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Heterosis studies for yield and yield components in rice hybrids using CMS System

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Abstract
The present experiment was conducted to determine the extent of heterosis over better parent and standard check in order to identify promising hybrids with high mean performance and high magnitude of heterosis for yield and yield components. Three CMS lines viz., IR 58025A, IR 68897A and JMS 13A were selected and randomly crossed with eight Rajendra Nagar lines. 24 F_1 s along with parents and check DRRH-3 were evaluated in Randomized Block Design (RBD) with three replications. These hybrids showed considerable variation among them for all the sixteen parameters viz., days to 50% flowering, plant height, panicle length, panicle weight, productive tillers per plant, unproductive tillers per plant, flag leaf length, flag leaf width, number of filled grains per panicle, spikelet fertility, grain yield per plant, productivity per day, 1000 grain weight, grain length, grain breadth and length-breadth ratio. Heterobeltiosis and standard heterosis were studied in 24 crosses among 16 characters. Among 24 hybrids three hybrids viz., IR 58025A x RNR 21301(34.45), JMS 13A x RNR 21604 (21.40) and JMS 13A x RNR 21218 (20.93) showed positive standard heteosis in yield over DRRH-3 check.

Keywords: standard heterosis, Rajendra Nagar lines, CMS lines, agro-morphological characters and check DRRH-3

Introduction

Rice is the premier food crop in India occupying nearly 43.0 million hectares area with annual production of 106.54 million tonnes and productivity of 2424 kg ha^{-1} (Indiastat, 2014-2015) [13]. At present growth of population rice requirement increases dramatically; hence it is a challenging task to ensuring food and nutritional security to the country. Therefore, enhancing productivity of rice through novel genetic approaches like hybrid rice was felt necessary. Exploitation of heterosis is considered to be one of the outstanding achievements of plant breeding. The presence of heterosis is an important pre-requisite for successful production of hybrid varieties. Hybrid vigour in rice was first reported by Jones (1926) [14]. Among the all possible alternatives, hetrosis is an important approach for increasing rice production. Heterosis has been commercially exploited in rice with a yield advantage of 20-25% over the best pure lines (Rather *et al*. 2001) [19]. The discovery of CMS (Cytoplasmic Male Sterile) in rice (Athwal and Virmani, 1972; Erickson, 1969; Shinjyo, 1969) [5, 10] suggested that breeders could develop commercially viable F_1 hybrids. Significant heterosis, heterobeltiosis and standard heterosis have been reported by number of workers (Ali and khan 1995; Mishra and Pandey, 1998, Faiz *et al*. 2006, Bagheri and Jeoldar, 2010; Kumari Priyanka *et al*. 2014; Savita Bhatti *et al*. 2015) [2, 17, 11, 6, 15].

Identifying high yielding hybrids is expensive and involves testing large number of hybrid combinations, therefore present investigation was aimed to evaluate rice hybrids for yield for successful commercial cultivation.

Material and Methods

The present material comprised 3 CMS lines viz., IR 58025A, IR 68897A and JMS 13A were crossed with 8 Rajendra Nagar genotypes in line x tester design during Rabi 2014-15. The resultant 24 hybrids along with 3 CMS parents, 8 male parents and check DRRH-3 were evaluated in randomized block design with three replications at Rice Research Centre, Agriculture Research Institute, PJTSAU, Hyderabad during Kharif 2015-16. Each genotype was planted in two rows of two meters length with a spacing of 20 x 15 cm spacing. All the necessary recommended package of practices were followed to raise the good crop.

The data was recorded from average of 5 randomly selected plants from each replication for quantitative characters viz., days to 50% flowering, plant height, panicle length, panicle weight, productive tillers per plant, unproductive tillers per plant, flag leaf length, flag leaf width, number of filled grains per panicle, spikelet fertility, grain yield per plant, productivity per day, 1000 grain weight, grain length, grain breadth and length-breadth ratio. The general reference for data collection was standard evaluation system for rice (Anonymous, 2002; Virmani *et al*. 1997) [4]. Heterobeltiosis was expressed as per cent increase or decrease observed in F_1 over the better parent as per the formula of Liang *et al*. (1971) [16].

$$Hbt = [F1 – BP/BP] \times 100$$
$$Hs = [F1 – SC /SC] \times 100$$

Where; Hbt = Heterobeltiosis; Hs = Stanadard Heterosis; BP = Better Parent; SC = Standard Check

To estimate significant differences among hybrids and parents, the mean value of each character were subjected to Analysis of Variance (ANOVA) as suggested by Steel and Torrie (1980) [27].

Results and Discussion

The analysis of variance showed that highly significant differences among treatments for all the characters under study. In case of replications, for the most of the characters, there was no significant difference except for flag leaf width, grain yield per plant and productivity per day. ANOVA revealed that lines showed significant differences for plant height, grain length and grain breadth except days to 50% flowering, panicle length, panicle weight, number of productive tillers per plant, number of unproductive tillers per plant, flag leaf length, flag leaf width, spikelet fertility, number of filled grains per panicle, grain yield plant, productivity per day, 1000 grain weight and length-breadth ratio. Testers showed significant differences for all the characters except number of unproductive tillers per plant, flag leaf width, and 1000 grain weight and length-breadth ratio. Negative heterosis is desirable for days to 50% flowering this will make the hybrids as early maturing hybrids and they will fit well in multiple cropping systems. For days to 50% flowering all 24 hybrids showed negative standard heterosis over DRRH-3. The standard heterosis ranged from -20.60 (IR 68897A × RNR 21615) to -5.65 (IR 58025A × RNR 21615), when compared with check DRRH-3. The highest negative significant standard heterosis (-20.60) was observed in IR 68897A x RNR 21615. Presence of negative standard heterosis was observed by Anjuchaudary *et al.* (2007) [3], Eradasappa *et al*. (2007) [9] and Srijan *et al.* (2016). Short plant character is important to hybrid to withstand lodging. Hence, heterosis in negative direction which implies short stature is desirable for this trait. Out of 24 hybrids 13 hybrids were showed negative standard heterosis while other 4 hybrids showed positive standard heterosis. The standard heterosis ranged from -16.04 (IR 68897A × RNR 21288) to 10.24 (JMS 13A × RNR 21604), when compared with check DRRH-3. The hybrid IR 68897A x RNR 21288 showed highest negative standard heterosis (-16.04) over check DRRH-3. Standard heterosis of similar nature was observed by Deoraj *et al.* (2007) [8]. Panicle length is positively correlated with yield. Hence, significant positive heterosis is desirable for this trait. Out of 24 hybrids 6 hybrids showed significant positive standard heterosis and other 4 hybrids showed negative standard heterosis. The standard heterosis ranged from -21.21 (IR 68897A × RNR 15048) to 24.24 (JMS 13A × RNR 21301), when compared with check DRRH-3. Among hybrids JMS 13A x RNR 21301 hybrid showed highest significant positive standard heterosis (24.24) over check DRRH-3. Sanjeev Kumar *et al*. (2010) reported similar results for panicle length trait. Panicle weight is important trait to hybrids for yield. It is positively associated with yield. Hence, positive heterosis direction can increase the yield. Out of 24 hybrids 7 hybrids showed positive standard heterosis. The standard heterosis ranged from -47.14 (IR 68897A × RNR 21304 and IR 68897A x RNR 21288) to 34.24 (IR 58025A × 21615), when compared with check DRRH-3. Among 7 hybrids IR 58025A x RNR 21615 showed highest positive standard heterosis (34.24), heterobeltiosis (66.75) and average heterosis (71.93). Both positive and negative standard heterosis were reported by Saidaiah *et al.* (2012). Number of productive tillers per plant is known to directly contribute towards grain yield. It is directly correlated with yield. Hence, heterosis over better parent and standard checks in positive direction is desirable for this trait. The standard heterosis ranged from - 44.74 (IR 58025A × RNR 21615) to 31.58 (IR 58025A × RNR 21301), when compared with check DRRH-3. Among 24 hybrids only one hybrid *i.e* IR 58025A x RNR 21301 showed significant positive standard heterosis (31.58) over check DRRH-3. Gouri Shankar *et al.* (2010) [12] reported standard heterosis and heterobeltiosis in both directions. Number of unproductive tillers negatively correlated with yield. Hence, negative heterosis is desirable. Out of 24 hybrids, 10 hybrids showed significant negative heterosis. The standard heterosis ranged from -50.00 (JMS 13A x RNR 21615, JMS 13A x RNR 15048, IR 58025A x RNR 21301, IR 58025A x RNR 21288, IR 58025A x MTU 1010, IR 68897A x RNR 21615 and IR 68897A x RNR 21304) to 50.00 (JMS 13A x RNR 21301, IR 58025A x RNR 21604, IR 68897A x RNR 21301 and IR68897A x RNR 21288), when compared with check DRRH-3. Higher flag leaf length is a desirable feature of hybrid rice for efficient photosynthesis at and after flowering. Significant standard heterosis for flag leaf length was observed in 11 hybrids, over the check DRRH-3. The standard heterosis ranged from -24.21 (JMS 13A × RNR 15048) to 24.21 (IR 58025A × RNR 21615 and IR 58025A x RNR 15048), when compared with check DRRH-3. The hybrids IR 58025A x RNR 21615 and IR 58025A x RNR 15048 showed highest significant positive standard heterosis (24.21) over DRRH-3. Higher flag leaf width is a desirable feature of hybrids for efficient photosynthesis. The standard heterosis ranged from -56.16 (JMS 13A × MTU 1010) to -16.44 (IR 58025A × RNR 15048), when compared with check DRRH-3. Out of 24 hybrids none of the hybrid showed positive standard heterosis over check DRRH-3.

Spikelet fertility is positively related to yield. Hence, significant positive heterosis is desirable trait in hybrids. Among 24 hybrids 3 hybrids showed significant positive standard heterosis. The standard heterosis ranged from -22.09 (IR 68897A × RNR 21615) to 4.88 (JMS 13A x RNR 21301), when compared with check DRRH-3. Highest significant positive standard heterosis was observed in JMS 13A x RNR 21301 (4.88) over check DRRH-3. Both positive and negative standard heterosis was observed by earlier researchers like Tiwari *et al.* (2011) and Saidaaiah *et al.* (2012). Number of filled grains per panicle is the most important yield contributing character in the hybrids. Out of 24 hybrids 13 hybrids showed significant positive standard heterosis over check DRRH-3. The standard heterosis ranged from -36.96

(IR 68897A × RNR 21615) to 94.66 (IR JMS 13A × RNR 21218), when compared with check, DRRH-3. Highest significant standard heterosis was observed in JMS 13A x RNR 21218 (94.66) followed by IR 58025A x RNR 21615 (88.71) and JMS 13A x RNR 21604 (74.33).similar type of significant positive standard heterosis was observed by Rukmini Devi *et al.* (2014) and Srijan *et al.* (2016) [26]. Grain yield per plant is the ultimate product of hybrids. Among 24 hybrids 3 hybrids showed significant positive standard heterosis. The standard heterosis ranged from -62.49 (IR 68897A × RNR 21615) to 34.45 (IR 58025A × RNR 21301), when compared with check DRRH-3. Highest significant positive standard heterosis was observed in IR 58025A x RNR 21301 (34.45) followed by JMS 13A x RNR 21604 (21.40) and JMS 13A x RNR 21218 (20.93) over check DRRH-3. Standard heterosis of both positive and negative nature was observed by Saidaiah *et al.* (2012) and Srijan *et al.* (2016) [26]. Productivity per day will be based on days to 50% flowering and grain yield per plant. The standard heterosis ranged from -57.18 (IR 68897A × RNR 21604) to 45.02 (IR 58025A × RNR 21301), when compared with check DRRH-3. Among 24 hybrids highest significant positive standard heterosis for productivity per day was observed in IR 58025A x RNR 21301(45.02) over check DRRH-3. 1000 grain weight of a genotype serves as an indicator to the end product i.e., grain yield. The standard heterosis ranged from -46.00 (IR 58025A × RNR 15048) to 6.14 (IR 58025A × RNR 21218), when compared with check, DRRH-3. Highest significant positive heterosis was observed in IR 58025A X RNR 21218 (6.14) followed by IR 58025A x RNR 21304 (5.00), JMS 13A x RNR 21615 (4.51) and JMS 13A x RNR 21301 (3.57) over check DRRH-3. Similar results were reported by Akarsh Paarihar and Pathak (2008) [1]. Long grain type is most preferred hence positive significant standard heterosis is desirable. The standard heterosis ranged from 38.65 (IR 68897A × 21301) to 73.80 (IR 58025A × RNR 21604), when compared with check, DRRH-3. Out of 24 hybrids highest positive significant standard heterosis was observed in IR 58025A × RNR 21604 (73.80) followed by JMS 13A × RNR 21604 (65.40), JMS 13A x RNR 21301 (65.34), IR 58025A × RNR 21304 (63.07) and IR 58025A × RNR 21218 (60.31). For this character, both significant positive heterobeltiosis and heterosis was reported by Sanjeev Kumar *et al*. (2010) and Panwar and Mashiat Ali (2010) [18]. Higher grain breadth was not preferred. Slender grain type is most preferred. Hence, negative significant standard heterosis is desirable. The standard heterosis ranged from -24.49 (IR 58025A × RNR 15048) to 11.93 (JMS 13A × RNR 21218), when compared with check, DRRH-3. Among 24 hybrids highest negative significant standard heterosis was observed in IR 58025A × RNR 15048 (-24.49), followed by IR 68897A × RNR 15048 (-19.15), JMS 13A x RNR 15048(-9.58), IR 68897A × RNR 21301 (-9.11) and IR 68897A × RNR 21288 (-8.63). For this character, both significant negative heterobeltiosis and heterosis was reported by Sanjeev Kumar *et al*. (2010) and Panwar and Mashiat Ali (2010) [18]. Long/medium slender grain type is most preferred so, positive significant standard heterosis is desirable Srijan *et al.* (2016) [26]. The standard heterosis ranged from 28.76 (JMS 13A × RNR 21218) to 85.10 (IR 58025A × RNR 15048), when compared with check, DRRH-3. The hybrid IR 58025A × RNR 15048 (85.10) with highest positive significant standard heterosis is followed by IR 58025A × RNR 21604 (75.82), IR 68897A × RNR 15048 (72.03), IR 58025A × RNR 21218 (70.33) and JMS 13A × RNR 15048 (65.23). For this character, both significant positive heterobeltiosis and heterosis was reported by Sanjeev Kumar *et al*. (2010) and Panwar and Mashiat Ali (2010) [18] respectively, whereas standard heterosis of similar nature was reported by Sanghera and Hussain (2012) and Dar *et al.* (2014) [7].

From the above results observed and discussion made, it is clear that heterosis for grain yield per plant is mainly because of simultaneous manifestation of heterosis for yield component traits. Out of 24 hybrids studied, the significant standard heterosis for grain yield is observed in 3 hybrids, over best check DRRH-3, viz., IR 58025A × RNR 21301 (34.45), JMS 13A x RNR 21604 (21.40) and JMS 13A × RNR 21218 (20.93). Along with grain yield per plant, IR 58025A × RNR 21301 showed significant superiority over check for the characters, such as days to 50% flowering, plant height, panicle weight, number of productive tillers/plant, number of unproductive tillers/plant, flag leaf length, number of filled grains per panicle, productivity/day, grain length, grain breadth and length-breadth ratio; similarly JMS 13A × RNR 21604 showed significant superiority over check for the characters, such as days to 50 per cent flowering, number of filled grains per panicle, grain yield/plant, productivity/day, grain length and length-breadth ratio and JMS 13A × RNR 21218 showed days to 50% flowering, panicle length, number of filled grains per panicle, grain yield per plant, productivity/day, grain length, and length-breadth ratio. Hence, these three hybrids are the identified best experimental hybrids identified based on standard heterosis for grain yield and other yield attributing characters. Among 24 hybrids 3 hybrids recorded higher mean performance, significant SCA effects and standard heterosis to the extent of 20.93 to 34.45%. Hence, these hybrids may be further tested over locations and years for commercial exploitation.

Estimates of heterosis, heterobeltiosis and standard heterosis (over DRRH-3) for Days to 50% flowering, Plant height, Panicle length and Panicle weight

Hybrid	Days to 50% flowering			Plant height			Panicle length			Panicle weight		
	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3
JMS 13A x RNR 21615	-6.42**	-9.49**	-17.61*	9.77**	8.04	5.46**	-4.96	-11.84*	1.52	33.58**	27.93**	5.72*
JMS 13A x RNR 21604	-10.00**	-11.31**	-19.27**	15.36**	12.94**	10.24**	-2.68	-9.08	4.7	10.72**	8.45**	-10.38**
JMS 13A x RNR 21304	4.36*	0.36	-8.64**	5.11**	1.4	-1.02	-1.55	-3.95	10.61	40.37**	27.93**	5.72*
JMS 13A x RNR 21218	-3.88*	-5.11*	-13.62**	6.75**	1.75	-0.68	3.97	0	15.15*	31.38**	20.89**	-0.1
JMS 13A x RNR 21301	3.62	-0.73	-9.63**	2.66	-2.8	-5.12**	12.71**	7.89	24.24**	23.90**	17.72**	-2.72
JMS 13A x RNR 21288	-0.19	-3.28	-11.96**	-8.16**	-12.59**	-14.68**	-19.56**	-23.68**	-12.12*	31.27**	24.18**	2.62
JMS 13A x MTU 1010	-0.74	-1.46	-10.30**	-1.57	-2.08	-3.41*	-8.11	-10.53*	3.03	14.21**	5.13	3.3
JMS 13A x RNR 15048	-2.93	-3.28	-11.96**	5.44**	2.65	5.80**	-24.14**	-27.63**	-16.67**	-42.43**	-52.07**	-40.45**
IR 58025A x RNR 21615	6.57**	2.53	-5.65**	15.70**	1.08	-4.44*	8.06	3.08	1.52	71.93**	66.75**	34.24**
IR 58025A x RNR 21604	1.66	-0.36	-8.31**	28.07**	12.41**	5.12**	21.60**	15.15*	15.15**	32.85**	31.81**	6.11*
IR 58025A x RNR 21304	1.51	-2.89	-10.63**	23.94**	10.23**	0	17.59**	6.78	16.97**	-0.85	-8.55**	-26.38**
IR 58025A x RNR 21218	-2.21	-3.97	-11.63**	26.98**	14.20**	1.02	15.48**	6.27	13.03*	54.72**	44.10**	16.00**
IR 58025A x RNR 21301	2.65	-2.17	-9.97**	21.49**	9.94**	-4.10*	5.84	-2.16	3.03	64.93**	58.67**	27.74**
IR 58025A x RNR21288	-4.87*	-8.30**	-15.61**	25.05**	12.62**	-0.68	11.64*	4.11	7.58	69.81**	62.65**	30.94**
IR 58025A x MTU 1010	-1.65	-2.89	-10.63**	15.32**	-1.04	-2.39	23.66**	12.50*	22.73**	4.29	-5.13	-6.79*
IR 58025A x RNR 15048	-2.37	-3.25	-10.96**	9.63**	-7.62**	-4.78**	14.06**	5.8	10.61	-22.60**	-36.22*	-20.76**
IR 68897A x RNR 21615	-6.46**	-6.64**	-20.60**	-0.95	-6.14**	-11.26**	-2.88	-4.19	-3.03	-19.29**	-20.10**	-38.31**
IR 68897A x RNR 21604	-1.73	-3.76	-14.95**	9.58**	4.38*	-2.39	-1.81	-2.4	-1.21	-27.46**	-28.40**	-43.26**
IR 68897A x RNR 21304	1.18	0.78	-14.62**	-3.85*	-7.07**	-15.70**	-7.98	-11.48*	-3.03	-27.19**	-31.53**	-47.14**
IR 68897A x RNR 21218	-5.75**	-7.87**	-18.27**	2.52	0.31	-11.26**	3.65	1.14	7.58	-16.14**	-20.35**	-38.51**
IR 68897A x RNR 21301	0	-0.78	-15.95**	5.44**	3.87*	-9.39**	-1.69	-3.6	1.52	-20.79**	-22.24**	-39.96**
IR 68897A x RNR 21288	0.78	0.39	-14.29**	-2.84	-4.80*	-16.04**	-14.07**	-14.96**	-12.12*	-29.95**	-31.53**	-47.14**
IR 68897A x MTU 1010	-1.33	-4.07	-13.95**	-3.17	-10.03**	-11.26**	-12.10*	-15.28**	-7.58	-32.89**	-40.08**	-41.13**
IR 68897A x RNR 15048	-2.47	-5.51*	-14.62**	-6.18**	-14.57**	-11.95**	-23.42**	-24.64**	-21.21**	-43.09**	-53.86**	-42.68**

Estimates of heterosis, heterobeltiosis and standard heterosis (over DRRH-3) for no. of productive tillers per plant, no. of unproductive tillers per plant, flagflag leaf length and flag leaf width

Hybrid	No. of productive tillers per plant			No. of unproductive tillers			Flag leaf length			Flag leaf width		
	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3
JMS 13A x RNR 21615	8.82	5.71	-2.63	-60.00**	-66.67**	-50.00**	-14.97**	-16.52**	1.05	-26.98**	-36.99**	-36.99**
JMS 13A x RNR 21604	-2.86	-8.11	-10.53	0	0	0	-10.38**	-14.78**	3.16	-7.69	-17.81**	-17.81**
JMS 13A x RNR 21304	22.39**	20.59**	7.89	-16.67**	-16.67*	-16.67*	-9.13**	-12.17**	6.32	-4.76	-17.81**	-17.81**
JMS 13A x RNR 21218	16.67**	7.69	10.53	0	0	0	-15.26**	-15.74**	3.16	30.88**	-35.62**	-35.62**
JMS 13A x RNR 21301	22.39**	20.59**	7.89	100.00**	50.00**	50.00**	-7.87**	-10.43**	8.42*	-14.73**	-24.66**	-24.66**
JMS 13A x RNR 21288	-4.35	-8.33	-13.16*	0	0	0	-6.98**	-11.30**	7.37*	-10.40*	-23.29**	-23.29**

JMS 13A x MTU 1010	-8.11	-17.07**	-10.53	33.33**	0	0	-17.97**	-22.61**	-6.32	-55.24**	-56.16**	-56.16**
JMS 13A x RNR 15048	-1.45	-5.56	-10.53	-50.00**	-50.00**	-50.00**	-27.64**	-37.39**	-24.21**	-17.29**	-24.66**	-24.66**
IR 58025A x RNR 21615	-41.67**	-43.24**	-44.74**	-16.67**	-44.44**	-16.67*	13.03**	6.50*	24.21**	24.44**	5.66	-23.29**
IR 58025A x RNR 21604	0	0	-2.63	100.00**	50.00**	50.00**	7.09*	4.15	13.68**	21.28**	0	-21.92**
IR 58025A x RNR 21304	-21.13**	-24.32**	-26.32**	33.33**	0	0	-10.38**	-14.26**	-3.16	-26.67**	-37.74**	-54.79**
IR 58025A x RNR 21218	2.63	0	2.63	33.33**	0	0	7.33**	-1.12	21.05**	6	-15.87**	-27.40**
IR 58025A x RNR 21301	40.85**	35.14**	31.58**	0	0	-50.00**	5.52*	0.37	14.74**	26.88**	5.36	-19.18**
IR 58025A x RNR 21288	9.59	8.11	5.26	-33.33**	-50.00**	-50.00**	-4.1	-7.00*	2.11	5.62	-9.62	-35.62**
IR 58025A x MTU 1010	7.69	2.44	10.53	0	0	-50.00**	6.00*	3.92	11.58**	10.28*	-15.71**	-19.18**
IR 58025A x RNR 15048	-4.11	-5.41	-7.89	33.33**	0	0	29.67**	20.41**	24.21**	25.77**	1.67	-16.44**
IR 68897A x RNR 21615	-26.47**	-28.57**	-34.21**	-66.67**	-66.67**	-50.00**	8.01**	4.69	22.11**	-12.38*	-13.21*	-36.99**
IR 68897A x RNR 21604	-31.43**	-35.14**	-36.84**	-33.33**	-44.44**	-16.67*	-5.63*	-5.77	3.16	-21.10**	-24.56**	-41.10**
IR 68897A x RNR 21304	-10.45	-11.76	-21.05**	-60.00**	-66.67**	-50.00**	-8.66**	-10.07**	1.58	-12.38*	-13.21*	-36.99**
IR 68897A x RNR 21218	-13.89**	-20.51**	-18.42**	-20.00**	-33.33**	0	-3.77	-8.86**	11.58**	-16.52**	-23.81**	-34.25**
IR 68897A x RNR 21301	7.46	5.88	-5.26	50.00**	0	50.00**	-2.16	-4.24	9.47**	-12.96*	-16.07**	-35.62**
IR 68897A x RNR 21288	-4.35	-8.33	-13.16*	20.00**	0	50.00**	-7.83**	-7.96*	1.05	-9.62	-9.62	-35.62**
IR 68897A x MTU 1010	-13.51	-21.95**	-15.79**	0	-33.33**	0	-1.94	-2.88	6.32	-27.87**	-37.14**	-39.73**
IR 68897A x RNR 15048	-24.62**	-27.78**	-31.58**	-20.00**	-33.33**	0	1.06	-8.65**	0	-16.07**	-21.67**	-35.62**

Estimates of heterosis, heterobeltiosis and standard heterosis (over DRRH-3) for spikelet fertility, No. of filled grains per panicle, grain yield per plant and productivity per day

Hybrid	Spikelet fertility %			No. of filled grains per panicle			Grain yield per plant			Productivity per day		
	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3
JMS 13A x RNR 21615	-1.21	-1.85	-1.71	-11.83**	-34.73**	30.80**	5.84**	0.44	-20.72**	13.89**	11.76**	-8.36**
JMS 13A x RNR 21604	1.57	0.44	0.59	18.74**	-13.01**	74.33**	57.90**	53.79**	21.40**	72.92**	72.75**	41.64**
JMS 13A x RNR 21304	-6.80**	-7.95**	-7.81**	-10.32**	-35.45**	29.36**	-3.67	-10.38**	-29.26**	-5.15	-7.85*	-24.44**
JMS 13A x RNR 21218	0.17	-0.04	0.11	31.67**	-2.87	94.66**	59.62**	53.20**	20.93**	67.29**	64.51**	34.89**
JMS 13A x RNR 21301	6.93**	4.72**	4.88**	-23.69**	-44.88**	10.47**	29.69**	19.88**	-5.37**	28.55**	24.51**	2.09
JMS 13A x RNR 21288	0.04	-1.94	-1.79	-20.94**	-42.93**	14.37**	9.49**	1.08	-20.21**	11.63**	7.25*	-12.06**
JMS 13A x MTU 1010	3.34**	1	1.15	-9.40**	-29.41**	41.48**	9.84**	9.59**	-13.50**	12.42**	10.39**	-6.11**
JMS 13A x RNR 15048	-6.93**	-7.04**	-6.90**	-39.91**	-40.06**	20.74**	-37.95**	-37.96**	-51.03**	-35.51**	-36.67**	-46.14**
IR 58025A x RNR 21615	-8.79**	-12.94**	-5.33**	89.88**	84.17**	88.71**	-34.98**	-36.80**	-55.21**	-38.69**	-40.94**	-53.38**
IR 58025A x RNR 21604	-1.4	-6.31**	1.88	-0.73	-5.21	-2.87	0.69	-4.65	-28.65**	1.05	-4.31	-21.70**
IR 58025A x RNR 21304	-10.99**	-15.52**	-8.13**	1.08	-6.01	-3.7	-23.36**	-23.93**	-48.33**	-25.37**	-27.39**	-43.84**
IR 58025A x RNR 21218	-0.44	-4.56**	3.78**	13.60**	9.62**	12.32**	32.07**	26.90**	-7.89**	32.28**	27.18**	0.81
IR 58025A x RNR 21301	-6.69**	-12.15**	-4.47**	66.99**	56.11**	59.96**	100.83**	100.70**	34.45**	93.36**	88.71**	45.02**
IR 58025A x RNR 21288	0.52	-5.28**	3.01*	38.41**	29.26**	32.44**	22.51**	22.42**	-18.09**	25.19**	23.20**	-6.91**
IR 58025A x MTU 1010	-5.22**	-10.94**	-3.16*	6.32*	1.83	13.96**	-8.24**	-15.06**	-33.26**	-8.34**	-14.75**	-27.49**
IR 58025A x RNR 15048	-9.23**	-12.91**	-5.29**	-46.22**	-59.43**	-18.28**	-41.33**	-45.79**	-57.23**	-42.48**	-46.50**	-54.50**

IR 68897A x RNR 21615	-24.60**	-27.73**	-22.09**	-30.31**	-34.54**	-36.96**	-40.16**	-47.08**	-62.49**	-38.67**	-45.41**	-56.91**
IR 68897A x RNR 21604	-23.26**	-26.78**	-21.07**	-19.63**	-23.35**	-28.54**	-41.38**	-49.35**	-62.10**	-40.29**	-47.68**	-57.18**
IR 68897A x RNR 21304	-21.75**	-25.42**	--19.60**	-18.67**	-20.28**	-29.77**	-34.41**	-40.90**	-59.85**	-35.19**	-41.79**	-54.98**
IR 68897A x RNR 21218	-22.86**	-25.74**	-19.95**	-25.80**	-29.96**	-33.26**	-29.73**	-38.50**	-55.36**	-26.71**	-34.89**	-48.39**
IR 68897A x RNR 21301	-19.32**	-23.73**	-17.79**	-26.00**	-27.88**	-35.73**	-36.07**	-42.04**	-61.17**	-36.36**	-42.68**	-55.95**
IR 68897A x RNR 21288	-19.29**	-23.63**	-17.67**	-19.53**	-21.48**	-30.18**	-34.86**	-40.87**	-60.50**	-34.65**	-40.69**	-55.19**
IR 68897A x MTU 1010	-19.74**	-24.28**	-18.37**	-32.08**	-40.37**	-33.26**	-41.53**	-50.49**	-61.10**	-41.56**	-49.63**	-57.16**
IR 68897A x RNR 15048	-19.55**	-22.49**	-16.44**	-51.33**	-65.44**	-30.39**	-37.18**	-46.90**	-58.10**	-35.79**	-44.65**	-52.93**

Estimates of heterosis, heterobeltiosis and standard heterosis (over DRRH-3) for 1000 grain weight, grain length, grain breadth and length- breadth ratio

Hybrid	1000-grain weight			Grain length			Grain breadth			Length-breadth ratio		
	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3	Heterosis	Heterobeltiosis	DRRH-3
JMS 13A x RNR 21615	31.82**	17.84**	4.51**	-1.09	-11.41**	55.28**	0.08	-0.91	2.83	-1.07	-10.58**	51.37**
JMS 13A x RNR 21604	15.78**	5.16**	-6.74**	4.37**	-5.64**	65.40**	0	-1.66	2.04	4.41**	-4.02*	62.48**
JMS 13A x RNR 21304	20.21**	9.35**	-3.03**	-0.91	-10.61**	56.69**	-8.01**	-8.14**	-4.40*	7.63**	-3.01	64.18**
JMS 13A x RNR 21218	2.60**	-8.50**	-18.85**	-8.31**	-17.96**	43.80**	8.52**	7.87**	11.93**	-15.45**	-23.94**	28.76**
JMS 13A x RNR 21301	31.93**	16.79**	3.57**	6.52**	-5.67**	65.34**	3.07	-0.91	2.83	3.83*	-4.71**	61.31**
JMS 13A x RNR 21288	-5.83**	-16.14**	-25.63**	-9.49**	-19.92**	40.37**	-3.67*	-8.77**	-5.34*	-5.73**	-12.28**	48.50**
JMS 13A x MTU 1010	-3.33**	-13.32**	-3.10**	-12.32**	-12.67**	54.29**	0.07	-3.38	7.69**	-12.43**	-15.14**	43.66**
JMS 13A x RNR 15048	-10.94**	-18.96**	-28.13**	-4.87**	-14.81**	49.33**	-2.78	-12.86**	-9.58**	-2.36	-2.39	65.23**
IR 58025A x RNR 21615	-1.90*	-14.93**	-19.05**	-6.67**	-17.67**	49.45**	7.96**	3.55	5.34*	-14.15**	-26.96**	42.35**
IR 58025A x RNR 21604	13.55**	-0.02	-4.86**	7.56**	-4.26**	73.80**	2.27	-1.25	-0.94	4.38**	-9.79**	75.82**
IR 58025A x RNR 21304	25.13**	10.34**	5.00**	1.12	-10.17**	63.07**	5.88**	0.45	4.55*	-5.45**	-19.79**	56.34**
IR 58025A x RNR 21218	28.93**	11.54**	6.14**	0.21	-11.69**	60.31**	-3.85*	-8.12**	-5.81**	3.17*	-12.61**	70.33**
IR 58025A x RNR 21301	-1.57*	-15.45**	-19.54**	-9.92**	-21.43**	42.64**	-2.57	-3.77	-7.85**	-7.73**	-20.39**	55.16**
IR 58025A x RNR 21288	16.24**	0.43	-4.44**	-5.58**	-17.71**	49.39**	-1.01	-1.34	-7.85**	-4.60**	-16.63**	62.48**
IR 58025A x MTU 1010	-3.94**	-11.08**	-0.6	-14.44**	-15.58**	53.25**	-6.73**	-14.28**	-4.46*	-9.09**	-17.51**	60.78**
IR 58025A x RNR 15048	-35.66**	-43.25**	-46.00**	-12.90**	-23.18**	39.45**	-14.03**	-19.16**	-24.49**	1.69	-5.03**	85.10**
IR 68897A x RNR 21615	-26.94**	-45.15**	-23.59**	-1.32	-5.03**	42.45**	-12.86**	-15.93**	-8.01**	12.58**	12.26**	54.38**
IR 68897A x RNR 21604	-29.86**	-46.70**	-25.75**	4.08**	1.19	51.78**	-2.1	-6.17**	2.67	5.99**	4.33*	48.10**
IR 68897A x RNR 21304	-27.95**	-45.19**	-23.64**	3.98**	0.86	51.29**	-10.44**	-12.63**	-4.40*	16.02**	15.30**	58.56**
IR 68897A x RNR 21218	-24.80**	-43.64**	-21.49**	-2.02	-5.81**	41.29**	-9.04**	-11.91**	-3.61	7.43**	6.56**	46.54**
IR 68897A x RNR 21301	-23.57**	-43.04**	-20.65**	-2.75*	-7.57**	38.65**	-11.40**	-16.93**	-9.11**	9.65**	8.13**	52.94**
IR 68897A x RNR 21288	-11.76**	-33.94**	-7.97**	-1.46	-6.42**	40.37**	-9.63**	-16.50**	-8.63**	8.72**	5.65**	53.99**
IR 68897A x MTU 1010	-36.80**	-43.04**	-20.65**	-10.05**	-16.84**	46.93**	-16.42**	-17.18**	-7.69**	7.72**	0.49	59.61**
IR 68897A x RNR 15048	-29.07**	-46.02**	-24.80**	-2.87*	-6.54**	40.18**	-15.64**	-26.11**	-19.15**	12.19**	1.7	72.03**

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