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DEVELOPING GALL MIDGE RESISTANT RICE (*ORYZA SATIVA* L.) HYBRIDS USING THREE LINE APPROACH

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ABSTRACT

Six cytoplasmic male sterile lines (CMS) and seven testers of rice procured from Regional Agricultural Research Station (RARS), Polasa, Jagtial were crossed in Line × Tester mating design to develop heterotic rice hybrids resistant to gall midge. Among six CMS (Cytoplasmic Male Sterile) lines evaluated, the lines JMS 19A and JMS 20A had desired performance. The highest standard heterosis for grain yield and other yield attributes over the check varieties (US 312 and JGL 384) was recorded in the cross combination JMS 19A × JR 80 followed by JMS 19A × JBR 6 and JMS 19A × JR 83 involving these CMS lines. Further, these crosses exhibited moderate resistance to gall midge. Therefore, these aforesaid lines are promising genotypes in the future to develop successful three-line gall midge resistant rice hybrids for the Northern Telangana zone.

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). This population will increase to over 4.6 billion by 2050 (Honarnejad *et al*., 2000) 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, Srividya *et al*., 2010). 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). Plant breeding strategies leading to the selection of hybrids need the expected level of heterosis as well as the specific combining ability. In breeding high yielding varieties of crop plants for qualitative and quantitative traits, plant breeders often face the problem of selecting parents and crosses. 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). In the F_1 hybrids, the effect of heterosis is expected to show increased grain yield and resistance to biotic and abiotic stresses. The heterosis has been widely used in rice by several workers like Ranjith Raja Ram *et al*. (2019) and Gowayed Salah *et al*. (2020). 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. In the light of the above facts and considering the potentials of resistance breeding, the present study was undertaken.

MATERIALS AND METHODS

Experimental details and field layout

Experimental field trials were carried out during *Rabi* 2016 and *Kharif* 2017 at Regional Agricultural Research Station (RARS), Polasa, Jagtial. During *Rabi* 2016, six wild abortive (WA) CMS lines along with their seven testers were characterized for yield and its component traits. Test crosses were made during the same year between six CMS lines and seven testers in Line X Tester mating design. In *Kharif* 2017, the seeds of 42 F_1 hybrids along with parents and checks were planted in the field to identify best restorers among the male parents based on spikelet fertility. Heterosis was estimated over better parent and over two standard checks (US 312 and JGL 384) for various traits of commercial importance to identify best performing hybrids. During both seasons of the study, planting material was raised in a randomized complete block design (RCBD) with two replications. Each entry was planted in two rows of four meters length with a spacing of 20 × 15 cm. Standard agronomical packages of practices were followed to raise good crops. The plant protection measures were not taken to record the incidence of gall midge. Ten plants of each entry were randomly selected to record data on gall midge resistance, yield and other related traits. Based on the spikelet fertility percentage, the genotypes were classified as per the criteria proposed by Govinda and Virmani (1988) and Virmani *et al.* (1997) i.e., effective restorers (spikelet fertility >75%), partial restorers (spikelet fertility: 50.1-75%).

Screening for gall midge resistance

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 US 312 and resistant check JGL 384. For scoring the gall midge incidence a total number of tillers and the total number of tillers with silver shoot were recorded and the per cent tiller infestation was calculated as follows

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

To check the level of resistance or susceptibility, the percentage silver shoot in each entry in each replication was converted to a 0-9 scale by following the IRRI Standard Evaluation System (SES) given in Table 1.

Statistical analysis

The data generated was subjected to statistical analysis. To estimate the significance of differences among the genotypes (hybrids, parents and checks), the mean data for each character was subjected to Analysis of Variance (ANOVA). The t-test was applied to determine the significant difference of F_1 hybrids from respective better parents and standard checks (US 312 and JGL 384) using the formulae suggested by Wynne *et al.* (1970).

RESULTS AND DISCUSSION

Evaluation of fertility restoration, yield and its related traits

In the present investigation, the ANOVA revealed a considerable amount of variation among the genotypes for all the traits under study (Table 2).

The CMS line JMS 20A followed by JMS 19A exhibited desirable performance for most of the yield-related characters such as the number of productive tillers per plant and the number of grains per panicle.The lines also recorded the lowest gall midge incidence when compared with other CMS lines. A large number of productive tillers is a desirable trait and in this study the highest number of productive tillers among CMS lines were recorded in JMS 20A (10.50). High seed yield is the ultimate aim of any crop improvement program. Seed yield for CMS lines was recorded in their respective maintainer lines. In this study, the highest grain yield per plant was recorded in JMS20B (23.80 g/plant) followed by JMS 19B (21.80 g/plant). Based on the overall performance of CMS lines, JMS 20A followed by JMS 19A may be considered as most promising for the development of hybrids with resistance to gall midge (Table 3).

The 42 crosses derived from the CMS lines were evaluated for spikelet fertility. Spikelet fertility is an important criterion for identifying restorer (Ikehashi and Araki, 1984; Virmani, 1996). Based on the estimates, male parents were classified into 18 effective restorers, and 24 partial restorers (Table 4). In crosses 43% effective fertility restoration and 57% partial fertility restoration was observed (Figure 1). In this study, the cross combination which had the highest restoration ability was JMS 20A × JR 85 and minimum restoration ability was exhibited by JMS 11A × JMBR 31.

Screening for gall midge resistance

Northern Telangana region is a traditional area for gall midge biotype-3 and varieties immune to biotype-3 have been developed and extensively grown by the farming community. To develop resistant varieties to a mixed population of gall midge, thirteen parents having different resistant genes and their forty-two single crosses along with two checks were screened in the present study.

The results revealed that among lines JMS 20B was highly resistant with no damage and JMS 21B and JMS 19B were recorded as resistant and moderately resistant and the tester JR 85 was found to be moderately resistant to gall midge damage.

Table 1: Standard Evaluation Systems for evaluating rice gall midge (IRRI)

Scale	Damaged plants (silver shoots)	Reaction
0	No damage	Highly resistant (HR)
1	Less than 1%	Resistant (R)
3	1-5 %	Moderately Resistant (MR)
5	6-10 %	Moderately Susceptible (MS)
7	11-25 %	Susceptible (HS)
9	More than 25%	Highly Susceptible (S)

Table 2: Analysis of variance for yield and its attributing traits

S. No	Characters	Mean squares Replication (d.f.= 1)	Treatment (d.f.= 12)	Error (d.f.= 12)
1	No. of productive tillers/ plant	16.96	2.00	1.13
2	Spikelet fertility (%)	33.93	83.90**	50.76
3	No. of grains per Panicle	32.35	2464.49*	563.85
4	1000 grain weight (g)	0.20	23.45**	0.54
5	Grain yield per plant (g)	4.83	29.25**	4.13
6	Incidence of gall midge (%)	6.33	85.26**	2.39

*,** = Significant at 0.05 and 0.01 respectively

Table 3: Gall midge incidence, yield and its attributing traits of CMS lines and testers

Lines and testers	No. of productive tillers/ plant	1000 grain weight (g)	No. of grains per panicle	Spikelet fertility (%)	Grain yield per plant (g)	Incidence of gall midge (%)
CMS 64B	8.50	18.40	180.00	64.40	21.60	12.22
JMS 11B	8.50	17.13	158.50	60.60	20.80	16.25
JMS 19B	9.00	14.87	240.50	73.80	21.80	1.61
CMS 52B	7.50	21.69	124.50	58.40	20.60	13.05
JMS 21B	6.50	20.34	156.50	68.25	17.80	1.81
JMS 20B	10.50	13.15	209.50	73.00	23.80	0.00
JR 83	9.00	21.12	194.00	72.45	32.40	18.05
JR 85	9.50	18.29	198.00	80.75	28.00	1.01
JR 80	8.50	23.91	169.00	73.05	20.80	8.95
JMBR 44	8.00	24.20	203.50	73.50	23.20	9.12
JMBR 31	9.00	23.66	139.50	74.60	24.60	11.61
JR 67	8.50	19.49	153.50	78.25	24.20	18.40
JBR 6	7.50	17.58	231.50	70.20	27.00	6.94

Table 4: Evaluation of crosses for identification of restorers

Sl. No.	Cross	Spikelet fertility (%)	Inference
1	CMS 64A × JR 83	67.90	Partial restoration
2	CMS 64A × JR 85	69.95	Partial restoration
3	CMS 64A × JR 80	58.00	Partial restoration
4	CMS 64A × JMBR 44	68.20	Partial restoration
5	CMS 64A × JMBR 31	71.05	Partial restoration
6	CMS 64A × JR 67	63.40	Partial restoration
7	CMS 64A × JBR 6	66.30	Partial restoration
8	JMS 11A × JR 83	77.35	Effective restoration
9	JMS 11A × JR 85	72.25	Partial restoration
10	JMS 11A × JR 80	59.55	Partial restoration
11	JMS 11A × JMBR 44	56.60	Partial restoration
12	JMS 11A × JMBR 31	51.10	Partial restoration
13	JMS 11A × JR 67	70.35	Partial restoration
14	JMS 11A × JBR 6	77.95	Effective restoration
15	JMS 19A × JR 83	84.20	Effective restoration
16	JMS 19A × JR 85	82.70	Effective restoration
17	JMS 19A × JR 80	76.80	Effective restoration
18	JMS 19A × JMBR 44	77.50	Effective restoration
19	JMS 19A × JMBR 31	65.80	Partial restoration
20	JMS 19A × JR 67	83.70	Effective restoration
21	JMS 19A × JBR 6	82.05	Effective restoration
22	CMS 52A × JR 83	69.55	Partial restoration
23	CMS 52A × JR 85	82.80	Effective restoration
24	CMS 52A × JR 80	63.30	Partial restoration
25	CMS 52A × JMBR 44	69.75	Partial restoration
26	CMS 52A × JMBR 31	70.95	Partial restoration
27	CMS 52A × JR 67	72.20	Partial restoration
28	CMS 52A × JBR 6	65.45	Partial restoration
29	JMS 21A × JR 83	75.30	Effective restoration
30	JMS 21A × JR 85	74.50	Partial restoration
31	JMS 21A × JR 80	71.15	Partial restoration
32	JMS 21A × JMBR 44	78.20	Effective restoration
33	JMS 21A × JMBR 31	80.65	Effective restoration
34	JMS 21A × JR 67	82.75	Effective restoration
35	JMS 21A × JBR 6	85.95	Effective restoration
36	JMS 20A × JR 83	82.05	Effective restoration
37	JMS 20A × JR 85	86.25	Effective restoration
38	JMS 20A × JR 80	70.60	Partial restoration
39	JMS 20A × JMBR 44	74.60	Partial restoration
40	JMS 20A × JMBR 31	76.15	Effective restoration
41	JMS 20A × JR 67	66.90	Partial restoration
42	JMS 20A × JBR 6	76.10	Effective restoration

Table 5: Reaction of genotypes against gall midge

S. No.	Genotypes	Damaged plants(silver shoots)	Scale(0-9)	Gall midge reaction
1	CMS 64B	11-25 %	7	Susceptible
2	JMS 11B	11-25 %	7	Susceptible
3	JMS 19B	1-5 %	3	Moderately resistant
4	CMS 52B	11-25 %	7	Susceptible
5	JMS 21B	Less than 1%	1	Resistant
6	JMS 20B	No damage	0	Highly resistant
7	JR 83	11-25 %	7	Susceptible
8	JR 85	1-5 %	3	Moderately resistant
9	JR 80	6-10 %	5	Moderately susceptible
10	JMBR 44	6-10 %	5	Moderately susceptible
11	JMBR 31	11-25 %	7	Susceptible
12	JR 67	11-25 %	7	Susceptible
13	JBR 6	6-10 %	5	Moderately susceptible
14	CMS 64A × JR 83	11-25 %	7	Susceptible
15	CMS 64A × JR 85	1-5 %	3	Moderately resistant
16	CMS 64A × JR 80	6-10 %	5	Moderately susceptible
17	CMS 64A × JMBR 44	1-5 %	3	Moderately resistant
18	CMS 64A × JMBR 31	11-25 %	7	Susceptible
19	CMS 64A × JR 67	11-25 %	7	Susceptible
20	CMS 64A × JBR 6	6-10 %	5	Moderately susceptible
21	JMS 11A × JR 83	11-25 %	7	Susceptible
22	JMS 11A × JR 85	1-5 %	3	Moderately resistant
23	JMS 11A × JR 80	6-10 %	5	Moderately susceptible
24	JMS 11A × JMBR 44	11-25 %	7	Susceptible
25	JMS 11A × JMBR 31	11-25 %	7	Susceptible
26	JMS 11A × JR 67	6-10 %	5	Moderately susceptible
27	JMS 11A × JBR 6	1-5 %	3	Moderately resistant
28	JMS 19A × JR 83	1-5 %	3	Moderately resistant
29	JMS 19A × JR 85	No damage	0	Highly resistant
30	JMS 19A × JR 80	1-5 %	3	Moderately resistant
31	JMS 19A × JMBR 44	No damage	0	Highly resistant
32	JMS 19A × JMBR 31	1-5 %	3	Moderately resistant
33	JMS 19A × JR 67	Less than 1%	1	Resistant
34	JMS 19A × JBR 6	1-5 %	3	Moderately resistant
35	CMS 52A × JR 83	11-25 %	7	Susceptible
36	CMS 52A × JR 85	1-5 %	3	Moderately resistant
37	CMS 52A × JR 80	6-10 %	5	Moderately susceptible
38	CMS 52A × JMBR 44	11-25 %	7	Susceptible
39	CMS 52A × JMBR 31	11-25 %	7	Susceptible
40	CMS 52A × JR 67	11-25 %	7	Susceptible
41	CMS 52A × JBR 6	6-10 %	5	Moderately susceptible
42	JMS 21A × JR 83	Less than 1%	1	Resistant
43	JMS 21A × JR 85	1-5 %	3	Moderately resistant
44	JMS 21A × JR 80	1-5 %	3	Moderately resistant
45	JMS 21A × JMBR 44	Less than 1%	1	Resistant
46	JMS 21A × JMBR 31	Less than 1%	1	Resistant
47	JMS 21A × JR 67	Less than 1%	1	Resistant
48	JMS 21A × JBR 6	1-5 %	3	Moderately resistant
49	JMS 20A × JR 83	1-5 %	3	Moderately resistant
50	JMS 20A × JR 85	1-5 %	3	Moderately resistant
51	JMS 20A × JR 80	1-5 %	3	Moderately resistant
52	JMS 20A × JMBR 44	6-10 %	5	Moderately susceptible
53	JMS 20A × JMBR 31	6-10 %	5	Moderately susceptible
54	JMS 20A × JR 67	Less than 1%	1	Resistant
55	JMS 20A × JBR 6	1-5 %	3	Moderately resistant
57	US 312	11-25 %	7	Susceptible
59	JGL 384	No damage	0	Highly resistant

Among crosses, the crosses JMS 19A × JR 85 and JMS 19A × JMBR 44 were found highly resistant to gall midge with no silver shoots and the crosses JMS 19A × JR 67, JMS 21A × JR 83, JMS 21A × JMBR 44, JMS 21A × JMBR 31, JMS 21A × JR 67 and JMS 20A × JR 67 were resistant with scale less than one. Whereas, thirteen crosses *viz.*, CMS 64A × JR85, CMS 64A × JMBR44, JMS 11A × JR 85, JMS 11A × JBR6, JMS 19A × JR 83, JMS 19A × JR 80, JMS 19A × JMBR 31, JMS 19A × JBR 6, CMS 52A × JR 85, JMS 21A × JR 85, JMS 21A × JR 80, JMS 21A × JBR 6, JMS 20A × JR 83, JMS 20A × JR 85, JMS

Table 6: Estimates of heterosis of crosses over better parent and standard checks

Crosses	Productive tillers per plant			Spikelet fertility (%)			No. of grains per panicle			1000-grain weight (g)			Grain yield per plant (g)		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
CMS 64A × JR 83	33.33*	41.18*	95.12*	-6.28	2.03	16.17	2.84	-16.18	-21.3	12.71*	20.89*	61.10*	32.10*	67.19*	83.30*
CMS 64A × JR 85	-10.53	0.00	38.21*	-13.37	5.11	19.67	-13.38	-27.94*	-32.35*	9.13*	1.93	35.83*	25.71*	37.50*	50.75*
CMS 64A × JR 80	11.76	11.76	54.47*	-20.60*	-12.85	-0.77	61.94*	22.48	14.99	0.52	22.04*	62.62*	83.33*	54.69*	69.59*
CMS 64A × JMBR 44	23.53	23.53	70.73*	-7.21	2.48	16.68	22.11	4.41	-1.97	-8.97*	11.88*	49.09*	85.34*	67.97*	84.15*
CMS 64A × JMBR 31	-5.56	0.00	38.21*	-4.76	6.76	21.56	8.33	-18.07	-23.08	0.02	20.16*	60.12*	39.84*	34.38*	47.32*
CMS 64A × JR 67	-5.88	-5.88	30.08	-18.98*	-4.73	8.47	36.94*	3.57	-2.76	-2.44	-3.45	28.65*	9.09	3.13	13.06
CMS 64A × JBR 6	0.00	0.00	38.21*	-5.56	-0.38	13.43	-9.50	-11.97	-17.36	8.32*	1.17	34.81*	51.48*	59.77*	75.16*
JMS 11A × JR 83	4.76	29.41*	78.86*	6.76	16.23	32.34*	-6.44	-23.74	-28.40*	15.64*	24.04*	65.29*	-9.26	14.84	25.91
JMS 11A × JR 85	-38.10*	-23.53	5.69	-10.53	8.56	23.61*	-31.31*	-42.86*	-46.35*	12.30*	4.29	38.97*	-30.00	-23.44	-16.06
JMS 11A × JR 80	-19.05	0.00	38.21*	-18.48	-10.52	1.88	24.56	-11.55	-16.96	7.26*	30.21*	73.51*	60.55*	36.72*	49.89*
JMS 11A × JMBR 44	-28.57*	-11.76	21.95	-22.99*	-14.95	-3.17	2.70	-12.18	-17.55	-0.93	21.76*	62.25*	1.72	-7.81	1.07
JMS 11A × JMBR 31	-14.29	5.88	46.34*	-31.50*	-23.22*	-12.57	1.26	-32.56*	-36.69*	3.19	23.97*	65.19*	1.63	-2.34	7.07
JMS 11A × JR 67	-14.29	5.88	46.34*	-10.10	5.71	20.36	54.26*	2.73	-3.55	18.09*	16.86*	55.72*	33.88*	26.56	38.76*
JMS 11A × JBR 6	-19.05	0.00	38.21*	11.04	17.13	33.36*	-17.93	-20.17	-25.05*	16.63*	4.14	38.77*	18.52	25.00	37.04*
JMS 19A × JR 83	5.56	11.76	54.47*	14.09	26.52*	44.05*	-6.24	-5.25	-11.05	4.33	11.91*	49.12*	46.30*	85.16*	103.00*
JMS 19A × JR 85	-21.05	-11.76	21.95	2.41	24.27*	41.49*	-1.87	-0.84	-6.90	10.99*	3.07	37.35*	10.00	20.31	31.91*
JMS 19A × JR 80	5.88	5.88	46.34*	4.07	15.40	31.39*	12.27	13.45	-6.51	0.56	22.09*	62.69*	180.77*	128.13*	150.11*
JMS 19A × JMBR 44	18.75	11.76	54.47*	5.01	16.45	32.59*	12.68	13.87	6.90	-13.30*	6.55	41.98*	20.69	9.38	19.91
JMS 19A × JMBR 31	11.11	17.65	62.60*	-11.80	-1.13	12.57	-5.20	-4.20	-10.06	-9.38*	8.86*	45.06*	11.38	7.03	17.34
JMS 19A × JR 67	5.88	5.88	46.34*	6.96	25.77*	43.20*	12.06	13.24	6.31	-1.69	-2.72	29.63*	80.17*	70.31*	86.72*
JMS 19A × JBR 6	6.67	-5.88	30.08	11.18	23.29*	40.38*	45.95*	47.48*	38.46*	6.23	-5.15	26.39*	83.70*	93.75*	112.42*
CMS 52A × JR 83	22.22	29.41*	78.86*	-4.00	4.51	18.99	-22.68	-36.97*	-40.83*	15.36*	27.01*	69.25*	22.84*	55.47*	70.45*
CMS 52A × JR 85	-5.26	5.88	46.34*	2.54	24.42*	41.66*	-49.49	-57.98	-60.55*	3.78	14.27*	52.27*	-14.29	-6.25	2.78
CMS 52A × JR 80	-11.11	-5.88	30.08	-13.35	-4.88	8.30	34.62	-4.41	-10.26	4.43	26.78*	68.94*	47.12*	19.53	31.05*
CMS 52A × JMBR 44	-5.56	0.00	38.21*	-5.10	4.81	19.33	10.07	-5.88	-11.64	2.15	25.54*	67.29*	26.72*	14.84	25.91
CMS 52A × JMBR 31	22.22	29.41	78.86*	-4.89	6.61	21.39	51.61*	-11.13	-16.57	3.25	24.04*	65.29*	71.54*	64.84*	80.73*
CMS 52A × JR 67	-5.56	0.00	38.21*	-7.73	8.49	23.52*	22.80	-20.80	-25.64*	6.02	16.73*	55.55*	15.70	9.38	19.91
CMS 52A × JBR 6	5.56	11.76	54.47*	-6.77	-1.65	11.98	7.34	4.41	-1.97	-5.51	4.04	38.63*	38.52*	46.09*	60.17*
JMS 21A × JR 83	-38.89*	-35.29*	-10.57	3.93	13.15	28.83	-13.92	-29.83*	-34.12*	3.98	11.53*	48.61*	-22.22*	-1.56	7.92
JMS 21A × JR 85	10.53	23.53	70.73*	-7.74	11.95	27.46*	7.32	-10.71	-16.17	-7.72*	-4.70	27.00*	12.86	23.44	35.33*
JMS 21A × JR 80	0.00	0.00	38.21*	-2.60	6.91	21.73	50.30*	6.72	0.20	-0.21	21.15*	61.43*	19.23	-3.13	6.21
JMS 21A × JMBR 44	12.50	5.88	46.34*	6.39	17.51	33.79*	8.35	-7.35	-13.02	-1.63	20.89*	61.10*	32.76*	20.31	31.91*
JMS 21A × JMBR 31	-16.67	-11.76	21.95	8.11	21.19*	37.98*	6.39	-30.04*	-34.32*	-3.09	16.43*	55.14*	30.89*	25.78	37.90*
JMS 21A × JR 67	-5.88	-5.88	30.08	5.75	24.34*	41.57*	52.72*	0.42	-5.72	11.11*	14.75*	52.91*	28.10*	21.09	32.76*
JMS 21A × JBR 6	6.67	-5.88	30.08	22.44*	29.15*	47.05*	-6.05	-8.61	-14.20	-3.59	-0.43	32.68*	10.37	16.41	27.62
JMS 20A × JR 83	27.78*	35.29*	86.99*	12.40	23.29*	40.38*	-35.56*	-43.28*	-46.75*	-8.26*	-1.60	31.12*	-12.35	10.94	21.63
JMS 20A × JR 85	-31.58*	-23.53	5.69	6.81	29.60*	47.56*	25.30	10.29	3.55	0.60	-6.58	24.49*	-21.43	-14.06	-5.78
JMS 20A × JR 80	0.00	0.00	38.21*	-3.35	6.09	20.79*	26.49	11.34	4.54	-8.13*	11.53*	48.61*	19.33	10.94	21.63
JMS 20A × JMBR 44	5.88	5.88	46.34*	1.50	12.1	27.63*	9.31	-3.78	-9.66	0.50	23.51*	64.58*	12.82	4.88	14.99
JMS 20A × JMBR 31	-5.56	0.00	38.21*	2.08	14.43	30.28*	26.97	11.76	4.93	-21.28*	-5.43	26.01*	19.51	14.84	25.91
JMS 20A × JR 67	5.88	5.88	46.34*	14.50	0.53	14.46*	8.35	-4.62	-10.45	-16.83*	-17.69*	9.68	30.17*	23.05	34.90*
JMS 20A × JBR 6	0.00	0.00	38.21*	4.25	14.35	30.20*	-1.51	-4.20	-10.06	-2.05	-12.54*	16.54*	22.96	29.69*	42.18*

Check 1 - US 312, Check 2 - JGL 384, A - Hererosis over better parent, B - Heterosis over check 1, C - Heterosis over check 2, *Significant at 5 per cent level, **Significant at 1 per cent level

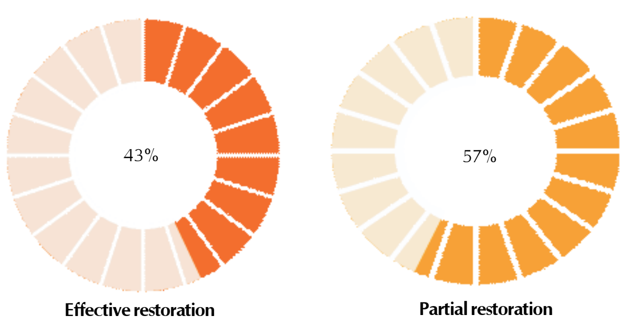

Figure 1: Percentage effective and partial fertility restoration in crosses

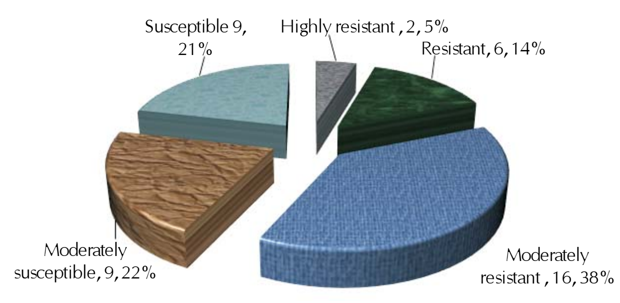

Figure 2: Reaction of hybrids against gall midge

20A × JR 80, and JMS 20A × JBR 6 were found as moderately resistant to gall midge with scale 1 to 5 per cent. The remaining eighteen crosses recorded moderately susceptible and susceptible reactions to gall midge (Table 5 and Figure 2). A high incidence of gall midge was recorded in susceptible check US 312. Similar work was carried out by Parikh *et al.* (2017) for gall midge resistance in rice and Vanita Navnath Salunkhe (2014) in safflower against macrophomina root rot.

Estimation of heterosis

Heterosis (%) over better parent and over standard checks (US 312 and JGL 384) for each trait under study was estimated for all cross combinations. The heterosis varied from cross to cross and trait to trait. None of the test crosses recorded significantly desirable heterosis for all the traits. For the traits where increasing trend is desirable, the hybrids with significant and positive heterotic effects were considered superior. For the characters where decreased expressions are favoured, the crosses with significant negative heterosis were considered promising (ChuwangHijam and Singh, 2019 and Gowayed Salah *et al.,* 2020).

The highest positive standard heterosis for grain yield over the checks was recorded in JMS 19A × JR 80 followed by JMS 19A × JBR 6 and JMS 19A × JR 83. Significant positive heterosis for grain yield per (g) has been reported by many researchers, some of them are Chuwang Hijam and Singh (2019) and Gowayed Salah *et al.* (2020)

These crosses also revealed significant heterosis for the number of productive tillers per plant, spikelet fertility and 1000 grain weight (Table 6). All the three crosses exhibited moderate resistance to gall midge (Table 5). These results are generally analogous to the findings of Rama Krishna Prasad *et al.* (2019) in rice and Ulaganathan *et al.* (2015) in maize. Therefore, these crosses will be considered for finding transgressive segregants in late segregating generations to develop rice hybrids with gall midge resistance and yield improvement.

CONCLUSIONS

The present study opens up a new avenue for commercial exploitation of heterosis in rice. The introduction of gall midge resistant rice hybrids needs to be backed up with a robust and durable hybrid seed production system. This is possible only at the availability of an adaptable, reliable and stable set of resistant parental lines. The development of CMS lines in an adaptable background along with the availability of suitable and effective fertility restorers is indispensable for the development of three-line rice hybrids. These lines can be useful as parents for the development of successful three-line gall midge resistant rice hybrids after further evaluation at different locations and seasons. Moreover, new molecular approaches such as QTL mapping would improve the efficiency of hybrid prediction, and lead to an accelerated understanding of the mechanism of heterosis. Further advances in marker technology may reduce the cost of QTL mapping and make it more applicable for breeding programs.

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