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Study on Gene Action and Combining Ability of Yield and Quality Components in Rice (*Oryza sativa* L)

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In the present research work six CMS lines viz., JMS 11A, JMS 21A, CMS 11A, CMS 23A, CMS 52A and JMS 18A were mated with seven testers viz., JGL 32979, JGL 32994, JGL 33060, JGL 33080, JGL 33366, JGL 34561 and JGL 34564 in Line X Tester mating design resulting in 42 hybrids. The parents and their 42 hybrids along with four checks (US 312, 27P63, NLR 34449 and TN 1) were evaluated by planting in Randomized Block Design with two replications at Regional Agricultural Research Station, Polasa, Jagtial. The data was collected on days to 50 per cent flowering, plant height (cm), panicle length (cm), number of productive tillers per plant, number of grains per panicle, spikelet fertility (%), 1000- grain weight (g), grain yield per plant (g), hulling percentage, milling percentage, head rice recovery, kernel length (mm), kernel breadth (mm) and kernel L/B ratio.

Introduction

Rice (*Oryza sativa* L.) is a cereal crop belonging to family Graminae. It is one of the world's most important food crops and a primary source of food for more than half of the world population growing in at least 143 countries under diverse condition. Therefore, rice plays an important role in ensuring food security and contributing to poverty and malnutrition alleviation in Asia and the world. Its improvement for higher yield in sustainable agriculture system is also vital to provide energy and nutritional needs of growing world population.

The global area under rice production is 1.5 billion hectares with a production of 481.54 million tons per annum (IRRI, 2018). In India it is grown in about 43.77 million hectares with a production of 112.758 million tonnes and productivity of 2576 kg per hectare (www.indiastat.com, 2017-18). While, in Telangana State it is grown in an area of 9.15 lakh hectares with a production of 33.15 lakh tonnes and productivity 3624 kg/ha (www.indiastat.com, 2017-2018).

Yield levels has become major concern in view of continuously increasing population pressure in the country i.e., population has been increasing very rapidly at the rate of 1.5 per cent while food grain production stagnated at 1 per cent. Therefore, there is urgent need to enhance the productivity levels in the country. Among the many genetic approaches being explored to break the yield barrier in rice and increase productivity, hybrid rice technology appears to be most feasible and readily adoptable one. This would offer an alternative to raise further the rice yield potential by exploiting the genetic expression of heterosis or hybrid vigour.

The selection of appropriate parents for hybridization programme could be made on the basis of their ability to transmit desirable performance to their crosses. The combining ability is a powerful tool to discriminate parents as good or poor combiners. It not only helps in choosing an appropriate parental material but also provide the nature of gene action and for developing suitable breeding methodology for the crop.

Sprague and Tatum (1942) elaborated the concept of combining ability, they defined general combining ability (GCA) as the "average performance of a line in hybrid combinations" while the specific combining ability (SCA) is the "deviation from performance predicted on the basis of GCA". In any hybrid breeding programme, plant breeder's aim is to identify parents with good general combining ability and crosses showing high specific combining ability. Combining ability in turn reveals the nature and mode of gene action which unravels the sound breeding methodology. One of the main problems for plant breeders in developing hybrid varieties is to select good parents and crosses. Line x Tester mating design (Kempthorne, 1957) provides reliable information about the general and specific combining ability (GCA and SCA) of parents and their cross combinations within affordable resources (Sarkar *et al.,* 2002).

Materials and Methods

The experimental material for the present study comprised of six lines viz., JMS 11A, JMS 21A, CMS 11A, CMS 23A, CMS 52A and JMS 18A, seven restorer lines viz., JGL 32979, JGL 32994, JGL 33060, JGL 33080, JGL 33366, JGL 34561 and JGL 34564 and their 42 hybrids. All 42 hybrids along with parents and checks (US 312, 27P63, NLR 34449 and TN 1) were evaluated their mode of gene action and estimate their combining ability. The 30 days old seedlings of 59 entries (6 lines, 7 testers, 42 hybrids and 4 checks) were transplanted in the main field in Randomized Block Design. Each entry was planted in two rows of four meters length with a spacing of 20 x 15 cm in two replications. Standard agronomical package of practices were followed to raise good crop.

Observations were recorded for yield and yield attributing characters by randomly choosing five plants from each entry in each replication and their means were used for the statistical analysis. The plants were selected from the middle rows to minimize error due to the border effect. The details of 14 observations taken are given below.

Replication wise mean value for all the characters were subjected to statistical analysis for computing mean, variance, general combining ability (gca) and specific combining ability (sca) and gene action. The data recorded on the material generated as per Line x Tester model of Kempthorne (1957) was subjected to analysis of variance as per the Line x Tester model given by Singh and Chaudhary (1985).

Combining ability analysis was carried out by the method suggested by Kempthorne (1957). The standard errors (SE) pertaining to gca and sca effects of different combinations and 't' test is used to calculate the test of significance. The calculated value of 't' was compared with table value of ' t' at 5 % and 1 % levels of significance i.e. 1.96 and 2.58 respectively.

Results and Discussion

Data recorded on 42 hybrids, six lines and seven testers along with checks was used for combining ability analysis using Line X Tester mating design (L x T) proposed by Kempthorne (1957) (Table 1). The results of analysis are discussed under the following subheads:

ANOVA for line x tester

General combining ability effects and Specific combining ability effects

GCA and SCA variance and gene action

Analysis of variance

The analysis of variance for combining ability of all the traits under study is been presented in the table 2.

The variance due to treatments was highly significant for all the characters under study. The parents exhibited significant differences for all the traits studied except for number of productive tillers per plant.

The variance due to crosses was found highly significant for all of the characters except plant height. The variance due to parent vs. crosses was also found highly significant for most of the characters except plant height, number of productive tillers per plant and head rice recovery.

The variance due to lines was found significant for all the traits except number of productive tillers per plant, where as the variance due to testers was found non-significant for plant height, number of productive tillers per plant and hulling per cent. When the effects of crosses was partitioned into lines, testers and line x tester effects, the interaction effects (lines x testers) were found to be significant for all the traits except plant height and number of productive tillers per plant under study. This suggested that sufficient variability is available in the material used for study.

Combining ability effects

The general combining ability (GCA) effects of thirteen parents i.e., six lines and seven testers and specific combining effects (SCA) effects of forty two hybrid combinations estimated according to procedure described by Kempthorne, 1957 (Line x Tester mating design).

General combining ability

The character wise results of GCA effects of the parents have been presented in (Table 3).

Days to 50 per cent flowering

The gca effects for days to 50 per cent flowering among lines ranged from -4.76 (CMS 23B) to 4.09 (JMS 18B). Among testers gca effects ranged from -3.22 (JGL 34561) to 2.85 (JGL 33060). This indicated that line, CMS 23B (-4.76) and tester JGL 34561 (-3.22) are good general combiners for days to 50 per cent flowering because they exhibited high negative significant gca effects which is desirable for this character.

Among the 42 hybrids, 20 hybrids recorded significant sca effects. Nine of those hybrids have shown the positive significant sca effects and eleven hybrids have shown the negative significant sca effects. The cross CMS 52A X JGL 33060 (-11.35) exhibited highest negative and significant sca effect, followed by JMS 18A X JGL 34561 (-10.34), JMS 21A X JGL 33080 (-7.23) and CMS 23A X JGL

32979 (-6.90) which is desirable for earliness.

Plant height (cm)

With regard to plant height, a total of only three parents recorded significant gca effect. However, only one parent (one line) out of three parents recorded significant negative gca effects for this trait.

Among three parents CMS 23B (- 6.25) showed negative significant gca which indicated that it possess genes for dwarfness and considered as good general combiner for dwarf plant stature.

The range of sca effects for this trait varied from -4.97 (CMS 23A X JGL 32979) to 6.39 (JMS 21A x JGL 32979). Out of 42 hybrids, 5 hybrids recorded significant negative sca effects, while 5 hybrids recorded positive and significant sca effects. The cross CMS 23A X JGL 32979 (-4.97) exhibited greatest significant negative sca effect followed by JMS 11A X JGL 32994 (-4.67) and CMS 11A X JGL 33060 (-2.54), which is desirable for this trait.

Panicle length (cm)

The gca effects among lines varied from -1.61 (CMS 23B) to 1.49 (JMS 11B) and in tester only one negative significant gca observed that is -0.77 (JGL 32979). The line JMS 11B (1.49) recorded high positive significant gca effect for the trait.

The best specific combiners for this trait are CMS 52A X JGL 33366 (2.29), CMS 11A X JGL 32994 (2.18) and JMS 21A X JGL 33060 (1.74).

Number of productive tillers per plant

The parents possessed non- significant gca effects except for testers JGL 33080 (-0.89), JGL 34561 (0.85), JGL 32994 (0.97) with a range from -0.58 (CMS 52B) to 0.66 (CMS 23B) for lines and from -0.42 (JGL 33366) to 0.05 (JGL 32979) for testers.

Out of 42 crosses, only one crosse viz., JMS 11A X JGL 33060 (2.68) recorded significant and positive sca effect for this trait with a range from -2.61 (CMS 11A X JGL 33060) to 2.68 (JMS 11A X JGL 33060).

1000- Grain weight (g)

The gca effects of lines for this trait was ranged from -0.89 (JMS 18B) to 0.54 (CMS 11B) while in testers it ranged from -5.19 (JGL 32994) to 3.34 (JGL 33080). Highly positive significant gca effects was observed for the line CMS 11B (0.54) and tester JGL 33080 (3.34) and identified as good general combiners for the trait.

Among the 42 hybrids, 23 hybrids recorded significant sca effects. Ten of those hybrids have shown the positive significant sca effects and thirteen hybrids have shown the negative significant sca effects. The range of sca effects for this trait was from -2.90 (JMS 11A X JGL 33080) to 3.59 (CMS 23A X JGL 34564). The best specific combiners identified for this trait are CMS 23A X JGL 34564 (3.59), CMS 52A X JGL 32979 (2.89) and JMS 21A X JGL 32979 (1.62).

Number of grains per panicle

The line, JMS 11B (11.69) recorded significant and positive gca effect, while JMS 21B (-8.52) and JMS 18B (-7.38) recorded negative significant gca effects. The tester JGL 32994 (58.58) recorded highly positive gca effect while, JGL 33080 (-40.91), JGL 32979 (-33.83) and JGL 33366 (-7.50) recorded highly negative gca effect. Among the parents, JMS 11B and JGL 32994 were identified as best general combiners for the trait.

Table.1 Different observation parameter data of rice

Morphological characteristics		Grain quality parameters	
1	Days to 50 per cent flowering	09	**Hulling %**
2	Plant height (cm)	10	**Milling %**
3	Panicle length (cm)	11	**Head rice recovery (%)**
4	Number of productive tillers per plant	12	**Kernel length (mm)**
5	Number of grains per panicle	13	**Kernel breadth (mm)**
6	Spikelet fertility (%)	14	**Kernel L/B ratio**
7	1000- grain weight (g)		
8	**Grain yield per plant (g)**		

Table.2 Analysis of variance for combining ability (Line x Tester) for yield and quality traits in rice

Source of Variations	df	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	1000 grain weight (g)	No. of grains per panicle	Spikelet fertility (%)	Grain yield per plant (g)
Replicates	1	6.14**	0.20	2.88	1.36	1.89	268.94	22.05**	**11.40**
Treatments	54	84.84**	69.54**	5.20**	3.41*	20.51**	5533.58**	274.28**	**101.36****
Parents	12	133.05**	190.43**	4.70**	2.71	18.78**	7849.55**	239.92**	**32.91****
Parents (Line)	5	54.13**	108.66*	3.22*	2.77	25.64**	7079.48**	265.51**	**34.18****
Parents (Testers)	6	112.78**	22.77	4.34*	1.34	16.04**	7894.45**	235.78**	**35.29****
Parents (L vs T)	1	649.23**	1605.28**	14.30**	10.60*	0.94	11430.48**	136.76**	**12.21**
Parents vs Crosses	1	30.79**	4.89	25.77**	1.67	7.01*	14945.08**	274.37**	**894.76****
Crosses	41	72.04**	35.73	4.85**	3.65*	21.34**	4626.18**	284.33**	**102.05****
Line Effect	5	174.04*	151.05**	15.44*	2.51	6.51	808.56	398.63*	**90.74**
Tester Effect	6	56.01	35.51	2.62	5.69	109.38**	13079.02*	976.54**	**147.01**
Line * Tester Eff.	30	58.25**	16.56	3.53**	3.44	6.21**	3571.88**	126.84**	**94.94****
Error	54	4.20	23.37	1.06	1.81	0.63	102.85	9.07	**5.34**
Total	**109**	**44.16**	**46.03**	**3.13**	**2.60**	**10.49**	**2794.82**	**140.58**	**52.97**

Table.2 (…continued)

Source of Variations	df	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernal length (mm)	Kernel breadth (mm)	Kernel length / breadth ratio
Replicates	1	6.14	5.23	0.03	0.00	0.04	**0.00**
Treatments	54	18.81**	31.83**	49.58**	0.66**	0.04**	**0.26****
Parents	12	16.53**	37.61**	84.38**	0.40**	0.08**	**0.14****
Parents (Lines)	5	25.60**	74.93**	103.73**	0.21*	0.02**	**0.10****
Parents (Testers)	6	2.95	10.28*	25.90*	0.61**	0.14*	**0.17****
Parents (L vs T)	1	52.74**	15.36	338.52**	0.05	0.01	**0.07***
Parents vs Crosses	1	43.80*	177.38**	13.24	1.36**	0.58**	**0.11***
Crosses	41	18.87**	26.59**	40.28**	0.72**	0.03**	**0.30****
Line Effect	5	22.79	17.48	57.90	0.56	0.11*	**0.63***
Tester Effect	6	12.82	35.93	25.30	1.92**	0.08	**0.71***
Line * Tester Eff.	30	19.43**	26.24**	40.34**	0.51**	0.02**	**0.17****
Error	54	4.07	4.12	6.48	0.04	0.04	**0.01**
Total	**109**	**11.39**	**17.86**	**27.77**	**0.35**	**0.02**	**0.14**

Significant at 5 per cent level ** Significant at 1 percent level

Table.3 Estimates of general combining ability (GCA) effects for lines and testers for yield and quality traits in rice

Source	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tiller per plant	1000 - grain weight(g)	No. of grains per panicle	Spikelet fertility (%)	Grain yield per plant (g)
PARENTS								
LINES								
JMS 11B	1.16 *	2.52	1.49 **	-0.03	0.45 *	11.69 **	-8.35 **	**-3.58 ****
JMS 21B	-3.26 **	0.17	0.41	-0.14	0.45 *	-8.52 *	2.51 *	**-0.55**
CMS 11B	3.23 **	0.07	-0.53	0.26	0.54 *	4.11	-3.06 **	**1.82 ***
CMS 23B	-4.76 **	-6.25**	-1.61 **	0.66	0.29	2.04	0.5	**2.32 ****
CMS 52B	-0.47	0.75	-0.18	-0.58	-0.85 **	-1.95	0.93	**2.28 ****
JMS 18B	4.09 **	2.79 *	0.43	-0.14	-0.89 **	-7.38 *	7.46 **	**-2.30****
TESTERS								
JGL 32979	-0.81	-1.02	-0.77 *	0.05	2.53 **	-33.83 **	-3.57 **	**-0.04**
JGL 32994	1.85 *	-1.6	0.2	0.97 *	-5.19 **	58.58 **	7.18 **	**5.95 ****
JGL 33060	2.85 **	3.57*	-0.45	-0.16	-2.33 **	8.50 *	8.20 **	**-5.63 ****
JGL 33080	1.52 *	-0.5	0.4	-0.89 *	3.34**	-40.91 **	9.68 **	**0.3**
JGL 33366	-0.56	-0.95	0.53	-0.42	-0.77 *	-7.50 *	-5.95 **	**0.67**
JGL 34561	-3.22**	0.37	0.03	0.85 *	1.94 **	2.83	-0.47	**-2.21 ***
JGL 34564	-1.64 *	0.14	0.04	-0.4	0.47 *	12.33 **	-15.06 **	**0.95**
CD 95% GCA	1.1	2.61	0.55	0.72	0.43	5.47	1.62	**1.24**
(Line)								
CD 95% GCA	**1.19**	**2.81**	**0.6**	**0.78**	**0.46**	**5.91**	**1.757**	**1.34**

Table.3 (…Continued)

Sources	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breath (mm)	Kernel L/B ratio
PARENTS						
LINES						
JMS 11B	-0.88	0	-0.9	0.19 *	-0.15 **	**0.36 ****
JMS 21B	-1.02	-2.14 **	-1.19	-0.07	-0.05	**-0.04**
CMS 11B	-1.16 *	0.57	2.52 **	0.1	0.09 **	**-0.09 ***
CMS 23B	1.83 *	0.57	2.09 *	-0.36 **	0.07 **	**-0.27 ****
CMS 52B	-0.02	0	-2.76 **	0.05	0.04 *	**-0.04**
JMS 18B	1.26 *	1	0.23	0.09	-0.04 *	**0.08 ***
TESTERS						
JGL 32979	0.97	-0.31	1.28	-0.1	0.05 *	**-0.12 ***
JGL 32994	0.31	1.85 *	0.11	-0.64 **	-0.02	**-0.29 ****
JGL 33060	-1.35 *	-2.64 **	0.45	-0.11	0.04 *	**-0.12 ***
JGL 33080	-1.52 *	-1.64 *	-2.54 *	0.55 **	-0.05	**0.29 ****
JGL 33366	0.14	1.52 *	-1.04	0.13 *	-0.02	**0.07 ***
JGL 34561	0.97	1.52 *	1.78 *	-0.22 **	0.01	**-0.17 ****
JGL 34564	0.47	-0.31	-0.04	0.39 **	-0.05 *	**0.34 ****
CD 95% GCA	1.08	1.09	1.37	0.11	0.03	**0.06**
(Line)						
CD 95% GCA	**1.17**	**1.18**	**1.48**	**0.12**	**0.03**	**0.07**

Table.4 Estimates of specific combining ability (sca) effects for yield and quality traits in rice

S.No.	Crosses	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	1000-grain weight (g)	No. of grains per Panicle	Spikelet fertility (%)	Grain yield per plant (g)
1	JMS 11A XJGL 32979	0.16	0.13	-0.90	-0.23	-0.07	-8.52	5.88 *	**-2.34**
2	JMS 11A XJGL 32994	-3.50 *	-4.67*	0.46	1.35	0.69	-101.44**	1.06	**0.84**
3	JMS 11A XJGL 33060	2.00	2.83	-0.28	2.68 *	1.61 *	22.14*	-1.44	**4.50 ***
4	JMS 11A XJGL 33080	-2.16	3.42*	0.36	-0.68	-2.9 **	-19.94*	6.28 *	**-0.94**
5	JMS 11A XJGL 33366	0.91	-2.32	0.92	-1.60	1.31 *	-22.35 *	-2.75	**0.85**
6	JMS 11A XJGL 34561	2.58	-2.66	0.92	-1.43	-1.15 *	64.81 **	-9.06 **	**-0.14**
7	JMS 11A XJGL 34564	0.00	3.27*	-1.48 *	-0.07	0.59	65.31 **	0.03	**-2.76**
8	JMS 21A XJGL 32979	1.59	6.39	0.82	-0.22	1.62 *	-4.31	-1.51	**13.04 ****
9	JMS 21A XJGL 32994	-6.07 **	1.37	0.63	0.33	0.67	45.77 **	3.90	**-9.39 ****
10	JMS 21A XJGL 33060	10.92 **	-1.20	1.74 *	-0.40	-1.58*	-54.14 **	-0.62	**-0.55**
11	JMS 21A XJGL 33080	-7.23 **	-0.82	0.23	1.52	1.23 *	-11.72	-1.25	**0.63**
12	JMS 21A XJGL 33366	-1.65	-2.07	-2.69**	-0.09	-0.84	-23.64 *	-9.74 **	**0.39**
13	JMS 21A XJGL 34561	-3.48 *	-1.90	-0.44	-1.07	0.01	12.52	13.75 **	**-3.92 ***
14	JMS 21A XJGL 34564	5.92 **	-1.77	-0.30	-0.06	-1.12	35.52 **	-4.50 *	**-0.20**
15	CMS 11A XJGL 32979	3.59 *	0.86	0.07	-0.58	0.32	-34.45 **	-1.97	**-8.11 ****
16	CMS 11A XJGL 32994	1.92	2.04*	2.18 *	1.80	1.34 *	-0.86	1.81	**12.21 ****
17	CMS 11A XJGL 33060	-0.57	-2.54*	0.54	-2.61 *	1.04	12.21	-3.08	**1.18**
18	CMS 11A XJGL 33080	-3.23 *	-1.05	0.48	-0.23	-1.18 *	32.63 **	-3.64	**-6.36 ****
19	CMS 11A XJGL 33366	1.84	-0.70	-2.04 *	1.14	-1.04	33.71 **	2.74	**1.18**
20	CMS 11A XJGL 34561	0.51	0.01	-0.09	1.36	1.41 *	-25.61 **	-2.07	**-5.38 ***

21	CMS 11A XJGL 34564	-4.07 *	1.39	-1.15	-0.87	-1.89 **	-17.61 *	6.23*	**5.26 ***
22	CMS 23A XJGL 32979	-6.90 **	-4.97*	0.05	1.06	-2.87**	27.11 **	-7.95 **	**-1.95**
23	CMS 23A XJGL 32994	-1.07	-1.89	-0.03	-2.24 *	0.99	3.20	-13.3**	**9.46 ****
24	CMS 23A XJGL 33060	-1.07	0.62*	-0.97	0.38	-0.26	15.78 *	7.07 *	**-3.88 ***
25	CMS 23A XJGL 33080	5.26 *	2.10	-0.63	0.11	1.17 *	7.70	8.60 **	**-7.67 ****
26	CMS 23A XJGL 33366	0.34	0.55	0.03	0.44	-0.87	50.28 **	-7.62 **	**-7.05 ****
27	CMS 23A XJGL 34561	6.01 **	4.02	0.93	0.61	-1.75 *	-37.04**	2.29	**7.62 ****
28	CMS 23A XJGL 34564	-2.57	-0.44	0.62	-0.37	3.59**	-67.04**	10.94 **	**3.48 ***
29	CMS 52A XJGL 32979	1.31	-1.19*	1.31	1.31	2.89**	60.61**	-6.70 *	**1.47**
30	CMS 52A XJGL 32994	6.64 **	1.79	-1.96 *	-0.79	-2.39**	10.70	8.76 **	**-11.19 ****
31	CMS 52A XJGL 33060	-11.35 **	1.81*	-1.21	0.03	-1.18 *	-4.71	2.08	**-3.62 ***
32	CMS 52A XJGL 33080	2.47	-0.40	-0.76	0.46	0.70	-11.79	-8.66 **	**15.55 ****
33	CMS 52A XJGL 33366	1.56	-1.05	2.29 *	0.24	-0.09	6.78	7.68 **	**0.43**
34	CMS 52A XJGL 34561	4.72 *	1.11	-1.00	-0.88	1.60 *	-39.54**	6.13 *	**-3.80 ***
35	CMS 52A XJGL 34564	-5.35**	-2.05	1.33	-0.37	-1.53 *	-22.04*	-9.23 **	**1.15**
36	JMS 18A XJGL 32979	0.23	-1.22	-1.35	-1.32	-1.90 *	-40.4**	12.26 **	**-2.11**
37	JMS 18A XJGL 32994	2.07	1.35	-1.28	-0.44	-1.31 *	42.63**	-2.22	**-1.93**
38	JMS 18A XJGL 33060	0.07	-1.52*	0.17	-0.10	0.37	8.71	-3.92	**2.37**
39	JMS 18A XJGL 33080	4.90*	-3.24	0.31	-1.17	1.06	3.13	-1.31	**-1.20**
40	JMS 18A XJGL 33366	-3.01 *	5.60	1.48 *	-0.14	1.53 *	-44.7**	9.69 **	**4.18 ***
41	JMS 18A XJGL 34561	-10.34 **	-0.57	-0.31	1.42	-0.11	24.88*	-11.03**	**5.63 ****
42	JMS 18A XJGL 34564	6.07 **	-0.39	0.97	1.77	0.36	5.88	-3.46	**-6.93 ****
	CD 95 % SCA	**2.92**	**6.90**	**1.47**	**1.92**	**1.14**	**14.48**	**4.30**	**3.30**

*Significant at 5 per cent level ** Significant at 1 percent level

Table.4 (…continued)

S.No.	Crosses	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio
1	JMS 11A XJGL 32979	-0.11	-1.83	-2.42	0.11	-0.08	**0.18 ***
2	JMS 11A XJGL 32994	0.54	0.00	4.73 *	0.00	-0.14 *	**0.18 ***
3	JMS 11A XJGL 33060	-1.78	2.5	4.40 *	0.56 **	0.03	**0.24 ***
4	JMS 11A XJGL 33080	-6.61 **	-5.50 **	-6.59**	0.15	0.13 *	**-0.03**
5	JMS 11A XJGL 33366	0.71	-2.66	-4.09 *	0.51 *	0.21 **	**-0.05**
6	JMS 11A XJGL 34561	5.88 **	7.33 **	2.07	-0.97 **	-0.08	**-0.47 ****
7	JMS 11A XJGL 34564	1.38	0.16	1.90	-0.38 *	-0.04	**-0.05**
8	JMS 21A XJGL 32979	-1.97	3.31 *	-4.14 *	0.23	-0.10 *	**0.30 ***
9	JMS 21A XJGL 32994	-1.31	-3.85 *	-1.97	0.07	0.19 **	**-0.19 ***
10	JMS 21A XJGL 33060	2.35	-3.35 *	-2.31	-0.11	-0.05	**-0.04**
11	JMS 21A XJGL 33080	2.52	1.64	-7.31 **	-0.31 *	-0.06	**-0.04**
12	JMS 21A XJGL 33366	1.85	1.47	6.19 *	-0.21	-0.08	**-0.05**
13	JMS 21A XJGL 34561	-3.97 *	-2.52	4.35 *	-0.12	-0.02	**-0.06**
14	JMS 21A XJGL 34564	0.52	3.31 *	5.19 *	0.46 *	0.09	**0.04**
15	CMS 11A XJGL 32979	-1.83	-0.40	-1.85	0.812**	0.14 *	**0.10**
16	CMS 11A XJGL 32994	0.83	0.42	1.31	-0.24	-0.14 *	**0.07**
17	CMS 11A XJGL 33060	-3.50 *	-4.07 *	-3.02	-0.36 *	0.02	**-0.17**
18	CMS 11A XJGL 33080	-4.33 *	-5.07 *	1.97	-0.19	0.14 *	**-0.46 ****
19	CMS 11A XJGL 33366	4.00 *	3.76 *	6.47 **	0.38 *	-0.13 *	**0.48***
20	CMS 11A XJGL 34561	4.16 *	3.76 *	-4.35 *	-0.71 **	0.05	**-0.35 ***
21	CMS 11A XJGL 34564	0.66	1.59	-0.52	0.32 *	-0.10 *	**0.32 ***
22	CMS 23A XJGL 32979	-0.83	-2.40	0.57	-0.27	-0.14 *	**0.09**
23	CMS 23A XJGL 32994	-0.16	2.42	-3.26	0.10	0.01	**0.03**
24	CMS 23A XJGL 33060	3.50 *	1.92	3.40	0.10	0.04	**0.01**
25	CMS 23A XJGL 33080	4.66 *	6.92 **	1.40	0.15	-0.03	**0.10**
26	CMS 23A XJGL 33366	-4.00 *	-2.23	2.90	-0.68 **	-0.08	**-0.34 ****

27	CMS 23A XJGL 34561	-2.83	-6.23 **	-1.92	0.90 **	0.05	**0.39 ****
28	CMS 23A XJGL 34564	-0.33	-0.40	-3.09	-0.32 *	0.07	**-0.28 ***
29	CMS 52A XJGL 32979	1.02	-1.83	5.42 *	-0.57 **	0.06	**-0.36 ****
30	CMS 52A XJGL 32994	-0.31	2.00	-2.40	-0.37 *	0.12 *	**-0.35 ****
31	CMS 52A XJGL 33060	-0.64	3.50 *	0.26	0.13	-0.15 *	**0.32 ****
32	CMS 52A XJGL 33080	3.52 *	-0.50	3.26	0.18	-0.01	**0.11**
33	CMS 52A XJGL 33366	-2.14	0.33	-5.23 *	-0.19	-0.04	**-0.09**
34	CMS 52A XJGL 34561	-0.97	-1.66	1.92	1.09 **	0.08	**0.46 ****
35	CMS 52A XJGL 34564	-0.47	-1.83	-3.23	-0.27	-0.05	**-0.09**
36	JMS 18A XJGL 32979	3.73 *	3.16 *	2.42	-0.30 *	0.13 *	**-0.33 ****
37	JMS 18A XJGL 32994	0.40	-1.00	1.59	0.43 *	-0.05	**0.26 ***
38	JMS 18A XJGL 33060	0.07	-0.50	-2.73	-0.32 *	0.08	**-0.34 ****
39	JMS 18A XJGL 33080	0.23	2.50	7.26 **	0.00	-0.17 **	**0.31 ****
40	JMS 18A XJGL 33366	-0.42	-0.66	-6.23 *	0.19	0.05	**0.07**
41	JMS 18A XJGL 34561	-2.26	-0.66	-2.07	-0.18	-0.08	**0.02**
42	JMS 18A XJGL 34564	-1.76	-2.83	-0.23	0.19	0.03	**0.06**
	CD 95 % SCA	**2.88**	**2.90**	**3.63**	**0.30**	**0.09**	**0.17**

*Significant at 5 per cent level ** Significant at 1 percent level

Table.5 Promising general and specific combiners for grain yield and quality traits among parent line

S. no	Parent	Characters
1	CMS 23B	**Days to 50% flowering, grain yield per plant, hulling percentage, kernel breadth.**
2	CMS 52B	**Grain yield per plant and kernel breadth**
3	CMS 11B	**1000 grain weight, grain yield per plant, head rice recovery, kernel breadth**
4	**JGL 32994**	**Number of grain per panicle, number of productive tillers per plant, grain yield per plant, spikelet fertility, milling percentage.**

Table.6 Promising general and specific combiners for grain yield and quality traits in hybrid crosses

S. no	Cross	Characters
1	CMS 52A X JGL 33080	Grain yield per plant and hulling percentage.
2	JMS 21A X JGL 32979	1000 grain weight, grain yield per plant, milling percentage, kernel l/b ratio.
3	CMS 11A X JGL 32994	Plant height, 1000 grain weight, grain yield per plant.
4	CMS 23A X JGL 32994	Grain yield per plant.
5	CMS 23A X JGL 34561	Grain yield per plant, kernel length and kernel L/B ratio.
6	JMS 11A X JGL 33060	Number of productive tillers per plant, 1000 grain weight, number of grains per panicle, grain yield per plant, head rice recovery, kernel length, kernel l/b ratio.
7	JMS 21A X JGL 32979	1000 grain weight, grain yield per plant, milling percentage, kernel l/b ratio.
8	CMS 11A X JGL 33366	Number of grains per panicle, hulling percentage, milling percentage, head rice recovery, kernel length, kernel l/b ratio.
9	CMS 11A X JGL 34564	Days to 50% flowering, spikelet fertility, grain yield per plant, kernel length, kernel l/b ratio.
10	CMS 23A X JGL 33080	1000 grain weight, spikelet fertility, hulling percentage, milling percentage.

Table.7 Estimates of general and specific combining ability variance, proportionate gene action and degree of dominance in rice

Source of variation	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	1000 grain weight (g)	No. of grains per panicle	Spikelet fertility (%)	Grain yield per plant (g)
σ^2 gca	17.05	10.75	1.22	0.35	8.81	1052.45	104.38	**17.46**
σ^2 sca	27.02	-3.4	1.23	0.81	2.78	1734.51	58.88	**44.79**
σ^2 gca / σ2 sca	0.63	-3.15	0.99	0.43	3.16	0.6	1.77	**0.39**
Degree Of Dominance $\frac{\sqrt{\sigma 2\ sca}}{\sqrt{\sigma 2\ 2gca}}$	**1.25**	**0.56**	**1**	**1.52**	**0.56**	**1.28**	**0.75**	**1.6**

Table.7 (…continued)

Source of variation	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio
σ^2 gca	2.11	3.47	5.403	0.185	0.01	**0.10**
σ^2 sca	7.68	11.05	16.93	0.23	0.02	**0.08**
σ^2 gca / σ2 sca	0.27	0.31	0.31	0.78	0.82	**1.27**
Degree Of Dominance $\frac{\sqrt{\sigma 2\ sca}}{\sqrt{\sigma 2\ 2gca}}$	**1.90**	**1.78**	**1.77**	**1.12**	**1.10**	**0.88**

Among the 42 crosses, 27 crosses exhibited significant sca effects, where thirteen crosses recorded positive sca effects and fourteen crosses recorded negative sca effects. The crosses JMS 11A X JGL 34564 (65.31) followed by JMS 11A X JGL 34561 (64.81), CMS 52A X JGL 32979 (60.61), CMS 23A X JGL 33366 (50.28), JMS21A X JGL 32994 (45.77) identified as good specific combiners for number of grains per panicle.

Spikelet fertility (%)

The range of gca effects for this trait varied between -8.35 (JMS 11B) to 7.46 (JMS 18B) among lines, while it was between -15.06 (JGL 34564) to 9.68 (JGL 33080) among testers. The line JMS 18B (7.46) and tester JGL 33080 (9.68) recorded high positive significant gca effects. The best general combiners identified for this trait are JMS 18B (7.46) and JGL 33080 (9.68). Among the 42 crosses, 22 crosses exhibited significant sca effects, where twelve crosses recorded positive sca effects and ten crosses recorded negative sca effects. The crosses JMS 21A X JGL 34561 (13.7) followed by JMS 18A X JGL 32979 (12.26), CMS 23A X JGL 34564 (10.94), JMS 18A X JGL 33366 (9.69) identified as good specific combiners for spikelet fertility.

Grain yield per plant (g)

This trait recorded a range of -3.58 (JMS 11B) to2.32 (CMS 23B) among lines, while a range of -5.63 (JGL 33060) to 5.95 (JGL 32994) was observed among testers for gca effects. The parents CMS 23B (2.32), CMS 52B (2.28) among lines and JGL 32994 (5.95) among testers exhibited significant gca effects in positive direction and considered as good general combiners for grain yield per plant

Ten hybrids expressed significant and positive sca effects for grain yield per plant. The best specific combiners identified for this trait are CMS 52A X JGL 33080 (15.55), JMS 21A X JGL 32979 (13.04), CMS 11A X JGL 32994 (12.21), CMS 23A XJGL 32994 (9.46) and CMS 23A X JGL 34561 (7.62).

Hulling percentage

For this trait, highly significant and positive gca effects were observed for CMS 23B (1.83) line with a range from -1.16 (CMS 11B) to1.83 (CMS 23B) for lines and testers found to be negatively significant with range from-1.52 (JGL 33080) to -1.35 (JGL 33060) for tester.

Out of 42 crosses, seven crosses recorded significant positive sca effects for this trait with a range from -6.61 (JMS 11A X JGL 33080) to 5.88 (JMS 11A X JGL 34561) with JMS 11A X JGL 34561 (5.88) showing highest positive significant followed by CMS 23A X JGL 33080 (4.66), CMS 11A X JGL 34561 (4.16) for this trait and are said to be best specific combiners.

Milling percentage

Among the lines and testers only JGL 32994 (1.85) tester recorded highly positive and significant gca effects and identified as good general combiner for the trait. sca effects ranged from -5.50 (JMS 11A X JGL 33080) to 7.33 (JMS 11A X JGL 34561) for this trait. Eight crosses were found with highly positive and significant sca effects and registered as best specific combiners with (JMS 11A X JGL 34561) (7.33) showing highly positive significant for the trait

Head rice recovery percentage (%)

The range of gca effects for this trait varied between -2.76 (CMS 52B) to 2.52 (CMS 11B) among lines, while it varied between -2.54 (JGL 33080) to 1.78 (JGL 34561) among testers. The line CMS 11B and tester JGL 34561 recorded highly positive and significant gca effects and they were considered as good general combiners for this trait.

The range of sca effects for this trait varied from -7.31 (JMS 21A X JGL 33080 to 7.26 (JMS 18A X JGL 33080). Out of 42 hybrids, eight hybrids recorded positive significant sca effect. The best specific combiners for this trait are JMS 18A X JGL 33080 (7.26), CMS 11A X JGL 33366 (6.47) and JMS 21A X JGL 33366 (6.19).

Kernel length (mm)

Among the lines JMS 11B (0.19) recorded highest positive and significant gca effects with a range from -0.36 (CMS 23B) to 0.19 (JMS 11B) while, in testers JGL 33080 (0.55) and JGL 34564 (0.39) recorded positive and significant gca effects. The line JMS 11B and tester JGL 33080 were found to be good general combiners for this trait.

Nine hybrids expressed significant positive sca effects for kernel length. The cross, CMS 52A X JGL 34561 (1.09) recorded highest positive sca effect followed by CMS 23A X JGL 34561 (0.90) and CMS 11A X JGL 32979 (0.81) are said to be best specific combiners for the trait.

Kernel breadth (mm)

Significant positive gca effects were recorded in CMS 11B (0.09), CMS 23B (0.07), CMS 52B (0.04) lines and JGL 32979 (0.05) and JGL 33060 (0.04) testers which varied from-0.15 (JMS 11B) to 0.09 (CMS 11B) among lines and from -0.05 (JGL 34564) to 0.05 (JGL 32979) in testers. The best general combiners identified for this trait are CMS 11B (0.09), CMS 23B (0.07), JGL 32979 (0.05) and JGL 33060 (0.04).

Seven hybrids expressed significant positive sca effects for kernel breadth. The cross, JMS 11A X JGL 33366 (0.21) recorded highest positive sca effect followed by JMS 21A X JGL 32994 (0.19), CMS 11A X JGL 32979 (0.14) and CMS 11A X JGL33080 (0.14) are said to be best specific combiners for the trait.

Kernel L/B ratio

With respect to kernel L/B ratio the gca effects exhibited range from -0.27 (CMS 23B) to 0.36 (JMS 11B) among lines, while it varied from-0.29 (JGL 32994) to 0.34 (JGL 34564) among testers. High positive significant gca effects recorded for JMS 11B (0.36) and JM 18B (0.08) among lines. In case of testers, JGL 34564 (0.34) recorded highest positive significant gca effect followed by JGL 33080 (0.29).

A range of -0.47 (JMS 11A X JGL 34561) to 0.48 (CMS 11A X JGL 33366)was recorded for sca effects with regard to this trait. Ten crosses exhibited negative significant sca effect, among which JMS 11A X JGL 34561 (-0.47) recorded low significant sca effect and eleven crosses exhibited positive significant sca effect, among which CMS 11A X JGL 33366 (0.48) the cross CMS 52A X JGL 34561 (0.46) recorded high significant sca effect. The best specific combiners identified for this trait are CMS 11A X JGL 33366 (0.48), CMS 52A X JGL 34561 (0.46) and CMS 23A X JGL 34561 (0.39).

Specific combining ability effects

From the table 6 we can observe, the crosses JMS 11A X JGL 32994, CMS 11A X JGL 34564 and JMS 18A XJGL 33366 were identified as good specific combiners for days to 50 per cent flowering, JMS 11A X JGL 32994, CMS 11A X JGL 32994 and CMS 52A X JGL32979 were good specific combiners for plant height, JMS 11A X JGL

33060, JMS 21A X JGL 32979, CMS 11A X JGL 32994, CMS 23A X JGL 33080, CMS 52A X JGL 32979, and CMS 52A X JGL 34561 for 1000- grain weight, CMS 11A X JGL 34564, CMS 23A X JGL 33080, CMS 52A X JGL and JMS 18A X JGL 33366 for spikelet fertility, CMS 11A X JGL 33366 and JMS 11A X JGL 33060 for number of grains per panicle while, JMS 18A X JGL 33366 was good specific combiner for panicle length, JMS 11A X JGL 33060 was good specific combiner for number of productive tillers per plant. JMS 11A X JGL 32994, JMS 11A X JGL 33060 and CMS 11A X JGL 33366 for head rice recovery and kernel l/b ratio, CMS 11A X JGL 33366 and CMS 23A X JGL 33080 for hulling percentage, JMS 21A X JGL 32979 and CMS 23A X JGL 33080 for milling were the potential hybrids with high sca effects.

The lines CMS 23B, CMS 52B, CMS 11B and tester JGL 32994 were recorded significant gca effects for grain yield per plant. These parents resulted in the production of best single crosses CMS 52A X JGL 33080, JMS 21A X JGL 32979, CMS 11A X JGL 32994, CMS 23A X JGL 32994, and CMS 23A X JGL 34561 with positive sca effects for grain yield indicating the possibility of production of desirable crosses, with high sca effects from low yielding parents. The superior crosses identified with high x high gca effects can be exploited through pedigree breeding method and the better crosses with high x low and low x low gca effects can be improved through biparental mating and recurrent selection method.

GCA and SCA variance and gene action

The knowledge of the nature and magnitude of gene action controlling inheritance of characters related to productivity would add in the choice of efficient breeding methods and thus accelerate the pace of its genetic improvement and also breaking the yield barriers. General combining ability effects and additive x additive gene action are theoretically fixable. On the other hand, specific combining ability attributed to non-additive gene action may be due to dominance or epistasis or both and is not fixable. The success of hybrid programme based on the results of combining ability depends on the extent of genetic parameters remaining stable over environments and the preponderance of non-additive gene action is a very good prospect for the exploitation of desirable traits through hybrid breeding. The estimates of gca and sca variances, their ratios and gene action are presented in (Table 7).

In the present study, the results pertaining to the estimate of combining ability revealed that mean sca variance was relatively greater in magnitude than gca variance for all the traits except plant height, 1000- grain weight, spikelet fertility and kernel L/B ratio indicating that these traits were predominantly under the control of non-additive gene action.

In conclusions this study, the parents CMS 23B, CMS 52B, CMS 11B and JGL 32994 recorded significant positive gca effects for grain yield per plant and its related traits, these parents may be utilized in the development of superior hybrids. While the hybrids, CMS 52A X JGL 33080, JMS 21A X JGL 32979, CMS 11A X JGL 32994, CMS 23A X JGL 32994, and CMS 23A X JGL 3456 exhibited positive sca effects for grain yield per plant.

The results pertaining to the estimate of combining ability revealed that mean sca variance was relatively greater in magnitude than gca variance for all the traits except plant height, 1000- grain weight, spikelet fertility and kernel L/B ratio indicating that these traits were predominantly under the control of non-additive or dominant and epistatic gene action.

The good general combiners identified in the present study can be used in future breeding programme to develop new commercial rice hybrids. The hybrids developed may be further tested extensively in different agro-climatic zones over seasons and years for their resistance reaction superiority and stability before commercial release

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