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Studies on Combining Ability and Gene Action for Yield and Quality Traits in Hybrid Rice (*Oryza sativa* L.)

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A B S T R A C T

Combining ability for yield and yield attributing traits in 24 hybrids generated by crossing four male sterile lines with six testers in line x tester fashion were studied along with their parents and checks (BIO 799 and PA 6129). The analysis revealed greater SCA variance than GCA variance for all the characters under study except for number of productive tillers per plant, hulling percentage, amylose content (%), gel consistency (mm), alkali spreading value, kernel breadth (mm), kernel length (mm) and L/B ratio which indicated the predominance of non-additive gene action in the inheritance of most of the traits and suggested for improvement through heterosis breeding. Among the parental lines, JMS 17B, CMS 14B, JGL 34990 and JMBR 44 were the best general combiners for grain yield and its contributing traits. Hence, these parents may be utilized in the development of superior hybrids. The hybrids CMS 14A X JGL 34985, JMS 18A X IRTON 270, JMS 17A X IRTON 270, CMS 14A X JGL 34990, JMS 18A X JGL 34450, JMS 13A X JGL 34450, JMS 13A X JMBR 44 and CMS 14A X JGL 35039 were the best specific combiners for grain yield and its contributing traits. Therefore, these promising hybrids based on *per se* performance, *sca* effects, *gca* effects of male and female parents could be recommended for heterosis breeding.

Introduction

Rice is a highly self-pollinated crop belongs to the gramineae family, producing edible starchy cereal grains and originated in South East Asia. The genus *Oryza* has two cultivated and 22 wild species. The cultivated species are *Oryza sativa* and *Oryza glaberrima*. *Oryza sativa* is grown all over the world and species glaberrima has been cultivated in few areas like West Africa. The global area under rice is 1.58 billion hectares with a production of 470.2 million tonnes per annum. While in India it is grown in about 43.79 million hectares with a production of 116.48 million tonnes and productivity of 2659 kg/ha. Whereas, in Telangana State it is grown in 19.32 lakh hectares with the production of 66.70 million tonnes and productivity of 3452 kg/ha (www.indiastat.com,2018-19).Rice is the leading food crop in the world, directly feeding nearly half of the world's population. Rice is the predominant food crop in India in terms of area, production and productivity. Rice plays an important role in ensuring food security and contributing to poverty and malnutrition alleviation.

To meet the demand of increasing population and to combat food security in India, the present yield levels needs to be increased up to 121 million tonnes by 2050 and the production of rice needs to be increased by almost two million tons every year. In India, population improvement rate is 1.04%.

Till date High Yielding Varieties (HYV's) have satisfied rice demand but they have reached their saturated levels. To meet the demand of increasing population adoption of hybrid rice technology is an alternative. Since rice is a self-pollinated crop, hybrid seed production must be based on male sterility systems.

Success of Hybrid Rice Technology depends on efficient and economic seed production which demands the parental genotypes having efficacy to combine and give rise to improved genotypic combinations as the performance of a F_1 hybrid depends on choice of parents. Parents with favourable alleles on crossing could produce heterotic hybrids. Selection of parents with high GCA and hybrids with high SCA is a backbone for hybrid seed production in rice. The yield of F_1 hybrids will decrease by 0.8% when the seed purity decreases by 1%, so it is very important to establish a sustainable system of seed production to ensure the purity of hybrid seeds in hybrid rice development.

Parental genotypes which are considered to be superior must prove to be a good donor and a good combiner for desirable traits. Combining ability analysis (Sprague and Tatum, 1942) is one of the valuable tools available to ascertain the combining ability effects and helps in selecting the desirable parents and crosses in a large number of germplasm lines for the further exploitation. Combining ability is used in understanding the nature of gene action involved in the expression of quantitative traits and to predict the performance of the progenies.

The GCA is the average performance of a genotype in a series of hybrid combinations, whereas SCA refers to the performance of a combination of specific genotype in a particular cross. General combining ability of parents provides useful information on their selection and specific combining ability for better performance of hybrids besides elucidating the nature and magnitude of gene action in the inheritance of a particular character.

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 GCA and SCA variances provide an estimation for additive and non-additive gene actions, respectively (Falconer, 1967). Keeping this in view, the present investigation was carried out to study the combining ability and gene action in order to identify good combiners and superior hybrid combinations.

Materials and Methods

The present investigation was undertaken during *Rabi*, 2018-19 (crossing programme) and *Kharif*, 2019 (evaluation) at Regional Agricultural Research Station (RARS), Polasa, Jagtial of Telangana state and the experimental material used for the present experiment comprised of four lines *viz.*, JMS 17A, JMS 13A, JMS 18A, CMS 14A, six restorer lines *viz*., JGL 35039, JGL 34450, JGL 34985, JGL 34990, JMBR 44 and IRTON 270 and their 24 hybrids produced by crossing lines and testers in Line X tester fashion along with two hybrid checks (BIO-799 and PA 6129). Four lines and six testers were planted in a crossing block with a spacing of 20 x 15 cm and crossing programme is carried out in a four x six, Line x tester mating design to produce 24 hybrids during *Rabi*, 2018-19.

Hybridization and clipping method was followed to obtain hybrids and during *Kharif*, 2019, 30 days old seedlings of 36 entries (four lines, six testers, 24 hybrids and 2 checks) were transplanted in the main field in Randomized Block Design in two replications. Each entry was planted in two rows of four meters length with a spacing of 20 x 15 cm in two replications.

Five sample plants were randomly selected from each entry excluding the border plants to minimize error due to the border effect and the following data were recorded: Days to 50% 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), L/B ratio, amylose content (%), gelatinization temperature (^{O}C), gel consistency (mm) and alkali spreading value. Collected data were subjected to statistical analysis using line × tester analysis by Kempthorne (1957).

Results and Discussion

General and specific combining ability

The analysis of variance for combining ability of all the traits under study is presented in the (Table 1) which showed that the variance due to treatments, parents and crosses was found significant for all the characters except for kernel length (mm), kernel breadth (mm) and L/B ratio.

The variance due to parents *vs* crosses was found to be significant for all the traits under study except for plant height (cm), panicle length (cm), 1000-grain weight (g), kernel length (mm), kernel breadth (mm), L/B ratio and alkali spreading value. The variance due to lines was found significant for all the traits except for panicle length (cm), number of productive tillers per plant, kernel length (mm), kernel breadth (mm), L/B ratio and alkali spreading value.

Whereas variance due to testers was found to be non-significant for kernel length (mm), kernel breadth (mm) and L/B ratio and significant for all other characters. When the effects of parents were partitioned into lines, testers and line × tester effects, the interaction effects (lines × testers) were found to be significant for all the traits except for kernel length (mm), kernel breadth (mm) and L/B ratio under study.

This suggest that sufficient variability is available in the material under study.Similar works have been reported by Hasan *et al.,* (2015) for parent *vs* crosses and testers, Archana Devi *et al.,* (2017) for parents, crosses, parents *vs* crosses, lines and line x tester interaction, Elshenawy *et al.,* (2018) for lines, Amitkumar *et al.,* (2019) for parents and parents *vs* crosses and Bano and Singh (2019) for parents *vs* crosses.

The results revealed that none of the parents showed significant *gca* effects for all the traits. Positive significant *gca* and *sca* effect is desirable for all the traits under study except for days to 50 per cent flowering and plant height where negative significant *gca* and *sca* effect is desirable. Character wise estimation of *gca* effects is presented in the (Table 2).

Table.1 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	No. of grains per panicle	Spikelet fertility (%)	1000 -grain weight (g)	Grain yield per plant (g)	Hulling (%)
Replicates	1	0.75	16.45**	4.20*	0.19	72.52**	0.00	0.14	0.35	28.99**
Treatments	33	25.86**	49.94**	6.30**	6.53**	8022.18**	100.23**	29.20**	96.96**	42.43**
Parents	9	10.76**	51.10**	7.24**	6.94**	12116.53**	28.89**	49.47**	87.80**	7.27**
Parents(Lines)	3	15.17**	64.97**	1.81	2.13	3371.46**	18.33**	17.30**	60.70**	8.27**
Parents(Tester)	5	9.93**	47.77**	10.94**	11.13**	19666.28**	40.33**	70.26**	119.74**	8.12**
Parents(L vsT)	1	1.63	26.13**	5.00*	0.41	603.01**	3.33	41.98**	9.41**	0.00
Parents*vs*Crosses	1	67.81**	1.29	0.64	13.77**	176.67**	420.61**	2.17	42.85**	16.40**
Crosses	23	29.95**	51.60**	6.18**	6.06**	6761.14**	114.21**	22.45**	102.90**	57.32**
Line Effect	3	25.81**	16.58**	3.32*	10.85**	2628.69**	257.25**	4.38*	64.62**	83.22**
Tester Effect	5	13.78**	93.29**	6.86**	10.74**	13167.34**	110.33**	33.35**	125.72**	161.99**
Line x TesterEff.	15	36.17**	44.70**	6.53**	3.54**	5452.24**	86.90**	22.43**	102.95**	17.25**
Error	33	0.96	4.17	1.31	0.48	214.49	4.45	0.78	2.44	3.79
Total	37	13.23	26.93	3.81	3.46	4058.30	51.56	14.78	48.96	23.18

Table.1 (cont.)

Source of Variations	Df	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Amylose content (%)	Gelatinization Temperature (^{O}C)	Gel consisteny (mm)	Alkali spreading value
Replicates	1	15.50**	0.52	0.10	0.01	0.01	0.00	0.33	10.08**	0.00
Treatments	33	58.08**	182.76**	0.38	0.06	0.05	20.72**	49.72**	600.94**	2.01*
Parents	9	13.73**	143.64**	00.71	0.03	0.08	24.19**	48.47**	667.27**	2.27*
Parents(Lines)	3	9.19**	85.74**	00.10	0.03	0.02	25.99**	38.46**	513.33**	2.13
Parents(Testers)	5	19.16**	195.29**	00.98	0.04	0.11	27.77**	63.68**	892.55**	2.73*
Parents(L vs T)	1	0.21	59.07**	11.15	0.00	0.06	0.88	2.41	2.70	0.41
Parents *vs*Crosses	1	25.12**	23.08**	00.02	0.16	0.10	25.70**	15.56**	538.31**	0.12
Crosses	23	76.86**	205.01**	00.27	0.07	0.04	19.15**	51.70**	577.71**	2.00*
Line Effect	3	25.51**	189.90**	00.36	0.14	0.05	7.15**	30.39**	532.03**	1.42
Tester Effect	5	52.08**	176.14**	00.40	0.05	0.05	66.09**	105.85**	1860.70**	5.28**
Line x Tester Eff.	15	95.40**	217.66**	00.20	0.06	0.04	5.90**	37.91**	159.18**	1.02
Error	33	4.64	9.43	00.09	0.02	0.02	0.04	0.26	1.80	0.01
Total	37	31.16	94.67	00.23	0.04	0.04	10.22	24.62	297.08	1.00

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

Table.2 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 tillers per plant	No. of grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Amylose content (%)	Gelatinization temperatue (^{O}C)	Gel consistency (mm)	Alkali spreading value
Parents																		
Lines																		
JMS 17B	-0.21	1.63*	0.24	0.23	3.98	5.54**	0.50	1.83**	2.40**	4.91**	-0.12	0.13*	-0.08	0.81**	-0.58**	-7.04**	-0.38**	4.91**
JMS 13B	-1.13**	-1.18	0.24	-0.94**	3.31	-5.21**	-0.48	-3.24**	-3.73**	-4.78**	0.11	0.05	0.00	-0.86**	-0.50*	5.04**	0.29**	-4.78**
JMS 18B	-0.79*	-0.26	0.31	-0.52*	-21.02**	1.63*	0.54*	-0.12	1.04	0.44	-0.18	-0.12*	-0.01	0.46**	2.33**	-4.29**	-0.21**	0.44
CMS14B	2.13**	-0.19	-0.79*	1.23**	13.73*	-1.96*	-0.57*	1.52*	0.29	-0.57	0.19*	-0.05	0.09*	-0.41**	-1.25**	6.29**	0.29**	-0.57
Testers																		
JGL 35039	1.04*	-5.90**	-1.49*	-1.94**	-26.06**	1.71*	-0.85*	-7.02**	-8.87**	-7.70**	-0.21	0.04	-0.15*	-3.70**	-6.25**	22.75**	1.21**	-7.70**
JGL 34450	-0.21	2.32*	0.13	1.06**	14.81*	4.83**	-0.30	-1.53*	3.24**	0.76	-0.02	-0.10*	0.07	1.57**	2.50**	-9.25**	-0.29**	0.76
JGL 34985	1.67**	-2.00*	0.20	0.44	40.56**	-6.42**	-1.48**	0.57	0.90	6.19**	-0.15	-0.08	0.04	-2.95**	-1.50**	12.38**	0.71**	6.19**
JGL 34990	0.17	0.45	-0.34	-0.81*	49.69**	0.96	-2.31**	3.81**	0.62	3.02*	-0.16	-0.02	-0.04	2.47**	2.88**	-13.13**	-0.79**	3.02*
JMBR 44	-2.08**	3.20**	1.38*	0.31	-32.56**	-0.54	2.10**	3.41**	3.19**	-0.69	0.19	0.06	0.02	-0.57**	-0.75**	2.38**	-0.04	-0.69
IRTON 270	-0.58	1.93	0.13	0.94**	-46.44**	-0.54	2.84**	0.75	0.92	-1.57	0.35*	0.10*	0.06	3.18**	3.13**	-15.13**	-0.79**	-1.57
CD95% GCA(Line)	0.58	1.22	0.68	0.41	8.75	1.26	0.53	0.93	1.16	1.83	0.18	0.08	0.08	0.11	0.30	0.80	0.07	1.83
CD 95% GCA(Tester)	0.72	1.49	0.84	0.51	10.71	1.54	0.64	1.14	1.42	2.25	0.22	0.09	0.10	0.14	0.37	0.98	0.09	2.25

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

Table.3 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	No. of grains per panicle	Spikelet fertility (%)	1000-grain weight (g)	Grain yield per plant (g)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Amylose content (%)	Gelatinization temperatue (^{O}C)	Gel consistency (mm)	Alkali spreading value
1	JMS 17A× JGL 35039	-0.04	-5.95**	0.99	-0.73	25.15*	-2.79	2.58**	-2.82*	4.87*	4.51*	1.84	0.24	0.29*	-0.08	-0.44**	2.08**	5.67**	0.13
2	JMS 17A× JGL 34450	3.21**	2.44	-0.28	2.27**	-7.23	6.58**	-3.39**	-1.06	-1.24	1.07	4.21	-0.10	-0.21*	0.19	1.55**	-0.67	-7.83**	-0.38**
3	JMS 17A× JGL 34985	2.33*	-5.00*	0.05	-2.10**	30.52*	-5.17*	-1.36*	-1.46	-2.90*	-2.26	2.05	-0.24	-0.30*	0.13	-1.04**	-3.67**	4.04**	0.63**
4	JMS 17A× JGL 34990	-5.17*	-1.00	0.34	0.15	-38.60*	3.46*	4.92**	-1.74	0.38	-6.72**	-8.54**	0.16	-0.01	-0.07	-1.65**	-0.04	6.54**	0.13
5	JMS 17A× JMBR 44	5.08**	5.20*	0.03	1.02*	5.65	-1.54	-1.37*	-0.84	-1.19	-6.57**	-14.71**	-0.21	-0.04	-0.18	1.74**	3.58**	-8.46**	-0.63**
6	JMS 17A× IRTON270	-5.42**	4.32*	-1.13	-0.60	-15.48	-0.54	-1.37*	7.92**	0.08	9.98**	15.16**	0.16	0.27*	0.01	-0.16	-1.29*	0.04	0.13
7	JMS 13A× JGL 35039	3.88**	3.41*	-2.66*	1.44*	44.81**	1.46	-6.87**	2.00	-6.41**	-3.02	-8.56**	0.16	-0.02	0.12	0.69**	-6.50**	-1.92	0.46**
8	JMS 13A× JGL 34450	-2.88**	6.34**	2.13*	-0.06	-88.56**	5.33*	3.49**	4.81**	-0.36	0.03	7.09*	0.23	0.04	0.04	0.28	2.25**	-4.42**	-0.04
9	JMS 13A× JGL 34985	1.75*	-1.19	-0.85	-0.94	21.69*	-6.92**	1.71*	-4.39**	1.28	0.71	0.07	-0.01	0.06	-0.09	0.94**	1.25*	-1.54	-0.04
10	JMS 13A× JGL 34990	1.75*	-2.54	-0.31	-0.19	15.56	0.71	-0.99	-0.08	0.60	2.06	-1.17	0.01	0.06	-0.09	1.18**	-0.13	-6.54**	-0.54**
11	JMS 13A× JMBR 44	-7.00**	-4.09*	0.33	0.19	19.81	-2.29	2.54**	3.37*	3.54*	-0.41	2.98	0.34	-0.04	0.23*	-1.69**	3.50**	9.96**	-0.29*
12	JMS 13A× IRTON270	2.50*	-1.92	1.38	-0.44	-13.31	1.71	0.12	-5.72**	1.35	0.62	-0.40	-0.72*	-0.09	-0.21*	-1.39**	-0.38	4.46**	0.46**
13	JMS 18A× JGL 35039	-3.46**	-0.67	0.51	0.02	-49.85**	-1.38	5.58**	-3.87*	-1.78	-12.81**	-10.88**	-0.36	-0.14	0.05	-0.74**	-0.83*	0.42	-0.04
14	JMS 18A× JGL 34450	-1.21	-5.88**	-0.60	-0.98	29.27*	-3.00	-1.64*	6.64**	0.32	1.89	-0.68	-0.26	0.09	-0.10	-1.20**	-1.58**	6.92**	0.46**
15	JMS 18A× JGL 34985	2.42*	1.98	-1.63	1.65*	-72.48**	1.75	-0.65	-5.11**	1.36	3.10	5.76*	0.05	0.13	-0.08	0.26	2.42**	-2.21*	-0.54**
16	JMS 18A× JGL 34990	2.92**	-0.32	-1.39	-1.10*	-11.10	-6.63**	-2.53**	-4.94**	1.89	1.01	3.24	0.12	0.02	0.11	-1.45**	-2.96**	10.29**	0.96**
17	JMS 18A× JMBR 44	-1.33	1.78	2.60*	-0.23	40.15**	-0.13	-0.31	-1.44	-0.23	7.29**	3.71	0.09	0.11	-0.02	2.89**	3.67**	-15.71**	-0.79**
18	JMS 18A× IRTON270	0.67	3.11*	0.50	0.65	64.02**	9.38**	-0.44	8.72**	-1.57	-0.48	-1.15	0.36	-0.20*	0.03	0.24	-0.71	0.29	-0.04
19	CMS 14A× JGL35039	-0.38	3.22*	1.16	-0.73	-20.10	2.71	-1.28	4.69**	3.32*	11.31**	17.61**	-0.04	-0.12	-0.09	0.49*	5.25**	-4.17**	-0.54**
20	CMS 14A× JGL34450	0.88	-2.90	-1.25	-1.23*	66.52**	-8.92**	1.54*	-10.40**	1.27	-3.00	-10.62**	0.13	0.09	-0.13	-0.63**	0.00	5.33**	-0.04
21	CMS 14A× JGL34985	-6.50**	4.22*	2.43*	1.40*	20.27	10.33**	0.31	10.95**	0.26	-1.55	-7.87*	0.21	0.11	0.03	-0.16	0.00	-0.29	-0.04
22	CMS 14A× JGL34990	0.50	3.87*	1.36	1.15*	34.15*	2.46	-1.40*	6.77**	-2.87*	3.65*	6.48*	-0.28	-0.07	0.04	1.93**	3.13**	-10.29**	-0.54**
23	CMS 14A× JMBR 44	3.25**	-2.89	-2.95*	-0.98	-65.60**	3.96*	-0.86	-1.09	-2.13	-0.30	8.02*	-0.22	-0.03	-0.03	-2.94**	-10.75**	14.21**	1.71**
24	CMS 14A×IRTON 270	2.25*	-5.51**	-0.75	0.40	-35.23*	-10.54**	1.70*	-10.92**	0.14	-10.11**	-13.61**	0.20	0.02	0.17	1.31**	2.38**	-4.79**	-0.54**
	CD 95% SCA	1.43	2.99	1.67	1.01	21.42	3.09	1.29	2.29	2.85	3.15	4.49	0.44	0.18	0.20	0.28	0.74	1.96	0.18

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

Table.4 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	No. of grains per panicle	Spikelet fertility (%)	1000 grain weight (g)	Grain yield per plant (g)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	L/B ratio	Amylose content (%)	Gelatinization temperature (^{O}C)	Gel consistency (mm)	Alkali spreading value
σ^2gca	3.77	10.15	0.76	2.06	1536.71	35.87	3.62	18.55	23.76	6.83	34.72	0.06	0.02	0.01	7.32	13.57	238.91	0.67
σ^2sca	17.61	20.27	2.61	1.53	2618.88	41.22	10.83	50.25	6.73	45.38	104.12	0.06	0.02	0.01	2.93	18.82	78.69	0.50
σ^2gca / σ^2sca	0.21	0.50	0.29	1.35	0.59	0.87	0.33	0.37	3.53	0.15	0.33	1.06	0.71	0.63	2.49	0.72	3.04	1.33
Degree of Dominance $\sqrt{\sigma^2 sca}$ $\sqrt{\sigma^2 gca}$	2.16	1.41	1.86	0.86	1.31	1.07	1.73	1.65	0.53	2.58	1.73	0.97	1.19	1.26	0.63	1.18	0.57	0.87

Results revealed that the line 'JMS 17B' to be a good general combiner of grain yield per plant (g) and some of its contributing traits *viz.*, spikelet fertility (%), hulling (%), milling (%), kernel length (mm), L/B ratio and alkali spreading value, the line 'CMS 14B' to be a good general combiner of grain yield per plant (g) and some of its contributing traits *viz.*,.

Number of productive tillers per plant, number of grains per panicle, head rice recovery (%), kernel breadth, gelatinization temperature (^{o}C) and gel consistency (mm), the tester 'JGL 34990' to be a good general combiner of grain yield per plant (g) and some of its contributing traits *viz.*.

Number of grains per panicle, milling (%), L/B ratio, amylose content (%) and alkali spreading value and the tester 'JMBR 44' to be a good general combiner of grain yield per plant (g) and some of its contributing traits *viz.*,days to 50% flowering, panicle length (cm), 1000-grain weight (g), hulling (%) and gelatinization temperature (^{o}C). Hence, these good general combiners may be extensively used in future for hybrid rice breeding programme.

Character wise estimation of *sca* effects is presented in the (Table 3) and results revealed that cross 'CMS 14A X JGL 34985 ' showed highest *sca* effect for grain yield per plant (g) and contributing characters like days to 50% flowering, panicle length (cm), number of productive tillers per plant and spikelet fertility (%) followed by the cross 'JMS 18A X IRTON 270' for grain yield per plant (g) and for other contributing traits *i.e.,* number of grains per panicle and spikelet fertility (%), the cross 'JMS 17A X IRTON 270' for grain yield per plant (g) and for other contributing traits *i.e.,* days to 50% flowering, milling (%), head rice recovery (%) and kernel breadth (mm), the cross 'CMS 14A X JGL 34990' for grain yield per plant (g) and for other contributing traits *i.e.,* number of grains per panicle, milling (%), head rice recovery (%), amylose content (%) and gelatinization temperature (^{o}C), cross 'JMS 18A X JGL 34450' for grain yield per plant (g) and for other contributing traits *i.e.*, plant height (cm), number of grains per panicle, gel consistency (mm) and alkali spreading value, the cross 'JMS 13A X JGL 34450' for grain yield per plant (g) and for other contributing traits *i.e.*, days to 50% flowering, spikelet fertility(%), panicle length (cm), 1000-grain weight (g), head rice recovery (%) and gelatinization temperature, the cross 'JMS 13A X JMBR 44' for grain yield per plant (g) and for other contributing traits *i.e.,* gelatinization temperature (^{o}C), L/B ratio, gel consistency (mm), days to 50% flowering, plant height (cm), 1000-grain weight (g) and hulling (%) and the cross 'CMS 14A X JGL 35039' for grain yield per plant (g) and for other contributing traits *i.e.,* hulling (%), milling (%), head rice recovery (%), amylose content (%) and gelatinization temperature (^{o}C).

The characters *viz.,* days to 50% flowering, plant height (cm), panicle length (cm), no. of grains per panicle, 1000 grain weight (g), grain yield per plant (g), spikelet fertility (%), milling (%), head rice recovery (%) and gelatinization temperature (^{o}C) exhibited greater SCA variance than GCA variance which indicated the predominance of non-additive gene action in the inheritance of above mentioned traits.

Therefore the hybrid breeding programme is more useful for the improvement of these traits. GCA variance is greater than SCA variance of some characters *viz.,* number of productive tillers per plant, hulling percentage, amylose content (%), gel consistency (mm) and alkali spreading value which indicated the predominace of additive gene action in the inheritance of above mentioned traits. GCA variance and SCA variance are equal for the characters kernel breadth (mm), kernel length (mm) and L/B ratio (Table 4). Predominance of non additive gene action for grain yield and its components was also reported by many other workers for grain yield per plant (g).

Similar results were reported by several workers for days to 50 per cent flowering (Jayasudha and Sharma, 2009 and Ghara *et al.*, 2012), plant height (cm) (Selvaraj*et al.*, 2011, Dorosti and Monajjem, 2014), number of grains per panicle (Satheesh Kumar *et al.*, 2016 and Rumanti *et al.*, 2017), grain yield per plant (g) (Arifulislam *et al.*, 2015, Santha *et al.*, 2017), 1000-grain weight (g) (Vanave *et al.*, 2018), milling percentage (%) (Thakare *et al.*, 2013 and Sreenivas *et al.*, 2014), head rice recovery (%) (Naseer Mohammad *et al.*, 2016 and Rukmini Devi *et al.*, 2018) and amylose content (%) (Maleki *et al.*, 2014).

In conclusion the predominance of specific combining ability (SCA) variance for most of the characters suggested the predominance of non-additive or dominant and epistatic gene action.

Hence, based on the results obtained in the present study the phenomenon of heterosis can be inferred to be playing important role in determining seed yield in case of rice hybrids and can be exploited commercially.

Parents JMS 17B, CMS 14A, JGL 34990 and JMBR 44 were best general combiners for yield and yield attributing traits and hybridsCMS 14A X JGL 34985, JMS 18A X IRTON 270, JMS 17A X IRTON 270, CMS 14A X JGL 34990, JMS 18A X JGL 34450, JMS 13A X JGL 34450, JMS 13A X JMBR 44 and CMS 14A X JGL35039. Hence, these parents and hybrids can be further used in the hybrid rice breeding programme.

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