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Studies on Combining Ability and Heterosis for Yield, Yield Contributing Traits in Rice (*Oryza sativa* L.) Hybrids

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ABSTRACT

The study was conducted during *kharif* (July-November, 2023) and *rabi* (December-March) 2023–24 at regional agricultural research station in polasa, Jagtial, Telangana, India to investigate general combining ability, specific combining ability and standard heterosis in rice. Twenty hybrids were developed during *kharif* season by crossing four CMS lines with five restorers using a line×tester mating design and later, during *rabi* (December-March) 2023–24, parents, hybrids and checks were evaluated using a RBD with three replications. Among the lines, JMS 24B exhibited promising performance as a general combiner for yield and related traits. Among the testers, the testers IR-23352-7R, KNM-7660 and IR 10198-66-2R displayed significant positive gca effects for yield and related traits were considered as best general combiners. Among the crosses, JMS 13A×IET-23993, CMS 59A×KNM 7660 and JMS 24A×RP-4516-3-6 were exhibited as best specific combining ability for yield and related traits. Of 20 hybrids, JMS 24A×IR-10198-66-2R had highest significant standard heterosis for yield over the JGL-24423 and KPH-473 checks. The highest significant standard heterosis for plant height was observed RMS 1A×RP 4516-3-6, JMS 13A×RP 4516-3-6 and JMS 24A×RP 4516-3-6, compared to the JGL 24423 and KPH-473 checks. RMS 1A×KNM 7660, RMS 1A×IR 10198-66-2R, and CMS 59A×KNM 7660 exhibited the highest significant standard heterosis for number of productive tillers plant^{-1}. These hybrids showing strong heterotic expression in F_1 generations can contribute to the identification of superior segregants in future generations.

KEYWORDS: Rice, yield contributing traits, combining ability, hybrids, heterosis

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1. INTRODUCTION

The gap between increase in population and consumption highlights the urgent need for improved breeding tools, improved crop varieties, and effective policies to boost rice production sustainably (Zhu et al., 2016). The most consistent features are the weight of the grains, number of panicles and number of grains panicle^{-1} (Anh et al., 2015; Osei et al., 2023). In addition, the grain yield is a complicated trait that depends on a wide range of component traits and reacts poorly to direct selection (Thorat et al., 2019; Taratima et al., 2023). Heterosis is the phenomenon of two genetically distinct parents producing an F_1 hybrid that surpasses the parental lines in multiple phenotypic characteristics (Birchler, 2015). Breeding strategies based on the selection of hybrids require an expected level of heterosis as well as the specific combining ability (Satheesh Kumar et al., 2016).

Identification of parents with good traits and studying its inheritance of the targeted traits to the progeny in different cross combination is vital to characterize the nature and magnitude of gene effects in the expression of different traits (Zewdu et al., 2020). Combining ability (CA) is ultimately helpful for the genetic understanding of the architecture of traits, which allows the breeder to plan an active program of breeding for genetic improvement of the current germplasm resources (Azad et al., 2022). CA evaluates the potential of parents to pass on genetic information to their progenies thereby facilitating the development of superior hybrids. A line×tester mating design proposed by Kempthorne in 1957 provides insights into heterosis, General Combining Ability (*GCA*) of parents and Specific Combining Ability (*SCA*) of hybrids along with the nature of gene action controlling the expression of traits (Nivedha, 2024). It is the most powerful tool for the estimation of the *GCA*, *SCA* and the exploitation of the heterosis (Bhatti et al., 2015; Fasahat et al., 2016). CA helps to define the pattern of gene effects in the expression of quantitative traits by identifying potentially superior parents and hybrids (Zhang et al., 2015). CA studies help to pinpoint optimal combiners that can be incorporated into crosses to exploit heterosis, accumulate fixable genes and acquire desirable segregants. This, in turn, enables breeders to effectively outline the breeding plan for the future enhancement of existing materials (Abd-El-Aty et al., 2023).

The line×tester analysis is used to investigate *GCA* and *SCA* effects. The *GCA* signifies additive gene effects, whereas *SCA* indicates the deviation of hybrid performance from the used parents, and it is related to non-additive gene effects (Bradshaw, 2017; Parimala et al., 2018; Salem et al., 2020). It determines gene action that is responsible for the expression of the studied traits (Mutimaamba et al., 2020) and necessary to assess the genetic potential of parents in hybrid combination through systematic studies in relation to general and specific combining abilities, which could be attributed to additive and non-additive components of gene action, respectively (Veeresha et al., 2015). Therefore, the knowledge of CA provides information on the nature and magnitude of gene effects that regulate grain yield and yield characters hence enabling the breeder to design an effective breeding method for genetic enhancement of grain yield and yield components (Yuga et al., 2018). Evaluating the nature and extent of heterosis for various characteristics is essential for identifying promising hybrid combinations, which can be utilized to create breeding materials for isolating transgressive segregants aimed at producing high-yielding pure line varieties/hybrids (Maneesha et al., 2025). The current study was to estimate general combining ability and specific combining ability for yield and yield contributing traits through line×tester analysis and to estimate the standard heterosis for yield and yield contributing traits.

2. MATERIALS AND METHODS

2.1. Experimental materials

The experiment was conducted during *kharif*, 2023 and *rabi*, 2023–24 at regional agricultural research station in polasa, Jagtial (18°49’40” N and 78°56’45” E), Telangana. The experimental material comprised of four CMS lines with superior agronomic characters and five restorer testers. The CMS lines were JMS 24A, JMS 13A, CMS 59A, RMS 1A, restorer lines were IET 23993, IR 23352-7R, IR-10198-66-2R, RP-4516-3-6 and KNM-7660 and checks were KPH-473 and JGL 24423.

The four CMS lines were crossed with five restorers using line×tester mating design (Kempthorne, 1957) during *kharif*, 2023 at Regional Agricultural Research Station in Polasa, Jagtial (18°49’40” N and 78°56’45” E). The obtained 20 F_1 hybrids and their parents were assessed in a randomized block design (RBD) with three replications during *rabi*, 2023–24 along with their parents and two checks (JGL 24423 and KPH-473). Each entry had three rows of three meters length, with spacing 15×15 cm^2. To ensure successful crop growth and weed free conditions, standard agronomic procedures were regularly implemented. Five plants, excluding those on the borders, were randomly selected, appropriately labelled for data collection and their mean values were statistically analyzed.

Observations were recorded on five randomly selected competitive plants for each entry in each replication. Data was collected for seven traits including days to 50% flowering, plant height (cm), number of productive tillers plant^{-1}, panicle length (cm), number of grains panicle^{-1}, 1000 grain weight (g) and grain yield plant^{-1} (g).

3. RESULTS AND DISCUSSION

Analysis of variance for combining ability, detailed in table 1, showed significant differences due to treatments and crosses for all traits evaluated. Significant differences were found due to parentage for all traits. However, differences due to interaction between parentage and crosses were significant for certain traits except for number of productive tillers plant^{-1}, number of grains panicle^{-1} and 1000-grain weight. Differences due to tester and line were significant for every trait. The interaction effect between line and tester was significant for all traits.

Table 1: Analysis of variance for combining ability (Line×Tester) for yield and yield contributing traits in rice

Source of variation	d.f.	Days to 50% flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000 grain weight (g)	Grain yield plant^{-1} (g)
Replicates	2	5.20	0.66	0.24	3.19	42.34	4.17**	11.26
Treatments	28	114.11**	509.95**	1.76**	5.98**	3389.12**	32.04**	79.11**
Parents	8	83.98**	671.15**	3.00**	4.68**	3772.33**	77.87**	56.63**
Parents (Line)	3	85.11**	64.27**	3.63**	7.62**	1422.52**	57.27**	17.93*
Parents (Testers)	4	87.76**	1158.19**	2.06*	3.44*	567.43**	4.53**	75.80**
Parents (L vs T)	1	65.75**	543.60**	4.81**	0.86	23641.35**	433.03**	96.09**
Parents vs. Crosses	1	1204.44**	173.21**	1.80	4.81*	5.97	0.31	87.74**
Crosses	19	69.41**	459.81**	1.24*	6.59**	3405.82**	14.41**	88.12**
Line effect	3	206.28*	120.21	0.84	16.62*	2343.31	18.18	88.76
Tester effect	4	60.52	1531.64**	1.56	6.80	4460.30	12.80	83.24
Line×tester Eff.	12	38.15**	187.43**	1.23*	4.02**	3319.96**	14.00**	89.59**
Error	56	2.5	8.51	0.57	1.03	78.45	0.43	4.82
Total	86	38.91	171.59	0.95	2.70	1155.50	10.81	29.16

*Significant at (p=0.05) level; **Significant at (p=0.01) level

Comparable outcomes have been identified by Hasan et al. (2014) for parent vs crosses and testers, Abo Yousef et al. (2020), El-mowafi et al. (2021) for parents vs crosses and line×tester interaction, Nagamani et al. (2022) for parents, crosses, testers, line×tester interaction, Saikiran et al. (2023) for crosses and line×tester interaction, Santhiya et al. (2024) and Reddy et al. (2024) for crosses.

The line×tester interaction contributed significantly to trait variations, with the following percentages (Table 2) : days to 50% flowering (34.71%), plant height (25.74%), number of productive tillers plant^{-1} (62.71%), panicle length (38.48%), number of grains panicle^{-1} (61.56%), 1000-grain weight (61.37%) and grain yield plant^{-1} (64.21%). Testers had a notable impact on the number of grains panicle^{-1} (27.57%) and the number of productive tillers plant^{-1} (26.55%). The high line×tester interaction contribution for all the traits, ranged from 25.74% (plant height) to 64.21% (grain yield plant^{-1}), underscores the importance of specific line and tester combinations in determining hybrid performance.

3.1. General combining ability and specific combining ability

Negative *GCA* were mandatory for days flowering and plant height and positive *GCA* were required for other

Table 2: Proportional contribution of lines, testers and their interactions

Sl. No.	Character	Contribution		
		Line (%)	Tester (%)	Lines×tester (%)
1.	Days to 50% flowering	46.92	18.35	34.71
2.	Plant height (cm)	4.12	70.12	25.74
3.	Number of productive tillers plant^{-1}	10.73	26.55	62.71
4.	Panicle length (cm)	39.79	21.71	38.48
5.	Number of grains panicle^{-1}	10.86	27.57	61.56
6.	1000-grain weight (g)	19.92	18.69	61.37
7.	Grain yield plant^{-1} (g)	15.90	19.88	64.21

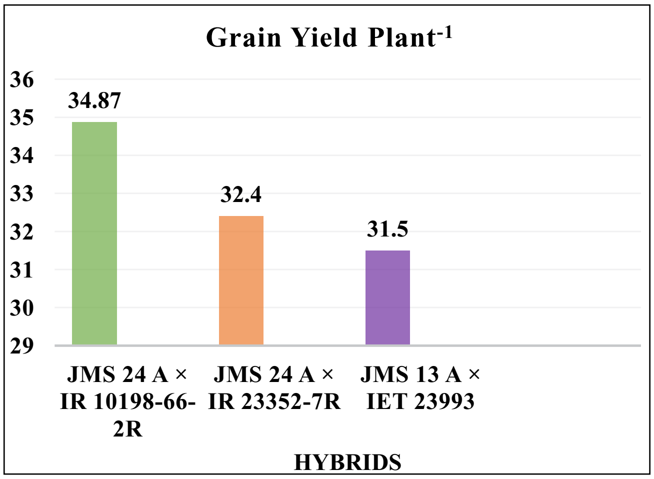

Figure 1: Top three hybrids identified based on mean performance of grain yield plant^{-1} (g)

traits included in the study. Among the lines, the line JMS 24B displayed positive significant effect of *gca* for number of grains panicle^{-1} and grain yield plant^{-1} and JMS 24B expressed negative significant *gca* effect for days to 50% flowering and plant height indicated as good general combining parent. Among the 5 testers, the testers IR 23352-7R displayed significant positive gca effects for 1000 grain weight and grain yield plant^{-1}, KNM 7660 displayed significant positive gca effects for number of productive tillers plant^{-1}, 1000 grain weight and IR 10198-66-2R recorded significant positive gca effects for grain yield plant^{-1} and number of grains panicle^{-1} were considered as best general combiners (Table 3).

Negative SCA effects were preferred for days to 50% flowering and plant height and positive *SCA* effects were preferable for other characters included in the study. Among the 20 hybrids, the cross CMS 59A×IET 23993 displayed high significant negative sca effect for days to 50% flowering and plant height followed by JMS 24A×IET 23993 and RMS 1A×IR 10198-66-2R.While JMS 13A×IET 23993 displayed high positively significant effect of sca for number of grains panicle^{-1} and grain yield plant^{-1}, CMS 59A×KNM 7660 displayed high significant positive sca effect for days to 50% flowering, grain yield plant^{-1}, 1000 grain weight, number of grains panicle^{-1} and RMS 1A×IR 23352-7R and JMS 24A×RP 4516-3-6 displayed high significant positive effect of sca for panicle length, number of grains panicle^{-1}, grain yield plant^{-1} were considered as best specific combiners. These hybrids could be used as good specific combining hybrids for days to 50% flowering, plant height longer panicle, number of grains panicle^{-1} and grain yield plant^{-1} (Table 4).

Table 3: Estimates of general combining ability (*GCA*) effects for lines and testers for yield and yield contributing traits in rice

Source	Days to 50% flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000 grain weight (g)	Grain yield plant^{-1} (g)
Parents							
Lines							
JMS 24B	-4.61**	-3.67**	-0.20	-0.32	14.30**	-1.12**	2.68**
JMS 13B	-1.01*	1.21	-0.13	-0.32	-15.10**	1.45**	-2.07**
CMS 59B	4.05**	3.00**	0.00	1.53**	-3.83	0.154	-2.04**
RMS 1B	1.58**	-0.57	0.33	-0.88**	4.63*	-0.49**	1.44**
Testers							
IET 23993	2.70**	17.57**	-0.55*	1.192**	1.51	0.19	1.84**
IR 23352-7R	0.20	1.43	0.12	0.292	0.26	0.84**	2.41**
IR-10198-66-2R	1.61**	-1.26	0.03	-0.52*	27.93**	-1.77**	1.37*
RP-4516-3-6	-2.13**	-13.37**	-0.05	-0.60*	-26.32**	0.16	-3.48**
KNM-7660	-2.38**	-4.37**	0.45*	-0.36	-3.40	0.58**	-2.14**
CD 95% GCA (Line)	0.82	1.52	0.39	0.42	4.62	0.34	0.97
CD 95% GCA (Tester)	0.92	1.70	0.44	0.47	5.17	0.39	1.08

*Significant at (p=0.05) level; **Significant at (p=0.01) level

These findings were in congruence with earlier reports of Yadav et al. (2021), Nagamani et al. (2022), Kushal et al. (2023) and Nivedha et al. (2024) found the top general combiner for earliness. Sreelakshmi et al. (2018), Abo Yousef et al. (2020), Nanditha et al. (2021), Nagamani et al. (2022), Kushal et al. (2023), Ibrahim et al. (2024) expressed

Table 4: Estimates of specific combining ability (*SCA*) effects for yield and yield contributing traits in rice

Sl. No.	Crosses	Days to 50% flowering	Plant height (cm)	Number of productive tillers plant^{-1}	Panicle length (cm)	Number of grains panicle^{-1}	1000 grain weight (g)	Grain yield plant^{-1} (g)
1.	JMS 24A×IET 23993	-3.96**	-5.65**	0.61	-1.19*	-37.71**	-0.83*	-7.48**
2.	JMS 24A×IR 23352-7R	0.53	-8.45**	0.28	-0.62	1.53	1.19**	3.54**
3.	JMS 24A×IR 10198-66-2R	-0.21	3.44*	0.36	-0.07	14.53**	0.21	7.05**
4.	JMS 24A×RP 4516-3-6	3.53**	5.63**	-0.55	1.80**	16.78**	-0.14	2.33*
5.	JMS 24A×KNM 7660	0.11	5.03**	-0.71	0.09	4.86	-0.43	-5.44**
6.	JMS 13A×IET 23993	5.10**	10.16**	0.88	1.46**	37.35**	-1.45**	7.97**
7.	JMS 13A×IR 23352-7R	-1.06	-3.6^{3}*	-0.11	-0.76	-27.40**	-0.67	-4.16**
8.	JMS 13A×IR 10198-66-2R	-2.81**	0.13	-0.70	-0.28	5.93	2.23**	-2.66*
9.	JMS 13A×RP 4516-3-6	-2.73**	-3.85*	0.05	-0.37	3.18	-0.50	-2.74*
10.	JMS 13A×KNM 7660	1.51	-2.82	-0.11	-0.04	-19.06**	0.39	1.58
11.	CMS 59A×IET 23993	-3.96**	-11.66**	-0.91*	-0.91	-24.25**	0.87*	-3.92**
12.	CMS 59A×IR 23352-7R	1.20	1.98	0.08	-0.34	-21.33**	0.30	-2.86*
13.	CMS 59A×IR 10198-66-2R	6.11**	3.94*	-0.16	1.13*	34.33**	-4.92**	-1.76
14.	CMS 59A×RP 4516-3-6	-1.13	4.52*	0.58	-0.18	-10.41*	2.12**	3.86**
15.	CMS 59A×KNM 7660	-2.21*	1.22	0.41	0.30	21.66***	1.61**	4.68**
16.	RMS 1A×IET 23993	2.83**	7.15**	-0.58	0.63	24.62**	1.41**	3.43**
17.	RMS 1A×IR 23352-7R	-0.66	1.09**	-0.25	1.73**	47.20**	-0.82*	3.49**
18.	RMS 1A×IR 10198-66-2R	-3.08**	-7.51**	0.50	-0.78	-54.80**	2.47**	-2.64*
19.	RMS 1A×RP 4516-3-6	0.33	-6.29**	-0.08	-1.24*	-9.55	-1.48**	-3.45**
20.	RMS 1A×KNM 7660	0.58	-3.43*	0.42	-0.35	-7.47	-1.58**	-0.83
21.	CD95% SCA	1.85	3.41	0.89	0.95	10.35	0.77	2.17

positively significant *gca* effects for 1000 grain weight(g), categorizing them as good general combiners and among the hybrids had positively significant and negatively significant *SCA* effects. Patel et al. (2015), Ambikabathy et al. (2019), Azad et al. (2022) and Nivedha et al. (2024) were evaluated hybrids and displayed significant negative *SCA* effects, indicates their potential for producing shorter, more stable plants that were less prone to lodging. Anandalekshmi et al. (2020) reported that amongst hybrids evaluated, none expressed positive and significant and ten hybrids showed positive non-significant for number of productive tillers plant^{-1}. This suggests that despite their lack of statistical significance, these hybrid combinations showed a tendency toward a greater number of productive tillers, which might be the cause of interaction of parental traits. Nanditha et al. (2021), Azad et al. (2022) and Nivedha et al. (2024) reported major role of additive gene action and non-additive gene action in rice for panicle length, presenting them as strong candidates for breeding programs aimed at enhancing this trait. Hasan et al. (2015), Vadivel et al. (2018), Ghidan et al. (2019) and Nivedha et al. (2024) were recorded the positive significant sca effects and nine hybrids have shown negative significant sca effects for grain yield plant^{-1}.

In this study, the ratio of *GCA* to *SCA* effects was below unity for all the traits, except for plant height. This ratio suggests

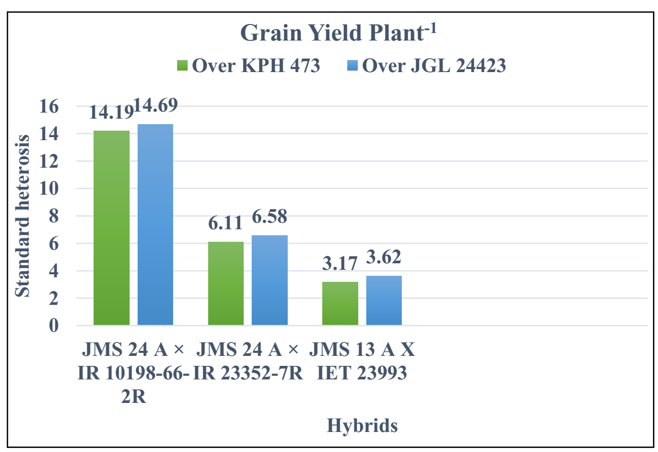

Figure 2: Top three hybrids identified based on standard heterosis percentage overchecks (KPH 473 and JGL 24423) for grain yield (g)

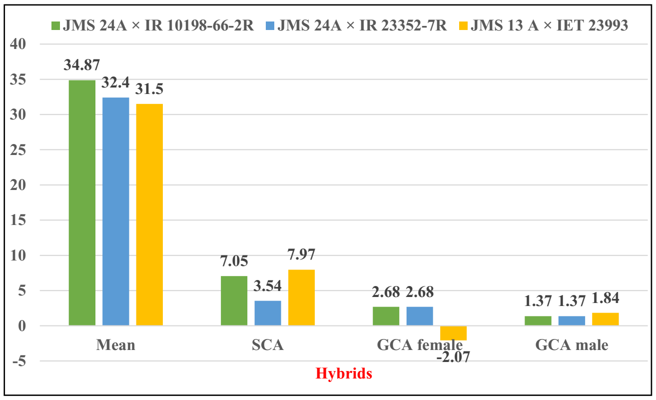

Figure 3: Top three hybrids identified based on high per se performance with *sca* effects and *gca* effects for grain yield plant^{-1} (g)

that these qualities were greatly influenced by specific gene combinations rather than by individual gene effects. This finding underscores the significance of non-additive gene action in the genetic control of these traits, emphasizing the need to focus on specific parental combinations when breeding for these characteristics (Table 5). These results were in congruence with previous findings of Vadivel et al. (2018), Sundaram et al. (2019), Nagamani et al. (2022) and Kushal et al. (2023) also indicating predominance of non-additive gene action in respect of days to 50% flowering, Hasan et al. (2014), Ramakrishna et al. (2022) shown high sca due to high×low or low×low combining parents, which further substantiate the operation of non-additive gene action for plant height, Madhuri et al. (2017), Gramaje et al. (2020) and Sharma et al. (2020) also shown additive gene action for panicle length, previous findings of Madhuri et al. (2017) and Singh et al. (2020) for number of productive tillers plant^{-1}, Vadivel et al. (2018) and Nagamani et al. (2022) for number of grains panicle^{-1}, Sundaram et al. (2019), Manivelan et al. (2022), Nagamani et al. (2022) and Nivedha et al. (2024) for grain yield plant^{-1}, Nanditha et al. 2021, Mohan et al. (2021) and Nagamani et al. (2022) for 1000-grain weight also indicating predominance of non-additive gene action.

Table 5: Estimates of general and specific combining ability variances and proportionate gene action in rice for the traits under study

Sl. No.	Character	Source of variation			Nature of gene action
		σ^2 *gca*	σ^2 *sca*	Variance ratio σ^2 *gca*/σ^2 *sca*	
1.	Days to 50% flowering	9.69	11.88	0.81	Non-additive
2.	Plant height (cm)	60.54	59.63	1.01	Additive
3.	Number of productive tillers plant^{-1}	0.04	0.21	0.19	Non-additive
4.	Panicle length (cm)	0.79	0.99	0.79	Non-additive
5.	Number of grains panicle^{-1}	246.17	1080.50	0.22	Non-additive
6.	1000-grain weight (g)	1.11	4.52	0.24	Non-additive
7.	Grain yield plant^{-1} (g)	6.01	28.25	0.21	Non-additive

3.2. Standard heterosis

Out of 20 hybrids studied, 15 hybrids exhibited significant negative standard heterosis for days to 50% flowering, 9 hybrids exhibited significant negative standard heterosis over KPH 473 and JGL 24423 for the trait plant height. Early maturity combined with short stature is considered as important traits to fit in multiple cropping systems and to withstand lodging. JMS 13A×IET 23993 showed positive non-significant standard heterosis over KPH 473 and 2 hybrids showed positive significant standard heterosis over JGL 24423for panicle length. For number of productive tillers plant^{-1}, 20 hybrids and 16 hybrids were shown positive significant standard heterosis over KPH 473 and JGL 24423 respectively. All 20 hybrids displayed significant negative standard heterosis over KPH 473 and JGL 24423 for the trait 1000 grain weight (g). One hybrid JMS 24A×IR 10198-66-2R displayed positive significant standard heterosis over KPH 473 and JGL 24423 and 3 hybrids JMS 24A×IR 23352-7R, JMS 13A×IET 23993 and RMS 1A×IR 23352-7R displayed positive non-significant standard heterosis over KPH 473 and JGL 24423 for grain yield plant^{-1} (Table 6). In which JGL 24423 is confirmed as the best check for grain yield plant^{-1}.

These results were accordance with Bhati et al. (2015) reported significant negative standard heterosis over the check for 1000 grain weight and significant positive standard heterosis over the check for grain yield plant^{-1}, Parimala et al. (2018) reported significant negative standard heterosis was observed in three hybrids for days to 50% flowering while only one hybrid IR-80555AxRNR-2456 (-11.26%) manifested significant negative standard heterosis over the check for the trait plant height. Twenty-one hybrids showed significant positive standard heterosis over the check ranged from 17.77% to 90.22% for grain yield plant^{-1}. Azad et al. (2022) displayed significant heterosis over BU dhan1 for

Table 6: Estimates of heterosis over standard check for yield and yield contributing traits in rice

Sl. No.	Crosses	Days to 50% flowering		Plant height (cm)		Number of productive tillers $plant^{-1}$	
		Checks		Checks		Checks	
		KPH 473	JGL 24423	KPH 473	JGL 24423	KPH 473	JGL 24423
1.	JMS 24A×IET 23993	-19.51**	-8.65**	-2.50	12.25**	38.10**	20.83*
2.	JMS 24A×IR 23352-7R	-17.68**	-6.57**	-22.25**	-10.49**	42.86**	25.00**
3.	JMS 24A×IR 10198-66-2R	-17.07**	-5.88**	-12.66**	0.56	42.86**	25.00**
4.	JMS 24A×RP 4516-3-6	-17.07**	-5.88**	-23.02**	-11.37**	28.57**	12.50
5.	JMS 24A×KNM 7660	-20.43**	-9.69**	-14.26**	-1.28	33.33**	16.67*
6.	JMS 13A×IET 23993	-7.93**	4.50**	19.05**	37.07**	42.86**	25.00**
7.	JMS 13A×IR 23352-7R	-15.85**	-4.50**	-12.17**	1.12	38.10**	20.83*
8.	JMS 13A×IR 10198-66-2R	-16.16**	-4.84**	-11.06**	2.40	28.57**	12.50
9.	JMS 13A×RP 4516-3-6	-19.51**	-8.65**	-27.85**	-16.93**	38.10**	20.83*
10.	JMS 13A×KNM 7660	-15.85**	-4.50**	-17.39**	-4.88	42.86**	25.00**
11.	CMS 59A×IET 23993	-11.59**	0.35	-1.84	13.01**	19.05*	4.17
12.	CMS 59A×IR 23352-7R	-9.15**	3.11**	-4.45	10.01**	42.86**	25.00**
13.	CMS 59A×IR 10198-66-2R	-3.35**	9.69**	-5.22*	9.13**	38.10**	20.83*
14.	CMS 59A×RP 4516-3-6	-13.41**	-1.73	-17.25**	-4.72	47.62**	29.17**
15.	CMS 59A×KNM 7660	-14.63**	-3.11**	-11.30**	2.12	52.38**	33.33**
16.	RMS 1A×IET 23993	-7.62**	4.84**	14.05**	31.31**	28.57**	12.50
17.	RMS 1A×IR 23352-7R	-13.11**	-1.38	0.28	15.45**	42.86**	25.00**
18.	RMS 1A×IR 10198-66-2R	-14.02**	-2.42**	-20.90**	-8.93**	52.38**	33.33**
19.	RMS 1A×RP 4516-3-6	-14.33**	-2.77**	-32.27**	-22.02**	42.86**	25.00**
20.	RMS 1A×KNM 7660	-14.33**	-2.77**	-19.89**	-7.77**	57.14**	37.50**

*Significant at (p=0.05) level; **Significant at (p=0.01) level

Table 6: Continue...

Sl. No.	Crosses	Panicle length (cm)		Number of grains $panicle^{-1}$	
		Checks		Checks	
		KPH 473	JGL 24423	KPH 473	JGL 24423
1.	JMS 24A×IET 23993	-9.85**	-4.03	-37.32**	-25.43**
2.	JMS 24A×IR 23352-7R	-11.11**	-5.38	-19.14**	-3.80
3.	JMS 24A×IR 10198-66-2R	-12.12**	-6.45*	0.32	19.35**
4.	JMS 24A×RP 4516-3-6	-5.30**	0.81	-24.56**	-10.25*
5.	JMS 24A×KNM 7660	-10.86**	-5.11	-19.30**	-3.98
6.	JMS 13A×IET 23993	0.25	6.72*	-15.47**	0.57
7.	JMS 13A×IR 23352-7R	-11.62**	-5.91*	-47.05**	-37.00**
8.	JMS 13A×IR 10198-66-2R	-12.88**	-7.26**	-17.86**	-2.28
9.	JMS 13A×RP 4516-3-6	-13.51**	-7.93**	-45.14**	-34.72**
10.	JMS 13A×KNM 7660	-11.36**	-5.65*	-44.82**	-34.35**
11.	CMS 59A×IET 23993	-1.77	4.57	-39.55**	-28.08**
12.	CMS 59A×IR 23352-7R	-3.03	3.23	-38.76**	-27.13**

Table 6: Continue...

Table 6: Continue...

Sl. No.	Crosses	Panicle length (cm)		Number of grains panicle^{-1}	
		Checks		Checks	
		KPH 473	JGL 24423	KPH 473	JGL 24423
13.	CMS 59A×IR 10198-66-2R	-0.51	5.91**	1.12	20.30**
14.	CMS 59A×RP 4516-3-6	-5.81**	0.27	-46.25**	-36.05**
15.	CMS 59A×KNM 7660	-3.03	3.23	-19.94**	-4.74
16.	RMS 1A×IET 23993	-5.05	1.08	-12.12**	4.55
17.	RMS 1A×IR 23352-7R	-4.29	1.88	-1.91	16.70**
18.	RMS 1A×IR 10198-66-2R	-16.92**	-11.56**	-37.48**	-25.62**
19.	RMS 1A×RP 4516-3-6	-18.94**	-13.71**	-41.79**	-30.74**
20.	RMS 1A×KNM 7660	-14.65**	-9.14**	-29.82**	-16.51**

*Significant at (*p*=0.05) level; **Significant at (*p*=0.01) level

Table 6: Continue...

Sl. No.	Crosses	1000 grain weight (g)		Grain yield plant^{-1} (g)	
		Checks		Checks	
		KPH 473	JGL 24423	KPH 473	JGL 24423
1.	JMS 24A×IET 23993	-24.83**	-25.84**	-31.88**	-31.58**
2.	JMS 24A×IR 23352-7R	-14.40**	-15.55**	6.11	6.58
3.	JMS 24A×IR 10198-66-2R	-28.42**	-29.39**	14.19**	14.69**
4.	JMS 24A×RP 4516-3-6	-22.24**	-23.29**	-17.14**	-16.78**
5.	JMS 24A×KNM 7660	-21.76**	-22.82**	-38.21**	-37.94**
6.	JMS 13A×IET 23993	-17.22**	-18.33**	3.17	3.62
7.	JMS 13A×IR 23352-7R	-11.65**	-12.84**	-34.72**	-34.43**
8.	JMS 13A×IR 10198-66-2R	-10.51**	-11.71**	-33.19**	-32.89**
9.	JMS 13A×RP 4516-3-6	-13.62**	-14.78**	-49.34**	-49.12**
10.	JMS 13A×KNM 7660	-8.49**	-9.72**	-30.79**	-30.48**
11.	CMS 59A×IET 23993	-13.23**	-14.40**	-35.70**	-35.42**
12.	CMS 59A×IR 23352-7R	-12.91**	-14.08**	-30.35**	-30.04**
13.	CMS 59A×IR 10198-66-2R	-43.46**	-44.22**	-30.13**	-29.82**
14.	CMS 59A×RP 4516-3-6	-8.44**	-9.67**	-27.62**	-27.30**
15.	CMS 59A×KNM 7660	-8.82**	-10.04**	-20.52**	-20.18**
16.	RMS 1A×IET 23993	-13.62**	-14.78**	-0.22	0.22
17.	RMS 1A×IR 23352-7R	-19.79**	-20.87**	1.86	2.30
18.	RMS 1A×IR 10198-66-2R	-17.18**	-18.29**	-21.62**	-21.27**
19.	RMS 1A×RP 4516-3-6	-25.02**	-26.03**	-40.17**	-39.91**
20.	RMS 1A×KNM 7660	-23.78**	-24.80**	-27.18**	-26.86**

*Significant at (*p*=0.05) level; **Significant at (*p*=0.01) level

panicle length and observed high heterotic hybrids for days to 50% flowering, grain yield plant^{-1} which was corroborative to the present findings. Manivelan et al. (2022) reported significant negative standard heterosis over the check for the trait plant height and reported significant negative standard heterosis over the check for panicle length. Nagamani et al. (2022) reported significant negative standard heterosis over KRH-4 for days to 50% flowering, significant positive

Table 7: Top ranking crosses based on high mean, *gca* effects, *sca* effects and standard heterosis for yield and its components in hybrid rice

Crosses and Trait	Mean	*SCA*	*GCA* female	*GCA* male	*GCA* status	Heterosis	
						KPH 473	JGL 24423
Days to 50% flowering							
JMS 24A×KNM 7660	87.00	0.11	-4.61**	-2.38**	H×H	-20.43**	-9.69**
JMS 24A×IET 23993	88.00	-3.96**	-4.61**	2.70**	H×L	-19.51**	-8.65**
JMS 13A×RP 4516-3-6	88.00	-2.73**	-1.01*	-2.13**	H×H	-19.51**	-8.65**
Plant height (cm)							
RMS 1A×RP 4516-3-6	64.93	-6.29**	-0.57	-13.37**	M×H	-32.27**	-22.02**
JMS 13A×RP 4516-3-6	69.17	-3.85*	1.21	-13.37**	L×H	-27.85**	-16.93**
JMS 24A×RP-4516-3-6	73.80	-3.67**	5.63**	-13.37**	L×H	-23.02**	-11.37**
Number of productive tillers plant^{-1}							
RMS 1A×KNM 7660	11.00	0.42	0.33	0.45*	M×H	57.14**	37.50**
RMS 1A×IR 10198-66-2R	11.00	0.50	0.33	0.03	M×M	52.38**	33.33**
CMS 59A×KNM 7660	10.00	0.41	0.00	0.45*	M×H	52.38**	33.33**
Panicle length (cm)							
JMS 13A×IET 23993	26.47	1.46**	-0.32	1.192**	L×H	0.25	6.72*
CMS 59A×IR 10198-66-2R	26.27	1.13*	1.53**	-0.52*	H×L	-0.51	5.91*
CMS 59A×IET 23993	25.93	-0.91	1.53**	1.192**	H×H	-1.77	4.57
Number of grains panicle^{-1}							
CMS 59A×IR 10198-66-2R	212.00	34.33**	-3.83	27.93**	L×H	1.12	20.30**
JMS 24A×IR 10198-66-2R	210.00	14.53**	14.30**	27.93**	H×H	0.32	19.35**
RMS 1A×IR 23352-7R	205.00	47.20**	4.63*	0.26	H×M	-1.91	16.70**
1000 grain weight (g)							
CMS 59A×RP 4516-3-6	23.50	2.12**	0.154	0.16	M×M	-8.44**	-9.67**
JMS 13A×KNM 7660	23.49	0.39	1.45**	0.58**	H×H	-8.49**	-9.72**
CMS 59A×KNM 7660	23.41	1.61**	0.154	0.58**	M×H	-8.82**	-10.04**
Grain yield plant^{-1} (g)							
JMS 24A×IR 10198-66-2R	34.87	7.05**	2.68**	1.37*	H×H	14.19**	14.69**
JMS 24A×IR 23352-7R	32.40	3.54**	2.68**	2.41**	H×H	6.11	6.58
JMS 13A×IET 23993	31.50	7.97**	-2.07**	1.84**	L×H	3.17	3.62

*Significant at (p=0.05) level; **Significant at (p=0.01) level

standard heterosis over the KRH-4 for number of productive tillers plant^{-1} and panicle length.

4. CONCLUSION

Based on overall performance, JMS 24B stood out among the lines, while KNM 7660 and IR 10198-66-2R excelled among the testers. Considering overall performance, hybrids JMS24A×IR 10198-66-2R, JMS 24A×IR 23352-7R and JMS 13A×IET 23993 (Depicted in the figures 1,2,3.) were identified as the best-performing hybrids in the investigation.

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