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Research Note

Heterosis studies for grain yield and yield attributes in rice (*Oryza sativa.* L) hybrids

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Abstract
In the current study, 20 elite rice genotypes were crossed with four CMS lines- CMS 23A, CMS 59A, CMS 64A and JMS 13A in a line x tester mating design and assessed alongside standard controls (JKRH 3333 and MTU 1001) to determine the best heterotic combinations in terms of grain yield and yield component characters at the Rice Research Centre, Rajendranagar. Eight restorer lines were found in *Kharif* 2018–19 based on pollen and spikelet fertility (MTU 1153, RNR 26015, RNR 28355, JGL 25960, MTU 1010, IET 27253, RNR 26085 and JAYA). The resulting 32 hybrids of 8 restorer lines and their corresponding CMS lines are studied for combing ability and heterosis. The degree of heterosis varied between traits. Three of the 32 hybrids under study had considerable standard heterosis for grain yield *viz.,* JMS 13A x MTU 1153, CMS 59A x RNR 26015 and CMS 64A x MTU 1153, which outperformed the best checks JKRH 3333 and MTU 1001. The best experimental hybrid, JMS 13A x MTU 1153, yielded the most grain yield per plant, 62.89g **(Table 1).** Further testing of these three experimental hybrids will take place in areas conducive to extensive commercialization.

Keywords: Rice, Heterosis, Heterobeltiosis, Standard heterosis, Grain yield, Line x Tester

Rice (*Oryza sativa* L.) is world's most significant staple food crop, feeds more than 70% of the world's population and is the least expensive source of energy and protein. According to Indiastat, the country with the most rice acreage is India, which has 44 million ha (24 percent of cropped area) and an annual production of 122.27 MT in 2020-21. Hybrid rice is a tried-and-true technology for increasing rice yield levels, as demonstrated in China and other South and Southeast Asian countries. In farmer fields in China and other nations, hybrid rice varieties surpassed semi-dwarf inbred high-yielding varieties by 1-1.5 t/ha (Virmani and Kumar, 2004).

The availability of diverse parental lines and genetic knowledge of a trait are critical factors in the development of heterotic hybrids. By carefully choosing maintainer and restorer lines based on genetic variation, hybrids with greater yield potential than their parents and traditional check types may be produced (Hasan *et al.,* 2012). Before starting any crop improvement programme or utilising the proper selection strategies, it is essential to understand the nature and scope of genetic variation that governs the inheritance of quantitative traits like yield and its components. According to FAORAP and APSA, the nation's hybrid rice plantings covered over 3.5 million hectares in 2020–21. According to the draft proceedings of the Indian Institute of Rice Research (IIRR)-2020, 123 hybrids have been released for commercial cultivation as a consequence of more than two decades of cooperative work, with all hybrids released in the nation based on the three-line breeding strategy. In the current study, 32 hybrids were produced utilising the CMS (Cytoplasmic Male Sterile) lines method and their yield and yield-contributing traits were examined in order to find possible cross combinations.

During the *kharif* season of 2018, 44 genotypes (4 'B' lines of corresponding male sterile lines, 8 restorer lines, 32 hybrids, two hybrids checks (JGL H1 and JKRH 3333) and two varietal checks (RNR 15048 and MTU 1001) were assessed at the Rice Research Centre in Rajendranagar, Hyderabad, using a randomised block design with two replications.

To cultivate and sustain a healthy crop, all recommended practices were followed. Plant height, panicle length, panicle weight, number of productive tillers per plant, pollen fertility percent, spikelet fertility percent, number of grains per panicle, grain yield per plant, 1000 grain weight, grain length, grain breadth and length-breadth ratio were all observed. The obtained data was subjected to analysis of variance and heterosis and standard heterosis over high yielding varietal and hybrid checks were computed and represented as follows:

Heterosis over mid parent: Heterosis was expressed as per cent increase or decrease observed in the F_1 over the mid-parent as per the following

$$\text{Heterosis} = \frac{\text{Mean of } F_1 - \text{Mean of mid parent}}{\text{Mean of mid parent}} \times 100$$

Heterosis over better parent: Heterobeltiosis was expressed as per cent increase or decrease observed in F_1 over the better parent as per the formula.

$$\text{Heterobeltiosis} = \frac{\text{Mean of } F_1 - \text{Mean of better parent}}{\text{Mean of better parent}} \times 100$$

Heterosis over standard checks: Standard heterosis was expressed as per cent increase or decrease observed in F_1 over standard checks.

$$\text{Standard heterosis} = \frac{\text{Mean of } F_1 - \text{Mean of check}}{\text{Mean of check}} \times 100$$

There was a substantial difference between all treatments, according to the analysis of variance **(Table 2).** It indicates that the genotypes are sufficiently diverse. As a result, additional heterotic investigations were conducted **(Table 3-10).**

For days to 50% flowering, standard heterosis over varietal check MTU 1001, ranged from -22.42 (CMS 23A x JAYA) to 0 (CMS 59A x IET 27253) and when compared to the hybrid check JKRH 3333, the standard heterosis ranged from -19.16 (CMS 23A x JAYA) to 4.21 (CMS 59A x IET 27253). Out of 32 hybrids, 29 hybrids exhibited substantial negative standard heterosis over the varietal check, MTU 1001 and 19 had significant negative standard heterosis over the hybrid check (JKRH 3333). In terms of significant negative standard heterosis for this trait, the combinations CMS 23A x JAYA (-22.42) and CMS 23A x MTU 1010 (-20.28) performed better over varietal check. Hybrids with significant negative standard heterosis indicate early flowering. Srijan *et al.* (2016), Parimala *et al.* (2018) and Essam *et al.* (2022) previously detected significant negative heterosis for this trait.

When compared to the hybrid check (JKRH 3333), the standard heterosis ranged from -24.83 (CMS 23A x JAYA) to 1.64 (CMS 59A x MTU 1010) for plant height and from -14.76 (CMS 23A x JAYA) to 15.26 (CMS 59A x MTU 1010) for varietal check (MTU 1001). Four hybrids out of 32 showed significant negative standard heterosis over the varietal check (MTU 1001). Twenty-eight hybrids had significantly lower standard heterosis than the hybrid control (JKRH 3333). The hybrid CMS 23A x JAYA recorded highest significant standard heterosis (-24.83) over the hybrid check JKRH 3333 followed by CMS 23A x JGL 25960 (-21.51) and CMS 23A x RNR 28355 (-17.80). The short plant type is an important hybrid trait for lodging resistance. Several rice researchers, including Kumari Priyanka *et al.* (2014) and Parimala *et al.* (2018) expressed significant negative heterosis over mid parent and better parent.

When compared to varietal check MTU 1001, the standard heterosis for number of productive tillers per plant ranged from -25.08 (CMS 23A x RNR 26085) to 48.53 (CMS 59A x RNR 26015). The standard heterosis over hybrid check JKRH 3333 ranged from -27.44 (CMS 23A x RNR 26085) to 43.85 (CMS 59A x RNR 26015). Three hybrids outperformed the hybrid check in terms of standard heterosis (JKRH 3333). The hybrid CMS 59A x RNR 26015 (48.53) had the highest standard heterosis when compared to the varietal check (MTU 1001) and the hybrid CMS 59A x RNR 26015 (43.85) had the highest standard heterosis when compared to the hybrid check (JKRH 3333). Rukmini Devi *et al.* (2014) and Sudeepthi *et al.* (2018) reported positive mid parental heterosis. The number of productive tillers per plant is known to have a direct impact on grain yield and can be utilised. The greater the number of productive tillers, the greater the yield and vice versa.

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Table 1. Mean performance of parents (8 lines and 4 testers), 4 checks and 32 hybrids for yield and yield contributing characters in rice

PARENTS	Days to 50% flowering	Plant height (cm)	Number of productive tillers per plant	Panicle length (cm)	Panicle weight (gm)	Number of grains per panicle	Pollen fertility (%)	Spikelet fertility (%)	1000 grain weight (g)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel length breadth ratio	Grain yield per plant (g)
TESTERS																
CMS 23 B	87	87.9	17	22.5	3.39	169	99.5	86.0	22.20	72.3	63.2	57.2	6.60	2.32	2.84	25.50
CMS 59 B	97	101.9	17	26.1	3.88	195	98.5	89.1	20.23	78.3	69.6	59.3	7.08	1.92	3.69	36.95
CMS 64 B	93	99.4	17	25.0	3.88	219	97.5	86.0	19.20	73.2	64.2	53.9	6.91	1.86	3.71	26.85
JMS 13 B	99	98.1	15	23.9	3.65	278	99.5	88.2	13.90	73.8	64.1	51.8	5.95	1.95	3.04	29.32
LINES																
MTU 1153	106	109.7	14	24.4	5.3	200	90.0	90.0	23.64	78.6	70.2	60.5	6.39	2.27	2.82	38.00
RNR 26015	97	118.7	16	26.1	3.65	171	85.0	87.4	21.47	68.4	54.6	46.6	7.93	1.76	4.49	33.03
RNR 28355	109	100.9	18	20.8	3.56	258	85.0	84.0	14.44	77.1	67.9	62.1	5.83	1.76	3.31	31.14
JGL 25960	95	103	13	21.6	4.80	194	91.0	87.1	23.53	75.3	67.4	60.0	6.46	2.33	2.77	28.02
MTU 1010	98	104.5	13	23.1	4.84	205	92.5	93.9	20.41	77.4	67.0	61.3	6.40	2.14	2.98	32.68
IET 27253	113	108	10	27.7	4.86	99	86.0	90.6	28.82	79.7	66.7	58.9	6.60	2.67	2.49	29.57
RNR 26085	109	105.6	8	28.4	4.23	196	82.5	70.1	21.58	75.8	62.0	56.65	6.69	2.21	3.02	37.25
JAYA	111	98.8	12	22.9	3.53	141	83.5	85.4	24.62	78.0	69.8	62.0	6.04	2.57	2.35	28.65
STANDARD CHECKS																
JGL H1	104	99.6	19	25.1	4.38	245	87.5	84.0	17.16	78.2	70.1	60.1	5.96	1.97	3.03	44.45
JKRH 3333	107	112.9	16	23.6	5.37	284.5	82.5	88.1	18.39	79.2	69.0	61.2	5.83	2.20	2.65	46.70
RNR 15048	106	109.7	17	25.9	4.01	334.5	87.5	87.4	12.66	80.0	70.3	66.1	5.54	1.77	3.13	39.95
MTU 1001	112	99.6	15	23.0	4.54	136.5	92.5	93.8	24.51	80.8	72.8	63.5	6.22	2.56	2.43	44.00

Table 1. Coninued..

HYBRIDS	Days to 50% flowering	Plant height (cm)	No of productive tillers per plant	Panicle length (cm)	Panicle weight (gm)	Number of grains per panicle	Pollen fertility (%)	Spikelet fertility (%)	1000 grain weight (g)	Hulling (%)	Milling (%)	Head rice recovery %	Kernel length (mm)	Kernel breadth (mm)	Kernel length breadth ratio	Grain yield per plant (g)
CMS 23A X MTU 1153	93	95.9	14	24.3	4.91	235	90.0	84.6	22.52	78.2	70.3	61.00	6.49	2.31	2.80	43.39
CMS 59A X MTU 1153	97	102.8	15	26.1	4.84	221	86.5	82.5	23.18	76.8	65.2	53.65	6.90	2.12	3.26	49.42
CMS 64A X MTU 1153	95	98.9	17	24.8	4.69	234	86.0	80.4	22.04	77.9	70.7	62.80	6.50	2.27	2.87	51.43
JMS 13A X MTU 1153	107	101.4	17	24.5	6.74	310	82.5	80.5	17.89	72.8	67.2	59.10	6.15	2.21	2.78	62.89
CMS 23A X RNR 26015	89	107.8	14	25.9	5.23	197	87.5	91.0	22.74	68.1	61.6	44.05	6.85	2.46	2.77	33.43
CMS 59A X RNR 26015	96	106	23	26.8	4.40	202	57.5	83.7	23.00	78.0	68.0	49.50	7.75	2.02	3.83	59.43
CMS 64A X RNR 26015	105	107.6	18	24.5	3.89	214	47.5	69.6	20.18	84.6	79.2	57.90	7.33	1.94	3.78	27.85
JMS 13A X RNR 26015	107	107	17	24.7	4.81	241	80.0	80.9	17.05	79.7	69.7	55.75	6.41	2.01	3.19	44.70
CMS 23A X RNR 28355	95	92.8	16	22.1	3.73	208	82.5	80.5	19.70	79.1	71.7	60.00	5.83	2.21	2.60	31.44
CMS 59A X RNR 28355	104	96	15	25.7	4.54	218	47.5	88.8	18.25	72.1	66.3	60.65	6.83	2.10	3.24	49.65
CMS 64A X RNR 28355	103	98.4	18	22.1	3.95	226	37.5	83.2	17.80	77.2	71.3	59.20	6.49	2.12	3.05	50.10
JMS 13A X RNR 28355	101	96.1	19	21.2	4.32	285	90.0	82.8	15.94	75.2	69.8	56.45	5.87	1.92	3.06	50.91
CMS 23A X JGL 25960	97	88.6	16	22.7	4.33	188	82.5	80.4	24.62	77.3	72.0	61.00	6.57	2.39	2.75	44.23
CMS 59A X JGL 25960	109	102.7	15	24.0	3.75	214	85.5	87.1	23.19	69.8	63.3	59.75	6.2	2.10	2.97	33.94
CMS 64A X JGL 25960	107	102.2	16	22.8	3.94	194	82.5	79.7	22.01	69.2	62.9	59.60	5.98	1.90	3.14	38.65
JMS 13A X JGL 25960	106	96.9	19	22.6	4.22	208	43.5	78.8	19.05	82.0	75.2	63.65	7.05	2.28	3.08	34.24
CMS 23A X MTU 1010	89	102.2	17	22.9	4.35	186	92.5	93.6	23.10	83.9	75.5	53.35	6.59	2.30	2.84	32.61
CMS 59A X MTU 1010	102	114.8	13	25.7	4.77	193	86.0	83.3	23.53	77.4	71.1	58.95	7.15	2.20	3.24	45.14
CMS 64A X MTU 1010	102	111.4	15	24.8	4.50	216	82.5	83.1	22.80	79.6	67.2	61.00	6.99	2.26	3.10	47.22
JMS 13A X MTU 1010	109	112.9	17	24.0	4.84	255	86.5	85.9	19.15	81.1	69.8	64.15	6.49	2.11	3.07	49.88

Table 1. Coninued..

HYBRIDS	Days to 50% flowering	Plant height (cm)	Number of productive tillers per plant	Panicle length (cm)	Panicle weight (gm)	Number of grains per panicle	Pollen fertility (%)	Spikelet fertility (%)	1000 grain weight (g)	Hulling (%)	Milling (%)	Head rice recovery %	Kernel length (mm)	Kernel breadth (mm)	Kernel length breadth ratio	Grain yield per plant (g)
CMS 23A X IET 27253	96	94	17	26.4	5.68	152	30.0	80.5	28.37	83.7	74.6	56.20	6.29	2.43	2.59	36.59
CMS 59A X IET 27253	112	98.7	18	25.3	5.22	178	47.5	93.0	26.85	75.5	69.7	63.30	6.73	2.26	2.98	46.26
CMS 64A X IET 27253	109	96.5	15	26.7	5.38	180	37.5	61.9	26.35	78.7	67.7	58.70	7.03	2.10	3.35	23.75
JMS 13A X IET 27253	106	105.7	13	26.9	6.68	238	47.5	73.8	21.92	78.8	68.9	57.40	6.64	2.28	2.91	41.67
CMS 23A X RNR 26085	97	99.8	12	27.3	6.14	211	82.5	74.9	25.10	79.1	67.1	60.80	6.87	2.31	2.97	45.59
CMS 59A X RNR 26085	102	105	13	27.1	6.61	240	82.5	80.7	23.70	78.0	67.5	52.25	7.12	2.10	3.39	38.97
CMS 64A X RNR 26085	101	101.6	15	28.4	6.87	213	42.5	73.0	24.43	77.1	67.7	56.30	7.01	2.16	3.24	52.43
JMS 13A X RNR 26085	104	110.2	12	26.3	6.95	282	82.5	80.0	20.55	79.2	68.9	49.05	6.65	2.17	3.06	44.43
CMS 23A X JAYA	87	84.9	14	22.1	3.5	140	92.5	84.3	25.77	84.9	74.9	61.60	6.06	2.44	2.48	24.90
CMS 59A X JAYA	105	99.9	15	22.6	4.78	209	42.5	80.7	24.50	77.7	70.1	57.20	6.74	2.12	3.18	34.98
CMS 64A X JAYA	105.	99	18	25.3	4.70	223	80.0	75.9	23.35	76.7	68.9	54.60	6.37	2.23	2.85	41.55
JMS 13A X JAYA	107	98.3	16	22.1	5.50	232	40.0	72.0	21.41	80.1	72.5	62.95	6.02	2.28	2.64	40.71
Mean	**101**	**101.9**	**15**	**24.5**	**4.72**	**213.7**	**76.3**	**83.0**	**21.60**	**77.4**	**68.6**	**58.1**	**6.55**	**2.17**	**3.04**	**39.67**
C.V.	1.50	2.01	7.56	3.79	7.42	8.86	6.01	4.31	3.77	1.97	3.07	3.96	2.73	3.82	4.04	7.630
S.E.	1.08	1.45	0.82	0.65	0.24	13.3	3.24	2.53	0.57	1.08	1.49	1.63	0.12	0.05	0.08	2.140
C.D. 5%	3.07	4.12	2.33	1.87	0.70	38.09	9.23	7.20	1.64	3.07	4.24	4.64	0.36	0.16	0.24	6.090
C.D. 1%	4.10	5.50	3.11	2.50	0.94	50.8	12.3	9.61	2.189	4.10	5.67	6.19	0.48	0.22	0.33	8.130
Range Lowest	87	84.9	8.15	20.8	3.39	98.5	30	61.9	12.66	68.1	54.6	44	5.54	1.76	2.35	23.75
Range Highest	113	118.7	22.8	28.4	6.95	334.5	99.5	93.9	28.82	84.9	79.2	66.1	7.93	2.67	4.49	62.89

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Table 2. Analysis of variance for different characters in rice

Source of variations	Degrees of freedom	Days to 50% flowering	Plant height (cm)	Number of productive tillers per plant	Panicle length (cm)	Panicle weight (g)	Number of grains per panicle	Pollen fertility (%)	Spikelet fertility (%)
Replicates	1	1.13	10.57	1.89	0.08	0.08	125.2	22	20.61
Treatments	43	92.44**	94.86**	13.66**	8.05**	1.88**	3167.2**	852.83**	91.95**
Parents	11	132.6	111.4	19.98	11.22	0.84	4531.4	85.73	67.6
Lines	7	101.1**	159.8**	6.55**	7.99**	0.90**	3077.8**	78.71**	7.45
Testers	3	83.45**	30.16**	11.30**	17.16**	0.78**	4922.4**	40.45	221.58**
L x T	1	500.5**	17.16	140.08**	15.98**	0.66**	13534.08**	270.7**	27.0
Crosses	31	81.16**	89.98	10.79**	7.14**	1.92**	2479.8**	895.6**	86.48**
Parents vs Crosses	1	0.12	63.28**	32.80**	1.24	12.12**	9469.1**	7963.1**	529.4**
Error	43	2.46	4.51	1.383	0.89	0.12	333.86	19.06	13.66
Total	87	46.91	49.24	7.45	4.42	0.99	1731.8	431.1	52.43

Table 2. Continued..

Source of variations	Degrees of freedom	1000 grain weight (g)	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel length breadth ratio	Grain yield per plant (g)
Replicates	1	0.95	1.205	61.05*	14.89	0.02	0.00	0.002	20.85
Treatments	43	21.95**	31.54**	37.14**	41.95**	0.45**	0.07**	0.31**	181.01**
Parents	11	33.99	21.11	38.42	43.65	0.64	0.18	0.71	35.46
Lines	7	28.93**	23.73**	50.27**	55.33**	0.90**	0.12**	0.72**	42.18**
Testers	3	28.22**	5.17	20.89**	11.8	0.17**	0.13**	0.23**	30.05**
L x T	1	86.69**	50.63**	8.08	57.42**	0.20**	0.75**	2.06**	4.69
Crosses	31	17.8**	33.7**	28.82**	42.63**	0.39**	0.04**	0.18**	172.2**
Parents vs Crosses	1	18.14**	79.47**	281.09**	1.96	0.03	0.03**	0.14**	2054.5**
Error	43	0.66	2.51	4.55	5.80	0.032	0.006	0.01	9.96
Total	87	11.19	16.84	21.31	23.77	0.23	0.04	0.16	94.63

When comparing panicle length to varietal check MTU 1001, the standard heterosis ranged from -8.03 (JMS 13A x RNR 28355) to 23.21 (CMS 64A x RNR 26085) and for hybrid check JKRH 3333, the standard heterosis ranged from -10.17 (JMS 13A x RNR 28355) to 20.34 (CMS 64A x RNR 26085). 14 hybrids out of 32 showed significant positive standard heterosis over varietal control (MTU 1001) and 12 hybrids showed significant positive standard heterosis over hybrid control JKRH 3333. The hybrids CMS 23A x RNR 26085 (23.21) and JMS 13A x RNR 26085(20.34) demonstrated substantial positive heterosis over mid parent and both checks. Bedi and Sharma, (2016) and Parimala *et al.* (2018) all observed standard heterosis of a similar nature. Hybrids are distinguished by longer panicles, which indicate their effectiveness at dividing assimilates into reproductive components. This is one of the crucial characteristics for hybrid plants to produce larger yields. When panicle weight was compared to varietal check MTU 1001, the standard heterosis ranged from -21.67 (CMS 23A x JAYA) to 52.92 (JMS 13A x RNR 26085) and in comparison to the hybrid control (JKRH 3333), the standard heterosis ranged from -33.77 (CMS 23A x JAYA) to 29.30 (JMS 13A x RNR 26085). Nine of the 32 hybrids demonstrated significant positive standard heterosis, while three hybrids demonstrated significant negative standard heterosis over varietal check MTU 1001. The hybrids *viz.,* JMS 13A x RNR 26085 (52.92) and CMS 59A x RNR 26085 (29.30) recorded the highest standard heterosis over varietal and hybrid checks.

Table 3. Heterosis, heterobeltiosis and standard heterosis of hybrids for days to 50% flowering and plant height (cm)

Cross	Days to 50% flowering				Plant height (cm)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	0.81	-5.10 **	-16.59**	-13.08**	-9.77	-12.62	-3.71	-15.10 **
CMS 59A X MTU 1153	-3.02 *	-14.22 **	-13.45**	-9.81**	-3.26	-6.31	3.21	-8.99 **
CMS 64A X MTU 1153	-2.56	-12.44 **	-14.80**	-11.21**	9.77	6.31	-0.65	-12.39 **
JMS 13A X MTU 1153	8.12 **	-3.62 *	-4.48**	-0.47	7.49	4.10	1.86	-10.18 **
CMS 23A X RNR 26015	-8.72 **	-9.18 **	-20.8**	-16.82**	-9.77	-12.62	8.23 **	-4.56 *
CMS 59A X RNR 26015	-8.83 **	-15.11 **	-14.35**	-10.75**	48.53**	43.85**	6.43 **	-6.15 **
CMS 64A X RNR 26015	1.70	-3.69 *	-6.28**	2.34	13.68	10.09	8.08 **	-4.69 *
JMS 13A X RNR 26015	2.65	-3.62 *	-4.48**	0.47	7.49	4.10	7.48 **	-5.22 **
CMS 23A X RNR 28355	-1.05	-3.57 *	-15.25**	-11.68**	5.86	2.52	-6.78 **	-17.80 **
CMS 59A X RNR 28355	0.73	-8.00 **	-7.17**	-3.27*	-3.58	-6.62	-3.56	-14.96 **
CMS 64A X RNR 28355	1.74	-5.53 **	-8.07**	-4.21**	14.01	10.41	-1.15	-12.84 **
JMS 13A X RNR 28355	-1.23	-9.05 **	-9.87**	-6.07**	23.78*	19.87*	-3.51	-14.92 **
CMS 23A X JGL 25960	-1.27	-1.52	-13.00**	-9.35**	3.26	0.00	-10.99 **	-21.51 **
CMS 59A X JGL 25960	2.84 *	-3.56 *	-2.69	1.40	-3.58	-6.62	3.16	-9.03 **
CMS 64A X JGL 25960	2.90 *	-1.84	-4.48**	-0.47	1.63	-1.58	2.61	-9.52 **
JMS 13A X JGL 25960	0.96	-4.52 **	-5.38**	-1.40	21.50*	17.67*	-2.71	-14.21 **
CMS 23A X MTU 1010	-12.75 **	-16.04 **	-20.18**	16.82**	7.49	4.10	2.66	-9.47 **
CMS 59A X MTU 1010	-6.64 **	-9.33 **	-8.52**	-4.67**	-15.31	-17.98	15.26 **	1.64
CMS 64A X MTU 1010	-5.36 **	-6.45 **	-8.97**	-5.14**	-5.54	-8.52	11.85 **	-1.37
JMS 13A X MTU 1010	0.23	-1.81	2.69	1.40	7.49	4.10	13.40 **	0.00
CMS 23A X IET 27253	-1.80	-2.55	-14.35**	-10.75**	7.49	4.10	-5.62 *	-16.78 **
CMS 59A X IET 27253	6.70 **	-0.89	0.00	4.21**	14.01	10.41	-0.85	-12.57 **
CMS 64A X IET 27253	5.85 **	0.00	-2.69	1.40	-4.89	-7.89	-3.11	-14.56 **
JMS 13A X IET 27253	1.93	-4.52 **	-5.38**	-1.40	-19.54	-22.08**	6.12 **	-6.42 **
CMS 23A X RNR 26085	-6.76 **	-11.47 **	-13.45**	-9.81**	-25.08**	-27.44**	0.25	-11.60 **
CMS 59A X RNR 26085	-8.35 **	-9.78 **	-8.97**	-5.14**	-16.29*	-18.93*	5.47 *	-6.99 **
CMS 64A X RNR 26085	-7.59 **	-7.80 **	9.87**	-6.07**	-5.54	-8.52	2.01	-10.05 **
JMS 13A X RNR 26085	-5.24 **	-5.88 **	-6.73**	-2.80	-22.80	-25.24	10.69 **	-2.39
CMS 23A X JAYA	-10.36 **	-11.73 **	-22.42**	-19.16**	-10.75	-13.56	-14.76 **	-24.83 **
CMS 59A X JAYA	0.72	-7.11 **	-6.28**	-2.34	-4.56	-7.57	0.30	-11.55 **
CMS 64A X JAYA	3.19 *	-3.23 *	-5.83**	-1.87	17.92*	14.20	-0.55	-12.31 **
JMS 13A X JAYA	3.65 **	-3.62 *	-4.48**	-0.47	0.98	-2.21	-1.31	-12.97 **

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 4. Heterosis, heterobeltiosis and standard heterosis of hybrids for number of productive tillers per plant and panicle length (cm)

Cross	Number of productive tillers per plant				Panicle length (cm)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	-9.33	20.40**	-9.77	-12.62	6.46	4.97	5.42	2.97
CMS 59A X MTU 1153	10.41	-14.66*	-3.26	-6.31	3.88	-5.95	13.23 **	10.59 *
CMS 64A X MTU 1153	31.90**	-3.16	9.77	6.31	-2.55	-12.68 **	7.59	5.08
JMS 13A X MTU 1153	10.55	-5.17	7.49	4.10	7.93 *	6.99	6.29	3.81
CMS 23A X RNR 26015	10.21	21.75**	-9.77	-12.62	5.18	-0.77	12.36 **	9.75 *
CMS 59A X RNR 26015	67.65**	28.81*8	48.53**	43.85**	-0.46	-3.42	16.27 **	13.56 **
CMS 64A X RNR 26015	35.01**	-1.41	13.68	10.09	-10.09 **	-13.73 **	6.29	3.81
JMS 13A X RNR 26015	9.45	-6.78	7.49	4.10	0.82	-5.36	7.16	4.66
CMS 23A X RNR 28355	9.61	-1.52	5.86	2.52	-8.20 *	-11.60 **	-4.12	-6.36
CMS 59A X RNR 28355	13.85	-10.30	-3.58	-6.62	-2.56	-7.39 *	11.50 **	8.90 *
CMS 64A X RNR 28355	41.99**	6.06	14.01	10.41	-17.23 **	-22.18 **	-4.12	-6.36
JMS 13A X RNR 28355	31.26**	15.15*	23.78*	19.87*	-11.48 **	-15.20 **	-8.03	-10.17 *
CMS 23A X JGL 25960	12.61	5.67	3.26	0.00	-3.51	-5.02	-1.52	-3.81
CMS 59A X JGL 25960	20.82*	-1.33	-3.58	-6.62	-7.07 *	-13.51 **	4.12	1.69
CMS 64A X JGL 25960	34.77**	4.00	1.63	-1.58	-12.62 **	-19.54 **	-0.87	-3.18
JMS 13A X JGL 25960	35.88**	24.33**	21.50*	17.67*	-3.42	-5.44	-1.95	-4.24
CMS 23A X MTU 1010	23.83**	22.22*	7.49	4.10	-3.57	-6.13	-0.43	-2.75
CMS 59A X MTU 1010	13.04	-3.70	-15.31	-17.98	-1.34	-7.21 *	11.71 **	9.11 *
CMS 64A X MTU 1010	33.95	7.41	-5.54	-8.52	-6.15	-12.68 **	7.59	5.08
JMS 13A X MTU 1010	27.17	22.22*	7.49	4.10	1.37	-1.84	4.12	1.69
CMS 23A X IET 27253	12.05	1.23	7.49	4.10	7.30 *	1.15	14.75 **	12.08 **
CMS 59A X IET 27253	35.66**	7.36	14.01	10.41	-6.12	-8.83 *	9.76 *	7.20
CMS 64A X IET 27253	19.43	-10.43	-4.89	-7.89	-1.92	-5.81	16.05 **	13.35 **
JMS 13A X IET 27253	-14.09	24.23**	-19.54	-22.08**	9.68 **	2.87	16.70 **	13.98 **
CMS 23A X RNR 26085	-25.69**	-35.39**	-25.08**	-27.44**	24.23 **	17.93 **	18.44 **	15.68 **
CMS 59A X RNR 26085	-5.86	-27.81**	-16.29*	-18.93*	11.64 **	-2.34	17.57 **	14.83 **
CMS 64A X RNR 26085	11.75	-18.54**	-5.54	-8.52	15.45 **	0.00	23.21 **	20.34 **
JMS 13A X RNR 26085	-21.6**5	-33.43**	-22.80	-25.24	20.59 **	15.07 **	14.32 **	11.65 **
CMS 23A X JAYA	3.59	3.01	-10.75	-13.56	-1.12	-4.32	-3.90	-6.14
CMS 59A X JAYA	28.51**	10.15	-4.56	-7.57	-8.30 *	-18.38 **	-1.74	-4.03
CMS 64A X JAYA	68.76**	36.09**	17.92*	14.20	1.30	-10.74 **	9.98 *	7.42
JMS 13A X JAYA	20.39*	16.54	0.98	-2.21	-0.56	-3.28	-3.90	-6.14

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 5. Heterosis, heterobeltiosis and standard heterosis of hybrids for panicle weight (g) and number of grains per panicle

Cross	Panicle weight (gm)				Number of grains per panicle			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	19.37 *	1.55	8.14	-8.56	25.74 **	14.67	71.79**	-17.57 *
CMS 59A X MTU 1153	17.38 *	-0.31	6.60	-9.86	65.54 **	31.16 **	61.90**	-22.32**
CMS 64A X MTU 1153	22.94 **	10.74	3.19	-12.74	28.57 **	19.69 *	71.43**	-17.75**
JMS 13A X MTU 1153	94.66 **	90.81 **	48.40 **	25.49 **	100.32**	83.98 **	127.11**	8.96
CMS 23A X RNR 26015	20.07 **	8.16	15.18	-2.60	-1.63	-3.91	43.96**	-30.93**
CMS 59A X RNR 26015	0.69	-9.47	-3.19	-18.14 *	37.31 **	3.33	47.62**	-29.17**
CMS 64A X RNR 26015	-4.00	-8.03	-14.30	-27.53 **	9.35	9.21	56.41**	-24.96**
JMS 13A X RNR 26015	29.74 **	23.97 *	5.83	-10.51	43.15 **	23.33 *	76.19**	-15.47 *
CMS 23A X RNR 28355	-14.45	-22.93 **	-17.93 *	-30.60 **	-1.89	-5.03	52.01**	-27.07**
CMS 59A X RNR 28355	4.00	-6.48	0.00	-15.44 *	37.85 **	0.00	60.07**	-23.20**
CMS 64A X RNR 28355	-2.53	-6.61	-12.98	-26.42 **	9.18	3.43	65.57**	-20.56**
JMS 13A X RNR 28355	16.66	11.47	-4.84	-19.53 **	58.55 **	30.43 **	108.79**	0.18
CMS 23A X JGL 25960	2.12	10.43	-4.62	-19.35 **	-21.99**	-32.25 **	37.73**	-33.92**
CMS 59A X JGL 25960	-11.87	-22.84 **	-17.49 *	-30.23 **	13.56	-23.06 **	56.41**	-24.96**
CMS 64A X JGL 25960	-0.06	-6.97	-13.31	-26.70 **	-17.97 *	-30.09 **	42.12**	-31.81**
JMS 13A X JGL 25960	17.47	15.62	-7.15	-21.49 **	-0.84	-25.23 **	52.01**	-27.07**
CMS 23A X MTU 1010	-14.20 *	-17.92 *	-4.29	-19.07 **	-8.03	-9.05	36.26 *	-34.62**
CMS 59A X MTU 1010	-6.00	-9.91	5.06	-11.16	28.98 *	-3.75	41.03**	-32.34**
CMS 64A X MTU 1010	-5.61	-15.09 *	-0.99	-16.28 *	9.23	8.00	58.24**	-24.08**
JMS 13A X MTU 1010	9.56	-8.68	6.49	-9.95	49.27 **	27.25 **	86.45**	-10.54
CMS 23A X IET 27253	33.92 **	17.46 *	25.08 **	5.77	-19.31 *	-25.92 **	10.99	-46.75**
CMS 59A X IET 27253	22.80 **	7.51	14.96	-2.79	31.73 *	3.80	30.04 *	-37.61**
CMS 64A X IET 27253	36.46 **	27.04 **	18.37 *	0.09	-1.77	-7.93	31.87 *	-36.73**
JMS 13A X IET 27253	86.08 **	83.15 **	47.08 **	24.37 **	52.56 **	39.18 **	74.36**	-16.34 *
CMS 23A X RNR 26085	46.31 **	26.96 **	35.20 **	14.33 *	-8.97	-18.41 *	54.21**	-26.01**
CMS 59A X RNR 26085	57.13 **	36.11 **	45.54 **	23.07 **	34.64 **	-6.98	75.82**	-15.64 *
CMS 64A X RNR 26085	76.27 **	62.22 **	51.16 **	27.81 **	-6.28	-17.64 *	55.68**	-25.31**
JMS 13A X RNR 26085	95.91 **	95.22 **	52.92 **	29.30 **	41.35 **	9.30	106.59**	-0.88
CMS 23A X JAYA	-26.14 **	-26.45 **	-21.67 **	-33.77 **	-29.65**	-31.54 **	2.56	-50.79**
CMS 59A X JAYA	-1.04	-1.65	5.17	-11.07	43.15 **	8.01	3.11 **	-26.54**
CMS 64A X JAYA	4.04	-2.08	3.41	-12.56	14.65	14.07	63.37**	-21.62**
JMS 13A X JAYA	32.09 **	14.69	21.12 *	2.42	38.42 **	19.64 *	69.60**	-18.63**

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

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Table 6. Heterosis, heterobeltiosis and standard heterosis of hybrids for pollen fertility (%) and spikelet fertility (%)

Cross	Pollen fertility (%)				Spikelet fertility (%)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	-6.25	-9.55 *	-2.70	9.09	-5.88	-9.83 *	-9.82 *	-3.92
CMS 59A X MTU 1153	-6.74	-13.07 **	-6.49	4.85	-6.57	-8.96 *	-12.10**	-6.34
CMS 64A X MTU 1153	-5.49	-13.57 **	-7.03	4.24	3.05	-6.46	-14.32**	-8.70 *
JMS 13A X MTU 1153	-9.84 *	-17.09 **	-10.81 *	0.00	-6.01	-6.33	-14.20**	-8.58 *
CMS 23A X RNR 26015	-8.38 *	-11.17 *	-5.41	6.06	-0.52	-3.02	-3.00	3.35
CMS 59A X RNR 26015	-37.67 **	-41.62 **	-37.84 **	-30.30**	-6.84	-7.59	-10.77 *	-4.93
CMS 64A X RNR 26015	-47.51 **	-51.78 **	-48.65 **	-42.42**	-12.58**	-21.92 **	-25.83**	-20.97**
JMS 13A X RNR 26015	-12.09 **	-18.78 **	-13.51 **	-3.03	-7.32	-9.28 *	-13.83**	-8.18
CMS 23A X RNR 28355	-13.16 **	-15.38 **	-10.81 *	0.00	-10.43**	-14.19 **	-14.17**	-8.55
CMS 59A X RNR 28355	-48.23 **	-51.28 **	-48.65 **	-42.42**	0.61	-1.95	-5.33	0.87
CMS 64A X RNR 28355	-58.33 **	-61.54 **	-59.46 **	-54.55**	6.59	-3.25	-11.35**	-5.54
JMS 13A X RNR 28355	-0.55	-7.69	-2.70	9.09	-3.36	-3.71	-11.77**	-5.99
CMS 23A X JGL 25960	-14.06 **	-17.09 **	-10.81 *	0.00	-11.66**	-14.32 **	-14.30**	-8.69 *
CMS 59A X JGL 25960	-7.82	-14.07 **	-7.57	3.64	-2.57	-3.87	-7.18	-1.10
CMS 64A X JGL 25960	-9.34 *	-17.09 **	-10.81 *	0.00	0.71	-9.62 *	-15.06**	-9.49 *
JMS 13A X JGL 25960	-52.46 **	-56.28 **	-52.97 **	-47.27**	-9.18 *	-10.64 *	-16.01**	-10.51 *
CMS 23A X MTU 1010	1.37	0.00	0.00	12.12 *	1.77	-0.30	-0.29	6.24
CMS 59A X MTU 1010	-1.70	-3.89	-6.49	4.85	-7.81 *	-8.11	-11.27**	-5.46
CMS 64A X MTU 1010	-4.35	-8.33	-10.81 *	0.00	3.84	-7.65	-11.40**	-5.60
JMS 13A X MTU 1010	-0.29	-3.89	-6.49	4.85	-2.09	-4.63	-8.51 *	-2.51
CMS 23A X IET 27253	-66.20 **	-67.57 **	-67.57 **	-63.64**	-11.19**	-14.24 **	-14.22**	-8.61 *
CMS 59A X IET 27253	-44.44 **	-44.77 **	-48.65 **	-42.42**	4.53	2.69	-0.85	5.65
CMS 64A X IET 27253	-55.22 **	-55.88 **	-59.46 **	-54.55**	-21.38**	-29.16 **	-34.02**	-29.69**
JMS 13A X IET 27253	-43.62 **	-44.12 **	-48.65 **	-42.42**	-14.53**	-15.53 **	-21.31**	-16.16**
CMS 23A X RNR 26085	-7.04	-10.81 *	-10.81 *	0.00	-15.76**	-20.18 **	-20.17**	-14.94**
CMS 59A X RNR 26085	-3.51	-4.07	-10.81 *	0.00	-7.57 *	-10.94 *	-14.01**	-8.38
CMS 64A X RNR 26085	-49.25 **	-50.00 **	-54.05 **	-48.48**	-5.30	-13.14 **	-22.25**	-17.15**
JMS 13A X RNR 26085	-2.08	-2.94	-10.81 *	0.00	-5.54	-6.29	-14.76**	-9.18 *
CMS 23A X JAYA	0.82	0.00	0.00	12.12 *	-6.88	-10.22 *	-10.20 *	-4.32
CMS 59A X JAYA	-51.98 **	-53.30 **	-54.05 **	-48.48**	-9.19 *	-10.94 *	-14.01**	-8.38
CMS 64A X JAYA	-7.78	-12.09 *	-13.51 **	-3.03	-3.44	-12.87 **	-19.11**	-13.82**
JMS 13A X JAYA	-54.15 **	-56.04 **	-56.76 **	-51.52**	-16.48**	-17.32 **	-23.24**	18.21

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 7. Heterosis, heterobeltiosis and standard heterosis of hybrids for 1000 grain weight (g) and hulling per cent

Cross	1000 grain weight (g)				Hulling per cent			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	5.70	1.44	-8.12 *	22.46 **	4.41 *	0.97	-3.28	-1.26
CMS 59A X MTU 1153	-9.14 **	-19.58 **	-5.43	26.05 **	1.02	-3.64	-5.01 *	-3.03
CMS 64A X MTU 1153	0.71	-0.70	-10.06 **	19.87 **	5.23 **	2.84	-3.59	-1.58
JMS 13A X MTU 1153	-23.59 **	-27.35 **	-27.01 **	-2.72	-3.16	-6.67 **	-9.96**	-8.08 **
CMS 23A X RNR 26015	11.93 **	11.44 **	-7.20 *	23.68 **	-12.52**	-13.02 **	-15.71**	-13.95**
CMS 59A X RNR 26015	-6.21 *	-20.19 **	-6.14	25.10 **	-1.23	-2.07	-3.46	-1.45
CMS 64A X RNR 26015	-3.47	-6.49	-17.67 **	9.73 *	9.83 **	8.04 **	4.70 *	6.88 **
JMS 13A X RNR 26015	-23.98 **	-30.76 **	-30.44 **	-7.29	2.01	1.79	-1.36	0.69
CMS 23A X RNR 28355	-0.50	-3.45	-19.60 **	7.15	4.98 *	2.13	-2.16	-0.13
CMS 59A X RNR 28355	-24.00 **	-36.69 **	-25.54 **	-0.76	-5.72 **	-9.54 **	-10.82**	-8.96 **
CMS 64A X RNR 28355	-12.68 **	-17.49 **	-27.36 **	-3.18	3.66	1.91	-4.45 *	-2.46
JMS 13A X RNR 28355	-27.23 **	-35.25 **	-34.94 **	-13.30**	-0.56	-3.59	-6.99**	-5.05 *
CMS 23A X JGL 25960	43.54 **	20.65 **	0.47	33.90 **	2.28	-0.13	-4.33 *	-2.34
CMS 59A X JGL 25960	8.55 *	-19.55 **	-5.39	26.10 **	-9.06 **	-12.42 **	-13.67**	-11.87**
CMS 64A X JGL 25960	24.10 **	2.02	-10.18 **	19.71 **	-7.49 **	-8.71 **	-14.41**	-12.63**
JMS 13A X JGL 25960	-1.08	-22.62 **	-22.26 **	3.62	8.10 **	5.19 *	1.48	3.60
CMS 23A X MTU 1010	4.87	-2.30	-5.75	25.61 **	7.53 **	6.74 **	3.77	5.93 **
CMS 59A X MTU 1010	-10.29 **	-18.35 **	-3.98	27.98 **	-2.21	-2.89	-4.27 *	-2.27
CMS 64A X MTU 1010	0.87	-3.53	-6.94 *	24.03 **	3.17	1.34	-1.48	0.57
JMS 13A X MTU 1010	-20.65 **	-22.23 **	-21.87 **	4.13	3.58	3.18	0.31	2.40
CMS 23A X IET 27253	35.49 **	32.13 **	15.77 **	54.30 **	14.78 **	8.07 **	3.53	5.68 **
CMS 59A X IET 27253	6.78 *	-6.83 *	9.57 **	46.03 **	1.96	-5.27 *	-6.62**	-4.67 *
CMS 64A X IET 27253	22.40 **	22.10 **	7.51 *	43.28 **	9.15 **	3.83	-2.66	-0.63
JMS 13A X IET 27253	-4.88	-10.96 **	-10.55 **	19.22 **	7.72 **	1.09	-2.47	-0.44
CMS 23A X RNR 26085	44.03 **	22.98 **	2.41	36.49 **	2.39	2.19	-2.10	-0.06
CMS 59A X RNR 26085	9.54 **	-17.78 **	-3.30	28.87 **	-0.48	-2.07	-3.46	-1.45
CMS 64A X RNR 26085	35.63 **	13.21 **	-0.33	32.84 **	0.82	-0.06	-4.64 *	-2.65
JMS 13A X RNR 26085	5.22	-16.53 **	-16.14 **	11.77 *	2.09	1.54	-2.04	0.00
CMS 23A X JAYA	17.32 **	9.54 **	5.16	40.16 **	11.13 **	9.62 **	5.01 *	7.20 **
CMS 59A X JAYA	-6.41 *	-15.00 **	-0.04	33.22 **	0.23	-2.51	-3.90	-1.89
CMS 64A X JAYA	3.52	-0.76	-4.73	26.97 **	1.55	1.25	-5.07 *	-3.09
JMS 13A X JAYA	-11.06 **	-13.04 **	-12.63 **	16.45 **	4.47 *	2.69	-0.93	1.14

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 8. Heterosis, heterobeltiosis and standard heterosis of hybrids for milling percent and head rice recovery (%)

Cross	Milling per cent				Head rice recovery (%)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	7.90 **	4.85	-3.43	1.81	3.04	-0.41	-3.86	-0.25
CMS 59A X MTU 1153	0.42	-2.17	-10.37 **	-5.50	-7.62 *	-8.99 *	-15.51**	-12.34 **
CMS 64A X MTU 1153	12.93 **	11.86 **	-2.82	2.46	10.32 **	9.79 *	-1.10	2.61
JMS 13A X MTU 1153	1.05	-3.72	-7.62 *	-2.61	-0.84	-4.68	-6.93	-3.43
CMS 23A X RNR 26015	-9.80 **	-11.49 **	-15.32 **	-10.72**	-26.95**	-28.14 **	-30.63**	-28.02**
CMS 59A X RNR 26015	-0.18	-2.30	-6.52 *	-1.45	-16.28**	-16.53 **	-22.05**	-19.12**
CMS 64A X RNR 26015	20.27 **	13.71 **	8.79 **	14.70 **	-0.13	-2.36	-8.82 *	-5.39
JMS 13A X RNR 26015	0.00	-0.14	-4.19	1.01	-8.08 *	-10.08 *	-12.20**	-8.91 *
CMS 23A X RNR 28355	9.26 **	6.94 *	-1.51	3.84	4.17	-2.12	-5.51	-1.96
CMS 59A X RNR 28355	1.30	-0.60	-8.93 **	-3.98	7.49	2.88	-4.49	-0.90
CMS 64A X RNR 28355	13.03 **	11.14 **	-1.99	3.33	7.10	4.50	-6.77	-3.27
JMS 13A X RNR 28355	4.14	-0.07	-4.12	1.09	-2.59	-8.95 *	-11.10**	-7.76
CMS 23A X JGL 25960	9.83 **	7.46 *	-1.03	4.34	7.82 *	-0.49	-3.94	-0.33
CMS 59A X JGL 25960	-3.25	-5.10	-13.05 **	-8.33 *	7.85 *	1.36	-5.91	-2.37
CMS 64A X JGL 25960	-0.24	-1.87	-13.53 **	-8.83 **	9.86 *	5.21	-6.14	-2.61
JMS 13A X JGL 25960	12.24 **	7.66 *	3.30	8.91 **	11.81 **	2.66	0.24	4.00
CMS 23A X MTU 1010	9.98 **	7.47 *	3.71	9.34 **	-12.40**	-12.97 **	-15.98**	-12.83**
CMS 59A X MTU 1010	3.83	1.21	-2.34	2.97	-1.30	-2.56	-7.17	-3.68
CMS 64A X MTU 1010	1.66	-4.27	-7.62 *	-2.61	4.14	0.83	-3.94	-0.33
JMS 13A X MTU 1010	-0.29	-0.57	-4.05	1.16	4.73	3.47	1.02	4.82
CMS 23A X IET 27253	22.65 **	11.26 **	2.47	8.04 *	4.12	-8.32 *	-11.50**	-8.17 *
CMS 59A X IET 27253	15.00 **	4.57	-4.19	1.01	19.98 **	7.46	-0.24	3.51
CMS 64A X IET 27253	16.16 **	9.19 *	-6.94 *	-1.88	13.65 **	3.62	-7.56	-4.08
JMS 13A X IET 27253	10.81 **	-1.29	-5.29	-0.14	5.66	-7.42	-9.61 *	-6.21
CMS 23A X RNR 26085	-0.52	-1.18	-7.76 *	-2.75	-1.46	-2.09	-4.25	-0.65
CMS 59A X RNR 26085	0.33	-0.59	-7.21 *	-2.17	-13.67**	-15.86 **	-17.72**	-14.62**
CMS 64A X RNR 26085	4.15	-0.37	-7.01 *	-1.96	-5.18	-9.34 *	-11.34**	-8.01
JMS 13A X RNR 26085	0.00	-1.36	-5.36	-0.22	-20.95**	-21.01 **	-22.76**	-19.85**
CMS 23A X JAYA	11.42 **	11.13 **	2.88	8.47 *	1.52	0.49	-2.99	0.65
CMS 59A X JAYA	4.55	4.01	-3.71	1.52	-3.87	-4.75	-9.92 *	-6.54
CMS 64A X JAYA	6.53 *	2.30	-5.29	-0.14	-6.43	-9.08 *	-14.02**	-10.78 *
JMS 13A X JAYA	5.65 *	3.79	-0.41	5.00	3.15	1.53	-0.87	2.86

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 9. Heterosis, heterobeltiosis and standard heterosis of hybrids for kernel length (mm) and kernel breadth (mm)

Cross	Kernel length (mm)				Kernel breadth (mm)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	-0.19	-1.67	4.26	11.32 **	3.58	-0.43	-9.57 **	5.23
CMS 59A X MTU 1153	4.15	3.76	10.84 **	18.35 **	-15.12 **	-20.60 **	-17.19 **	-3.64
CMS 64A X MTU 1153	-2.14	-2.84	4.50	11.58 **	0.00	-2.37	-11.33 **	3.18
JMS 13A X MTU 1153	-2.73	-6.82*	-1.20	5.49	-9.70 **	-14.01 **	-13.67 **	0.45
CMS 23A X RNR 26015	1.59	-3.25	10.04**	17.50 **	21.28 **	14.92 **	-3.71	12.05 **
CMS 59A X RNR 26015	12.89 **	9.46**	24.50**	32.93 **	-11.98 **	-24.34 **	-21.09 **	-8.18 *
CMS 64A X RNR 26015	6.42 **	3.53	17.75 **	25.73 **	-6.17	-12.42 **	-24.22 **	-11.82 **
JMS 13A X RNR 26015	-2.25	-9.39**	3.05	10.03 **	-10.24 **	-21.60 **	-21.29 **	-8.41 *
CMS 23A X RNR 28355	-12.39**	-15.62 **	-6.27*	0.09	10.47 **	3.26	-13.48 **	0.68
CMS 59A X RNR 28355	0.70	-1.23	9.72 **	17.15 **	-7.17 *	-21.16 **	-17.77 **	-4.32
CMS 64A X RNR 28355	-4.63	-6.15 *	4.26	11.32 **	4.17	-4.06	-16.99 **	-3.41
JMS 13A X RNR 28355	-9.34 **	-15.04 **	-5.62	0.77	-13.42 **	-25.29 **	-25.00 **	-12.73 **
CMS 23A X JGL 25960	6.43 *	2.65	5.62	12.78 **	16.59 **	11.42 **	-6.64 *	8.64 *
CMS 59A X JGL 25960	-1.03	-6.24 *	0.16	6.95 *	-9.19 **	-21.35 **	-17.97 **	-4.55
CMS 64A X JGL 25960	-5.34 *	-10.60 **	-3.86	2.66	-8.63 *	-14.00 **	-25.59 **	-13.41 **
JMS 13A X JGL 25960	17.55 **	16.63 **	13.25 **	20.93 **	0.99	-11.09 **	-10.74 **	3.86
CMS 23A X MTU 1010	2.97	2.89	5.86	13.04 **	5.10	2.20	-9.38 **	5.45
CMS 59A X MTU 1010	9.62 **	7.52 **	14.86 **	22.64 **	-10.73 **	-17.42 **	-13.87 **	0.23
CMS 64A X MTU 1010	6.88 **	4.48	12.37 **	19.98 **	0.78	-0.44	-11.72 **	2.73
JMS 13A X MTU 1010	4.34	1.49	4.26	11.32 **	-12.60 **	-17.70 **	-17.38 **	-3.86
CMS 23A X IET 27253	-12.20 **	-20.67 **	1.12	7.98 *	24.30 **	13.29 **	-5.08	10.45 **
CMS 59A X IET 27253	-7.64 **	-15.12 **	8.19 **	15.52 **	2.14	-15.17 **	-11.52 **	2.95
CMS 64A X IET 27253	-3.83	-11.34**	13.01 **	20.67 **	5.53	-5.19	-17.97 **	-4.55
JMS 13A X IET 27253	-4.94 *	-16.26**	6.75 *	13.98 **	5.42	-11.09 **	-10.74 **	3.86
CMS 23A X RNR 26085	12.30 **	7.26 *	10.36 **	17.84 **	18.16 **	7.69	-9.77 **	5.00
CMS 59A X RNR 26085	14.18 **	7.14 *	14.46 **	22.21 **	-5.30	-21.35 **	-17.97 **	-4.55
CMS 64A X RNR 26085	11.94 **	4.71	12.61 **	20.24 **	8.79 *	-2.26	-15.43 **	-1.59
JMS 13A X RNR 26085	12.00 **	10.01 **	6.83 *	14.07 **	0.35	-15.37 **	-15.04 **	-1.14
CMS 23A X JAYA	-5.83 *	-6.26 *	-2.65	3.95	8.93 **	4.50	-4.69	10.91 **
CMS 59A X JAYA	2.78	1.35	8.27 **	15.61 **	-15.28 **	-20.60 **	-17.19 **	-3.64
CMS 64A X JAYA	-3.12	-4.78	2.41	9.35 **	-1.76	-4.28	-12.70 **	1.59
JMS 13A X JAYA	-3.68	-6.81 *	-3.21	3.34	-6.83 *	-11.09 **	-10.74 **	3.86

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

Table 10. Heterosis, heterobeltiosis and standard for kernel length breadth ratio and grain yield per plant (g)

Cross	Kernel length breadth ratio				Grain yield per plant (g)			
	Heterosis		Standard heterosis		Heterosis		Standard heterosis	
	MP	BP	MTU 1001	JKRH 3333	MP	BP	MTU 1001	JKRH 3333
CMS 23A X MTU 1153	-3.69	-6.03	15.43**	5.85	49.17 **	32.79 **	-1.38	-7.08
CMS 59A X MTU 1153	22.33**	14.79 **	34.16**	23.02 **	79.46 **	67.10 **	12.32	5.82
CMS 64A X MTU 1153	-1.88	-4.80	18.31**	8.49	63.92 **	38.07 **	16.89 *	10.13
JMS 13A X MTU 1153	7.22	-1.94	14.61**	5.09	132.26 **	119.47 **	42.93 **	34.67 **
CMS 23A X RNR 26015	-16.85**	-24.80**	14.20**	4.72	-3.96	-9.51	-24.01**	-28.40**
CMS 59A X RNR 26015	24.11 **	3.93	57.82**	44.72 **	78.67 **	60.84 **	35.07 **	27.26 **
CMS 64A X RNR 26015	12.82 **	2.57	55.76**	42.83 **	-24.92 **	-25.22 **	-36.69**	-40.35**
JMS 13A X RNR 26015	5.54	-13.55*	31.28**	20.38 **	36.29 **	20.99 *	1.60	-4.27
CMS 23A X RNR 28355	-21.43**	-29.11**	8.23	-0.75	5.63	-3.79	-28.55**	-32.68**
CMS 59A X RNR 28355	4.68	-12.53**	33.54**	22.45 **	75.99 **	67.88 **	12.84	6.32
CMS 64A X RNR 28355	-9.21 **	-17.65**	25.72**	15.28 **	56.32 **	34.50 **	13.86	7.28
JMS 13A X RNR 28355	0.91	-17.52**	25.93**	15.47 **	83.44 **	77.67 **	15.70 *	9.01
CMS 23A X JGL 25960	-8.79 *	-9.69 *	13.17*	3.77	42.69 **	35.36**	0.53	-5.28
CMS 59A X JGL 25960	7.32	-2.46	22.22**	12.08 *	15.27	14.78	-22.85**	-27.31**
CMS 64A X JGL 25960	3.71	3.28	29.42**	18.68 **	16.13	3.77	-12.15	-17.23 *
JMS 13A X JGL 25960	14.26 **	1.31	26.95**	16.42 **	18.12	16.78	-22.18**	-26.68**
CMS 23A X MTU 1010	-2.15	-4.86	16.87**	7.17	-7.72	-14.18	-25.89**	-30.17**
CMS 59A X MTU 1010	22.03 **	14.89 **	33.33**	22.26 **	33.61 **	18.80 *	2.60	-3.33
CMS 64A X MTU 1010	6.16	2.65	27.57**	16.98 **	25.50 **	24.26 **	7.32	1.11
JMS 13A X MTU 1010	18.65 **	8.87	26.34**	15.85 **	49.68 **	31.28 **	13.38	6.82
CMS 23A X IET 27253	-30.61**	-42.27**	6.79	-2.08	11.37	10.78	-16.84 *	-21.65**
CMS 59A X IET 27253	-14.67**	-33.70**	22.63**	12.45 *	47.78 **	40.05**	5.14	-0.94
CMS 64A X IET 27253	- 10.84**	-25.47**	37.86**	26.42 **	-32.41 **	-36.24 **	-46.02 **	-49.14**
JMS 13A X IET 27253	-14.89**	-35.15**	19.96**	10.00 *	35.12 **	26.17 *	-5.28	-10.76
CMS 23A X RNR 26085	-5.48	-10.12 *	22.43**	12.26 *	42.86 **	39.50 **	3.61	-2.38
CMS 59A X RNR 26085	17.07 **	2.57	39.71**	28.11 **	28.38 **	25.14 *	-11.42	-16.54 *
CMS 64A X RNR 26085	2.37	-2.11	33.33**	22.26 **	53.33 **	40.77 **	19.17 *	12.28
JMS 13A X RNR 26085	8.03 *	-7.55	25.93**	15.47 **	48.60 **	42.66 **	0.98	-4.86
CMS 23A X JAYA	- 13.64**	-16.75**	2.26	-6.23	-17.96	-23.81 *	-43.41**	-46.68**
CMS 59A X JAYA	20.91 **	14.80**	30.86**	20.00 **	21.47 *	18.28	-20.50**	-25.10**
CMS 64A X JAYA	-1.55	-5.63	17.28**	7.55	27.32 **	11.54	-5.57	-11.03
JMS 13A X JAYA	3.22	-4.51	8.85	-0.19	43.68 **	42.09 **	-7.47	-12.82

*Significant at 5% level, **Significant at 1% level, MP=Mid parent, BP= Better parent

The standard heterosis over check variety (MTU 1001) for number of grains per panicle ranged from 2.56 (CMS 23A x JAYA) to 127.11 (JMS 13A x MTU 1153). Thirty hybrids out of 32 had a considerable and favourable heterosis. Similar results reported by Krishna *et al.* (2016), Manjunath *et al.* (2019) and Essam *et al.* (2022). The number of grains per panicle is positively related to grain yield and is known to contribute to grain yield by increasing the number of grains.

When pollen fertility percent was compared to varietal check MTU 1010, the standard heterosis ranged from –67.57 (CMS 23A x IET 27253) to 0.00 (CMS 23A x MTU 1010). Out of 32 hybrids, 22 had significant negative standard heterosis, whereas none had substantial positive standard heterosis. Standard heterosis ranged from -63.64 (CMS 64A x IET 27253) to 12.12 (CMS 23A x MTU 1010) over hybrid check JKRH 3333. Ramesh *et al.* (2017) and Bedi and Sharma, (2016) detected typical positive heterosis for this feature.

When compared to the varietal check MTU 1001 for spikelet fertility percent, the standard heterosis varied from – 34.02 (CMS 64A x IET 27253) to – 0.29 (CMS 23A x MTU 1010). Out of 32 hybrids, 27 had significant negative standard heterosis, while none had significant positive standard heterosis. Standard heterosis ranged from -29.69 (CMS 64A x IET 27253) to 6.24(CMS 23A x MTU 1010) over hybrid check JKRH 3333. Among the 32 hybrids, 14 had significant negative standard heterosis, while four had non-significant positive standard heterosis over the hybrid check (JKRH 3333). Another important factor that has a direct impact on the final product is the spikelet fertility percentage. Saravanan *et al*. (2018) and Manjunath *et al.* (2019) observed favourable heterosis However, Pratap *et al*. (2013) found significant negative standard heterosis for this trait.

The standard heterosis over varietal check MTU 1001 ranged from -34.94 (JMS 13A x RNR 28355) to 15.77(CMS 23A x IET 27253) for 1000 grain weight. Three hybrids demonstrated statistically significant positive standard heterosis. The standard heterosis ranged from -13.30 (JMS 13A x RNR 28355) to 54.30 (CMS 23A x IET 27253). Out of the 32 hybrids tested, 24 significantly outperformed the hybrid control (JKRH 3333) in terms of positive standard heterosis. The hybrid CMS 23A x IET 27253 showed highest positive and significant heterosis over better parent (32.13) and both the standard checks MTU 1001 and JKRH 3333 (15.77 and 54.30). Deoraj singh *et al.* (2007), Thorat and Kunkerkar, (2017), Vanave *et al.* (2018) and Mohammad, I. (2022) observed significant positive heterobeltiosis and standard heterosis for this trait.

For hulling percent, the traditional heterosis over hybrid check JKRH 3333 ranged from -13.95 (CMS 23A x RNR 26015) to 7.20. (CMS 23A x JAYA) and seven hybrids had substantial negative standard heterosis, whereas four hybrids displayed significant positive standard heterosis. Over the varietal check MTU 1001, the standard heterosis ranged from -15.71 (CMS 23A x RNR 26015) to 5.01 (CMS 23A x JAYA). Only two hybrids out of 32 exhibited much more positive standard heterosis than varietal check MTU 1010. Singh, R.K. (2005), Utharasu and Anandakumar, (2013), Krishna *et al.* (2016) and Manjunath *et al.* (2019) reported positive standard heterosis for this character.

For milling percent, the standard heterosis over the hybrid check JKRH 3333 ranged from -10.72 (CMS 23A x RNR 26015) to 14.70 (CMS 64A x RNR 26015). Five hybrids demonstrated significant positive standard heterosis over hybrid check JKRH 3333. The standard heterosis over varietal check, MTU 1001, ranged from -15.32 (CMS 23A x RNR 26015) to 8.79 (CMS 64A x RNR 26015). One hybrid showed significant positive standard heterosis among the 32 hybrids and twelve hybrids showed significant negative standard heterosis.

For head rice recovery percent, standard heterosis over varietal check MTU 1001 ranged from -30.63 (CMS 23A x RNR 26015) to 1.02 (JMS 13A x MTU 1010). The standard heterosis over the hybrid check JKRH 3333 ranged from -28.02 (CMS 23A x RNR 26015) to 4.82 (JMS 13A x MTU 1010). None of the 32 hybrids demonstrated significant positive standard heterosis over varietal and hybrid checks. When compared to varietal check MTU 1001, the standard heterosis for kernel length (mm) ranged from -6.27 (CMS 23A x RNR 28355) to 24.50 (CMS 59A x RNR 26015). Sixteen of the 32 hybrids had significant positive standard heterosis, while only one had substantial negative standard heterosis. The standard heterosis over hybrid check JKRH 3333 ranged from 0.09 (CMS 23A x RNR 28355) to 32.93 (CMS 59A x RNR 26015). Twenty six of the hybrids studied showed significant positive standard heterosis, while none showed significant negative heterosis. Because long grain type is preferred, positive significant standard heterosis is desired. Sandhya Kishore *et al.* (2009), Sanjeev Kumar *et al.* (2010) and Bedi and Sharma, (2016) revealed significant positive heterobeltiosis and heterosis for this character, respectively, whereas the same kind of standard heterosis was described by Dar *et al.* (2015) and Parimla *et al.* (2018).

When compared to varietal check MTU 1001, the standard heterosis for kernel breadth varied from -25.59 (CMS 64A x JGL 25960) to -3.71 (CMS 23A x RNR 26015). Twenty-nine hybrids out of 32 showed significant negative standard heterosis. For this character, both significant negative heterosis, heterobeltiosis and standard heterosis was observed by Sandhya kishore *et al.* (2009), Srijan *et al.* (2016) and Parimla *et al.* (2018) respectively. The most preferred grain type is slender grain. As a result, negative significant standard heterosis is preferable.

When compared to varietal check MTU 1001, the standard heterosis for kernel length-breadth ratio was between 2.26 (CMS 23A x JAYA) to 57.82 (CMS 59A x RNR 26015). Twenty eight of the 32 hybrids had significant positive standard heterosis. The standard heterosis over hybrid check JKRH 3333 ranged from -6.23 (CMS 23A x JAYA) to 44.72 (CMS 59A x RNR 26015). There was significant positive standard heterosis in 21 of the hybrids and no substantial negative standard heterosis in any of the hybrids. Positive considerable standard heterosis is desirable as it corresponds to the chosen long/medium slender grain type. Sanjeev Kumar *et al.* (2010) was proved significant positive heterobeltiosis and heterosis for this character respectively. Whereas, Sanghera and Hussain (2012), Dar *et al.* (2015) and Saravanan *et al.* (2018) reported identical standard heterosis.

When compared to varietal check MTU 1001, the standard heterosis for grain yield per plant (g) ranged from -46.02 (CMS 64A x IET 27253) to 42.93 (JMS 13A x MTU 1153). Five of the 32 hybrids had significant positive standard heterosis, while ten had significant negative standard heterosis. The standard heterosis over the hybrid check JKRH 3333 ranged from -49.14 (CMS 64A x IET 27253) to 34.67 (JMS 13A x MTU 1153). Two hybrids demonstrated statistically significant positive standard heterosis. JMS 13A x MTU 1153 and CMS 59 x RNR 26015 hybrids demonstrated significant positive heterosis over the better parent and both varietal (MTU 1001) and hybrid check (JKRH 3333). CMS 64A x MTU 1153 hybrid which showed significant positive heterosis, heterobeltiosis and standard heterosis over varietal check in terms of yield, component characteristics, as well as being early and dwarf with good head rice recovery. These findings clarify why it is advantageous for grain production to have high heterosis of different component traits. Sanjeev Kumar *et al.* (2010) observed both significant positive heterobeltiosis and heterosis for this character, as did Chamundeswari *et al.* (2012), Utharasu *et al.* (2013) and Parimala *et al.* (2018), whereas identical standard heterosis was reported by Dar *et al.* (2015), Ramesh *et al.* 2017, Gokulakrishnan *et al.* (2018), Manjunath *et al.* (2019) and Mohammad, I. (2022).

According to this study, the simultaneous expression of heterosis for yield component characteristics is the main source of heterosis for grain yield per plant. JMS 13A x MTU 1153, CMS 59A x RNR 26015 and CMS 64A x MTU 1153 were promising hybrids with favourable SCA impacts, heterosis and per se performance for grain yield, its constituents and grain quality attributes. It is advised that these three experimental hybrids undergo further testing in additional environments and through further seasons to assess their viability for wide spread commercialization.

One of the inventions responsible for the dramatic increase in rice productivity over the past century was hybrid rice. However, the development of traits in parental lines for an ideal plant type with significant yield, grain quality and resistance/tolerance to numerous biotic and abiotic stresses is required in order to meet the challenge of rising demand for rice and making hybrid more sustainable under impeding climatic changes. It is simple to improve the parents and hybrids for desirable traits with high precision when conventional plant breeding is combined with cutting-edge molecular techniques.

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