=plant height, TPP= tillers per plant, PPP= panicles per plant, PL= panicle length, PW= panicle weight, SPP =spikelets per panicle, SF=spikelet fertility, TGWT= 1000 grain weight, YPP=yield per plant.

TABLE III

General Combining Ability Effects due to twenty advanced restorers (testers)

Tester	DFF	PH	TPP	PPP	PL	PW	SPP	SF	1000 GW	YPP
1A	0.85	2.24	-0.239	-1.113	0.648	-0.120	-17.969 **	-0.612	-0.356	-3.809 *
R1	0.5	-14.04 **	1.366	0.38	-1.18	-0.44	-19.6 **	-2.85 *	-2.41 *	-7.05 **
R2	1.62	-15.17 **	-1.09	-1.94	-2.78 *	-0.20	-9.51 **	-1.03	1.49 -	4.02 **
R3	-1.06	2.3 *	-2.67	15.03 **	0.80	-0.02	10.60 **	0.41	1.06	4.06 **
R4	-1.25	6.1	0.52	0.07	0.27	0.95	52.10 **	6.34 **	1.83	11.02 **
R5	1.75	-16.78 **	-3.62 **	-4.04	-0.42	-0.52	-9.51 **	-3.78 **	-1.07	-5.68 **
R6	4.0**	-20.52 **	-1.92	-1.93	-1.14	-0.30	-30.2 **	-3.90 **	-2.08	-11.57 **
R7	-0.62	6.35 **	-0.92	-1.95	0.07	-0.05	-17.7 **	0.74	0.32	-3.81 **
R8	-0.87	-0.96	2.01	1.28	0.28	0.05	14.23 **	2.93 **	0.92	7.52 **
R9	1.12	-2.43	2.31 *	1.14	-0.72	-0.24	-15.5 **	-0.42	-1.68	-1.01
R10	-1.3	8.73 **	1.47	0.05	1.39	-0.16	-11.8 **	4.68 **	0.33	2.28 *
R11	0.55	7.03 **	-1.07	-2.11 *	0.33	0.17	1.35	0.38	0.47	3.64 **
R12	-0.25	4.55 **	0.71	-0.55	2.21 *	0.19	1.23	0.95	0.31	1.03
R13	0.12	9.76 **	2.11 *	1.45	0.14	0.33	26.98 **	-1.57	1.87	3.88 **
R14	-0.75	-8.4	-2.29 *	-1.61	-0.27	-0.34	-15.6 **	-1.88	-0.03	-2.36 *
R15	-1.5	0.82	1.99	1.07	1.07	0.21	14.60 **	6.72 **	0.06	8.91 **
R16	0.75	5.82 **	-2.73 *	-3.59	0.82	0.08	-12.1 **	-1.07	-0.31	-6.40 **
R17	-1.37	6.75 **	-1.53	-2.69 *	0.20	0.19	19.98 **	0.06	0.09	3.22 **
R18	-0.37	11.62 **	1.09	0.258	-0.23	-0.03	-4.39 **	-1.12	0.88	-2.69 *
R19	-0.75	9.25 **	0.92	-0.09	0.42	0.48	25.98 **	-0.50	-0.43	7.15 **
R20	0.25	-0.78	1.31	-0.21	-1.53	-0.24	-20.7 **	-5.10 **	-1.66	-8.06 **
SE	6.57	29.81	1.09	5.28	0.39	0.03	134.56	3.19	0.48	12.13

*and ** significant at 5% and 1% level, respectively.

DFF=days to 50% flowering, PH=plant height, TPP= tillers per plant, PPP= panicles per plant, PL= panicle length, PW= panicle weight, SPP =spikelets per panicle, SF=spikelet fertility, TGWT= 1000 grain weight, YPP=yield per plant.

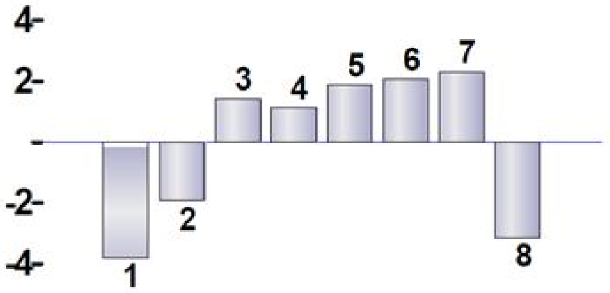

Fig. 1 : GCA effects of lines (1 to 8) for grain yield per plant

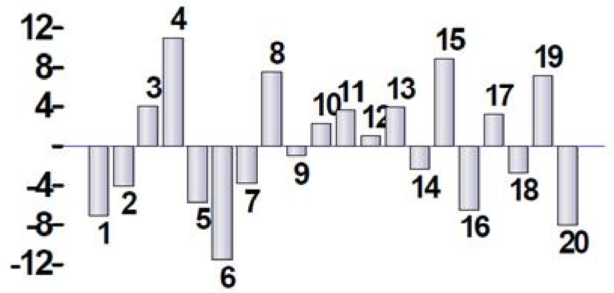

Fig.2 : GCA effects of testers (1 to 20) for grain yield per plant

7A (-3.37) among the lines. The tester R18 showed positive and highlysignificant GCA effect (11.62). On the other hand, the tester R6 (-20.25) also recorded highly significant negative GCA effect. Significant negative GCA effects for plant height and growth duration are useful for the development of early dwarf CMS lines and varieties. The results were in agreement with the findings of Rashid *et al.* (2007), Hossain *et al.* (2009) and Devi *et al.* (2018).

Among the lines, 2A showed highest positive GCA effect (1.75) for tillers per plant and the tester R9 exhibited significant positive GCA effect (2.31) when testers were considered. Similarly, 5A registered highest positive and significant GCA effect (5.65) for panicles per plant among lines and R3 registered highly significant positive GCA effect (15.03) among testers. Desirable GCA effects were also observed in 4A for panicle length (1.01) and in R12, which exhibited significant positive GCA effect (2.21). Considering the exhibition of useful GCA effects, the restorers were identified as good general combiners for the traits concerned. However, none of parents were found significant and positive GCA effect for panicle weight. These results were in accordance with the findings of Hossain *et al*. (2009).

Spikelets per plant is the important yield determining component in rice. 3A line showed highly significant positive GCA effect (11.93) followed by 7A (5.88) and 2A (3.73) among lines. Among testers, R4 showed highly significant and positive GCA effect (52.10) followed by R13 (26.98), R19 (25.98), R17 (19.98) and R8 (14.23). For spikelet fertility, line 6A showed positive GCA effect (2.35). However, testers R15 (6.72), R4 (6.34) and R10 (4.68) showed highly significantly positive GCA effects.

Highest positive GCA effect (2.31) for grain yield per plant was recorded by the line 7A followed by 6A (2.07) and highest negative and significant GCA effect (-3.80) was evident for the line 1A. Among testers, the tester R4 recorded highly significant positive GCA effect (11.02) followed by R15 (8.90), R8 (7.52) and R19 (7.15). Other testers like R3 (4.06), R13 (3.88), R11 (3.64), and R17 (3.22) showed significant positive GCA effects. These parents have great potential for utilization in hybrid rice breeding programme. Higher GCA effects in parents were also reported earlier by Saidaiah *et al.* (2010), Devi *et al*. (2014), Kishor *et al*. (2017) and Devi *et al*. (2018).

Proportional contribution of CMS lines, restorer testers and their interaction to total variances : The relative contribution of line, tester and their interaction to total variances for ten yield and its related traits in rice are presented in Table IV. The proportion contributed by CMS lines to total variances for all the traits were low and ranged from 1.93 per cent for panicle weight to 6.28 per cent for panicle length. However, testers showed relatively higher contribution as evident by the wide range of variation observed for tillers per plant (13.79%) to plant height (52.93%). This indicates that the new advance breeding testers used in the study contributed more positive alleles for those characters having predominance for additive gene action. It is clear from the Table IV that testers contribution was more for most of the yield attributing traits. On the other hand, proportion contributed by L x T interaction is highest in the respective hybrid. Panicles per plant recorded highest contribution of 87.44 per cent followed by tillers per plant (83.83%), spikelets per panicle (77.78%), spikelet fertility (76.61%), panicle weight (76.38%) and grain yield per plant (72.02%). This

TABLE IV

Proportional contribution of CMS lines, restorer testers and their interaction to total variances

Contributor	DFF	PH	TPP	PPP	PL	PW	SPP	SF	TGWT	YPP
Lines	3.22	4.45	2.36	3.24	6.28	1.93	3.20	5.01	5.34	3.68
Testers	27.56	52.93	13.79	9.30	17.81	21.68	19.01	18.36	28.98	24.29
L x T	69.21	42.60	83.83	87.44	75.90	76.38	77.78	76.61	65.67	72.02

DFF=days to 50% flowering, PH=plant height, TPP= tillers per plant, PPP= panicles per plant, PL= panicle length, PW= panicle weight, SPP =spikelets per panicle, SF=spikelet fertility, TGWT= 1000 grain weight, YPP=yield per plant.

indicated that these characters are predominantly governed by non-additive gene action and are most important characters contributing to yield in hybrid rice. Similar results were also reported by Hossain *et al*. (2009), Akter *et al*. (2010), Devi *et al*. (2014) and Singh *et al*. (2015).

Best specific cross combinations : Out of 160 hybrids evaluated for yield and its attributing traits, top ten hybrids were selected based on *per se* performance and specific combining ability (Table V). The hybrid combination 7A/R19 recorded highest mean yield per plant of 79.42 gms with an estimated yield of 19855 kg/ha followed by the cross combinations 5A/R19, 5A/R4, 3A/R8, 8A/R17, 4A/R11, 7A/R3, 6A/R17, 3A/R15 and 3A/R13.

Specific combining ability effects: Specific combining ability effects of top ten best performing hybrids with respect to grain yield per plant are presented in Table VI. All the ten hybrid combinations showed highly significant SCA effect. Although rice is a self-pollinated crop, presence of high significant values for SCA indicates role of non-additive gene action for development of successful commercial rice hybrids. Similar results were reported by Patil *et al*. (2012) and Thorat *et al*. (2017).

TABLE V

Top ten best performing hybrid combinations based on mean yield per plant

Rank	Hybrid combination	Mean grain yield per plant (gm)	Estimated grain yield per ha. (kg)
1	7A XR19	79.42	19855
2	5A XR19	78.99	19747
3	5A X R4	68.46	17115
4	3A X R8	67.95	16987
5	8A XR17	67.45	16862
6	4A XR11	65.62	16405
7	7A X R3	65.1	16275
8	6A XR17	60.21	15052
9	3A XR15	60.1	15025
1	03A XR13	59.95	14987
Check1	MC 13	40.2	10050
Check2	DRH 836	42.31	10577
Check3	KRH 4	49.91	12477

TABLE VI

Specific Combining Ability effects of top ten best performing hybrids with respect to grain yield per plant

Hybrid	7A/R19	5A/ R19	5A/R4	3A/R8	8A/R17	4A/R11	7A/R3	6A/ R17	3A/ R15	3A/R13
SCA effect	32.82 **	32.8 **	18.4 **	21.85 **	30.22 **	23.72 **	21.5 **	17.77 **	13.22 **	17.5 **

** significant at 1% level.

TABLE VII

Mid-parent, Better parent and Standard heterosis of top ten best performing hybrids with respect to grain yield per plant

Hybrid combination	Mid-parent	Better-parent	Standard heterosis		
			Check 1	Check 2	Check 3
7A X R19	182.28 **	139.58 **	102.29 **	85.86 **	59.25 **
5A X R19	206.94 **	138.28 **	101.2 **	84.86 **	58.39 **
5A X R4	198.43 **	148.4 **	74.38 **	60.22 **	37.28 **
3A X R8	178.14 **	103.26 **	73.08 **	59.02 **	36.25 **
8A X R17	165.97 **	130.2 **	71.8 **	57.85 **	35.25 **
4A X R11	189.01 **	133.94 **	67.14 **	53.57 **	31.58 **
7A X R3	121.81 **	82.97 **	65.82 **	52.35 **	30.54 **
6A X R17	161.73 **	105.49 **	53.36 **	40.91 **	20.73 **
3A X R15	126.37 **	58.9 **	54.61 **	42.05 **	21.72 **
3A X R13	201.33 **	146.1 **	52.7 **	40.3 **	20.21 **

Estimation of Heterosis : Mid-parent, better parent and standard heterosis of top ten best performing hybrids with respect to mean grain yield per plant are presented in Table VII. Test hybrids showed highly significant mid-parent, better-parent heterosis or heterobeltiosis and standard heterosis over commercial check hybrids. Similar results were reported by Bhati *et al.* (2017) and Thorat *et al.* (2017).

The present investigation envisaged that the newly evolved CMS lines *viz.,* 5A (panicles per plant), 6A (plant height) and 7A (spikelets per panicle) and the restorer testers, R3 (plant height, panicles per plant, spikelets per panicle and grain yield per plant) R4 (spikelets per panicle, spikelet fertility and grain yield per plant), R11 (plant height and grain yield per plant), R13 (plant height, spikelets per panicle and grain yield per plant), R15 (spikelets per panicle, spikelet fertility and grain yield per plant), R17 (plant height, spikelets per panicle and grain yield per plant) and R19 (plant height, spikelets per panicle and grain yield per plant) were the best general combiners in the desirable direction. Hence, they can be better utilized in developing rice hybrids as well as high yielding varieties. Also hybrid combinations 7A/R19, 5A/R19, 5A/R4, 3A/R8, 8A/R17, 4A/R11, 7A/R3, 6A/R17, 3A/R15 and 3A/R13 can be potential hybrids in future.

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