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Research Article

HETEROTIC EXPRESSIONS EVALUATION FOR GRAIN YIELD AND QUALITY TRAITS IN CMS BASED RICE HYBRIDS

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Abstract- An experiment was conducted to evaluate the heterotic expressions of twenty one crosses for twenty grain yield and quality traits. These crosses were generated in Line x Tester fashion by using three CMS lines and seven testers. A standard check Indira Sona, first hybrid rice of Chhattisgarh was used to estimate the standard heterosis. In present investigation we found that hybrid IR-58025A x Karmamahsuri showed significant negative heterosis for days to 50% flowering and plant height both so that this will be effective for developing short duration, semidwarf rice hybrid. Two hybrids, IR-79156A x RIL-62 and IR-79156A x Bagdidhan were showed significant positive relative heterosis, heterobeltiosis and standard heterosis over Indira Sona for grain yield per plant. Hybrid, IR-79156A x Bagdidhan showed significant positive standard heterosis for grain yield per plant and biological yield per plant which may be utilized in developing high yield potential hybrids. Crosses, CRMS-32A x Bagdidhan, IR-79156A x RIL-62 and IR-58025A x Karmamahsuri showed significant positive relative heterosis, heterobeltiosis and standard heterosis for head rice recovery. In view of both, grain yield and grain quality together, hybrid IR-79156A x RIL-62 exhibited significant relative heterosis, heterobeltiosis and standard heterosis for grain yield as well as for head rice recovery and other quality characteristics in the desirable range. So these promising cross combinations could be further used in rice breeding programme for developing high yielding rice hybrids with good grain quality.

Keywords- Heterosis, Rice, Hybrid, Grain yield, Grain quality

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Introduction

Rice (*Oryza sativa*) is the most important staple food for more than half of the world's population. About 90% populations of Asian countries are uses rice as their main food [1]. It is predicted that the world's population will continue increases so that rice production is required to increase every year to meet feed the increasing population. To boost rice production and productivity, heterosis breeding in rice is a promising technique by producing hybrid rice [2].Hybrid rice breeding utilizes concepts, skills, and procedures that are prominently different from those used for inbred rice breeding. The increased yield of rice hybrids alone does not guarantee profitability to farmers if their grain quality is not acceptable and if they get a low price in the market [3]. It means, besides grain yield of hybrid rice their grain quality parameters have also been given special attention to increase their market value and consumer satisfaction [4]. Therefore, rice plays an important role in providing food security, alleviating malnutrition and poverty in Asia and the World. Heterosis is an important phenomenon that exhibits superior phenotypes (according to trait of interest) comparative to its parents, including dwarfness, earliness, superior biomass production, better grain yield, good grain quality etc. [5]. Since, long time heterosis has been effectively utilized to increase rice production with good quality traits. Heterosis has been commercially exploited in rice with a yield advantage of 20%-25% over best pure line [6, 7]. Heterosis phenomenon in rice was first observed by Jones (1926)[8] and Ramaiah (1933)[9] who found that some F_1 hybrids had more culms and higher yield than their parents. During the 1960s, suggestions for commercial exploitation of heterosis in rice were made in China [10], India [11] and USA[12]. Ample numbers of male sterile lines, their maintainer lines and restorer lines in rice have been developed to generate good rice hybrid worldwide. At present time CGMS system (Three line system) and EGMS system are mostly used for developing rice hybrids. The three line system of hybrid seed production involved CMS line, maintainer line and restorer lines which are being for large scale hybrid rice seed production in the world. After China, India is the first country to exploit the hybrid rice technology on a commercial scale. In India, a total of 78 rice hybrids were released for commercial cultivation till 2015 in which 34 hybrids were developed by public sector whereas 44 hybrids were developed private sectors [13].Hence, the present study was undertaken to assess the extent of heterosis and to identify best cross combinations on the basis of grain yield and quality traits for future utilization in breeding programmes.

Materials and Methods

The present study was conducted at the Research cum Instructional Farm, Department of Genetics and Plant breeding, IGKV, Raipur (Chhattisgarh). The experimental material comprised of three CMS lines *viz*., IR-58025A (WA source), IR-79156A (WA source) and CRMS-32A (Kalinga source), Total seven rice varieties/ landraces *viz*., Kanakgopala, Bagdidhan, RIL-62, Inger-2-114, Karma Mahsuri, TOX981-11-2-3 and Suraksha as tester and Indira Sona as standard check which is the first hybrid of Chhattisgarh. Total twenty one crosses were attempted by adopting LxT mating design [14]. About 21 days old seedlings of 21 hybrids and their 10 parents (three CMS lines with their maintainer line and seven testers) along with a standard checks *viz.,* Indira Sona (Hybrid check) were planted in main field by using randomized complete block design (RCBD) with two replications. Planting distance between row to row was 20 cm and plant to plant was 15 cm. All recommended agronomical practices were followed to raise the ideal crop stand. Observations of total 20 grain yield and quality traits were taken on five randomly selected plants of each genotype. Observations of grain yield and quality traits of all CMS lines were recorded through their maintainer line (B line).

The mean value data of each trait over five plants were used for statistical analysis. The mid parent heterosis, heterobeltiosis and standard heterosis were estimated as suggested by Hays *et al.*, (1955) [15] and Liang *et al.* (1971) [16]. All statistical analysis was processed by WINDOSTAT Version 9.1 software.

Results and Discussion:

Investigations on heterosis provides fundamental information regarding the utility of the cross combinations and its use for commercial exploitation. The magnitude of heterosis for yield, yield components and quality traits depends to a large extent on genetic variation, genetic base and adaptability of parents. The presence of significant amount of non additive gene action is a prerequisite for the commercial exploitation of heterosis in rice. Hybrid rice not only gives higher yields, but also permits to reduce the environmental footprint of rice production. The estimates of relative heterosis, heterobeltiosis and standard heterosis for yield, yield attributing traits and quality traits were showed that considerable amount of heterosis existed both in positive and negative directions for all the traits [Table-I].

Table-1 *Relative heterosis, heterobeltiosis and standard heterosis for grain yield, yield components and quality traits*

Cross	Days to 50% flowering			Plant height (cm)			Flag leaf area(cm²)			Productive tillers/ plant		
	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis
IR-58025A												
IR-58025AxKanakgopala	6.30**	6.01*	6.01*	24.64**	20.60**	-9.27**	4.60	3.47	9.10	-10.00	-28.00	-21.74
IR-58025AxBagdidhan	3.00	2.72	3.28	11.52**	-17.05**	19.68**	12.60*	-11.88*	60.84**	-23.40	-28.00	-21.74
IR-58025AxRIL-62	-1.41	-4.37	-4.37	20.79**	11.26**	-7.05**	4.61	-1.25	14.73	19.15*	12.00*	21.74*
IR-58025AxInger-2-114	3.08	0.55	0.55	20.73**	3.40	2.05	5.80	-16.55**	49.07**	0.00	-16.00	-8.70
IR-58025AxKarmamahsuri	-8.11**	-9.09**	-7.10**	11.07**	-5.81*	-4.79*	-1.52	-12.25	15.75	-10.20	-12.00	-4.35
IR-58025AxTOX981-11-2-3	-4.23*	-7.18**	-1.09	26.82**	8.71**	7.05**	-6.51	-20.22**	16.45*	-2.56	-24.00	-17.39
IR-58025AxSuraksha	-3.78	-4.81*	-2.73	7.65**	-10.88**	-4.40	-2.82	-8.79	7.27	-42.86**	-60.61**	13.04
IR-79156A												
IR-79156AxKanakgopala	8.57**	4.40	3.83	27.49**	24.25**	-6.53**	7.33	7.04	12.86	-28.57	-44.44*	-34.78
IR-79156AxBagdidhan	15.91**	10.87**	11.48**	19.66**	-10.56**	29.04**	-3.84	-24.30**	38.17**	-10.20	-18.52	-4.35
IR-79156AxRIL-62	-1.76	-2.91	-8.74**	7.50**	-0.31	-16.72**	15.69*	10.06	27.87**	-18.37	-25.93	-13.04
IR-79156AxInger-2-114	5.26*	3.45	-1.64	15.59**	-0.40	-1.70	8.16	-14.17**	53.31**	-18.18	-33.33*	-21.74
IR-79156AxKarmamahsuri	-1.97	-6.95**	-4.92*	12.27**	-4.22	-3.18	-4.19	-14.01*	13.43	-29.41	-33.33*	-21.74
IR-79156AxTOX981-11-2-3	-1.93	-8.72**	-2.73	23.07**	6.15*	4.53	26.29**	8.52	58.39**	-12.20	-33.33*	-21.74
IR-79156AxSuraksha	1.97	-3.21	-1.09	19.88**	-0.16	7.10**	3.91	-1.72	15.59	-39.78**	-57.58**	21.74
CRMS-32A												
CRMS-32AxKanakgopala	-0.78	-5.91**	4.37	-1.82	-9.75**	-19.02**	62.76**	60.75**	73.79**	-34.88	-50.00**	-39.13*
CRMS-32AxBagdidhan	8.01**	2.96	14.21**	2.51	-16.87**	19.94**	-5.07	-24.42**	37.95**	-8.00	-17.86	0.00
CRMS-32AxRIL-62	-7.73**	-14.78**	-5.46*	-2.61	-5.97*	-15.63**	-1.90	-5.31	10.01	-4.00	-14.29	4.35
CRMS-32AxInger-2-114	-5.04*	-11.82**	-2.19	-5.50*	-9.79**	-10.97**	26.32**	1.39	81.11**	-20.00	-35.71	-21.74
CRMS-32AxKarmamahsuri	-10.26**	-13.79**	-4.37	-10.84**	-15.85**	-14.93**	0.07	-8.95	20.10*	0.00	-7.14	13.04
CRMS-32AxTOX981-11-2-3	-0.50	-2.46	8.20**	5.34*	0.66	-0.87	14.20*	-0.60	45.08**	-28.57	-46.43**	-34.78
CRMS-32AxSuraksha	-6.15**	-9.85**	0.00	-4.49*	-12.30**	-5.92*	-18.27**	-21.56**	-7.75	-51.06**	-65.15**	0.00

*Significant at p=0.05% level, **Significant at p=0.01% level

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Cross	Panicle length (cm)			Pollenfertility (%)			Total spikelets/panicle			Spikelet fertility (%)		
	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis
IR-58025A												
IR-58025AxKanakgopala	7.45	-0.54	2.21	-76.25**	-87.50**	-87.68**	45.71**	36.85**	39.62**	59.28**	61.26**	71.44**
IR-58025AxBagdidhan	-0.36	-1.97	0.74	79.62**	-5.76	-0.70	6.53	-4.10	-14.06*	0.80	-17.09**	-14.45**
IR-58025AxRIL-62	7.72	-2.51	0.18	62.49**	-14.56**	-14.07**	36.64**	3.03	-7.67	1.44	-9.48	-23.23**
IR-58025AxInger-2-114	6.99	1.43	4.24	74.84**	-8.07	-7.30	-27.52**	-40.57**	-16.77*	-1.92	-17.48**	-19.55**
IR-58025AxKarmamahsuri	3.85	-3.23	-0.55	76.71**	-7.34	-1.09	11.32	3.98	-6.82	-6.63	-22.88**	-21.26**
IR-58025AxTOX981-11-2-3	19.33**	8.96**	11.97**	52.67**	-19.93**	-15.04**	25.03**	22.81**	14.11*	-11.78**	-28.65**	-23.09**
IR-58025AxSuraksha	9.38	-0.72	2.03	109.47**	10.66*	1.66	15.12*	12.18	0.53	7.82	-3.14	-19.09**
IR-79156A												
IR-79156AxKanakgopala	13.45*	8.45	4.05	25.14**	-34.13**	-35.09**	-5.51	-19.00**	-17.36**	-18.77**	-22.04**	-37.49**
IR-79156AxBagdidhan	7.45	5.56	4.97	80.96**	-5.06	0.05	33.87**	32.80**	-3.19	-13.08**	-22.77**	-20.31**
IR-79156AxRIL-62	16.55*	8.83	4.42	90.69**	0.27	0.84	46.13**	18.70*	-13.47*	19.26**	16.01**	-1.62
IR-79156AxInger-2-114	8.13	5.95	1.66	-65.55**	-81.89**	-81.73**	-18.58**	-38.10**	-13.31*	-25.86**	-32.44**	-34.14**
IR-79156AxKarmamahsuri	14.26*	9.98	5.52	66.86**	-12.51**	-6.61	27.63**	23.61**	-3.83	-3.06	-13.46**	-11.65**
IR-79156AxTOX981-11-2-3	14.87*	8.25	3.87	67.20**	-12.30**	-6.95	14.64*	2.29	-4.95	-11.61**	-22.94**	-16.93**
IR-79156AxSuraksha	17.83**	10.36	5.89	108.58**	10.19*	1.23	-3.64	-10.52	-23.91**	-14.22**	-15.95**	-29.78**
CRMS-32A												
CRMS-32AxKanakgopala	2.12	-6.02	-2.21	-60.26**	-78.95**	-79.26**	14.91**	11.80	14.06*	-77.43**	-81.90**	-86.66**
CRMS-32AxBagdidhan	-0.81	-3.01	0.92	95.77**	3.32*	8.87*	32.32**	15.34*	11.29	38.64**	-0.77	2.40
CRMS-32AxRIL-62	13.08*	1.77	5.89	94.22**	2.76	3.35	37.38**	1.10	-2.45	24.93**	-4.74	-19.21**
CRMS-32AxInger-2-114	8.54	2.30	6.45	-75.24**	-86.90**	-86.79**	32.24**	11.67*	56.39**	62.86**	72.95**	73.63**
CRMS-32AxKarmamahsuri	11.75*	3.54	7.73	69.76**	-10.47*	-4.43	0.21	-9.49	-12.67*	28.31**	-7.87	-5.94
CRMS-32AxTOX981-11-2-3	7.02	-2.83	1.10	91.86**	1.22**	7.39**	36.97**	34.44**	29.71**	26.60**	-10.56*	-3.58
CRMS-32AxSuraksha	10.78	0.00	4.05	90.53**	1.33	-6.91	15.40*	8.55	4.74	49.80**	14.82**	-4.08

*Significant at p=0.05% level, **Significant at p=0.01% level

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Cross	100 seed weight			Grain yield/plant			Harvest index			Biological yield/plant		
	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis
IR-58025A												
IR-58025AxKanakgopala	-5.26	-12.20	-20.00*	0.20	-10.32	-55.79**	-64.08**	-72.42**	-75.87**	48.29**	24.35**	-15.86**
IR-58025AxBagdidhan	36.84**	26.83**	15.56*	23.91*	3.64	-40.00**	7.09	3.99	-51.26**	14.81**	-6.30**	0.27
IR-58025AxRIL-62	15.56*	6.12	15.56*	27.70**	6.29	-37.72**	12.55	-17.48**	-17.06**	6.27*	-9.66**	-38.87**
IR-58025AxInger-2-114	47.92**	29.09**	57.78**	-2.36	-31.18**	-34.56**	-19.40**	-39.07**	-44.21**	25.32**	12.69**	-4.49*
IR-58025AxKarmamahsuri	-7.96	-27.78**	15.56*	1.36	-27.52**	-34.39**	27.16**	-2.33	-14.63*	-17.64**	-25.81**	-37.37**
IR-58025AxTOX981-11-2-3	15.79*	1.85	22.22**	-4.82	-33.03**	-35.96**	21.11*	-0.35	-27.66**	-19.68**	-35.54**	-27.91**
IR-58025AxSuraksha	3.85	-14.29*	20.00*	57.95**	13.97*	0.18	48.70**	31.57**	-19.88**	40.60**	10.69**	30.36**
IR-79156A												
IR-79156AxKanakgopala	25.00**	11.11	11.11	-0.19	-4.98	-53.16**	-47.14**	-56.91**	-62.30**	-20.73**	-32.78**	-55.75**
IR-79156AxBagdidhan	27.50**	13.33	13.33	56.51**	38.48**	19.82**	0.79	-9.25	-49.96**	50.93**	21.88**	30.43**
IR-79156AxRIL-62	6.38	2.04	11.11	44.56**	27.25**	25.44**	42.86**	10.62	11.18	-3.55	-17.06**	-45.41**
IR-79156AxInger-2-114	2.00	-7.27	13.33	-33.42**	-51.11**	-53.51**	-21.75**	-37.32**	-42.61**	-12.48**	-22.25**	-34.10**
IR-79156AxKarmamahsuri	-7.69	-25.00**	20.00*	43.64**	7.17	-2.98	55.71**	26.97**	10.98	-5.21*	-15.65**	-28.80**
IR-79156AxTOX981-11-2-3	3.03	-5.56	13.33	4.38	-23.49**	-26.84**	41.17**	24.20**	-9.84	-25.67**	-40.96**	-33.97**
IR-79156AxSuraksha	-7.41	-20.63**	11.11	-4.37	-27.94**	-36.67**	18.40*	12.80	-31.30**	-18.28**	-36.30**	-24.98**
CRMS-32A												
CRMS-32AxKanakgopala	-5.56	-8.11	-24.44**	-20.93	-33.45**	-67.19**	-79.64**	-83.81**	-85.83**	59.23**	48.40**	-21.31**
CRMS-32AxBagdidhan	36.11**	32.43**	8.89	70.11**	34.55**	-22.11**	9.73	1.70	-47.40**	50.66**	12.66**	20.56**
CRMS-32AxRIL-62	4.65	-8.16	0.00	27.38**	0.30	-41.23**	10.90	-16.02**	-15.59**	12.95**	6.93	-43.29**
CRMS-32AxInger-2-114	-6.52	-21.82**	-4.44	-38.15**	-58.12**	-60.18**	-70.13**	-76.63**	-78.60**	3.75	-15.66**	-28.52**
CRMS-32AxKarmamahsuri	-10.09	-31.94**	8.89	59.60**	9.50	-0.88	29.43**	3.00	-9.97	30.46**	6.21*	-10.35**
CRMS-32AxTOX981-11-2-3	9.89	-7.41	11.11	20.22**	-18.72**	-22.28**	19.68*	2.47	-25.62**	3.22	-23.92**	-14.91**
CRMS-32AxSuraksha	8.00	-14.29*	20.00*	40.26**	-2.99	-14.74**	37.45**	27.09**	22.60**	5.06*	-23.82**	-10.28**

*Significant at p=0.05% level, **Significant at p=0.01% level

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Cross	Paddy L/B Ratio			Brown rice L/B ratio			Kernel L/B ratio			Cooked rice L/B ratio		
	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis
IR-58025A												
IR-58025AxKanakgopala	9.94	-6.50	18.54*	2.63	-13.76*	11.25	-6.34	-20.51**	-0.63	16.82**	14.44**	16.82**
IR-58025AxBagdidhan	-3.36	-17.33**	4.81	-0.58	-16.22*	8.08	4.22	-12.41*	9.49	17.34**	12.78**	15.12**
IR-58025AxRIL-62	-0.96	-15.82*	6.73	8.17	-8.11	18.54*	-4.40	-16.08*	4.91	6.09	5.70	8.70*
IR-58025AxInger-2-114	-6.61	-25.79**	-5.91	-2.24	-22.24**	0.32	-4.59	-18.48**	1.90	6.17	1.35	13.80**
IR-58025AxKarmamahsuri	2.56	-13.22*	10.03	-1.03	-11.67	13.95	-0.64	-11.14	11.08	24.03**	18.52**	20.98**
IR-58025AxTOX981-11-2-3	-2.39	-20.48**	0.82	3.47	-14.00*	10.94	0.38	-16.08*	4.91	17.00**	14.07**	16.45**
IR-58025AxSuraksha	8.98	-9.32	14.97	15.66*	-1.11	27.58**	15.77*	-0.13	24.84**	13.37**	6.70*	23.44**
IR-79156A												
IR-79156AxKanakgopala	10.03	-1.47	10.71	-0.15	-15.76*	7.61	-2.50	-18.13**	5.06	7.39*	0.68	12.67**
IR-79156AxBagdidhan	-7.87	-16.99*	-6.73	-12.46	-25.93**	-5.39	-19.79**	-33.29**	-14.40	14.31**	5.24	17.77**
IR-79156AxRIL-62	11.61	-0.12	12.23	-0.51	-15.14*	8.40	-11.93*	-23.55**	-1.90	-4.40	-8.28*	2.65
IR-79156AxInger-2-114	7.20	-10.76	0.27	-1.32	-21.22**	0.63	-15.10*	-28.24**	-7.91	13.83**	13.64**	27.60**
IR-79156AxKarmamahsuri	20.25**	7.09	20.33*	4.22	-6.58	19.33*	-7.39	-18.13**	5.06	19.00**	8.95*	21.93**
IR-79156AxTOX981-11-2-3	30.09**	11.25	25.00**	6.47	-11.17	13.47	3.28	-14.55*	9.65	2.81	-4.05	7.37
IR-79156AxSuraksha	9.99	-3.79	8.10	-1.30	-15.26*	8.24	-1.45	-15.91*	7.91	-4.15	-5.72	9.07*
CRMS-32A												
CRMS-32AxKanakgopala	-5.28	-15.76*	-3.85	-6.97	-21.63**	0.48	-19.51**	-32.97**	-12.18	17.72**	12.26**	21.17**
CRMS-32AxBagdidhan	-11.10	-20.46**	-9.20	-22.46**	-34.49**	-16.01*	-21.82**	-35.51**	-15.51*	-3.09	-9.28*	-2.08
CRMS-32AxRIL-62	0.34	-10.83	1.79	-10.16	-23.49**	-1.90	-13.54*	-25.60**	-2.53	8.16*	5.60	13.99**
CRMS-32AxInger-2-114	38.18**	14.32*	30.49**	20.00**	-4.33	22.66**	4.18	-12.68*	14.40	-0.94	-2.86	9.07*
CRMS-32AxKarmamahsuri	3.27	-8.66	4.26	-5.52	-15.45*	8.40	-9.03	-20.29**	4.43	16.46**	8.41*	17.01**
CRMS-32AxTOX981-11-2-3	30.03**	10.47	26.10**	18.69**	-1.11	26.78**	19.35**	-2.05	28.32**	14.21**	8.41*	17.01**
CRMS-32AxSuraksha	-2.49	-15.28*	-3.30	-11.75	-24.35**	-3.01	-11.06	-24.76**	-1.42	3.47	0.00	15.69**

*Significant at p=0.05% level, **Significant at p=0.01% level

Cont...

Cross	Hulling %			Milling %			Head Rice Recovery			Elongation ratio		
	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis	Mid	Better	Standard Heterosis
IR-58025A												
IR-58025AxKanakgopala	-2.78	-2.78	-1.59	-2.06*	-3.41**	-3.29**	-11.05**	-17.82**	-1.39**	7.38**	-2.60	0.38
IR-58025AxBagdidhan	-4.63**	-5.56**	-4.40*	-8.11**	-10.26**	-5.72**	-18.00**	-24.24**	-9.09**	16.05**	5.62**	8.05**
IR-58025AxRIL-62	-1.10	-1.93	-0.73	-0.33	-1.23	0.72	-17.99**	-23.72**	-9.78**	-2.13	-8.37**	-11.88**
IR-58025AxInger-2-114	-5.72**	-6.52**	-5.38**	-17.70**	-17.73**	-17.62**	-64.46**	-66.59**	-61.39**	-5.68**	-19.42**	-4.60*
IR-58025AxKarmamahsuri	-1.75	-1.81	-0.61	0.60	-0.79	-0.66	27.19**	2.72**	4.50**	9.91**	8.44**	-6.51**
IR-58025AxTOX981-11-2-3	1.40	0.48	1.71	0.71	-0.51	2.10*	7.39**	-1.08**	19.48**	6.14**	2.11	-7.28**
IR-58025AxSuraksha	0.62	-1.81	-0.61	0.67	-0.79	-0.66	-0.16	-5.74**	7.97**	8.94**	0.00	0.38
IR-79156A												
IR-79156AxKanakgopala	0.56	-1.69	-0.49	-5.67**	-6.85**	-6.97**	-13.31**	-17.53**	-1.04**	4.13*	-6.32**	-3.45
IR-79156AxBagdidhan	1.19	-0.12	-0.86	-2.41**	-4.82**	0.00	2.09**	-2.89**	16.54**	2.90	-7.12**	-4.98*
IR-79156AxRIL-62	1.06	-0.37	-0.86	-0.20	-1.23	0.72	5.54**	1.10**	19.57**	-1.72	-8.76**	-12.26**
IR-79156AxInger-2-114	3.18*	1.72*	1.22*	-5.95**	-6.04**	-5.98**	-31.48**	-33.63**	-23.29**	-4.20*	-18.77**	-3.83*
IR-79156AxKarmamahsuri	0.25	-1.93	-0.86	2.20**	0.92	0.79	19.66**	-5.60**	2.25**	10.91**	8.44**	-6.51**
IR-79156AxTOX981-11-2-3	-1.37	-2.71	-3.30	-2.60**	-3.91**	-1.38	-1.51**	-6.59**	12.81**	7.52**	2.53	-6.90**
IR-79156AxSuraksha	0.19	0.00	-3.30	0.80	-0.53	-0.66	3.11**	0.30	14.89**	1.05	-8.02**	-7.66**
CRMS-32A												
CRMS-32AxKanakgopala	0.31	-2.05	-0.86	-2.86**	-4.20**	-4.08**	-17.67**	-18.98**	-2.77**	-1.33	-3.72*	-0.77
CRMS-32AxBagdidhan	2.69	1.23	0.49	0.35	-2.00*	2.96**	2.79**	1.15**	21.39**	9.75**	7.49**	9.96**
CRMS-32AxRIL-62	1.06	-0.49	-0.98	-2.28**	-3.16**	-1.25	-15.66**	-16.40**	-1.13**	-1.78	-2.73	-4.60*
CRMS-32AxInger-2-114	2.43	0.86	0.37	3.71**	3.68**	3.81**	-21.48**	-21.68**	-9.00**	-19.29**	-26.21**	-12.64**
CRMS-32AxKarmamahsuri	2.97	0.60	1.71	2.46**	1.05	1.18	28.52**	-1.12**	14.89**	1.46	-4.69*	-6.51**
CRMS-32AxTOX981-11-2-3	6.24**	4.67*	4.03*	2.20**	0.96*	3.62**	-1.28**	-3.15**	16.97**	7.10**	3.13**	1.15
CRMS-32AxSuraksha	0.57	0.51	-3.06	-2.27**	-3.68**	-3.55**	-6.87**	-7.53**	7.45**	9.27**	8.02**	8.43**

*Significant at p=0.05% level, **Significant at p=0.01% level

For days to 50% flowering, crosses IR-58025A x Karmamahsuri and CRMS-32A x RIL-62 showed significant negative relative heterosis, heterobeltiosis and standard heterosis over the check (Indira Sona). At mean time negative heterosis is required for days to 50% flowering so these two hybrids can be used for developing early maturing hybrids. While crosses IR-79156A x Bagdidhan and CRMS-32A x Bagdidhan showed significant positive relative heterosis, heterobeltiosis and standard heterosis over the check therefore these two can be used for developing late maturing hybrids. For plant height, crosses CRMS-32A x Karmamahsuri, CRMS-32A x Inger-2-114 and IR-58025A x Karmamahsuri showed significant negative heterosis over mid parent, better parent and check which can be utilized for developing semidwarf or dwarf hybrids. Hybrid IR-58025A x Karmamahsuri showed significant negative heterosis for days to 50% flowering and plant height both so that this will be effective for developing short duration, semidwarf rice hybrid. Similar types of results were depicted by [6, 17-20]. Hybrids, CRMS-32A x Inger-2-114, CRMS-32A x Kanakgopala and IR-79156A x TOX981-11-2-3 showed significant positive heterosis (all type of heterosis) for flag leaf area so that it can be estimated that these hybrids have more photosynthetic efficiency than other hybrids. Hybrids, IR-58025A x RIL-62 and IR-58025A x TOX981-11-2-3 showed significant positive relative heterosis, heterobeltiosis and standard heterosis for productive tiller/ plant and panicle length, respectively. Longer panicle length and higher productive tillers are closely associated with higher number of spikelet per panicle, resulting in higher production and productivity so that above mentioned two hybrids could be very useful for developing high yielding rice hybrids. This result was supported by [21, 22]. Crosses, CRMS-32A x Bagdidhan and CRMS-32A x TOX981-11-2-3 were showed significant positive heterosis for pollen fertility whereas crosses, CRMS-32A x Inger-2-114 and IR-58025A x Kanakgopala showed significant positive heterosis for spikelet fertility percentage. Crosses, IR-58025A x Inger-2-114 and IR-58025A x Bagdidhan were positive significant for hundred seed weight in which IR-58025A x Inger-2-114 showed highly significant standard heterosis. This type of result was also found by [23, 24, 17]. Out of 21 hybrids, only two hybrids (IR-79156A x RIL-62 and IR-79156A x Bagdidhan) were showed significant positive relative heterosis, heterobeltiosis and standard heterosis over Indira Sona for grain yield per plant. Most of the hybrids showed positive significant relative heterosis for grain yield while very less hybrids showed significant heterobeltiosis and standard heterosis. Crosses, IR-79156A x Bagdidhan and IR-58025A x Suraksha showed significant positive heterosis for biological yield per plant. Hybrid, IR-79156A x Bagdidhan showed significant positive standard heterosis for grain yield per plant and biological yield per plant which may be utilized in developing high yield potential hybrids as suggested by [25, 18]. Rice is marketed according to three grain size and shape classes (long, medium and short). Kernel dimension are primary quality factors in most phase of processing, drying, handling equipment, breeding and grading. A quality grain is that which meets the end user specifications with respect to range of predetermined quality and safety standards. In this regards, hybrids, IR-58025A x Suraksha and CRMS-32A x TOX981-11-2-3 showed significant positive standard heterosis for kernel L/B ratio whereas crosses, IR-79156A x Inger-2-114, IR-58025A x Suraksha and IR-79156A x Karmamahsuri showed significant positive standard heterosis for cooked rice L/B ratio. For other parameters, hybrids CRMS-32A x TOX981-11-2-3 and IR-79156A x Inger-2-114 showed significant positive heterosis over mid parent, better parent and standard check for hulling percentage while hybrids, CRMS-32A x Inger-2-114 and CRMS-32A x TOX981-11-2-3 showed significant positive heterosis for milling percentage. Crosses CRMS-32A x Bagdidhan, IR-79156A x RIL-62 and IR-58025A x Karmamahsuri showed significant positive relative heterosis, heterobeltiosis and standard heterosis for head rice recovery while CRMS-32A x Bagdidhan, CRMS-32A x Suraksha and IR-58025A x Bagdidhan showed significant positive heterosis for elongation ratio. Similar type of heterotic result for grain quality traits were reported [26, 17, 5, 18, 20, 6].

The best heterotic hybrids based on *per se* performance, significant SCAeffects and significant positive standard heterosis for grain yield, yield attributing traits and quality traits are presented in [Table-II]. Based on results, it is found that crosses IR-79156A x RIL-62 and IR-79156A x Bagdidhan were good for developing high yielding rice hybrids. The higher yield by these two hybrids could be the result of more panicle length, more productive tillers per plant, good net assimilation rate, good leaf area index, good harvest index and 100 grain weight and these crosses may be used in future breeding programmes for development of high yielding hybrids and varieties. While crosses CRMS-32A x Bagdidhan, IR-79156A x RIL-62 and IR-58025A x Karmamahsuri were found good for developing good quality hybrids. At present time, people prefer good quality premium rice so that these three hybrids could be used for commercial exploitation of heterosis in hybrid rice. Considering both grain yield and grain quality together, hybrid IR-79156A x RIL-62 exhibited significant relative heterosis, heterobeltiosis and standard heterosis for grain yield as well as for head rice recovery and other quality characteristics in the desirable range. Hence, it needs further testing in replicated trails over locations for stability in performance prior to commercial exploitation in wider area.

Table-II *The best hybrids identified for grain yield and quality traits based on per se performance, standard heterosis and SCA effect.*

S. No.	Character	Hybrids	*Per se* performance	SCA effect	Standard Heterosis
1	Days to 50% flowering	IR-58025A x Karmamahsuri	85.00	-0.55	-7.10**
		CRMS-32A x RIL-62	86.50	-1.02	-5.46*
2	Plant height (cm)	CRMS-32A x Karmamahsuri	97.70	-2.33	-14.93**
		CRMS-32A x Inger-2-114	102.25	-2.48	-10.97**
		IR-58025A x Karmamahsuri	109.35	1.00*	-4.79*
3	Flag leaf area(cm2)	CRMS-32A x Inger-2-114	52.45	4.02*	81.11**
		CRMS-32A x Kanakgopala	50.33	10.36**	73.79**
		IR-79156A x TOX981-11-2-3	45.87	5.25**	58.39**
4	Productive tillers/ plant	IR-58025A x RIL-62	14.00	1.48*	21.74*
5	Panicle length (cm)	IR-58025A x TOX981-11-2-3	30.40	1.88*	11.97**
6	Pollen fertility (%)	CRMS-32A x Bagdidhan	83.78	7.03**	8.87*
		CRMS-32A x TOX981-11-2-3	82.64	11.75**	7.39**
7	Total spikelets/ panicle	CRMS-32A x Inger-2-114	293.70	65.00**	56.39**
		IR-58025A x Kanakgopala	262.20	51.95**	39.62**
		CRMS-32A x TOX981-11-2-3	243.60	7.03*	29.71**
8	Spikelet fertility (%)	CRMS-32A x Inger-2-114	19.43	21.66**	73.63**
		IR-58025A x Kanakgopala	21.04	3.14*	71.44**
9	100 seed weight	IR-58025A x Inger-2-114	3.55	0.65**	57.78**
		IR-58025A x Bagdidhan	2.60	0.08*	15.56*
10	Grain yield/plant	IR-79156A x RIL-62	21.25	2.26*	25.44**
		IR-79156A x Bagdidhan	22.85	1.73*	19.82**
11	Harvest Index	CRMS-32A x Suraksha	36.88	4.28*	22.60**
12	Biological yield/plant	IR-79156A x Bagdidhan	95.80	16.21**	30.43**
		IR-58025A x Suraksha	95.75	19.55**	30.36**
13	Paddy L/B Ratio	CRMS-32A x Inger-2-114	4.75	0.86**	30.49**
		CRMS-32A x TOX981-11-2-3	4.55	0.37*	26.10**
14	Brown Rice L/B Ratio	IR-58025A x Suraksha	4.03	0.39*	27.58**
		CRMS-32A x TOX981-11-2-3	4.00	0.41*	26.78**
15	Kernel L/B ratio	IR-58025A x Suraksha	3.94	0.31*	24.84**
		CRMS-32A x TOX981-11-2-3	4.05	0.49**	28.32**
16	Cooked rice L/B ratio	IR-79156A x Inger-2-114	3.38	0.30**	27.60**
		IR-58025A x Suraksha	3.27	0.14*	23.44**
		IR-79156A x Karmamahsuri	3.22	0.06*	21.93**
17	Hulling %	CRMS-32A x TOX981-11-2-3	85.10	1.72*	4.03*
		IR-79156A x Inger-2-114	82.80	2.30*	1.22*
18	Milling %	CRMS-32A x Inger-2-114	78.95	6.32**	3.81**
		CRMS-32A x TOX981-11-2-3	78.80	0.06*	3.62**
19	Head Rice Recovery %	CRMS-32A x Bagdidhan	70.10	3.95**	21.39**
		IR-79156A x RIL-62	69.05	7.29**	19.57**
		IR-58025A x Karmamahsuri	60.35	3.63**	4.50**
20	Elongation Ratio	CRMS-32A x Bagdidhan	1.43	0.04*	9.96**
		CRMS-32A x Suraksha	1.41	0.07**	8.43**
		IR-58025A x Bagdidhan	1.41	0.04*	8.05**

*Significant at p=0.05% level, **Significant at p=0.01% level

Conclusion

Innovations that increase crop yields safeguard the environment and benefit communities will play an essential role in building sustainable solutions. Hybrid rice is an innovation that can feed World's growing population and at the same time reduce the environmental footprint of agriculture. In present investigation, hybrids showing significant positive standard heterosis with significant SCA effect could be most promising hybrids and need to be tested in large scale so that they may be considered for commercial exploitation.

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Abbreviations: SCA- Specific Combining Ability, GCA- General Combining Ability, CMS- Cytoplasmic Male Sterility, CGMS- Cytoplasmic Genetic Male Sterility, EGMS- Environmental Genetic Male Sterility.

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