

Studies on heterosis and combining ability for yield and its contributing traits using WA cytoplasmic male sterile lines in rice (*Oryza sativa* L.)

Abstract

The present study evaluated 20 F₁'s derived from five CMS lines and four testers along with their parents including a standard check, for their combining ability and heterosis concerning grain yield and ten yield-contributing traits. The research identified superior general and specific combiners. Among lines, IR 79156A and CRMS 31A were excellent general combiners and among testers, IR 10N134 and IR 14V1020 showed strong general combining ability for grain yield per plant. Significant specific combining ability was observed in the crosses, IR 79156A/IRRI-186 followed by IR 58025A/IR 14V1020, IR 68888A/IR 14A150 and CRMS 32A/IR 10N134 for grain yield. Understanding heterosis, defined by the superior performance of F₁ progeny over parents, is crucial for crop improvement. This research evaluated rice hybrids for their yield and its contributing traits. It is observed that, CRMS 32A/IR 14V1020, CRMS 31A/IR 14V1020 and CRMS 31A/IRRI-186 consistently matured earlier than their respective parents and the check. Concurrently, IR 79156A/IRRI-186, IR 58025A/IR 14V1020 and CRMS 31A/IR 10N134 demonstrated notable high heterosis for yield and related characteristics, compared to mid-parent, better-parent and standard check. These promising F₁ hybrids serve as critical resources for advancing new rice cultivar development programs.

Keywords: Combination, Combining ability, Rice, GCA effect, SCA effect, Heterosis, Rice, Wild-Abortive (WA)

Introduction

Rice (*Oryza sativa* L.), a semi-aquatic annual grass of the Poaceae family, is a staple crop globally, ranking after wheat and slightly above maize in total cereal grain production. Its adaptability allows for diverse food and industrial applications. India, a top global exporter, significantly contributes to the world's rice market, with a domestic output of 137.8 million tonnes in FY 2023-24, representing over 40 % of its total food grain production (Anonymous, 2024). Chhattisgarh, known as the "rice bowl of India," plays a crucial role, contributing 9.4 % of the national rice area and 6.5 % of total production in 2024-25, forming the backbone of its rural economy (Anonymous, 2025).

Developing high-yielding rice varieties is paramount. This study explores heterosis (hybrid vigor), the phenomenon where hybrid offspring exhibit superior phenotypic performance compared to their parents. We utilized the cytoplasmic male sterility (CMS) system, a maternally inherited trait leading to pollen infertility, to facilitate hybrid development. Among various CMS systems, the Wild Abortive (WA) cytoplasm is

predominantly used due to its stable and near-complete pollen sterility (Shinjyo and Omura, 1966). To identify promising parental lines and cross recombinants, line \times tester analysis was employed, allowing for the assessment of general combining ability (GCA) and specific combining ability (SCA) effects (Kamara *et al.*, 2021a). This analysis further elucidates the additive and non-additive gene effects influencing targeted traits (Kempthorne, 1957; Kamara *et al.*, 2021b). The findings of this research aim to identify superior rice hybrids with significant heterosis for improved yield and related traits.

Materials and Methods

The study was carried out at the Research cum Instructional Farm, Department of Genetics and Plant Breeding, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), to assess combining ability and heterosis in rice yield and its components. Twenty F_1 hybrids were developed in *Kharif*, 2023 through a Line \times Tester mating design, involving five lines (IR 58025A, IR 79156A, CRMS 31A, CRMS 32A, IR 68888A) and four testers (IR 10N134, IR 14A150, IR 14V1020, IRRI-186). In *Kharif*, 2024 these 20 F_1 's along with their parents and check (Chhattisgarh Dhan 1919), were evaluated in a Randomized Block Design with two replications. Seeds were initially planted under protected structure in late June, followed by transplanting of 25-30 days old seedlings to the main field. Data were collected on key quantitative traits, including: days to 50 % flowering, days to maturity, plant height (cm), panicle length (cm), number of effective tillers per plant, spikelet fertility (%), biological yield (g), 100-seed weight (g), harvest index (%) and grain yield per plant (g).

Table 1: List of lines and testers used as experimental material.

S. No.	LINES	SOURCE	S. No.	TESTERS	SOURCE
1.	IR 58025A	IRRI, Philippines	1.	IR 10N134	IRRI, Philippines
2.	IR 79156A	IRRI, Philippines	2.	IR 14A150	IRRI, Philippines
3.	CRMS 31A	CRRI, Cuttack, Odisha	3.	IR 14V1020	IRRI, Philippines
4.	CRMS 32A	CRRI, Cuttack, Odisha	4.	IRRI-186	IRRI, Philippines
5.	IR 68888A	IRRI, Philippines	5.	Chhattishgarh Dhan 1919 (Check)	IGKV, Raipur

Results and Discussion

Combining Ability

Analysis of variance for line \times tester.

Analysis of variance (ANOVA), presented in Table 2, revealed significant differences among treatments for all traits studied. Specifically, the variance due to parents was significant

for all traits except spikelet fertility and harvest index. The lines vs. testers interaction showed significant differences for all traits except plant height and spikelet fertility. Furthermore, variance attributed to crosses was significant for all traits except days to 50 % flowering and effective tillers per plant.

The parents vs. crosses variance exhibited significance for all characters except days to maturity, biological yield per plant and grain yield per plant. Variance due to lines was significant for all traits except days to maturity, panicle length, biological yield per plant, 100-grain weight and harvest index. Conversely, variance due to testers was non-significant for most characters, with exceptions noted for days to maturity, plant height and 100-grain weight. These findings align with previous research, where Abo Yousef *et al.* (2020), Shehab *et al.* (2023), Saran *et al.* (2025) and Bharti *et al.* (2025) reported similar results for variance due to parents vs. crosses and line \times tester interaction for plant height and grain yield.

General Combining ability

Analysis of variance for combining ability revealed significant General Combining Ability (GCA) effects, identifying several parental lines (females) and testers with strong potential for hybrid breeding programs.

Among the parental lines, CRMS 32A exhibited significant GCA effects for plant height ($p < 0.05$), indicating its consistent genetic influence on plant stature. The specific direction of this GCA (positive for biomass, negative for lodging resistance) would determine its suitability based on breeding objectives. For spikelet fertility ($p < 0.01$), IR 58025A/IR 10N134 and IR 58025A/IR 14V1020 demonstrated significant GCA effects, highlighting their superior genetic potential to increase the proportion of fertile spikelets, directly contributing to higher filled grains and overall grain yield. Most notably, IR 79156A displayed highly significant GCA effects ($p < 0.001$) for biological yield per plant, harvest index (HI) and grain yield per plant. This signifies its exceptional genetic capacity to accumulate total dry matter, efficiently partition photosynthates towards grain and ultimately enhance overall grain productivity, making it an exceptionally valuable parent for yield improvement (Table 3).

Analysis of general combining ability (gca) effects also identified IRRI-186, IR 14V1020, IR 14A150 and IR 10N134 as superior testers for various key agronomic traits. Irri-186 showed a highly desirable significant negative gca for days to maturity and a significant positive gca for harvest index, suggesting its potential for developing early-maturing varieties with improved grain partitioning efficiency. IR 14V1020 demonstrated significant gca effects for plant height and both IR 14V1020 and IR 10N134 exhibited significant positive gca for biological yield per plant and, critically, grain yield per plant. Additionally, IR 14A150 displayed a significant positive gca for spikelet fertility, a crucial trait for maximizing grain production. These findings underscore the value of these testers as excellent general combiners, capable of transmitting favorable genes for their respective traits, aligning with previous research by Dharwal *et al.* (2017) which also reported promising genotypes with high gca effects in rice. This supports their strategic use in developing improved rice varieties.

Specific Combining Ability

The specific combining ability (SCA) effects are crucial for identifying superior hybrid combinations with enhanced performance. The investigation into specific combining ability (SCA) revealed that non-additive gene action plays a pivotal role in determining hybrid performance across numerous agronomic traits, as evidenced by significant SCA effects (Table 4). Several hybrids consistently demonstrated superior SCA across multiple desirable traits. For instance, IR 79156A/IRRI-186 emerged as a strong specific combiner for panicle length, plant height, biological yield and grain yield. Other notable combiners for yield-related traits included IR 58025A/IR 14V1020 (spikelet fertility, biological yield, grain yield) and various combinations involving CRMS 31A, CRMS 32A and IR 68888A for spikelet fertility, biological yield per plant, harvest index and grain yield. For early flowering and maturity, IR 68888A/IRRI-186, CRMS 32A /IR 14V1020 and IR 79156A/IR 14A150 were identified as possessing significant SCA.

Notably, the magnitude of SCA variance was higher than that of general combining ability (GCA) variance for all traits, with the sole exception of days to 50 % flowering. This predominance of SCA variance suggests that specific gene combinations, rather than the average performance of parental lines, largely dictate the expression of these traits in the F₁ generation.

These findings are consistent with previous studies on hybrid rice, where similar positive SCA effects have been reported by Menaka and Ibrahim (2016), Rahman *et al.* (2022) Lakra *et al.* (2020) Furthermore, our results reinforce the broader agricultural principle highlighted by Sandhu *et al.* (2023), who emphasized the critical role of thoughtful parental selection, considering SCA effects, to enhance yield potential in breeding initiatives. The identification of these specific hybrid combinations as good specific combiners provides valuable insights for targeted breeding strategies aimed at developing high-yielding and agronomically superior rice varieties.

Heterosis

Heterosis, also known as hybrid vigor (Shull, 1948), describes the phenomenon where the F₁ progeny resulting from a cross between two genetically distinct parents exhibit traits that are superior to either parent. This can manifest as increased biomass, short stature, enhanced yield, improved stress tolerance, or earlier maturity (Table 5). Negative heterosis is highly desirable for both days to 50 % flowering and days to maturity, as it directly translates to earlier hybrid maturation. For days to 50 % flowering, four hybrids exhibited significant negative mid-parent heterosis, with CRMS 32A/IR 14V1020 showing the most pronounced effect (-5.71 %). Similarly, five hybrids demonstrated significant negative mid-parent heterosis for days to maturity, with CRMS 32A/IR 14V1020 again leading (-6.70 %). A substantial thirteen hybrids consistently displayed significant negative heterobeltiosis for both traits, with CRMS 32A/IR 14V1020 registering the most extreme values for both days to 50 % flowering (-10.81 %) and days to maturity (-11.86 %). The universal and significant negative standard heterosis observed across all twenty hybrids when compared to the check (CHHATTISHGARH DHAN 1919) further confirms their consistent superiority in earliness, indicating strong potential for commercial cultivation.

For plant height, desirable negative heterosis, crucial for lodging resistance, was observed in ten hybrids with significant negative mid-parent heterosis, led by CRMS 31A/IR 14V1020 (-26.47 %). Eleven hybrids also showed significant negative heterobeltiosis, with CRMS 31A/IR 14V1020 (-27.75 %) and CRMS 32A/IR 14V1020 (-27.19 %) being the most effective. However, only IR 79156A/IR 14A150 (-6.77 %) exhibited significant negative standard heterosis over Chhattishgarh Dhan 1919 indicating that most hybrids did not surpass the check in terms of reduced height.

Hybrids often exhibit longer panicles with a greater number of spikelets, a key factor in efficient assimilate partitioning and higher yields. Our study identified six hybrids showing significant positive mid-parent heterosis, led by IR 79156A/IRRI-186 (19.87 %). An equal number of hybrids (six) also displayed significant positive heterobeltiosis, indicating superiority over their better parents. Importantly, thirteen hybrids demonstrated significant positive standard heterosis compared to Chhattishgarh Dhan 1919 with IR 68888A/IR 14V1020 (20.51 %), IR 79156A/IRRI-186 (18.33 %) and IR 68888A/IR 10N134 (16.65 %) exhibiting the highest vigor, confirming their potential to enhance yield through improved panicle size.

The number of effective tillers per plant is a critical determinant of a rice genotype's yield potential, making positive heterosis highly desirable for this trait. Eleven hybrids exhibited significant positive mid-parent heterosis, with CRMS 31A/IRRI-186 (68.07 %) and CRMS 31A/IR 14A150 (67.26 %) showing the most substantial increases. Six hybrids also displayed significant positive heterobeltiosis (better-parent heterosis), notably CRMS 31A/IRRI-186 (51.29 %) and CRMS 31A/IR 14A150 (37.52 %), indicating their superiority over better parents. Furthermore, seven hybrids demonstrated significant positive standard heterosis over Chhattishgarh Dhan 1919 (check), with IR 79156A/IRRI-186 (45.11 %) and IR 79156A/IR 14V1020 (30.40 %) being particularly promising for enhancing tiller count in commercial varieties.

For spikelet fertility (%), five hybrids exhibited significant positive mid-parent heterosis, notably CRMS 31A/IR 14A150 (12.30 %), CRMS 31A/IR 10N134 (9.86 %) and IR 79156A/IR 14A150 (9.01 %). However, only IR 79156A/IR 14A150 (8.23 %) demonstrated significant positive heterobeltiosis (better-parent heterosis), with the remaining hybrids showing negative heterobeltiosis. Similarly, only IR 79156A/IR 14A150 (5.68 %) displayed significant positive standard heterosis over the Chhattishgarh Dhan 1919 (check), while the majority of hybrids exhibited negative standard heterosis for this trait.

For biological yield per plant, seven hybrids displayed significant positive mid-parent heterosis, led by IR 68888A/IR 10N134 (82.01 %) and IR 79156A/IRRI-186 (62.86 %). Three hybrids also showed significant positive heterobeltiosis, notably IR 68888A/IR 10N134 (56.97 %) and IR 79156A/IRRI-186 (44.76 %). Conversely, all eighteen hybrids consistently exhibited significant negative standard heterosis compared to Chhattishgarh Dhan 1919 (check), with no hybrid demonstrating significant positive standard heterosis, suggesting that hybrid biomass production generally did not exceed the commercial check.

For 100-grain weight (a critical seed index), six hybrids exhibiting significant positive mid-parent heterosis, with IR 58025A/IR 10N134 (19.92 %) and IR 58025A/IRRI-186 (12.76 %) showing the most substantial increases. Three hybrids also demonstrated significant positive heterobeltiosis (better-parent heterosis), notably IR 58025A/IR 10N134 (17.30 %) and IR 58025A/IRRI-186 (9.14 %). Importantly, all twenty hybrids consistently exhibited significant positive standard heterosis over Chhattishgarh Dhan 1919, confirming their widespread potential for enhancing grain weight compared to the commercial standard.

For harvest index, eight hybrids showed significant positive mid-parent heterosis, with CRMS 32A/IR 14A150 (47.58 %) and CRMS 32A/IRRI-186 (41.98 %) being the most prominent. Significant positive heterobeltiosis was observed in two hybrids: CRMS 32A/IR 14A150 (43.69 %) and CRMS 32A/IRRI-186 (41.16 %). Notably, all twenty hybrids exhibited significant positive standard heterosis when compared to Chhattishgarh Dhan 1919. These results are consistent with findings from other studies (Bedi *et al.*, 2016; Ray *et al.*, 2021; Daher *et al.*, 2024), collectively supporting the utility of hybrid vigor for improving harvest index.

For grain yield per plant, highest significant relative heterosis was recorded in IR 79156A/IRRI-186 (63.61 %), CRMS 31A/IR 10N134 (51.92 %) and IR 58025A/IR 14V1020 (45.90 %). Four hybrids, including IR 79156A/IRRI-186 (57.37 %) and IR 58025A/IR 14V1020 (31.45 %), exhibited significant positive heterobeltiosis. Furthermore, IR 79156A/IRRI-186 (63.57 %), IR 58025A/IR 14V1020 (55.93 %) and IR 79156A/IR 14V1020 (37.62 %) displayed significant positive standard heterosis over Chhattishgarh Dhan 1919 (Table 6). These hybrids, demonstrating robust F₁ heterotic expression, are promising candidates for identifying superior hybrids, consistent with findings by Gokulakrishnan *et al.* (2018), Naik *et al.* (2021), Gupta *et al.* (2024) and Sao *et al.* (2025) on exploiting heterosis for yield enhancement.

Conclusion

In conclusion, this study provides critical insights for rice hybrid breeding by identifying parental lines and F₁ combinations with high combining ability and heterotic potential for grain yield. Lines IR 79156A and CRMS 31A, along with testers IR 10N134 and IR 14V1020, were recognized as excellent general combiners. Concurrently, specific crosses including IR 79156A/IRRI-186, IR 58025A/IR 14V1020, IR 68888A/IR 14A150 and CRMS 32A/IR 10N134 were confirmed as superior specific combiners for grain yield per plant. The outstanding heterotic expression observed in hybrids such as IR 79156A/IRRI-186, CRMS 31A/IR 10N134 and IR 58025A/IR 14V1020 across all heterosis parameters (mid-parent, better-parent and standard check) underscores their immediate utility.

The knowledge and genetic material generated from this investigation offer significant advantages for future hybrid rice breeding programs. By strategically incorporating these findings, researchers can accelerate the development of hybrids with enhanced grain yield and other crucial agronomic traits. This research, therefore, leads to the development of hybrid rice and their further exploitation as commercial hybrids.

Table 2: Analysis of Variance (ANOVA) for Line X Tester analysis

SV	DF	DFE	DM	PH	PL	ET/P	SF	BY/P	100 GW	HI	GY/P
Replications	1	3.879	7.603	83.559	0.025	1.432	9.717	6.777	0.025	187.33	6.825
Treatments	28	27.36**	46.61**	253.33**	5.93**	7.96**	170.85**	275.38**	0.074**	132.86**	119.70**
Parents	8	60.62**	81.306**	335.42**	4.461**	6.661**	60.071	118.453**	0.13**	76.436	51.895**
Testers	3	23.125	48.458**	381.08**	3.567	4.491	21.397	19.837	0.18**	12.601	5.377
Lines	4	40.15**	4.35	336.023**	3.837	7.53**	100.858**	71.547	0.014	46.722	43.026**
Lines vs Testers	1	255.02**	487.66**	196.038	9.64**	9.696**	12.945	601.92**	0.42**	386.79**	226.92**
Crosses	19	12.551	33.10*	216.339*	6.494**	7.674	222.948**	353.85**	0.05**	154.31**	153.76**
Parents vs. Crosses	1	42.87**	25.9	299.547**	6.969**	23.961**	67.258*	39.95	0.034**	176.83**	15.00
Error	28	15.451	8.568	68.128	1.037	1.227	21.299	21.507	0.02	30.98	8.135

* Significant at p=0.05 % level, ** Significant at p=0.01 % level Where, SV=Source of Variation, DF=Degree of Freedom, DFE=Days to 50 % flowering, DM=Days to Maturity, PH=Plant Height, ET/P=Effective tillers per plant, SF=Spikelet Fertility, BY/P=Biological yield per plant, 100SW=100 Seed Weight, HI=Harvest Index, GY/P=Grain yield per plant.

Table 3: General combining ability effects of parents for yield and its contributing traits

Parents	Days to 50 % flowering	Days to maturity	Plant Height (cm)	Panicle Length (cm)	No. of effective tillers per plant	Spikelet fertility (%)	Biological yield/Plant (g)	100 Grain weight (g)	Harvest Index (%)	Grain yield/plant (g)
LINES										
IR 58025A	2.10	1.88	-0.67	0.95	0.00	5.11**	2.11*	0.20	-6.36**	1.60
IR 79156A	1.10	1.25	2.14	-0.68	1.80	1.28	4.05**	-0.08	6.47**	4.26**
CRMS 31A	-1.28	-0.25	-1.99	-1.45	1.01	4.06**	1.48	-0.07	1.05	2.36*
CRMS 32A	-0.15	-0.63	-2.34*	-0.27	-2.11	0.69	-7.76**	-0.03	3.71*	-5.27**
IR 68888A	-1.78	-2.25	2.85*	1.45	-0.70	-11.13**	0.12	-0.02	-4.86**	-2.95*
TESTERS										
IR 10N134	-0.03	-0.30	1.22	0.22	0.62	3.85*	7.66**	0.01	-2.05*	5.12**
IR 14A150	0.48	2.80*	2.15	-0.17	-0.39	4.29**	-10.93**	-0.05	1.08	-6.53**
IR 14V1020	0.88	0.60	-4.93**	-0.39	-0.31	-9.30**	6.31**	0.02	-1.55	4.49**
IRRI-186	-1.33	-3.10*	1.56	0.35	0.08	1.17	-3.04	0.01	2.52*	-3.08*

Table 4: Specific Combining Ability Effects of crosses for yield and its contributing traits

CROSSES	Days to 50 % flowering	Days to maturity	Plant Height (cm)	Panicle Length (cm)	No. of effective tillers per plant	Spikelet fertility (%)	Biological yield/Plant (g)	100 Grain weight (g)	Harvest Index (%)	Grain yield/plant (g)
IR 58025A/IR 10N134	-1.10	-0.58	-0.28	-0.81	-0.89	-2.95	-5.63**	0.13	4.77**	-0.22
IR 58025A/IR 14A150	0.40	2.33	10.29**	1.22	-0.69	-2.62	-4.22*	-0.12	0.45	-2.61
IR 58025A/IR 14V1020	0.00	-0.48	4.96**	-0.10	1.81	8.71**	8.33**	0.01	-4.21*	7.41**
IR 58025A/IRRI-186	0.70	-1.28	-14.97**	-0.31	-0.23	-3.14	1.52	-0.02	-1.01	-4.57**
IR 79156A/IR 10N134	-0.60	2.05	-2.03	-0.58	-0.69	-0.03	-15.65**	-0.03	2.49	-9.09**
IR 79156A/IR 14A150	-2.60	-9.05**	-21.61**	-0.67	-2.37	6.89**	-7.88**	-0.17	-5.88**	-5.56**
IR 79156A/IR 14V1020	2.50	4.15*	-2.99	-1.98	1.08	-2.94	2.77*	0.11	4.83**	0.59
IR 79156A/IRRI-186	0.70	2.85*	26.63**	3.23*	1.98	-3.92*	20.76**	0.09	-1.44	14.06**
CRMS 31A/IR 10N134	0.28	-0.45	-2.46	-0.18	-0.56	-3.06	-4.67**	-0.11	3.03*	-2.37
CRMS 31A/IR 14A150	0.78	3.45*	1.51	1.08	1.90	-1.70	6.36**	0.25	0.42	5.56**
CRMS 31A/IR 14V1020	-0.13	-0.85	-1.16	-1.45	-1.48	5.09**	-5.32**	-0.22	9.65**	-6.57**
CRMS 31A/IRRI-186	-0.93	-2.15	2.11	0.55	0.14	-0.32	3.64*	0.08	-13.11**	3.38*
CRMS 32A/IR 10N134	0.15	-0.08	0.17	0.76	2.33	2.59	7.97**	0.11	-10.33**	6.07**
CRMS 32A/IR 14A150	0.15	2.83	1.52	-0.76	0.72	-12.81**	-2.21	0.06	11.84**	-3.53*
CRMS 32A/IR 14V1020	-3.75*	-4.98**	-0.06	1.13	-1.14	5.82**	4.03*	-0.07	-10.61**	3.00*
CRMS 32A/IRRI-186	3.45*	2.23	-1.63	-1.12	-1.91	4.40*	-9.78**	-0.09	9.10**	-5.53**
IR 68888A/IR 10N134	1.28	-0.95	4.60**	0.81	-0.19	3.46*	17.97**	-0.10	0.03	5.62**
IR 68888A/IR 14A150	1.28	0.45	8.29**	-0.86	0.44	10.24**	7.95**	-0.01	-6.83**	6.14**
IR 68888A/IR 14V1020	1.38	2.15	-0.75	2.40	-0.27	-16.67**	-9.80**	0.18	0.34	-4.42*
IR 68888A/IRRI-186	-3.93*	-1.65	-12.14**	-2.35	0.02	2.97	-16.13**	-0.07	6.46**	-7.33**

Table 5: Best general and specific combiners for grain yield and its attributing traits in rice.

Traits	Best general combiner		Best specific combiner
	Lines	Testers	
Days to 50 % flowering	IR 68888A, CRMS 31A	IRRI-186, IR 10N134	IR 68888A/IRRI-186, CRMS 32A/IR 14V1020, IR 79156A/IR 14A150, IR 58025A/IR 10N134
Days to maturity	IR 68888A, CRMS 32A	IRRI-186, IR 10N134	IR 79156A/IR 14A150, CRMS 32A/IR 14V1020, CRMS 31A/IRRI-186, IR 68888A/IRRI-186
Plant Height (cm)	CRMS 32A, CRMS 31A	IR 14V1020, IR 10N134	IR 79156A/IR 14A150, IR 58025A/IRRI-186, IR 68888A/IRRI- 186, IR 79156A/IR 14V1020
Panicle Length (cm)	IR 68888A, IR 58025A	IRRI-186, IR 10N134	IR 79156A/IRRI-186, IR 68888A/IR 14V1020, IR 58025A/IR 14A150, CRMS 32A/IR 14V1020
No. of effective tillers per plant	IR 79156A, CRMS 31A	IR 10N134, IRRI-186	CRMS 32A/IR 10N134, IR 79156A/IRRI-186, CRMS 31A/IR 14A150, IR 58025A/IR 14V1020
Spikelet fertility (%)	IR 58025A, CRMS 31A	IR 14A150, IR 10N134	IR 68888A/IR 14A150, IR 58025A/IR 14V1020, IR 79156A/IR 14A150, CRMS 32A/IR 14V1020
Biological yield per Plant (g)	IR 79156A, IR 58025A	IR 10N134, IR 14V1020	IR 79156A/IRRI-186, IR 68888A/IR 10N134, IR 58025A/IR 14V1020, CRMS 32A/IR 10N134
100 Grain weight (g)	IR 58025A, IR 68888A	IR 14V1020, IR 10N134	CRMS 31A/IR 14A150, IR 68888A/IR 14V1020, IR 58025A/IR 10N134, IR 79156A/IR 14V1020
Harvest Index (%)	IR 79156A, CRMS 32A	IRRI-186, IR 14A150	CRMS 32A/IR 14A150, CRMS 31A/IR 14V1020, CRMS 32A/IRRI-186, IR 68888A/IRRI-186
Grain yield per plant (g)	IR 79156A, CRMS 31A	IR 10N134, IR 14V1020	IR 79156A/IRRI-186, IR 58025A/IR 14V1020, IR 68888A/IR 14A150, CRMS 32A/IR 10N134

Table 6: Estimates of Relative heterosis, heterobeltiosis, standard heterosis for yield and its contributing traits

CROSSES	Days to 50 % flowering			Days to maturity			Plant Height (cm)			Panicle Length (cm)		
	Mid	Better	Standard	Mid	Better	Standard	Mid	Better	Standard	Mid	Better	Standard
IR 58025A/IR 10N134	6.46**	0.00	-16.83**	1.29	-2.89**	-6.75**	1.06	-1.12	11.97**	0.55	-0.51	8.26**
IR 58025A/IR 14A150	7.93**	0.57	-14.90**	6.24**	1.65	-1.98*	13.20**	11.80**	24.22**	10.10**	7.72**	14.74**
IR 58025A/IR 14V1020	5.05**	-4.32**	-14.90**	-0.21	-6.32**	-5.95**	-11.56**	-22.19**	11.00**	-1.35	-4.48*	8.65**
IR 58025A/IRRI-186	8.41**	2.96**	-16.35**	1.11	-0.44	-9.52**	-13.96**	-16.92**	-3.32	5.21**	3.99*	10.77**
IR 79156A/IR 10N134	2.38*	-0.58	-17.31**	3.91**	-1.24	-5.16**	0.81	-0.13	13.09**	1.61	-5.59**	2.73
IR 79156A/IR 14A150	-0.30	-3.98**	-18.75**	-3.25**	-8.23**	-11.51**	-16.10**	-16.10**	-6.77*	3.29	-1.03	0.85
IR 79156A/IR 14V1020	3.45**	-2.70**	-13.46**	4.03**	-3.16**	-2.78**	-16.84**	-26.03**	5.52	-8.44**	-16.64**	-5.18**
IR 79156A/IRRI-186	3.61**	1.78*	-17.31**	5.15**	2.62**	-6.75**	26.59**	23.74**	43.99	19.87**	13.73**	18.33**
CRMS 31A/IR 10N134	-2.03*	-2.31*	-18.75**	-0.22	-4.55**	-8.33**	-13.74**	-21.40**	8.23**	-2.53	-6.95**	1.24
CRMS 31A/IR 14A150	-1.72	-2.84**	-17.79**	5.60**	0.82	-2.78**	-8.80*	-17.60**	13.46**	4.27	2.75	4.70*
CRMS 31A/IR 14V1020	-4.76**	-8.11**	-18.27**	-2.11*	-8.30**	-7.94**	-26.47**	-27.75**	3.07	-11.76**	-17.51**	-6.16**
CRMS 31A/IRRI-186	-3.81**	-4.65**	-21.15**	-1.33	-3.06**	-11.90**	-10.68**	-17.60**	13.46**	3.16	0.63	4.70*
CRMS 32A/IR 10N134	1.18	-1.16	-17.79**	-1.07	-4.55**	-8.33**	-0.66	-2.27	10.66**	1.98	0.76	9.64**
CRMS 32A/IR 14A150	0.88	-2.27*	-17.31**	3.85**	0.00	-3.57**	2.51	1.80	13.10**	-1.91	-3.91*	2.07
CRMS 32A/IR 14V1020	-5.71**	-10.81*	-20.67**	-6.70**	-11.86**	-11.51**	-17.64**	-27.19**	3.87	-1.19	-4.46*	8.67**
CRMS 32A/IRRI-186	4.79**	3.55**	-15.87**	1.32	0.44	-8.73**	-3.40	-6.23	9.12**	-2.29	-3.29	2.73
IR 68888A/IR 10N134	4.94**	-1.73*	-18.27**	-1.74*	-6.61**	-10.32**	12.31**	6.78	20.92**	10.94**	7.21**	16.65**
IR 68888A/IR 14A150	4.59**	-2.84**	-17.79**	1.95*	-3.29**	-6.75**	18.05**	13.27**	25.85**	6.69**	6.48**	8.49**
IR 68888A/IR 14V1020	2.38*	-7.03**	-17.31**	-0.64	-7.51**	-7.14**	-11.21**	-23.83**	8.67**	11.98**	5.94**	20.51**
IR 68888A/IRRI-186	-1.88	-7.10**	-24.52**	-2.01*	-4.37**	-13.10**	-5.30	-11.10**	3.45	1.88	0.63	4.70*

Con....

Table 6: Estimates of Relative heterosis, heterobeltiosis, standard heterosis for yield and its contributing traits

CROSSES	No. of effective tillers per plant			Spikelet fertility (%)			Biological yield per Plant (g)		
	Mid	Better	Standard	Mid	Better	Standard	Mid	Better	Standard
IR 58025A/IR 10N134	-5.95	-16.75**	-2.30	0.06	-1.90	-1.41	4.10	2.92	-31.57**
IR 58025A/IR 14A150	-4.20	-6.21	-11.49*	1.08	-1.07	-0.57	-38.82**	-40.37**	-58.24**
IR 58025A/IR 14V1020	31.27**	30.64**	18.10**	1.50	-3.53	-3.05	23.67*	16.03*	-11.98*
IR 58025A/IRRI-186	19.17**	9.66	-0.86	-4.33	-5.04	-4.56	-5.17	-5.39	-37.09**
IR 79156A/IR 10N134	5.95	2.84	20.69**	0.50	-0.05	-2.41	-4.01	-13.98	-44.11**
IR 79156A/IR 14A150	-12.29*	-18.68**	-10.17	9.01**	8.23**	5.68*	-35.65**	-44.17**	-60.90**
IR 79156A/IR 14V1020	30.40**	18.05**	30.40**	-15.04**	-18.13**	-20.06**	29.43**	8.64	-17.59**
IR 79156A/IRRI-186	55.67**	31.37**	45.11**	-8.09*	-8.73**	-9.63**	62.86**	44.76**	-4.18
CRMS 31A/IR 10N134	26.97**	-3.62	13.10*	9.86**	0.76	-2.69	29.29**	6.11	-31.05**
CRMS 31A/IR 14A150	67.26**	37.52**	29.77**	12.30**	3.17	-0.71	2.43	-18.30*	-42.79**
CRMS 31A/IR 14V1020	22.32**	2.70	-8.05	7.31*	1.42	-8.18**	12.05	-13.19	-34.15**
CRMS 31A/IRRI-186	68.07**	51.29**	14.94*	8.43**	-1.66	-2.62	20.95*	-1.44	-34.76**
CRMS 32A/IR 10N134	24.31**	-5.83	10.52	3.26	3.15	-0.17	30.03**	14.22	-25.78**
CRMS 32A/IR 14A150	3.94	-14.74*	-19.54**	-13.60**	-13.84**	-16.61**	-50.42**	-57.80**	-70.45**
CRMS 32A/IR 14V1020	-19.92**	-32.93**	-39.94**	-5.06	-8.12**	-11.08**	5.59	-12.97	-33.99**
CRMS 32A/IRRI-186	-18.62**	-26.93**	-44.48**	0.99	-0.15	-1.13	-47.94**	-54.63**	-69.97**
IR 68888A/IR 10N134	7.43	-16.75**	-2.30	-7.42*	-9.10**	-12.21**	82.01**	56.97**	2.00
IR 68888A/IR 14A150	17.54**	-1.04	-6.61	1.12	-0.54	-4.28	-1.68	-17.78*	-42.42**
IR 68888A/IR 14V1020	11.90	-3.72	-13.79*	-44.21**	-44.97**	-48.78**	-7.63	-25.14**	-43.21**
IR 68888A/IRRI-186	33.58**	23.53**	-6.15	-12.22**	-14.86**	-15.69**	-42.79**	-51.04**	-67.59**

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

Reference

- Anonymous, 2024. Ministry of Agriculture & Farmers Welfare. Final Estimates of Production of Major Agricultural Crops for the Year 2023-24. *Press Information Bureau*, 25 Sept. 2024, www.pib.gov.in/PressReleasePage.aspx?PRID=2058534.
- Anonymous, 2025. Unified Portal for Agricultural Statistics (UPAg). Statewise Rice Production Share, 2024-25. *UPAg*, 2024, <https://upag.gov.in/dash-reports/apymajorstates>.
- Abo-Yousef, M. I., Ghidan, W. F., Talha, I. A., Elsehely, A. B. and Tabl, D. M. 2020. Combining ability, heterosis and gene action for grain yield and its related traits of some WA-CMS with tester lines of rice (*Oryza sativa* L.). *J. Exp. Agric. Int.*, 42(9): 102-123.
- Bedi, S. and Sharma, D. 2016. Heterosis studies in hybrid rice (*Oryza sativa* L.). *Int. J. Forestry & Crop Improv.*, 7(1): 1-6.
- Bharti, V., Verma, R. K., Sao, A., & Soni, S. 2025. Genetic variability and diversity analysis in advance breeding lines of rice (*Oryza sativa* L.). *IJBS*, 7(1): 150-155.
- Daher, E. M., El-Naem, S. A., Ghazy, M. I. and Hefeina, A. G. 2024. Studies on combining ability and heterosis for Yield, its components and some grain quality traits in rice using line x tester under normal and water deficit. *Menoufia J. Plant Product.*, 9(2): 37-53.
- Dharwal, G., Verma, O.P and Verma, G.P. 2017. Combining ability analysis for grain yield and other associated traits in rice. *Int. J. Pure Appl. Biosci.*, 5(2): 96-100.
- Gokulakrishnan, J. 2018. Heterosis for yield and yield attributed traits in rice (*Oryza sativa* L.). *Hortic. Biotechnol. Res.*, 26-29.
- Gupta, P., Sao, A., Gauraha, D., Pachauri, A., Sahu, J. K., Chandra K. and Bhagat, V. 2024. Heterotic Analysis (*Oryza sativa* L.) in Drought Tolerant Rice Accessions. *J. Adv. Biol. Biotechnol.*, 27(3): 34-46.
- Gupta, P., Sao, A., Gauraha, D., Pachauri, A., Sahu, J. K., Chandra K. and Bhagat, V. 2024. Heterotic Analysis (*Oryza sativa* L.) in Drought Tolerant Rice Accessions. *J. Adv. Biol. Biotechnol.*, 27(3): 34-46.
- Kamara, M.M., Ghazy, N. A., Mansour, E., Elsharkawy, M.M., Kheir, A. M. S., Ibrahim, K. M. 2021 (a). Molecular Genetic Diversity and Line \times Tester Analysis for Resistance to Late Wilt Disease and Grain Yield in Maize. *Agron. J.*, 11: 898.
- Kamara, M.M., Ibrahim, K.M., Mansour, E., Kheir, A., Germoush, M.O., El-Moneim, A., Motawei, M.I., Alhusays, A.Y., Farid, M.A. and Rehan, M. 2021 (b). Combining ability and gene action controlling grain yield and its related traits in bread wheat under heat stress and normal conditions. *Agron. J.*, 11:1450.
- Kemphorne, O. 1957. An introduction of genetic statistics. John Willey and Sons Inc. New York, USA, 468-473.

- Lakra, P., Gauraha, D., Sharma, D., & Sao, A. 2020. Estimation of Combining Ability for Yield and its Contributing Traits in Rice (*Oryza sativa* L.). *Int. J. Curr. Microbiol. App. Sci*, 9(2): 2537-2543.
- Menaka, J and Ibrahim, S.M. 2016. Combining ability for yield and different quality traits in rice (*Oryza sativa* L.). *J. Appl. Nat. Sci.*, 8(4): 2298-2304.
- Naik, S.R., Singh, S.K., Singh, D.K., Khaire, A.R., Korada, M., Habde, S and Majhi, P.K. 2021. Estimation of heterosis for yield related traits and grain Zinc in rice (*Oryza sativa* L.). *Electron. J. Plant Breed.*, 12(4): 1227-1235.
- Rahman, M.M., Sarker, U., Swapan, M.A.H., Raihan, M.S., Oba, S., Alamri, S. and Siddiqui, M.H. 2022. Combining ability analysis and marker-based prediction of heterosis in yield reveal prominent heterotic combinations from diallel population of rice. *Agronomy*, 12(8): 1797.
- Ray, P., Patel, A., Chaudhari, K. N., Kapadia, C. V., Faldu, G. O., Patel, S. and Patel, H. 2024. Heterosis and inbreeding depression studies for seed cotton yield and its components in upland cotton (*Gossypium hirsutum* L.). *Plant Archives*, 24(2).
- Sandhu, S., Singh, R. and Rajput, J. 2023. Selection of parental lines based on specific combining ability effects in wheat breeding programs. *J. Agron. Crop Sci.*, 209(6): 799-808.
- Sao, A., Singh, U. and Verma, S. K. 2025. Unlocking Hybrid Potential: A Detailed Analysis of Heterosis, GCA and SCA For Enhancing Agronomic Performance and Yield in Rice (*Oryza sativa* L.). *Plant Arch.*, 25(1): 971-978.
- Saran, D., Gauraha, D., Ragi, S., Sao, A., & GJ, A. 2025. Studies on Genetic parameters for yield and yield attributing traits in rice (*Oryza sativa* L.). *Plant Archives*, 25(1): 1651-1657.
- Shehab, M.M., El-Naem, S.A., Daher, E.H.M and Hamad, H.S. 2023. Estimation of combining ability and heterosis for grain yield, yield components and some grain quality traits in rice under water deficit conditions. *Egypt. J. Agric. Res.*, 101(2): 438-460.
- Shinjo, C. and Omura, T. 1966 Cytoplasmic-genetic male sterility in cultivated rice, *Oryza sativa* L. I. Fertilities of F₁, F₂ and offsprings obtained from their mutual reciprocal backcrosses; and segregation of completely male sterile plants. *Jpn. J. Breed.*, 16(1): 179-180.