International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133; Print ISSN: 2664-7125; Impact Factor: RJIF 5.28
Received: 18-09-2020; Accepted: 11-10-2020; ; Published: 26-10-2020
Volume 2; Issue 4; 2020; Page No. 113-123

Heterosis and combining ability studies in rice hybrids (*Oryza sativa* L.) with an emphasis to gall midge resistance

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Abstract
The aim of this study was to develop rice hybrids with resistance to gall midge and make inferences regarding components of heterosis in hybrids obtained by crossing six lines and seven testers in Line X Tester mating design. General combining ability (GCA) of parents (six lines and seven testers) and specific combining ability (SCA) and heterosis among 42 hybrids for gall midge resistance, yield and its related traits were analyzed. The magnitude of SCA variances was higher than GCA variance for all the traits except panicle length and thousand-grain weight, where the GCA variance was higher. Among the lines, JMS 21A was found to be a good general combiner for spikelet fertility, number of grains per panicle, grain yield per plant and gall midge incidence. Among the testers, JR 67 recorded high grain yield per plant along with favorable GCA for the number of grains per panicle, grain yield per plant and gall midge incidence. Most of the hybrids recorded positive significant standard heterosis for grain yield per plant. Hybrid JMS 19A X JR 80 recorded significantly positive SCA effect and highest relative heterosis, heterobeltiosis and standard heterosis over checks for grain yield per plant along with moderate resistance to gall midge. The alleles that control resistance to gall midge resistance have a degree of dominance more than 1, which indicates a favorable situation for obtaining resistant hybrids.

Keywords: Rice, GCA, SCA, gall midge resistance, grain yield, heterosis

Introduction

Rice (*Oryza sativa* L.) is the world's most important cereal crop. Today, rice has a special position as a source of providing over 75 per cent of the Asian population and more than three billion of world populations meal which represents 50 to 80 per cent of their daily calorie intake (Khush 2005, Amirjani 2011) [13]. This population will increase to over 4.6 billion by 2050 (Honarnejad *et al*., 2000) [12]. Which demands more than 50 per cent of the rice needs to be produced than what is produced present to cope with the growing population (Ashikari *et al*., 2005 [3]. Srividya *et al*., 2010) [3]. This has to be achieved by the development of high yielding rice varieties with improved nutritional quality and tolerance to biotic and abiotic stresses. Among the available genetic resources to increase rice productivity, hybrid rice has fared well and secured a good track record in uplifting the curse of 'yield barrier'. Rice hybrids have a yield advantage of about 15 to 20 % or more over the best conventionally bred varieties (Virmani, 1996) [24]. Plant breeding strategies leading to the selection of hybrids need the expected level of heterosis as well as the specific combining ability. The prime initiative of rice breeders for developing superior hybrid rice cultivar is to choose suitable mating parents (Cao and Zhan 2014) [6]. These parental characteristics are heritable and were able to appear in the F_1 generation. Combining ability analysis is one of the valuable tools available to ascertain the combining ability effects and helps in selecting the desirable parents and crosses for the exploitation of heterosis. Many studies based on association analysis between combining ability and markers also revealed genomic loci significantly associated with the combining ability of parental traits (Xie *et al*., 2016) [25]. Despite breakthroughs in improving productive systems, pests have been major drawbacks for a more expressive increase in yields. Nearly 300 species of insect pests attack the rice crop at different stages and among them, Asian rice gall midge (GM), *Orseolia oryzae* (Wood-Mason) is one of the important insect which has been prevalent in almost all the rice-growing states. It was reported that the gall midge resistance in rice is controlled by a single dominant gene and it is possible to develop F_1 hybrids resistant to gall midge (Naikebawane *et al*., 2008) [18]. In the F_1 hybrids, the effect of heterosis is expected to show increased grain yield and resistance to biotic and abiotic stresses. An appreciable improvement in these aspects can be achieved when a donor for resistance with good combining ability for yield is identified. The ability of the hybrids to resist the attack of pests depends on the degree of resistance found in either one or both the parents. Therefore, to breed ideal rice hybrids with high grain yield (Yong *et al*., 2019), good quality (Machida *et al*., 2010) [16]. and strong resistance to gall midge, combining ability have been analyzed for available germplasm with limited numbers of parental lines by Sameena Begum *et al*. (2018) [22]. In this study heterosis was analyzed in the same germplasm along with combining ability by considering the potentials of resistance breeding.

Materials and Methods

Field experiment was conducted at Regional Agricultural Research Station (RARS), Polasa, Jagtial of Telangana state. Six cytoplasmic male sterile lines viz., CMS 64A, JMS 11A, JMS 19A, CMS 52A, JMS 21A and JMS 20A were crossed with seven restorer lines viz., JR 83, JR 85, JR 80, JMBR 44, JMBR 31, JR 67 and JBR 6 (Table 1) in a Line x Tester mating design during *rabi* 2016. The resultant 42 F_1 hybrids were evaluated along with the parents and four checks during *kharif*, 2017. Thirty days old seedlings of 57 entries (6 lines, 7 testers, 42 hybrids and 4 checks) were transplanted in a randomized block design (RBD) with two replications. Each entry was planted in two rows of four meters length with a spacing of 20 x 15 cm. Recommended package of practices were followed except spraying any pesticides. Observations were recorded on five randomly selected plants without border effect for days to 50 per cent flowering, plant height (cm), panicle length (cm), number of productive tillers per plant, number of grains per panicle, spikelet fertility percentage, 1000- grain weight (g) and grain yield per plant (g), incidence of gall midge (%), hulling percentage, milling percentage, head rice recovery percentage, kernel length(mm), kernel breadth(mm) and kernel L/B ratio.

Table 1: Salient features of parents and checks utilized for the research programme.

S. no	Genotype	Source	Salient features
		CMS lines	
1	CMS 64A	RARS, Jagtial	Short duration, medium slender, male sterile line, gall midge susceptible.
2	JMS 11A	RARS, Jagtial	Short duration, medium slender, male sterile line, gall midge susceptible.
3	JMS 19A	RARS, Jagtial	Medium duration, medium slender, male sterile line, moderately resistant to gall midge.
4	CMS 52A	RARS, Jagtial	Short duration, short medium, male sterile line, gall midge susceptible.
5	JMS 21A	RARS, Jagtial	Short duration, short medium, male sterile line, gall midge resistant.
6	JMS 20A	RARS, Jagtial	Short duration, short slender, male sterile line, highly resistant to gall midge.
		Restorer lines	
1	JR 83	RARS, Jagtial	Short duration, medium slender, restorer line, gall midge susceptible.
2	JR 85	RARS, Jagtial	Short duration, medium slender, restorer line, moderately resistant to gall midge.
3	JR 80	RARS, Jagtial	Medium duration, medium slender, restorer line, moderately susceptible to gall midge.
4	JMBR 44	RARS, Jagtial	Short duration, medium slender, restorer line, moderately susceptible to gall midge.
5	JMBR 31	RARS, Jagtial	Short duration, short slender, restorer line, gall midge susceptible.
6	JR 67	RARS, Jagtial	Short duration, short slender, restorer line, gall midge susceptible.
7	JBR 6	RARS, Jagtial	Medium duration, medium slender, restorer line, gall midge susceptible.
		Checks	
1	US 312	Private organization	Medium duration, medium slender, gall midge susceptible
2	HRI 174	Private organization	Medium duration, medium slender, gall midge susceptible
3	MTU 1010	RARS, Maruteru	Short duration, short medium, gall midge susceptible
4	JGL 384	RARS, Jagtial	Medium duration, medium slender, gall midge resistant

Gall midge incidence was recorded on a hill basis at 45 days after planting during *kharif*, 2017 season. The occurrence of silver shoots in randomly selected 10 plants was recorded and compared with susceptible check MTU 1010 and resistant check JGL 384. For scoring the gall midge incidence a total number of tillers and a total number of tillers with silver shoot were recorded and the per cent tiller infestation was calculated as follows.

$$\text{Per cent silver shoot} = \frac{\text{Number of infested tillers}}{\text{Total number of tillers}} \times 100$$

To check the level of resistance or susceptibility, the percentage silver shoot in each entry in each replication was converted to 0-9 scale by following the IRRI Standard Evaluation System (SES). The data was subjected to analysis of variance (Panse and Sukhatme, 1985) [20]. The GCA effects of thirteen parents i.e. six lines and seven testers and the SCA effects of forty two hybrids combinations were estimated according to Kempthorne (1957) [14]. in Line × Tester mating design. The variances for general combining ability (GCA) and specific combining ability (SCA) were tested against their respective error of variances derived from ANOVA reduced to mean level. The significance test for GCA and SCA effects was performed using a t-test. Heterosis was calculated as the percentage of F_1's performance in the favorable direction over the mid parent, better parent and standard checks HRI 174 and US 312 for each trait. The significance of heterosis was calculated as suggested by Liang *et al*. (1971) [15].

Results and Discussion

Estimations of GCA effects of rice CMS and restorer lines

In our study, the GCA effect values for CMS and restorer lines in rice varied significantly for all the studied traits. The 13 parents (6 CMS lines +7 restorer lines) of rice set showed both positive and negative GCA effect values. For example, the GCA of JMS 11A showed a negative effect for panicle length, number of grains per panicle, grain yield per plant, hulling percentage, kernel length, kernel breadth, but positive effect on plant height, incidence of gall midge, milling percentage, head rice recovery, and kernel L/B.

Among the 6 CMS lines, the GCA effects of JMS 21A showed maximum positive values for the number of grains per panicle, spikelet fertility, grain yield per plant, hulling percentage, milling percentage, head rice recovery and kernel breadth (Table 2). Also, the JMS 20A was observed to be good general combiner for panicle length, 1000 -grain weight, hulling percentage, kernel length and kernel breadth.

Among the 7 restorer lines, JBR 6 had maximum GCA effect values for the number of productive tillers per plant and grain yield per plant; JMBR 44 showed maximum positive GCA values for days to 50 per cent flowering, plant height and kernel breadth. Line JMS 21A and testers JR 83 and JR 67 displayed desirable negative GCA effects for gall midge incidence (Table 2).

In terms of elite parental lines, the JMS 21A, JMS 20A and restorers JBR 6, JR 67 and JMBR 44 had the most favorable GCA effects for the studied traits. The genitors with the highest general combining ability (GCA) values (gi) can be included in breeding programs of self-pollinating crops to develop genotypes that exceed their genitors in advanced generations (Fasahat *et al.*, 2016) [9]. Line JMS 21A showed significant and negative GCA values and low gall midge incidence indicating the high chances of success for selecting good GCA lines based on per se performance.

Table 2: Estimates of general combining ability (gca) effects for lines and testers for gall midge incidence, yield and its related traits in rice.

Source	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	1000 -grain weight (g)	No. of grains per panicle	Spikelet fertility (%)	Grain yield per plant (g)	Incidence of gall midge (%)
Parents									
Lines									
CMS 64B	-0.01	-12.26**	-2.30**	-0.29	-3.39**	-24.75**	-3.52	-8.45**	0.81
JMS 11B	2.77**	3.79**	-1.08**	0.20	0.07	-20.32*	3.24	-3.90**	2.12*
JMS 19B	-0.29	4.25**	1.09**	0.41	0.39	15.32	-3.04	4.42**	2.60**
CMS 52B	0.48	2.35**	0.05	-0.44	1.38**	-8.67	-3.36	-0.42	-0.78
JMS 21B	0.91**	1.46*	0.59*	0.34	-0.11	48.39**	6.08*	8.52**	-5.30**
JMS 20B	-3.86**	0.39	1.64**	-0.22	1.66**	-9.96	0.60	-0.16	0.55
Testers									
JR 83	-10.72**	-11.94**	1.64**	-0.54	-1.47**	-35.0**	4.68*	-4.60**	-4.89**
JR 85	3.27**	9.70**	0.85*	0.20	1.79**	15.91	-5.57*	3.23	0.68
JR 80	2.94**	5.27**	1.38**	-0.21	0.30	27.50*	-0.90	-3.13*	-1.48
JMBR 44	-2.39**	-4.81**	-0.33	0.61	1.72**	-28.75*	-5.47*	-2.10*	3.19**
JMBR 31	0.27	-4.92**	0.00	-0.54	-0.82**	4.58	1.90	-2.40*	1.88*
JR 67	3.44**	2.48**	-0.71*	-0.38	-3.10**	34.75**	1.70	3.98**	-3.37**
JBR 6	3.19**	4.22**	0.45	0.86*	1.57**	-19.00*	3.66	5.03**	3.99**
CD 95% GCA (Line)	0.50	1.06	0.57	0.59	0.39	15.97	3.63	1.81	1.45
CD 95% GCA (Tester)	0.54	1.15	0.62	0.63	0.42	17.25	3.92	1.95	1.57

Table 2: (Cont.)

Source	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio
Parents						
Lines						
CMS 64B	-3.52**	-0.71**	-1.54**	-0.51**	-0.11**	-0.06
JMS 11B	-0.29**	1.87**	3.46**	-0.06*	-0.08*	0.10*
JMS 19B	1.19**	-0.23	-4.30**	-0.09**	-0.09**	0.12*
CMS 52B	0.45**	-1.53**	3.77**	0.31**	0.05	0.05
JMS 21B	1.25**	2.68**	6.14**	-0.02	0.17**	-0.29**
JMS 20B	0.91**	-2.06**	-7.53**	0.38**	0.07*	0.06
Testers						
JR 83	1.74**	-0.26	-1.56**	-0.01	-0.07*	0.13**
JR 85	0.49**	1.24**	2.49**	0.33**	-0.03	0.26**
JR 80	-0.09	0.72**	-0.57*	0.17**	0.03	0.00
JMBR 44	-0.51**	0.10	0.92**	-0.07**	0.08*	-0.18*
JMBR 31	-0.62**	-0.96**	1.45**	-0.11**	0.04	-0.14*
JR 67	-0.27**	-0.37	-1.80**	-0.37**	0.08*	-0.06
JBR 6	-0.72**	-0.46*	-0.93**	0.07*	0.03	-0.00
CD 95% GCA (Line)	0.14	0.35	0.39	0.04	0.05	0.10
CD 95% GCA (Tester)	0.15	0.37	0.42	0.04	0.05	0.10

* Significant at 5 per cent level ** Significant at 1 percent level

Estimations of SCA effects of rice hybrids

SCA effects are connected with dominance and epistatic component of variations. Significant SCA showed the comparative importance of interactions in determining the performance of produced hybrids. SCA effect analysis revealed that eight crosses had significant positive SCA effects for grain yield per plant, whereas the other eight crosses expressed significant negative SCA effects for the same trait (Table 3).

Table 3: Estimates of specific combining ability (*sca*) effects for gall midge incidence, yield and its related traits in rice.

S. No.	Crosses	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No. of productive tillers per plant	1000-grain weight (g)	No. of grains per Panicle	Spikelet fertility (%)	Grain yield per plant (g)	Incidence of gall midge (%)
1	CMS 64A X JR 83	15.01**	4.54*	0.61	0.54	1.77*	34.50	-7.55	3.51	8.30**
2	CMS 64A X JR 85	-3.48**	-4.10*	0.61	1.79*	-2.76**	-37.91	-1.09	-4.11	6.76*
3	CMS 64A X JR 80	4.84**	-11.27**	-1.41	-786.00	-3.53**	32.50	7.42	1.25	-5.71*
4	CMS 64A X JMBR 44	-5.82**	0.31	1.00	-0.11	1.86**	-27.25	-3.39	0.01	1.05

5	CMS 64A X JMBR 31	-9.98**	-7.17**	-0.23	-1.45	3.06**	-28.58	-0.92	-2.48	-10.23**
6	CMS 64A X JR 67	-4.65**	3.41*	-0.61	0.38	-1.84**	-5.75	4.02	-2.86	-5.43*
7	CMS 64A X JBR 6	4.09**	14.27**	0.01	0.36	1.45*	32.50	1.51	4.68	5.25*
8	JMS 11A X JR 83	-5.77**	-3.81*	-0.49	1.04	-1.80*	48.07*	2.03	5.37*	-4.21*
9	JMS 11A X JR 85	9.22**	4.43*	-1.39	-0.70	0.54	-31.84	4.58	-9.66**	-1.85
10	JMS 11A X JR 80	-1.94*	10.27**	2.27*	-0.78	2.33**	-8.92	0.36	-0.89	0.49
11	JMS 11A X JMBR 44	-3.60**	-6.74**	-1.11	-0.61	0.37	-16.67	6.03	-0.52	-1.70
12	JMS 11A X JMBR 31	0.22	-4.82*	-0.74	0.04	-1.25*	-36.01	2.31	-0.62	6.39*
13	JMS 11A X JR 67	3.06**	-0.54	-1.42	-1.11	-0.87	11.82	-5.53	-4.21	0.20
14	JMS 11A X JBR 6	-1.19	1.22	2.90**	2.13*	0.67	33.57	-9.80*	10.54**	0.68
15	JMS 19A X JR 83	-2.70**	-2.66	0.71	-0.16	-0.33	-14.07	-2.48	4.24	-3.86*
16	JMS 19A X JR 85	1.29	-1.61	0.71	0.08	0.35	55.01*	-4.17	0.81	-1.63
17	JMS 19A X JR 80	0.63	0.61	-0.11	1.50	-0.15	0.42	1.35	10.57**	-6.08*
18	JMS 19A X JMBR 44	2.46**	-5.20**	-1.79*	-1.33	0.05	3.17	8.77	0.94	-0.38
19	JMS 19A X JMBR 31	-0.70	11.31**	0.76	-0.66	-2.04**	21.34	-6.25	-6.75*	3.21
20	JMS 19A X JR 67	-0.86	-5.00**	-0.11	-0.33	1.14*	-45.82*	-3.15	1.36	2.24
21	JMS 19A X JBR 6	-0.11	2.56	-0.18	0.91	0.97	-20.07	5.93	-11.18**	6.51*
22	CMS 52A X JR 83	-3.48**	-2.56	-0.03	-1.31	-0.86	-25.57	0.13	-6.51*	-0.33
23	CMS 52A X JR 85	3.01**	2.38	0.96	-0.06	0.97	-1.98	-2.30	1.05	-0.75
24	CMS 52A X JR 80	-1.65*	7.31**	-2.77**	-0.64	0.79	-15.07	-9.92*	-3.97	5.62*
25	CMS 52A X JMBR 44	1.17	1.99	0.84	0.02	-0.18	-7.32	-10.85*	-3.61	6.84**
26	CMS 52A X JMBR 31	2.51**	-5.88**	-0.28	1.19	0.96	43.34*	1.02	4.08	-1.77
27	CMS 52A X JR 67	-1.15	-0.20	1.02	0.52	0.73	-41.32	8.82	-2.69	-1.29
28	CMS 52A X JBR 6	-0.40	-3.03*	0.26	0.27	-2.41**	47.92*	13.10*	11.65**	-8.31**
29	JMS 21A X JR 83	-3.91**	-5.88**	0.01	-1.09	0.40	17.35	1.14	-4.25	2.20
30	JMS 21A X JR 85	-0.91	-2.33	-0.28	-0.34	0.87	0.44	5.50	15.51**	-1.85
31	JMS 21A X JR 80	-1.58*	-0.40	-0.01	0.57	-0.69	-10.14	1.52	-8.52**	-1.20
32	JMS 21A X JMBR 44	2.25*	5.58**	-0.09	0.23	-1.65*	3.10	-5.59	-10.15**	-4.30*
33	JMS 21A X JMBR 31	1.08	0.40	0.36	0.40	-1.39*	11.27	4.92	6.34*	-4.06*
34	JMS 21A X JR 67	0.91	-2.31	0.18	-0.76	0.40	62.60*	3.47	5.96*	1.74
35	JMS 21A X JBR 6	2.16*	4.95**	-0.18	0.98	2.06**	-84.64**	-10.98*	-4.88*	7.47**
36	JMS 20A X JR 83	0.86	10.38**	-0.82	0.97	0.82	-60.28*	6.72	-2.36	-2.10
37	JMS 20A X JR 85	-9.13**	1.23	-0.62	-0.77	0.02	16.29	-2.51	-3.60	-0.67
38	JMS 20A X JR 80	-0.29	-6.52**	2.04*	0.14	1.26*	1.21	-0.74	1.56	6.88**
39	JMS 20A X JMBR 44	3.53**	4.05*	1.16	1.81*	-0.44	44.96*	5.03	13.33**	-1.49
40	JMS 20A X JMBR 31	6.86**	6.17**	0.12	0.47	0.66	-11.369	-1.09	-0.56	6.45*
41	JMS 20A X JR 67	2.70**	4.65*	0.94	1.31	0.43	18.46	-7.64	2.44	2.53
42	JMS 20A X JBR 6	-4.54**	-19.97**	-2.82**	-3.94	-2.76**	-9.28	0.24	-10.80**	-11.59**
43	CD 95 % SCA	1.34	2.81	1.53	1.56	1.03	42.25	9.61	4.79	3.86

* Significant at 5 per cent level ** Significant at 1 percent level

Table 3: (cont.)

Sl. No.	Crosses	Hulling (%)	Milling (%)	Head rice recovery (%)	Kernel length (mm)	Kernel breadth (mm)	Kernel L/B ratio
1	CMS 64A X JR 83	4.54**	7.41**	6.29**	0.36**	0.01	0.23
2	CMS 64A X JR 85	2.13**	-0.03	-6.76**	0.01	-0.15*	0.33*
3	CMS 64A X JR 80	-1.12**	-1.03*	5.15**	-0.12*	0.06	-0.18
4	CMS 64A X JMBR 44	3.92**	3.69**	2.65**	-0.12*	0.01	-0.12
5	CMS 64A X JMBR 31	-7.74**	-11.91	-14.62**	0.06	0.11	-0.17
6	CMS 64A X JR 67	0.00	1.12*	-0.61	-0.27**	-0.10	0.01
7	CMS 64A X JBR 6	-1.74**	0.75	7.91**	0.07	0.07	-0.09
8	JMS 11A X JR 83	-1.51**	0.93*	3.54**	0.41**	-0.05	0.35*
9	JMS 11A X JR 85	-2.10**	-0.50	5.23**	-0.13*	0.05	-0.20
10	JMS 11A X JR 80	1.44**	5.44**	1.35*	0.42**	0.08	0.07
11	JMS 11A X JMBR 44	-0.80**	-3.63**	-2.09**	-0.42**	-0.01	-0.19
12	JMS 11A X JMBR 31	0.96**	-1.89**	5.72**	0.01	-0.07	0.13
13	JMS 11A X JR 67	-0.17	-2.82**	-5.31**	-0.02	0.00	-0.02
14	JMS 11A X JBR 6	2.18**	2.48**	-8.44**	-0.27**	-0.00	-0.14
15	JMS 19A X JR 83	-0.82**	-0.20	-0.04	-0.35**	0.06	-0.33*
16	JMS 19A X JR 85	0.66*	0.87	3.94**	-0.10	-0.07	0.09
17	JMS 19A X JR 80	-1.14**	-2.86**	-6.98**	-0.03	-0.00	-0.01
18	JMS 19A X JMBR 44	-1.44	-0.95*	-3.82**	0.16*	-0.00	0.05
19	JMS 19A X JMBR 31	1.04**	-0.80	-2.00**	-0.14*	0.08	-0.24
20	JMS 19A X JR 67	-0.87**	1.97**	6.22**	0.41**	0.07	0.11

21	JMS 19A X JBR 6	2.58**	1.98**	2.68**	0.06	-0.11	0.33*
22	CMS 52A X JR 83	-0.76**	-10.56**	-11.72**	-0.06	0.01	-0.05
23	CMS 52A X JR 85	0.10	1.36*	-2.08**	0.18*	0.07	-0.05
24	CMS 52A X JR 80	0.79**	1.57*	0.10	0.25**	0.09	-0.01
25	CMS 52A X JMBR 44	0.06	-0.97*	3.71**	0.20**	-0.10	0.28*
26	CMS 52A X JMBR 31	2.57**	10.31**	9.53**	-0.55**	-0.11	-0.08
27	CMS 52A X JR 67	0.97**	1.57*	6.65**	-0.19**	0.02	-0.13
28	CMS 52A X JBR 6	-3.74**	-3.28**	-6.20**	0.15**	0.00	0.06
29	JMS 21A X JR 83	-0.03	1.69**	-2.34**	-0.32**	-0.00	-0.18
30	JMS 21A X JR 85	-0.79**	-1.453*	1.94**	-0.17*	0.15*	-0.35*
31	JMS 21A X JR 80	0.19	1.00*	1.83**	-0.30**	-0.22*	0.20
32	JMS 21A X JMBR 44	-1.01**	0.2	-0.40	0.04	0.12	-0.11
33	JMS 21A X JMBR 31	1.44**	1.86**	1.75*	0.23**	0.06	0.03
34	JMS 21A X JR 67	0.42*	-0.68	-3.98**	0.14*	-0.09	0.22
35	JMS 21A X JBR 6	-0.22	-2.70**	1.19*	0.39**	-0.01	0.20
36	JMS 20A X JR 83	-1.40**	0.74	4.28**	-0.03	-0.00	-0.01
37	JMS 20A X JR 85	-0.00	-0.22	-2.27**	0.21**	-0.04	0.18
38	JMS 20A X JR 80	-0.17	-4.12**	-1.45*	-0.21**	-0.02	-0.06
39	JMS 20A X JMBR 44	-0.71**	1.59*	-0.04	0.13*	-0.02	0.10
40	JMS 20A X JMBR 31	1.71**	2.43**	-0.38	0.37**	-0.08	0.33*
41	JMS 20A X JR 67	-0.35	-1.17*	-2.96**	-0.06	0.10	-0.19
42	JMS 20A X JBR 6	0.94**	0.75	2.85**	-0.41**	0.08	-0.35*
43	CD 95 % SCA	0.38	0.92	1.03	0.10	0.14	0.26

* Significant at 5 per cent level ** Significant at 1 percent level

The crosses exhibited both significantly positive and negative SCA effects for grain yield per plant. This finding is in line with the result reported by Abebe *et al*. (2018) and Natol (2017) [19]. who reported both positive and negative significant SCA for grain yield. Positive SCA effects resulted from the crossing of lines from different heterotic groups but negative SCA effects due to the crossing of lines from the same heterotic group.

Hybrids JMS 21A X JR 80, JMS 20A X JMBR 44, CMS 52A X JBR 6, JMS 19A X JR 80, JMS 11A X JBR 6, JMS 21A X JMBR 31, JMS 21A X JR 67 and JMS 11A X JR 83 showed significant and positive SCA effects. Among them hybrid JMS 19A X JR 80 provided high mean grain yield and possessed desirable significantly high SCA effects, revealing good correspondence between mean grain yield and SCA effects. But remaining hybrids had positive significant high SCA effects which were not consistent with high mean grain yield performance. Abebe *et al*. (2018) and Gichuru *et al*. (2011) [11]. Reported similar results.

The crosses CMS 64A X JMBR 31 and JMS 20A X JR 85 were identified as good specific combiners for days to 50 per cent flowering, JMS 20A X JBR 6 and CMS 64A X JR 80 were good specific combiners for plant height, CMS 64A X JMBR 31 and JMS 11A X JR 80 for 1000- grain weight, JMS 21A X JR67 and JMS 19A X JR 85 for the number of grains per panicle CMS 52A X JBR 6 and CMS 52A X JR 67 for spikelet fertility, while JMS 11A X JBR 6 was good specific combiner for panicle length and the number of productive tillers per plant. CMS 64A X JR 83 for hulling percentage, CMS 52A X JMBR 31 for milling percentage and head rice recovery were the potential hybrids with high SCA effects. The cross JMS 20A X JBR 6 recorded the highest negative SCA effect and found to be a good specific combiner for gall midge resistance. Many authors reported similar results in rice Damodar Raju *et al.* (2014) [7]. Bhatti *et al.* (2015) [4]. Dharwal *et al.* (2017) [8]. and Rumanti *et al.* (2017) [21]. Further, predominance of variance due to SCA over GCA effects suggested that the exploitation of gall midge resistance through hybrid breeding is possible.

Heterosis studies

As both heterosis and specific combining ability effects (SCA) show a clear picture about the performance of the hybrids for continuously varying traits, both were considered in the selection of desired hybrids.

Yield is a complex character and is dependent on its component traits and their inheritance. 26 hybrids over HRI 174 and 15 hybrids over US 312 recorded significant positive standard heterosis for grain yield per plant (Table 4).

Table 4: Estimates of heterosis over standard checks (SH), better parent (BPH) and mid parent (MPH) for different yield and physical quality traits in rice.

S. No.	Crosses	Days to 50% flowering				Plant height (cm)				Panicle length (cm)			
		SH		BPH	MPH	SH		BPH	MPH	SH		BPH	MPH
		HRI 174	US 312			HRI 174	US 312			HRI 174	US 312		
1	CMS 64A X JR 83	-8.42*	-1.6 0	-2.63*	-1.07	0.76	-0.58	2.57	15.36*	8.99*	2.46	16.40*	20.00*
2	CMS 64A X JR 85	-26.73*	-21.28*	-19.57*	-10.84*	-15.73*	-16.85*	1.62	5.75*	1.12	-4.93	14.41*	14.65*
3	CMS 64A X JR 80	-8.91*	-2.13*	-10.68*	-5.64*	3.36*	1.99	-4.36*	12.03*	10.49*	3.87	17.06*	21.15*
4	CMS 64A X JMBR 44	-9.90*	-3.19*	-1.09	-0.82	1.51	0.17	-7.08*	9.33*	9.36*	2.82	-0.68	10.40*
5	CMS 64A X JMBR 31	-13.37*	-6.91*	-4.89*	-0.85	-11.86*	-13.03*	1.95	8.21*	-3.37	-9.15*	6.17	7.95*
6	CMS 64A X JR 67	-13.86*	-7.45*	-5.43*	-4.92*	193	0.58	15.87*	23.99*	7.49	1.06	14.80*	18.35*
7	CMS 64A X JBR 6	-10.89*	-4.26*	-7.22*	-4.76*	-5.55*	-6.80*	-3.44	8.40*	1.50	-4.58	14.83*	15.07*
8	JMS 11A X JR 83	-10.40*	-3.72*	-4.74*	-0.82	2.27	0.91	4.11*	10.19*	5.62	-0.70	8.46*	10.59*

9	JMS 11A X JR 85	-26.73*	-21.28*	-15.43*	-8.36*	-17.24*	-18.34*	-5.29*	-2.81	-5.62	-11.27*	-3.08	1.61
10	JMS 11A X JR 80	-6.44*	0.53	-8.25*	-0.79	5.13*	3.73*	-2.72	7.57*	7.49	1.06	10.38*	12.11*
11	JMS 11A X JMBR 44	-11.39*	-4.79*	-2.19*	0.00	5.55*	4.15*	-3.39*	7.36*	-4.49	-10.21*	-13.27*	-7.94*
12	JMS 11A X JMBR 31	-13.86*	-7.45*	-0.57	1.16	-7.40*	-8.63*	5.97*	6.53*	2.62	-3.52	5.38	8.95*
13	JMS 11A X JR 67	-9.90*	-3.19*	0.00	1.96*	-14.13*	-15.27*	-2.39	-2.06	-0.37	-6.34	2.31	4.31*
14	JMS 11A X JBR 6	-10.40*	-3.72*	-6.70*	-1.90*	-3.11	-4.40*	-0.95	4.63*	1.87	-4.23	4.62	9.68*
15	JMS 19A X JR 83	-9.90*	-3.19*	-4.71*	-4.46*	-4.04*	-5.31*	-2.31	9.13*	3.37	-2.82	10.40*	11.52*
16	JMS 19A X JR 85	-26.73*	-21.28*	-22.51*	-12.68*	-20.77*	-21.83*	-4.46*	-1.31	-3.37	-9.15*	5.31	7.28
17	JMS 19A X JR 80	-9.90*	-3.19*	-11.65*	-8.31*	0.42	-0.91	-7.08*	8.15*	4.87	-1.41	11.11*	12.68*
18	JMS 19A X JMBR 44	-10.89*	-4.26*	-5.76*	-3.74*	-1.68	-2.99	-10.01*	5.22*	7.87	1.41	-2.04	6.86
19	JMS 19A X JMBR 31	-12.38*	-5.85*	-7.33*	-1.67	-5.13*	-6.39*	9.73*	15.63*	1.12	-4.93	10.20*	10.66*
20	JMS 19A X JR 67	-10.89*	-4.26*	-5.76*	-3.49*	-9.59*	-10.79*	2.77	9.19*	4.12	-2.11	11.20*	12.32*
21	JMS 19A X JBR 6	-7.92*	-1.06	-4.12*	-3.38*	-5.63*	-6.89*	-3.53*	7.57*	0.75	-5.28	9.80*	11.85*
22	CMS 52A X JR 83	-6.93*	0.00	-1.05	7.74*	1.93	0.58	3.77*	15.10*	3.75	-2.46	9.92*	10.36*
23	CMS 52A X JR 85	-26.73*	-21.28*	-6.92*	-3.58*	-7.99*	-9.21*	10.95*	13.72*	-2.62	-8.45*	3.17	6.56
24	CMS 52A X JR 80	-22.77*	-17.02*	-24.27*	-14.52*	2.52	1.16	-5.14*	9.67*	7.49	1.06	13.89*	13.89*
25	CMS 52A X JMBR 44	-14.36*	-7.98*	-5.46*	1.17	-7.74*	-8.96*	-15.55*	-1.92	19.48*	12.32*	8.50*	16.85*
26	CMS 52A X JMBR 31	-15.84*	-9.57*	0.59	3.66*	-7.32*	-8.55*	7.20*	12.11*	9.74*	3.17	16.27*	18.38*
27	CMS 52A X JR 67	-9.90*	-3.19*	0.00	6.74*	-5.63*	-6.89*	7.27*	13.10*	7.12	0.7	13.49*	13.94*
28	CMS 52A X JBR 6	-10.89*	-4.26*	-7.22*	1.98*	-0.67	-1.99	1.55	12.42*	7.49	1.06	13.89*	17.62*
29	JMS 21A X JR 83	-18.32*	-12.23*	-13.16*	-4.62*	-19.93*	-21.00*	-18.49*	-6.21*	-2.25	-8.10*	4.40	5.88
30	JMS 21A X JR 85	-9.90*	-3.19*	16.67*	19.74**	-19.47*	-20.54*	-0.89*	3.63	-10.49*	-15.85*	-1.65	-0.21
31	JMS 21A X JR 80	-15.84*	-9.57*	-17.48*	-6.08*	-0.67	-1.99	-8.09	10.01*	-7.87	-13.38*	-2.38	-0.61
32	JMS 21A X JMBR 44	-7.92*	-1.06	1.64	9.73*	-3.11	-4.40*	-11.32*	6.62*	-0.37	-6.34	-9.52*	-0.93
33	JMS 21A X JMBR 31	-7.92*	-1.06	10.06*	14.46*	-14.72*	-15.85*	-1.36	7.30*	4.12	-2.11	14.40*	14.40*
34	JMS 21A X JR 67	-15.84*	-9.57*	-6.59*	0.59	-11.02*	-12.20*	1.15	10.90*	-1.87	-7.75*	4.80	6.29
35	JMS 21A X JBR 6	-7.92*	-1.06	-4.12*	6.29*	-11.35*	-12.53*	-9.37*	4.10*	-2.62	-8.45*	7.00	8.56*
36	JMS 20A X JR 83	-9.90*	-3.19*	-4.21*	0.28	-5.05*	-6.31*	-3.34	2.17	2.62	-3.52	9.60*	13.69*
37	JMS 20A X JR 85	-26.73*	-21.28*	-14.45*	-7.79*	-24.56*	-25.56*	-13.92*	-11.5*	-11.99*	-17.25*	-0.42	0.43*
38	JMS 20A X JR 80	-14.85*	-8.51*	-16.50*	-9.23*	0.25	-1.08	-7.24*	2.45	-0.37	-6.34	5.56	9.92*
39	JMS 20A X JMBR 44	-10.40*	-3.72*	-1.09	1.69	-1.6	-2.90	-9.93*	-0.04	4.68	-1.58	-4.93	6.27
40	JMS 20A X JMBR 31	-7.92*	-1.06	7.51*	8.77*	-12.45*	-13.61*	-0.10	0.58	-2.25	-8.10*	7.41	9.89*
41	JMS 20A X JR 67	-9.90*	-3.19*	0.00	2.54*	-10.93*	-12.12*	1.24	1.44	-5.99	-11.62*	0.40	4.15
42	JMS 20A X JBR 6	-13.86*	-7.45*	-10.31*	-5.18*	-1.51	-2.82	0.69	6.21*	3.37	-2.82	16.95*	17.95*

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

(Contd.)

S. No	Crosses	No. of productive tillers per plant				1000- grain weight (g)				No. of grains per Panicle			
		SH		BPH	MPH	SH		BPH	MPH	SH		BPH	MPH
		HRI 174	US 312			HRI 174	US 312			HRI 174	US 312		
1	CMS 64A X JR 83	50.00*	41.18*	33.33*	37.14*	5.31	20.89*	12.71*	20.50*	-14.56	-16.18	2.84	6.68
2	CMS 64A X JR 85	6.25	0.00	-10.53	-5.56	-11.21*	1.93	9.13*	9.45*	-26.55*	-27.94*	-13.38	-9.60
3	CMS 64A X JR 80	18.75	11.76	11.76	11.76	6.30	22.04*	0.52	13.63*	24.84	22.48	61.94*	67.05*
4	CMS 64A X JMBR 44	31.25	23.53	23.53	27.27*	-2.54	11.88*	-8.97*	3.45	6.42	4.41	22.11	29.60*
5	CMS 64A X JMBR 31	6.25	0.00	-5.56	-2.86	4.67	20.16*	0.02	12.54*	-16.49	-18.07	8.33	22.07
6	CMS 64A X JR 67	0.00	-5.88	-5.88	-5.88	-15.90*	-3.45	-2.44	0.38	5.57	3.57	36.94*	47.83*
7	CMS 64A X JBR 6	6.25	0.00	0.00	6.25	-11.88*	1.17	8.32*	10.76*	-10.28	-11.97	-9.50	1.82
8	JMS 11A X JR 83	37.50*	29.41*	4.76	12.82	8.05*	24.04*	15.64*	27.72*	-22.27	-23.74	-6.44	2.98
9	JMS 11A X JR 85	-18.75	-23.53	-38.10*	-35.00*	-9.16*	4.29	12.30*	15.98*	-41.76*	-42.86*	-31.31*	-23.70
10	JMS 11A X JR 80	6.25	0.00	-19.05	-10.53	13.42*	30.21*	7.26*	24.98*	-9.85	-11.55	24.56	28.55
11	JMS 11A X JMBR 44	-6.25	-11.76	-28.57*	-18.92	6.06	21.76*	-0.93	16.03*	-10.49	-12.18	2.70	15.47
12	JMS 11A X JMBR 31	12.50	5.88	-14.29	-7.69	7.98*	23.97*	3.19	19.71*	-31.26*	-32.56*	1.26	7.72
13	JMS 11A X JR 67	12.50	5.88	-14.29	-5.26	1.79	16.86*	18.09*	25.70*	4.71	2.73	54.26*	56.73*
14	JMS 11A X JBR 6	6.25	0.00	-19.05	-5.56	-9.29*	4.14	16.63*	18.16*	-18.63	-20.17	-17.93	-2.56
15	JMS 19A X JR 83	18.75	11.76	5.56	15.15	-2.52	11.91*	4.33	22.44*	-3.43	-5.25	-6.24	3.80
16	JMS 19A X JR 85	-6.25	-11.76	-21.05	-11.76	-10.22*	3.07	10.99*	22.42*	1.07	-0.84	-1.87	7.64
17	JMS 19A X JR 80	12.50	5.88	5.88	12.50	6.35	22.09*	0.56	23.99*	15.63	13.45	12.27	31.87*
18	JMS 19A X JMBR 44	18.75	11.76	18.75	22.58	-7.19*	6.55	-13.30*	7.40*	16.06	13.87	12.68	22.07
19	JMS 19A X JMBR 31	25.00	17.65	11.11	21.21	-5.17	8.86*	-9.38*	11.28*	-2.36	-4.20	-5.20	20.00
20	JMS 19A X JR 67	12.50	5.88	5.88	12.50	-15.26*	-2.72	-1.69	11.51*	15.42	13.24	12.06	36.80*
21	JMS 19A X JBR 6	0.00	-5.88	6.67	6.67	-17.38*	-5.15	6.23	15.10*	50.32*	47.48*	45.95*	48.73*
22	CMS 52A X JR 83	37.50*	29.41*	22.22	22.22*	10.64*	27.01*	15.36*	16.87*	-35.76*	-36.97*	-22.68	-5.81
23	CMS 52A X JR 85	12.50	5.88	-5.26	-2.70	-0.46	14.27*	3.78	12.60*	-57.17	-57.98	-49.49	-37.98*

24	CMS 52A X JR 80	0.00	-5.88	-11.11	-8.57	10.44*	26.78*	4.43	9.53*	-2.57	-4.41	34.62	55.03*
25	CMS 52A X JMBR 44	6.25	0.00	-5.56	0.00	9.35*	25.54*	2.15	7.76*	-4.07	-5.88	10.07	36.59*
26	CMS 52A X JMBR 31	37.50*	29.41	22.22	22.22*	8.05*	24.04*	3.25	7.75*	-9.42	-11.13	51.61*	60.23*
27	CMS 52A X JR 67	6.25	0.00	-5.56	-2.86	1.68	16.73*	6.02	11.67*	-19.27	-20.80	22.80	35.61
28	CMS 52A X JBR 6	18.75	11.76	5.56	15.15	-9.38*	4.04	-5.51	4.35	6.42	4.41	7.34	39.61*
29	JMS 21A X JR 83	-31.25*	-35.29*	-38.89*	-29.03*	-2.85	11.53*	3.98	5.94	-28.48*	-29.83*	-13.92	-4.71
30	JMS 21A X JR 85	31.25*	23.53	10.53	31.25*	-16.98*	-4.70	-7.72*	-2.82	-8.99	-10.71	7.32	19.89
31	JMS 21A X JR 80	6.25	0.00	0.00	13.13	5.53	21.15*	-0.21	7.84*	8.78	6.72	50.30*	56.07*
32	JMS 21A X JMBR 44	12.50	5.88	12.50	24.14	5.31	20.89*	-1.63	6.90*	-5.57	-7.35	8.35	22.50
33	JMS 21A X JMBR 31	-6.25	-11.76	-16.67	-3.23	1.42	16.43*	-3.09	4.23	-28.69*	-30.04*	6.39	12.50
34	JMS 21A X JR 67	0.00	-5.88	-5.88	6.67	-0.04	14.75*	11.11*	13.48*	2.36	0.42	52.72*	54.19*
35	JMS 21A X JBR 6	0.00	-5.88	6.67	14.29	-13.27*	-0.43	-3.59	3.41	-6.85	-8.61	-6.05	12.11
36	JMS 20A X JR 83	43.75*	35.29*	27.78*	31.43*	-14.29*	-1.60	-8.26*	13.09*	-42.18*	-43.28*	-35.56*	-33.09*
37	JMS 20A X JR 85	-18.75	-23.53	-31.58*	-27.78*	-18.62*	-6.58	0.60	17.05*	12.42	10.29	25.30	28.83*
38	JMS 20A X JR 80	6.25	0.00	0.00	0.00	-2.85	11.53*	-8.13*	1854*	13.49	11.34	26.49	40.03*
39	JMS 20A X JMBR 44	12.50	5.88	5.88	9.09	7.59*	23.51*	0.50	30.24*	-1.93	-3.78	9.31	10.90
40	JMS 20A X JMBR 31	6.25	0.00	-5.56	-2.86	-17.62*	-5.43	-21.28*	1.20	13.92	11.76	26.97	52.44*
41	JMS 20A X JR 67	12.50	5.88	5.88	5.88	-28.31*	-17.69*	-16.83*	-0.67	-2.78	-4.62	8.35	25.07
42	JMS 20A X JBR 6	6.25	0.00	0.00	6.25	-23.82*	-12.54*	-2.05	12.09*	-2.36	-4.20	-1.51	3.40

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

(Contd.)

S. No	Crosses	Spikelet fertility (%)				Grain yield per plant (g)				Hulling (%)			
		SH		BPH	MPH	SH		BPH	MPH	SH		BPH	MPH
		HRI 174	US 312			HRI 174	US 312			HRI 174	US 312		
1	CMS 64A X JR 83	-0.51	2.03	-6.28	-0.77	79.83*	67.19*	32.10*	58.52*	2.59*	1.05*	-1.89*	3.46*
2	CMS 64A X JR 85	2.49	5.11	-13.37	-3.62	47.90*	37.50*	25.71*	41.94*	376*	2.20*	-0.77*	0.92*
3	CMS 64A X JR 80	-15.02	-12.85	-20.60*	-15.61	66.39*	54.69*	83.33*	86.79*	4.07*	2.51*	-0.47	2.35*
4	CMS 64A X JMBR 44	-0.07	2.48	-7.21	-1.09	80.67*	67.97*	85.34*	91.96*	1.11*	-0.41	-3.31*	-2.33*
5	CMS 64A X JMBR 31	4.10	6.76	-4.76	2.23	44.54*	34.38*	39.84*	48.92*	0.22*	-1.29*	-4.16*	-1.62*
6	CMS 64A X JR 67	-7.11	-4.73	-18.98*	-11.11	10.92*	3.13	9.09	15.28	3.15*	1.59*	-1.36*	0.25
7	CMS 64A X JBR 6	-2.86	-0.38	-5.56	-1.49	71.85*	59.77*	51.48*	68.31*	1.21*	-0.31	-3.21*	-1.16*
8	JMS 11A X JR 83	13.33	16.23	6.76	16.27	23.53*	14.84	-9.26	8.49	4.94*	3.36*	4.88*	8.29*
9	JMS 11A X JR 85	5.86	8.56	-10.53	2.23	-17.65	-23.44	-30.00	-21.29	2.93*	1.38*	1.83*	2.35*
10	JMS 11A X JR 80	-12.75	-10.52	-18.48	-10.89	47.06*	36.72*	60.55*	64.32*	2.47*	0.93*	2.41*	3.05*
11	JMS 11A X JMBR 44	-17.07	-14.95	-22.99*	-15.59	-0.84	-7.81	1.72	4.89	2.59*	1.05*	0.12	1.31*
12	JMS 11A X JMBR 31	-25.13*	-23.22*	-31.50*	-24.41*	5.04	-2.34	1.63	7.76	1.17*	-0.35	1.11*	1.57*
13	JMS 11A X JR 67	3.08	5.71	-10.10	1.33	36.13*	26.56	33.88*	40.87*	4.13*	2.57*	2.89*	3.48*
14	JMS 11A X JBR 6	14.21	17.13	11.04	19.19*	34.45*	25.00	18.52	31.15*	2.59*	1.05*	2.34*	2.44*
15	JMS 19A X JR 83	23.37*	26.52*	14.09	15.15	99.16*	85.16*	46.30*	78.20*	-3.80*	-5.25*	0.95*	1.77*
16	JMS 19A X JR 85	21.17*	24.27*	2.41	7.02	29.41*	20.31	10.00	26.23*	4.82*	3.24*	3.71*	6.76*
17	JMS 19A X JR 80	12.53	15.40	4.07	4.60	145.38*	128.13*	180.77*	180.77*	2.34*	0.80*	3.58*	5.45*
18	JMS 19A X JMBR 44	13.55	16.45	5.01	5.23	17.65	9.38	20.69	27.27*	2.84*	1.29*	0.36	4.00*
19	JMS 19A X JMBR 31	-3.59	-1.13	-11.80	-11.32	15.13	7.03	11.38	20.70	0.83*	-0.69	1.68*	3.70*
20	JMS 19A X JR 67	22.64*	25.77*	6.96	10.10	83.19*	70.31*	80.17*	93.78*	3.73*	2.17*	2.49*	5.57*
21	JMS 19A X JBR 6	20.22*	23.29*	11.18	13.96	108.40*	93.75*	83.70*	107.53*	2.90*	1.35*	2.65*	5.25*
22	CMS 52A X JR 83	1.90	4.51	-4.00	6.30	67.23*	55.47*	22.84*	50.19*	1.54*	0.01	0.52	4.27*
23	CMS 52A X JR 85	21.32*	24.42*	2.54	19.01*	0.84	-6.25	-14.29	-1.23	2.71*	1.17*	1.62*	1.65*
24	CMS 52A X JR 80	-7.25	-4.88	-13.35	-3.69	28.57*	19.53	47.12*	47.83*	2.90*	1.36*	1.87*	3.00*
25	CMS 52A X JMBR 44	2.20	4.81	-5.10	5.76	23.53	14.84	26.72*	34.25*	1.97*	0.43	-0.49	0.22
26	CMS 52A X JMBR 31	3.96	6.61	-4.89	6.69	77.31*	64.84*	71.54*	86.73*	0.78*	-0.74*	-0.23	0.69*
27	CMS 52A X JR 67	5.79	8.49	-7.73	5.67	17.65	9.38	15.70	25.00	3.63*	2.08*	2.40*	2.50*
28	CMS 52A X JBR 6	-4.10	-1.65	-6.77	1.79	57.14*	46.09*	38.52*	57.14*	1.51*	-0.01	0.50	0.88*
29	JMS 21A X JR 83	10.33	13.15	3.93	7.04	5.88	-1.56	-22.22*	0.40	2.56*	1.02*	9.40*	13.83*
30	JMS 21A X JR 85	9.16	11.95	-7.74	0.00	32.77*	23.44	12.86	37.99*	2.28*	0.74*	1.19*	9.08*
31	JMS 21A X JR 80	4.25	6.91	-2.60	0.71	4.20	-3.13	19.23	28.50	2.90*	1.35*	4.14*	11.08*
32	JMS 21A X JMBR 44	14.58	17.51	6.39	10.34	29.41*	20.31	32.76*	50.24*	1.99*	0.46	-0.46	7.97*
33	JMS 21A X JMBR 31	18.17	21.19*	8.11	12.92	35.29*	25.78	30.89*	51.89*	2.34*	0.80*	3.21*	10.27*
34	JMS 21A X JR 67	21.25*	24.34*	5.75	12.97	30.25*	21.09	28.10*	47.62*	3.83*	2.26*	2.59*	10.65*
35	JMS 21A X JBR 6	25.93*	29.15*	22.44*	24.16*	25.21	16.41	10.37	33.04	2.37*	0.83*	2.13*	9.67*
36	JMS 20A X JR 83	20.22*	23.29*	12.40	12.82	19.33	10.94	-12.35	1.07	1.48*	-0.04	5.20*	6.70*
37	JMS 20A X JR 85	26.37*	29.60*	6.81	12.20	-7.56	-14.06	-21.43	-15.06	0.06	-1.45	-1.01*	1.30*
38	JMS 20A X JR 80	3.44	6.09	-3.35	-3.32	19.33	10.94	19.33	27.35*	1.32*	-0.2	2.55*	3.77*

39	JMS 20A X JMBR 44	9.30	12.1	1.50	1.84	12.82	4.88	12.82	14.26	2.65*	1.11*	0.18	3.20*
40	JMS 20A X JMBR 31	11.58	14.43	2.08	3.18	23.53	14.84	19.51	21.49	-6.90*	-8.30*	-6.11*	-4.82*
41	JMS 20A X JR 67	-1.98	0.53	14.50	-11.54	32.35*	23.05	30.17*	31.25*	2.62*	1.08*	1.40*	3.83*
42	JMS 20A X JBR 6	11.50	14.35	4.25	6.28	39.50*	29.69*	22.96	30.71*	0.98*	-0.54	0.74*	2.67*

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

(Contd.)

S. No.	Crosses	Milling (%)				Head rice recovery (%)				Kernel length (mm)			
		SH		BPH	MPH	SH		BPH	MPH	SH		BPH	MPH
		HRI 174	US 312			HRI 174	US 312			HRI 174	US 312		
1	CMS 64A X JR 83	8.30*	6.01*	-3.39*	1.25	-15.88*	-19.58*	-19.57*	-17.98*	-1.71	-4.17*	-1.71	0.00
2	CMS 64A X JR 85	1.41	-0.73	-9.54*	-7.12*	-15.88*	-19.58*	-19.57*	-17.98*	-5.13*	-7.50*	-12.60*	-9.02*
3	CMS 64A X JR 80	5.28*	3.06*	-6.08*	-3.62*	-1.36	-5.70*	-14.20*	-8.45*	5.13*	2.50*	0.00	2.50*
4	CMS 64A X JMBR 44	-1.09	-3.18*	-13.64*	-12.72*	-26.61*	-29.83*	-28.35*	-27.68*	3.42*	0.83	-7.63*	-2.42*
5	CMS 64A X JMBR 31	0.85	-1.28	-10.04*	-4.90*	-18.22*	-21.82*	-18.65*	-17.99*	2.56	0.00	2.56	6.19*
6	CMS 64A X JR 67	-0.54	-2.64*	-11.28*	-6.65*	-13.98*	-17.77*	-24.53*	-19.80*	-3.42*	-5.83*	-3.42*	-3.42*
7	CMS 64A X JBR 6	4.52*	2.31*	-6.76*	-1.67*	-5.00*	-9.18*	-5.51*	0.68	1.71	-0.83	1.71	4.39*
8	JMS 11A X JR 83	4.41*	2.20*	1.17	1.84*	-9.82*	-13.78*	-13.78*	-4.52*	3.42*	0.83	3.42*	5.22*
9	JMS 11A X JR 85	-16.07	-17.85*	-21.03*	-19.87*	-22.37*	-25.78*	-25.78*	-17.80*	6.84*	4.17*	-1.57	2.46*
10	JMS 11A X JR 80	4.06*	1.86	-2.18*	-0.69	2.34	-2.16	-10.98*	2.71*	17.09*	14.17*	11.38*	14.17*
11	JMS 11A X JMBR 44	3.60*	1.42	-9.54*	-4.83*	0.75	-3.68*	-1.64	7.91*	15.38*	12.50*	3.05*	8.87*
12	JMS 11A X JMBR 31	-1.15	-3.23*	-4.21*	-2.69*	9.95*	5.11*	11.16*	20.02*	10.26*	7.50*	10.26*	14.16*
13	JMS 11A X JR 67	14.18*	11.77*	10.64*	11.83*	21.40*	16.06*	6.52*	22.46*	-3.42*	-5.83*	-3.42*	-3.42*
14	JMS 11A X JBR 6	1.96*	-0.19	-1.20	0.12	10.34*	5.49*	25.13*	27.95*	-1.71	-4.17*	-1.71	0.88
15	JMS 19A X JR 83	-5.45*	-7.45*	-7.15*	-6.74*	-11.28*	-15.18*	-15.17*	-13.38*	11.97*	9.17*	15.93*	16.96*
16	JMS 19A X JR 85	8.62*	6.32*	2.21*	4.84*	-1.18	-5.53*	-5.52*	-3.52*	-3.42*	-5.83*	-11.02*	-5.04*
17	JMS 19A X JR 80	6.17*	3.92*	-0.20	2.42*	13.88*	8.87*	-0.94	5.82*	5.13*	2.50*	0.00	5.13*
18	JMS 19A X JMBR 44	9.08*	6.78*	-4.76*	1.25	8.15*	3.40*	5.59*	6.72*	0.00	-2.50	-10.69*	-3.31*
19	JMS 19A X JMBR 31	7.04*	4.78*	6.05*	6.56*	6.80*	2.10*	6.52*	7.24*	1.71	-0.83	7.21*	8.18*
20	JMS 19A X JR 67	7.83*	5.55*	6.77*	6.80*	11.64*	6.73*	-2.04	4.23*	4.27*	1.67	4.27*	7.02*
21	JMS 19A X JBR 6	4.90*	2.68*	3.93*	4.16*	-4.57*	-8.77*	-4.82	1.28	-1.71	-4.17*	3.60*	3.60*
22	CMS 52A X JR 83	1.75	-0.40	-4.98*	-2.60*	6.35*	1.67	1.68	4.75*	10.26*	7.50*	14.16*	17.81*
23	CMS 52A X JR 85	0.07	-2.04	-6.54*	-6.19*	-13.89*	-17.68*	-17.67*	-15.19*	8.55*	5.83*	0.00	9.01*
24	CMS 52A X JR 80	0.88	-1.25	-5.79*	-5.48*	-18.41*	-22.00*	-29.03*	-23.54*	18.80*	15.83*	13.01*	21.40*
25	CMS 52A X JMBR 44	-5.73*	-7.72*	-17.69*	-14.93*	-22.46*	-25.87*	-24.30*	-22.80*	8.55*	5.83*	-3.05*	7.17*
26	CMS 52A X JMBR 31	1.91	-0.24	-4.83*	-1.56	-17.23*	-20.87*	-16.32	-16.13*	10.26*	7.50*	18.35*	20.00*
27	CMS 52A X JR 67	1.57	-0.58	-5.15*	-2.38*	-16.87*	-20.52*	-27.06*	-21.73*	13.68*	10.83*	13.68*	19.28*
28	CMS 52A X JBR 6	-2.95*	-5.00*	-9.37*	-6.49*	-27.41*	-30.60*	-26.27*	-22.21*	1.71	-0.83	7.21*	9.68*
29	JMS 21A X JR 83	-0.19	-2.30*	-1.99*	8.53*	-15.34*	-19.06*	-19.05*	-2.03	3.42*	0.83	7.08*	9.01*
30	JMS 21A X JR 85	4.16*	1.96*	-1.99*	10.59*	-0.19	-4.58*	-4.57*	15.49*	-3.42*	-5.83*	-11.02*	-4.24*
31	JMS 21A X JR 80	1.82	-0.33	-4.28*	8.05*	-15.70*	-19.40*	-26.67*	-7.97*	4.27*	1.67	-0.81	5.17*
32	JMS 21A X JMBR 44	-2.37*	-4.43*	-14.75*	-0.69	-15.43*	-19.14*	-17.43*	-0.90	8.55*	5.83*	-3.05*	5.83*
33	JMS 21A X JMBR 31	1.91	-0.24	1.93	11.94*	-7.35*	-11.42*	-6.33*	10.85*	6.84*	4.17*	14.68*	14.68*
34	JMS 21A X JR 67	-1.57	-3.65*	-2.54*	7.51*	-13.26*	-17.08*	-23.89*	-4.80*	0.00	-2.50	0.00	3.54*
35	JMS 21A X JBR 6	-3.93*	-5.96*	-4.39*	5.24*	-12.93*	-16.76*	-1.26	11.32*	-10.26*	-12.50*	-5.41*	-4.55*
36	JMS 20A X JR 83	3.29*	1.11	0.75	1.09	-13.33*	-17.14*	-17.13*	-9.82*	-5.13	-7.50	-1.77	5.71*
37	JMS 20A X JR 85	3.73*	1.54	-2.39*	-0.64	0.85	-3.59*	-3.58*	4.92*	0.00	-2.50*	-7.87*	4.46*
38	JMS 20A X JR 80	2.13*	-0.03	-3.99*	-2.22*	3.96*	-0.61	-9.57*	2.63*	1.71	-0.83	-3.25*	8.18*
39	JMS 20A X JMBR 44	6.03*	3.79*	-7.42*	-2.30*	-1.81	-6.13*	-4.14*	3.32*	10.26*	7.50*	-1.53	13.16*
40	JMS 20A X JMBR 31	-5.81*	-7.80*	-8.13*	-6.97*	-13.62*	-17.42*	-12.67*	-7.39*	-8.55*	-10.83*	-1.83	3.88*
41	JMS 20A X JR 67	1.04	-1.09	-1.45	-0.71	4.91*	0.30	-7.94*	4.08*	-6.84*	-9.17*	-6.84*	1.87
42	JMS 20A X JBR 6	0.88	-1.25	-1.60	0.61	-3.80*	-8.03*	9.10*	9.44*	1.71	-0.83	7.21*	14.42*

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

(Contd.)

S.No	Crosses	Kernel breadth (mm)				Kernel L/B ratio			
		SH		BPH	MPH	SH		BPH	MPH
		HRI 174	US 312			HRI 174	US 312		
1	CMS 64A X JR 83	-12.2*	-14.29*	-2.70	2.86	12.08	11.89	-9.86	-3.40
2	CMS 64A X JR 85	-14.63*	-16.67*	6.06	6.06	11.21	11.01	-17.53*	-14.19*
3	CMS 64A X JR 80	-19.51*	-21.43*	-8.33	-4.35	30.65*	30.42*	5.07	7.11
4	CMS 64A X JMBR 44	-12.20*	-14.29*	-5.26	1.41	18.04*	17.83*	-5.07	-3.65

5	CMS 64A X JMBR 31	-9.76	-11.90*	0.00	5.71	13.66*	13.46*	-8.59	-0.46
6	CMS 64A X JR 67	-7.32	-9.52	8.57	11.76*	4.55	4.37	-15.92*	-13.42*
7	CMS 64A X JBR 6	-14.63*	-16.67*	2.94	4.48	20.14*	19.93*	-3.38	0.51
8	JMS 11A X JR 83	-19.51*	-21.43*	-10.81	-2.94	29.60*	29.37*	-2.12	7.95
9	JMS 11A X JR 85	-9.76	-11.90*	12.12	15.62*	18.39*	18.18*	-12.21*	-11.40*
10	JMS 11A X JR 80	-4.88	-7.14	8.33	16.42*	23.12*	22.90*	-7.01	-2.29
11	JMS 11A X JMBR 44	0.00	-2.38	7.89	18.84*	15.41*	15.21*	-12.83*	-8.79
12	JMS 11A X JMBR 31	-7.32	-9.52	2.70	11.76*	18.91*	18.71*	-10.19*	0.59
13	JMS 11A X JR 67	-9.76	-11.90*	5.71	12.12*	7.71	7.52	-18.65*	-13.68*
14	JMS 11A X JBR 6	-9.76	-11.90*	8.82	13.85*	8.93	8.74	-17.72*	-11.84*
15	JMS 19A X JR 83	-4.88	-7.14	541	5.41	17.69*	17.48*	9.27	10.53
16	JMS 19A X JR 85	-4.88	-7.14	5.41	11.43*	1.58	1.40	-24.68*	-15.39*
17	JMS 19A X JR 80	-4.88	2.38	16.22*	17.81*	0.18	0.00	-16.25*	-10.90*
18	JMS 19A X JMBR 44	-9.76	-11.90*	-2.63	-1.33	10.86	10.66	-8.13	-1.86
19	JMS 19A X JMBR 31	9.76	7.14	21.62*	21.62*	-7.36	-7.52	-11.98	-11.46*
20	JMS 19A X JR 67	4.88	2.38	16.22*	19.44*	-0.53	-0.70	-15.10*	-10.55*
21	JMS 19A X JBR 6	-9.76	-11.90*	0.00	4.23	8.93	8.74	-5.04	-0.96
22	CMS 52A X JR 83	0.00	-2.38	10.81	10.81*	10.33	10.14	2.44	6.06
23	CMS 52A X JR 85	-9.76	-11.90*	0.00	5.71	20.49*	20.28*	-10.65*	2.46
24	CMS 52A X JR 80	-9.76	-11.90*	0.00	1.37	31.70*	31.47*	10.10	19.75*
25	CMS 52A X JMBR 44	-4.88	-7.14	2.63	4.00	14.19*	13.99*	-5.37	3.33
26	CMS 52A X JMBR 31	-2.44	-4.76	8.11	8.11	13.31*	13.11*	8.92	10.88
27	CMS 52A X JR 67	-7.32	-9.52	2.70	5.56	22.94*	22.73*	4.93	13.04*
28	CMS 52A X JBR 6	-4.88	-7.14	5.41	9.86	7.01	6.82	-6.72	-0.49
29	JMS 21A X JR 83	0.00	-2.38	7.89	9.33	3.50	3.32	-3.90	-0.51
30	JMS 21A X JR 85	-7.32	-9.52	0.00	7.04	4.38	4.20	-22.60*	-11.24*
31	JMS 21A X JR 80	0.00	-2.38	7.89	10.81*	4.20	4.02	-12.88*	-5.25
32	JMS 21A X JMBR 44	-2.44	-4.76	5.26	5.26	11.21	11.01	-7.84	0.63
33	JMS 21A X JMBR 31	-9.76	-11.90*	-2.63	-1.33	18.39*	18.18*	13.80*	15.85*
34	JMS 21A X JR 67	-7.32	-9.52	0.00	4.11	7.88	7.69	-7.92	-0.81
35	JMS 21A X JBR 6	-7.32	-9.52	0.00	5.56	-2.98	-3.51	-15.42*	-9.77
36	JMS 20A X JR 83	0.00	-2.38	10.81	20.59*	-5.08	-5.24	-13.56	-12.72*
37	JMS 20A X JR 85	-9.76	-11.90*	12.12	15.62*	10.86	10.66	-17.79*	-9.38*
38	JMS 20A X JR 80	-2.44	-4.76	11.11	19.40*	4.20	4.02	-12.88*	-9.16
39	JMS 20A X JMBR 44	-9.76	-11.90*	-2.63	7.25	22.24*	22.03*	1.31	6.08
40	JMS 20A X JMBR 31	0.00	-2.38	10.81	20.59*	-8.58	-8.74	-16.75*	-14.50*
41	JMS 20A X JR 67	-14.60*	-16.67*	0.00	6.06	9.28	9.09	-6.73	-3.7
42	JMS 20A X JBR 6	-4.88	-7.14	14.71*	20.00*	7.01	6.82	-6.72	-4.68

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

The highest standard heterosis of 145.38 % was recorded in JMS 19A X JR 80 followed by JMS 19A X JBR 6 (108.40 %) and JMS 19A X JR 67 (83.19 %) over HRI 174 and by JMS 19A X JR 80 (128.13 %) followed by JMS 19A X JBR 6 (112.42 %) and JMS 19A X JR 67 (86.72 %) over US 312. Further, the hybrid JMS 19A X JR 80 exhibited the highest heterobeltiosis and relative heterosis of 180.77 % for grain yield per plant and identified as the best hybrid.

Maximum negative standard heterosis of -26.73 % (over HRI 174) and -21.28 % (over US 312) for days to 50 % flowering, was observed in the hybrids CMS 64AX JR85, JMS 11 A X JR 85, JMS 19A X JR 85, CMS 52 A X JR 85 and JMS 20A X JR 85. Maximum negative heterosis was registered by hybrid CMS 64A X JR 85 over better parent (-19.57 %) and JMS 19A X JR 85 over mid parent (-12.68 %). The maximum significant negative standard heterosis for plant height was manifested by JMS 20A X JR 85 *viz.*, -24.56 % over HRI 174 and -25.56 % over US 312. The hybrid JMS 21A X JR 83 recorded maximum negative heterotic effect over better parent (-18.49%) and JMS 20A X JR 85 recorded maximum relative heterosis of -11.54 %. CMS 64A X JR 80 exhibited positive and significant heterobeltiosis (17.06 %) and relative heterosis (21.15 %). CMS 52A X JMBR 44 showed high standard heterosis to the extent of 19.48 % over HRI 174 and 12.32 % over US 312 for panicle length. In the case of productive tillers per plant, hybrid CMS 64A X JR 83 recorded the highest heterosis over standard checks HRI 174 (50.00 %) and US 312 (41.18 %), better parent (33.33 %) and mid parent (37.14 %). Maximum, significant positive heterotic effect for 1000-grain weight over better parent 15.64 % and mid parent 27.72 % was recorded in JMS 11A X JR 83. Hybrid JMS 11A X JR 80 recorded the highest standard heterosis of 13.42 % (over HRI 174) and 30.21 % (over US 312). Hybrid JMS 19A X JBR 6 showed significant positive heterosis for the number of grains per panicle over HRI 174 (50.32 %) and US 312 (47.48 %), whereas hybrid CMS 64A X JR 80 recorded high significant positive heterosis over better parent (61.94 %) and mid parent (67.05 %). The highest significant heterosis was recorded by the cross JMS 20A X JR 85 over checks HRI 174 (26.37 %) and US 312 (29.60 %). Maximum positive significant heterotic effects over better parent 22.44 % and mid parent 24.16 % was exhibited by the cross JMS 21A X JBR 6. The highest standard heterosis of 4.94 % (over HRI 174) and 3.36 % (over US 312) and heterobeltiosis of 4.88 % were exploited in JMS 11A X JR 83 for hulling percentage. The hybrid JMS 11A X JR 67 registered significant positive standard heterosis, heterobeltiosis and relative heterosis for milling percentage. Hybrid JMS 11A X JBR 6 recorded high heterobeltiosis (25.13 %) and relative heterosis (27.95 %) for head rice recovery in a positive direction. The highest standard heterosis was observed in the cross JMS 11A X JR 67 over HRI 174 (21.40 %) and US 312 (16.06 %) for head rice recovery percentage. Hybrid CMS 52A X JR 80 exhibited high positive standard heterosis, heterobeltiosis and relative heterosis for kernel length. For kernel breadth, high positive standard heterosis, heterobeltiosis and relative heterosis were recorded by JMS 19A X JMBR 31. For kernel L/B ratio maximum heterobeltiosis and relative heterosis of 13.68 % and 13.04 % was registered in CMS 52A X JR 67. The hybrid CMS 52A X JR 80 recorded the highest significant and positive heterosis of 31.70 % (over HRI 174) and 31.47 % (over US 312) for this trait.

A full understanding of genetic basis of heterosis and combining ability remains elusive (Birchler, 2015) [5]. Which, however, does not affect the vital role heterosis and combining ability play in rice breeding. Combining heterosis in different traits such as yield-related traits and stress tolerance could improve gain yield (Fujimoto *et al.*, 2018) [10]. Although heterosis was greatly affected by environmental variables, it is a quantifiable, trait-specific phenotype. To be commercially advantageous, a hybrid should outperform its parents with respect to agronomic traits, especially the traits related to grain yield. Normally, grain yield heterosis is an important indicator of yield potential. Based on our analysis, lines, JMS 19A, JMS 21A and testers JR 67, JBR 6 had highly significant positive GCA effects for yield-related traits, which should have contributed to the improved hybrid yield. The hybrid JMS 19A X JR 80 (Fig. 1) provided high mean grain yield and possessed desirable significant-high SCA effects and positive heterosis for grain yield per plant (g) with a moderate resistance to gall midge. As a result, this hybrid could be used in breeding for high yielding and wide-adaptability. Consequently, elite inbred lines with improved combining ability and associated heterotic patterns could be explored for efficient hybrid breeding. Moaz S. Eltahawy *et al*. (2020) [17]. Undertook similar studies and identified thirty-nine significant SNPLDBs loci associated with the GCA of 9 quality-related traits in rice. They found that the genetic basis of trait GCA in parents is different from that of the trait itself.

JMS 19A X JR 80

Fig 1: Most promising experimental hybrid (JMS 19A X JR 80) identified in the present investigation based on overall performance

Conclusion

Information regarding combining ability is very important to select desirable parents and crosses. GCA analysis identified inbred lines JMS 21A, JMS 20A and restorers JBR 6, JR 67 and JMBR 44 as good general combiners for grain yield per plant and gall midge resistance. SCA effect analysis recognized that eight crosses were good specific combiners for grain yield per plant. Heterosis studies identified the hybrid JMS 19A X JR 80 with high mean grain yield, significant-high SCA effects and positive heterosis for grain yield per plant (g) with a moderate resistance to gall midge. So, this cross-combination with desirable SCA effects and better yield performance would be tested in a multi-location trial.

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