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Saurabh Dixit
Crop Research Station Masodha N D University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India

RM Tripathi
Crop Research Station Masodha N D University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India

SP Giri
Crop Research Station Masodha N D University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India

V Prasad
Crop Research Station Masodha N D University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India

Correspondence
Saurabh Dixit
Crop Research Station Masodha N D University of Agriculture and Technology, Ayodhya, Uttar Pradesh, India

Combining ability analysis for grain yield and yield contributing characters using cytoplasmic male sterility in rice (*Oryza sativa* L.)

Saurabh Dixit, RM Tripathi, SP Giri and V Prasad

Abstract
Thirteen genotypes of rice (three lines and ten testers) with thirty F_1s, develop through line x tester mating design to estimate general and specific combining ability variances and their effects. On the basis of desirable general combining ability IR 58025A was found good general combiner for earliness, dwarfness, total number of tillers per plant and number of panicle bearing tillers per plant. PMS 10A exhibited superior combining ability for number of fertile spikelet per panicle, panicle weight, test weight, grain yield, biological yield and harvest index. PMS 8A was found a poor general combiner for all characters. Among testers, NDRK 5026 followed by NDRK 5028 was found good general combiner for most of the characters. Other testers in this study were poor combiner for grain yield and its major components. Among the thirty hybrids studied, PMS 10A x NDRK 5028, IR58025A x Annada, IR58025A x Sarjoo 52 exhibited high specific combining ability effects for grain yield and biological yield, while PMS 10A x Jaya, PMA 10A x NDRK 5028 and PMS 8A x Vikas showed high sca effects for earliness and dwarfness. None of the cross exhibited high specific combining ability effects for all the characters together.

Keywords: Rice, combining ability, CMS, gca, sca, line x testers

Introduction
The rice requirement of the country increases at a rate of 25 to 30 million tons of milled rice each decade. Assuming that we achieve the target rice production of 120 million tones upto 2020AD by fully exploiting the untapped yield reservoir in the irrigated ecosystem and improving yield levels in rainfed ecologies. As per the information available on various aspects of hybrid rice outside China, especially in tropical countries could as yet exploit the hybrid rice technology commercially, due to lack of parental lines ideally suited to tropical environments.

Materials and Methods
The experimental material for the present investigation consist of thirty F_1s derived from the crosses of 3 cms lines *viz.* IR 58025A, PMS 8A and PMS 10A Possessing wild abortive (WA) cytoplasm as females with Sarjoo 52, NDRK 5026, NDRK 5028, Narendra 359, Jaya, IR 30, Indrasan, Vikas, Ratna and Annada as male parents in line x tester matting design. Thirty F_1s along with 13 parental lines (3 cms lines + 10 male parent) and a standard variety Sarjoo 52 were evaluated in randomized complete block design (RBD) with three replications at Crop Research Station Masodha, Faizabad during *Kharif* 2016. Each entry was sown in single row of 4 m length. Recommended cultural practices were followed for raising a good crop. The observations were recorded on ten characters listed in Table 1. For the estimation of general and specific combining ability variances the line x tester analysis as outlined by Kempthorne (1957) was followed.

Results and Discussion
The analysis of variance for combining ability revealed that the variance due to parents and crosses were highly significant for all the characters. Variance within crosses and parents were significant for all the traits. Mean squares due to parents vs. crosses were highly significantly for all the ten characters. Differences among female lines were observed to be significant for 50% flowering, number of total tillers per plant, number of panicle bearing tillers per plant, panicle weight and grain yield. Variation within lines was also significant for number of total tillers per plant, number of panicle bearing tillers per plant, panicle weight, grain yield and harvest index. The comparison between male and female indicated that genotypes were highly

significant for plant height, number of total tillers per plant, number of panicle bearing tillers per plant, number of fertile spikelets per panicle and test weight. Based on the criteria days to 50% flowering and plant height general combiners with negative values are desirable. Among male lines only three i.e. NDR 359, Annada, Sarjoo 52 and females IR 58025A showed significant and negative gca effects for dwarfness.

The desirable gca effects observed for different characters (Table 2) may serve as guideline in shorting out outstanding parents with favorable alleles for different component traits. The estimates of gca effects for total tillers per plant revealed that NDRK 5028, NDRK 5026 among males and IR 58025A among females were best general combiners with significant positive gca effects. Out of 13 lines used, the female parental line IR 58025A (1.87) and male parental NDRK 5026 (7.50) and NDRK 5028 (6.66) expressed positive and significant gca effects for number of panicle bearing tillers per plant. For number of fertile spikelets per panicle PMS 10A (21.28) among females and NDRK 5026 (45.22), NDRK 5028 (44.41), IR 30 (19.81), NDR 359 (15.62), Annada (7.53) and Indersan (1.64) among male parental lines expressed significant positive gca estimates. Among the males NDRK 5026 (1.77), Sarjoo 52 (0.74), NDRK 5028 (0.38) and females PMS 10A and PMS 8A showed positive and significant gca effects for panicle weight. Sarjoo 52 followed by NDRK 5026 among males and PMS 10A among females was found good general combiners with positive and significant gca effects for test weight. For grain yield per plant NDRK 5026, NDRK 5028, IR 30, Ratna and PMS 10A were found good general combiners with significant positive gca effects among male and female parental lines, respectively. Among ten testers (male) four genotypes IR 30 NDRK 5026, NDRK 5028, Jaya and only female line PMS 10A were found as good general combiners with significant positive gca effects for biological yield. NDRK 5026, NDRK 5028 and female line PMS 10A were found as good general combiners with significant positive gca effects for harvest index among male and female parental lines, respectively.

General combining ability effects (gca), largely involve additive genetic effects due to polygene which acts in additive manner, producing fixable effects while specific combining ability effects (sca) represents non-additive type of gene action (Griffings, 1956 b). Non-additive action results from dominance, epistasis and interaction effects which are non-fixable. The choice of parents especially for heterosis breeding should be based on combining ability test and their mean performance has also been suggested by Yadava and Murty (1996) [14]. Similar gene effects have been reported in rice by Bhanumati and Prasad (1991) [1] for plant height, number of filled grains, spikelet sterility and grain yield per plant. Ghosh (1993) [4] for panicle number per plant, panicle dry weight, grains per panicle, spikelet per panicle, 1000grain weight, harvest index and yield per plant; Chakraborty *et al.* (1994) [3] for plant height, panicle per plant, grain weight per panicle and yield per plant; Verma *et al.*(1995) [12] for biological yield and number of effective tillers per plant; Sharma *et al.*(1996) [8] for plant height, grain weight per panicle and grain yield per plant. However, contrary to these the pre dominant role of additive gene effects have been observed for yield and its component traits by Bhanumati and Prasad (1991) [1] for number of productive tillers and length of panicle; Singh and Singh (1991) [10] for plant height; Ghosh (1993) [4] for plant height and panicle length, grain yield, panicle length, kernel length, kernel width, 1000 grain weight; Chakraborty *et al.* (1994) [3] for days to fifty percent flowering, flag leaf length, spiklet per panicle and 1000 grain weight; Sharma *et al.*(1996) [8] for panicle bearing tillers per plant and fertile spikelet per panicle.

The significant negative sca effects (Table 3) for earliness and plant height were observed for five parent and thirteen cross combinations, respectively. Among 30 F_1s tested, 8 combination for number of total tillers per plant, five combinations for number of panicle bearing tillers per plants, seventeen crosses for number of fertile spikelets per panicle, nine combinations for panicle weight, seven combinations for test weight, twelve combinations for biological yields, seven combinations for harvest index and thirteen combinations for grain yield per plants had positive and significant sca effects. The specific combining ability (sca) is associated with interaction effect which may be due to dominance and epistatic component of variation that are non-fixable in nature. Best ranking general combiners and specific combiners are listed in Table 4. The crosses exhibiting high sca effects did not always involve parents with high gca effects. It may be suggested that interallelic interactions were also important for these characters (Waghmode *et al*.2015; Narasimman *et al.* 2007; Sharma and Mani, 2008 [13, 7, 9] and Bidhan Roy and Mandal, 2001) [2]. None of the crosses exhibited high specific combining ability (sca) effects for all characters together. Subramanian and Rathinam (1984) [11], Gosh (1993) could not record significant sca effects in any cross combinations for all the traits together in their study. Thus, in the present study non additive genes appeared to play a significant role in controlling the expression of all the traits. This suggests that there is scope for improvement of these characters by using hybrid breeding programme for exploitation of non additive gene action. Similar results have been reported earlier by Waghmode *et al.* (2015); Narasimman *et al.* (2007) [7]; Sharma and Mani, (2008) [9] and Chakraborty *et al.* (1994) [3].

Table 1: Analysis of variance for combining ability of ten characters in rice

Source of variation	d. f.	Days to 50% flowering	Plant height	No. of total tillers per plant	No. of panicle bearing tillers per plant	No. of fertile spikelets per panicle	Panicle weight	Test weight	Grain yield	Biological yield	Harvest index
Replication	2	3.64	14.19*	6.53**	3.97*	9.67*	0.14	2.45*	3.43	13.59	5.56
Treatment	42	74.73**	282.15**	49.30**	48.19**	9560.48**	3.47**	107.92**	541.10**	1748.39**	530.86**
Parents	12	117.10**	475.65**	6.54**	6.50**	14380.21**	2.16**	318.52**	319.32**	465.08**	1029.20**
Crosses	29	58.31**	200.61**	57.43**	55.33**	7226.48**	3.70**	7.61**	437.36**	1541.49**	279.15**
Parents vs. Crosses	1	42.43**	324.81**	326.57**	341.60**	19409.97**	12.66**	489.72**	6210.69**	23148.20**	1850.34**
Female	2	209.03*	342.64	85.65**	84.45**	12055.16	7.41**	8.01	644.82*	1353.35	96.29
Males	9	52.47	221.71	139.53**	140.87**	10278.29	6.62**	5.08	898.20**	2386.97	587.93**
Females vs. Males	18	44.48**	174.28**	13.24**	9.32**	5164.05**	1.83**	8.83**	183.90**.	1139.65**	145.08**
Error	84	3.56	4.65	1.24	1.10	2.86	0.07	0.78	3.17	6.06	12.14

*,** significant at 5 and 1 per cent probability levels, respectively

Table 2: Estimates of general combining ability (gca) effects of parents (females and males) for ten characters in rice

Parents	Days to 50% flowering	Plant height	No. of total tillers per plant	No. of panicle bearing tillers per plant	No. of fertile spikelets per panicle	Panicle weight	Test weight	Grain yield	Biological yield	Harvest index
Females										
PMS 8A	1.30**	0.65	-1.46**	-1.37**	-2.76**	0.17**	0.23	-4.21**	-5.49**	-1.35*
PMS 10A	1.97**	3.01**	-0.40*	-0.50*	21.28**	0.39**	0.36*	4.97**	7.49**	2.03**
IR 58025A	-3.0**	-3.66**	1.85**	1.87**	-18.52**	-0.56**	-0.59**	-0.76*	-2.00**	-0.68
SE(gi) Female	0.34	0.39	0.20	0.19	0.31	0.05	0.16	0.33	0.45	0.64
SE(gi-gj) Female	0.49	0.56	0.29	0.27	0.44	0.07	0.23	0.46	0.64	0.90
Male										
Jaya	-0.92	-7.16**	-1.57**	-1.21**	-36.69**	-1.52**	0.02	-11.05**	4.54**	-14.21**
Vikas	-0.03	5.88**	-0.59	-0.42	-57.99**	0.04	-1.25**	-0.57	0.54	-1.83
Indrasan	0.41	-0.76	-2.30**	-2.48**	1.64**	-0.23*	0.50	-4.11**	-8.18**	-1.53
IR 30	-0.37	-0.27	-0.37	-0.26	19.81**	-0.26**	-0.29	3.21**	26.79**	-7.71**
NDRK 5028	5.74**	4.94**	6.85**	6.66**	44.41**	0.33**	-0.46	10.51**	10.45**	11.32**
Ratna	0.86	-5.38**	-0.10	-0.12	-13.70**	-0.51**	-0.81**	2.02**	0.51	0.39
NDRK 5926	0.86	8.15**	7.36**	7.50**	45.22**	1.77**	0.78*	21.01**	17.84**	13.83**
Sarjoo 52	-1.37*	0.14	-3.10**	-3.26**	-25.85**	0.74**	1.18**	-3.53**	-8.31**	-0.19
Annada	-1.70**	-2.80**	-2.19**	-2.39**	7.53**	0.03	-0.20	-5.07**	-14.67	0.71
NDR 359	-3.48**	-2.74**	-3.97**	-4.01**	15.62**	-0.37**	0.53	-12.42**	-29.49**	-0.78
SE(gi) Male	0.63	0.72	0.37	0.35	0.56	0.09	0.29	0.59	0.82	1.16
SE(gi-gj) Male	0.89	1.02	0.53	0.49	0.80	0.13	0.41	0.84	1.16	1.64

*,** significant at 5 and 1 per cent probability levels, respectively

Table 3: Estimates of specific combining ability (sca) effects of crosses for ten characters in rice

Parents	Days to 50% flowering	Plant height	No. of total tillers per plant	No. of panicle bearing tillers per plant	No. of fertile spikelets per panicle	Panicle weight	Test weight	Grain yield	Biological yield	Harvest index
PMS 8A x Jaya	3.19**	-0.69	-0.03	-0.32	23.37**	-0.45**	1.04*	-0.43	24.35**	-8.74**
PMS 8A x Vikas	-8.03**	-8.45**	-0.98	-0.26	5.91**	-1.42**	-0.77	-6.90**	-3.90**	-8.42**
PMS 8A x Indrasan	-1.14	-5.09**	0.16	-0.12	10.94**	-0.15	-1.45**	0.72	3.07*	-2.04
PMS 8A x IR30	0.30	-1.35	-0.63	-0.67	66.84**	0.85**	0.93	5.34**	0.77	4.41*
PMS 8A x NDRK 5028	1.52	8.28**	-1.38*	-0.86	-27.80**	-0.49**	1.02*	1.42	-5.82**	9.78**
PMS 8A x Ratna	2.74	-0.47	-0.70	-0.34	29.05**	0.04	-2.63**	-4.93**	-2.95*	-4.78*
PMS 8A x NDRK 5026	0.74	-2.60*	-1.83**	-1.83**	-49.80**	-0.26	-1.34*	7.11**	9.38**	2.05
PMS 8A x Sarjoo 52	-1.03	1.67	1.83**	1.59*	-70.00**	0.16	0.17	-1.49	-13.93**	4.83*
PMS 8A x Annada	1.30	7.29**	2.06**	2.06**	-10.91**	0.79**	0.34	-2.74**	-4.21**	-3.71
PMS 8A x NDR 359	0.41	1.42	1.50*	0.75	22.40**	0.93**	2.69**	1.90	-6.76**	6.63**
PMS 10A x Jaya	-6.08**	-8.59**	-0.09	0.15	-1.04	0.32*	-1.78**	-4.87**	-23.77*	2.87
PMS 10A x Vikas	9.03**	9.97**	-1.47*	-1.18	-22.54	1.61**	1.41**	0.47	-1.23	1.96
PMS 10A x Indrasan	-1.74	12.15**	-0.17	0.61	28.79**	0.80**	2.76**	4.87**	13.35**	-0.09
PMS 10A x IR30	0.70	8.56**	1.44*	0.92	-43.91**	-0.76**	0.15	6.63**	20.29**	0.51
PMS 10A x NDRK 5028	-2.41*	-7.25**	1.54*	0.89	16.40**	-0.16	-1.30*	10.22**	36.46**	-10.66**
PMS 10A x Ratna	-3.19**	-6.77**	-0.16	0.06	-43.13**	-0.14	0.19	2.88**	-1.60	2.37
PMS 10A x NDRK 5026	1.14	-2.03	-2.43**	-2.23**	23.48**	-0.10	0.07	-10.34**	-18.93**	-1.17

PMS 10A x Sarjoo 52	2.37*	-3.22*	0.24	-0.54	8.62**	-0.49**	-0.72	-5.92**	-5.78**	-4.63*
PMS 10A x Annada	1.03	-4.34**	1.86**		12.04**	-0.50**	0.44	-6.21	-16.19**	2.14
PMS 10A x NDR 359	-0.86	1.52	-0.76	-0.12	21.28**	-0.59**	-1.22*	2.27*	-2.60	6.69**
IR 58025A x Jaya	2.89*	9.28**	0.13	0.17	-22.33**	0.13	0.74	5.30**	-0.58	5.88**
IR 58025A x Vikas	-1.00	-1.52	2.45**	1.45*	16.63**	-0.19	-0.65	6.42**	5.13**	6.45**
IR 58025A x Indrasan	2.89*	-7.06**	0.00	-0.49	-39.74**	-0.65**	-1.30*	-5.59**	-16.42**	2.13
IR 58025A x IR30	-1.00	-7.21**	-0.81	-0.25	-22.94**	-0.09	-1.08*	-11.97**	-21.06	-4.91*
IR 58025A x NDRK 5028	0.89	-1.02	-0.16	-0.03	11.39**	0.65**	0.28	-11.64**	-30.64**	0.88
IR 58025A x Ratna	0.44	7.23**	0.86	0.28	14.08**	0.10	2.44**	2.05*	4.55**	2.41
IR 58025A x NDRK 5026	-1.89	4.63**	4.26**	4.06**	26.32**	0.37*	1.27*	3.23**	9.55**	-0.88
IR 58025A x Sarjoo 52	-1.33	1.55	-2.07**	-1.05	61.39**	0.33*	0.55	7.40**	19.71**	-0.02
IR 58025A x Annada	-2.33*	-2.94*	-3.92**	-3.52**	-1.12	-0.30	-0.78	8.95**	20.40**	1.57
IR 58025A x NDR 359	0.44	-2.94*	-0.74	-0.63	-43.68**	-0.34*	-1.47**	-4.17**	9.36**	-13.32**
SE (Sij)	1.09	1.25	0.64	0.61	0.98	0.15	0.51	1.03	1.42	2.01
SE (Sij-Skl)	1.54	1.76	0.91	0.86	1.38	0.22	0.72	1.45	2.01	2.84

*, ** significant at 5 and 1 per cent probability levels, respectively

Table 4: Best general and specific combiners for different yield and related characters

Characters	Best general combiners	Best specific combiners
Days to 50% flowering	NDR 359, Annada, Sarjoo 52	PMS 8A x Vikas, PMS 10A x Jaya, PMS 10A x Ratna
Plant height	Jaya, Ratna, Annada	PMS 10A x Jaya, PMS 8A x Vikas, PMS 10A x NDRK 5028
No. of total tillers per plant	NDRK 5026, NDRK 5028	IR 58025A x NDRK 5026, IR 58025A x Vikas, PMS 8A x Annada
No. of panicle bearing tillers per plant	NDRK 5026, NDRK 5028	IR 58025A x NDRK 5026, PMS 8A x Annada, PMS 8A x Sarjoo 52
No. of fertile spikelets per panicle	NDRK 5026, NDRK 5028, IR 30	PMS 8A x IR30, IR 58025A x Sarjoo 52, PMS 8A x Ratna
Panicle weight	NDRK 5026, Sarjoo 52, NDRK 5028	PMS 8A x NDR 359, PMS 8A x Annada, IR 58025A x NDRK 5028
Test weight	Sarjoo 52, NDRK 5026	PMS 8A x Indrasan, PMS 8A x NDR 359, IR 58025A x Ratna
Grain yield	NDRK 5026, NDRK 5028, IR 30	PMS 10A x NDRK 5028, IR 58025A x Annada, PMS 8A x NDRK 5026
Biological yield	IR 30, NDRK 5028, NDRK 5026	PMS 10A x NDRK 5028, PMS 8A x Jaya, IR 58025A x Annada
Harvest index	NDRK 5026, NDRK 5028	PMS 8A x NDRK 5028, PMS 10A x NDR 359, PMS 8A x NDR 359

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