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Nature of gene action and combining ability for yield and its related traits in hybrid rice

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ABSTRACT

A study was undertaken with a fixed effect model i.e. line x tester mating design involving 3 CMS line and 20 elite genotypes of rice to identify heterotic combinations expressing high hybrid vigour. On the basis of overall performance the male lines, IR 35454-18-1-1-2R followed by IET 201108 and IR 52256-9-2-2-1R were identified as most promising parents having good general combining ability for grain yield and major components. Out of 60 crosses, about 30% crosses showed significant and desirable sca effects for grain yield along with its three important traits, viz., number of fertile spikelets, number of spikelets per panicle and biological yield. The crosses NMS 4A x IR 633-76-1R, IR 58025A x IR 19058-107-1R, IR 58025A x IR32419-28-3-1-3-3R, NMS 4A x IR35454-18-1-1-2R and NMS 4A x IR 5226-9-2-2-1R exhibited high estimates for parents and good sca effects, hence, they may be considered for hybrid breeding programme. The higher magnitude of sca than gca variance, greater values of average degree of dominance and lower predictability ratio was observed in all the characters studied. This suggested significant role of non-additive gene action which resulted from dominance, over dominance, epistatic and various other interaction effects. Results on gene action and combining ability indicated that both general and specific combining ability effects are important but predominance of non-additive genetic variance indicated the presence of heterozygosity in the population.

Key words : *rice, combining ability, gene action, hybrid vigour, yield, agro-morphological traits*

Hybridization is the most potent technique for breaking yield barriers and evolving varieties having a built-in high yield potential. Identification of superior parents are important pre-requisite for launching effective and efficient breeding programme. Selection of parents on the basis of phenotypic performance alone is not a sound procedure since phenotypically superior lines may yield poor recombination. It is therefore, essential that parents should be chosen on the basis of their genetic value. Combining ability analysis provide information on additive and non-additive variances (i.e. dominance and epistasis), which are important to decide the proper parents for hybridization to produce superior hybrids. The choice of parents particularly for heterosis breeding should be based on combining ability test and *per se* performance (Yuan and Virmani, 1986). There are several techniques for the evaluation of varieties for their genetic makeup. Of these, line x tester mating design is a good approach for screening the large number of germplasm on the basis of their gene effects. General combining ability effects often are larger than specific combining ability effects, but enough exceptions exist to make further use of hybrids worthwhile. Gene action and combining ability interest in gene action and combining ability in relation to heterosis lies in determining whether heterosis is fixable and/or predictable. Heterosis can result from partial to complete dominance, over dominance, epistasis, and combinations of these. Hence, a study on combining ability was undertaken to identify superior parents with constellation of traits for more efficient and better partitioning of photosynthates through heterosis breeding.

MATERIAL AND METHODS

The parental materials comprised of 3 CMS lines viz; IR58025A, NMS4A and PMS10A used as females (lines) were crossed with 20 diverse genotypes used as male (testers) in a line x tester mating design. The resultant sixty hybrids along with their 23 parents and one standard check variety (Sarjoo-52) were evaluated in a randomized block design with three replications at Crop Research Station-Masodha, Narendra Deva University of Agriculture and Technology, Kumarganj, Faizabad. Each genotype was raised in 2.5 m long single row plot keeping 20 x 15 cm spacing. The recommended agronomic practices followed to raise good crop stand. Data were recorded on 10 randomly selected plants from each replication for various quantitative traits studied were *viz*., days to 50% flowering, plant height, pollen fertility, effective tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, number of fertile spikelets, spikelet fertility, 100 grain weight, grain yield plant^{-1}, biological yield and harvest index. Mean values were subjected to analysis of variance to test the significance for each character as per methodology advocated by Panse and Sukhatme (1967). Estimates of combining ability were computed according to Kempthorne (1957) and average degree of dominance by Kempthorne and Curnow (1961).

RESULTS AND DISCUSSION

The analysis of variance (Table 1) revealed that highly significant differences among lines for various characters under study i.e. days to 50% flowering, effective tillers per plant, panicle length (cm), number of spikelets per panicle, number of fertile spikelets, spikelet fertility%, grain yield per plant, biological yield, harvest index except plant height, pollen fertility and 100 grain weight while, variance among males (testers) were highly significant for all traits. The variances among crosses due to males and females (lines x testers) interaction component, indicating their sca effects were highly significant for all the traits except for 100 grain weight and contributed heavily towards combining ability. The predominance of sca effects suggested that dominance and epistatic gene interactions were important for controlling these traits confirming the earlier findings of Panwar (2005), Kumar *et al.* (2006) and Salgotra *et al.* (2009).

The proportional contribution to the total variance by lines, testers and interaction revealed that the testers and line x tester interaction have contributed more than lines in respect of all the characters (Table 4). The portioning of combining ability variance into fixable and non fixable variances indicated that both additive and non-additive gene action playing a significant role

Table 1. Analysis of variance for combining ability for different characters in rice.

Source of Variation	d.f	Days to 50% flowering	Plant height (cm)	Pollen fertility (%)	Panicle bearing tillers plant^{-1}	Panicle	No. of length (cm)	No. of spikelets panicle^{-1}	Spikelet fertile spikelets	100-grain fertility (%)	Grain weight (g)	Biological yield plant^{-1} (g)	Harvest yieldindex (g) (%)
Replications	2	4.148	2.664	8.663	28.509	0.896	4.771	31	8.173	0.263	31.286	4.427	53.447
Treatments	82	58.77**	149.523**	800.797**	19.779*	45.394**	743.789**	2903.65**	827.503**	1.057**	191.073**	279.939**	293.609**
Female (lines)	2	6.208**	0.333	0.65	31.55**	15.393**	1695.517**	635.783**	28.246**	0.163	272.393**	248.321**	221.319**
Males (testers)	19	31.542**	98.234**	12.289**	21.396**	33.957**	698.588**	392.365**	27.045**	1.04**	79.233**	131.482**	105.606**
Females x Males (lines x testers)	38	37.58**	88.69**	27.282**	15.831**	60.736**	853.606**	488.675**	23.922**	0.519	97.672**	226.82**	112.445**
Parents	22	78.993**	98.753**	2789.196**	22..534**	31.963**	441.573**	7502.783**	2262.308**	1.922**	238.647**	332.089**	660.198**
Crosses	59	34.572**	88.768**	21.551*8	18.156**	50.575**	832.031**	462.647**	25.074**	0.674	97.657**	196.847**	113.934**
Parents vs Crosses	1	1041.531**	4855.013**	3031.476**	54.916**	34.995**	2192.517**	45742.06**	16604.69**	4.595**	4655.558**	4036.336**	2829.241*
Error	164	2.689	4.742	7.106	1.599	2.723	4.596	6.407	2.327	0.052	2.57	4.927	5.173

* Significant at 5% level and **1% probability level of significance

Table 4. Contributions of parents (males and females) for different characters and their genetic components in rice

Character	Females (Line)	Males (Tester)	Interaction Line x Tester	*gca* variance	*sca* variance	Average degree of dominance	Predictability ratio
Days to 50% flowering	0.609	29.381	70.01	0.542	11.63	4.632	0.085
Plant height	0.013	35.637	64.35	1.142	4.95	4.95	0.075
Pollen fertility	0.102	18.364	81.534	0.603	3.339	3.339	0.152
Panicle bearing tillers plant^{-1}	5.891	37.951	56.158	0.308	3.922	3.922	0.114
Panicle length (cm)	1.032	21.622	77.347	1.045	4.301	4.301	0.097
No. of spikelets panicle^{-1}	6.908	27.039	66.054	9.964	5.329	5.329	0.065
No. of fertile spikelets	4.658	27.311	68.03	0.736	14.777	14.777	0.009
Spikelet fertility(%)	3.819	34.734	61.447	0.108	8.167	8.167	0.029
100- grain weight (g)	0.818	49.654	49.528	0.002	8.059	8.059	0.025
Grain yield plant^{-1} (g)	9.455	26.128	64.417	2.265	3.741	3.741	0.125
Bilogical yield (g)	4.276	21.51	74.214	1.07	8.314	8.314	0.028
Harvest index (%)	6.585	29.85	63.565	1.479	4.917	4.917	0.076

in controlling the expression of all the characters. The information regarding general combining ability (gca) effects of the parents is of prime importance as it helps in successful prediction of genetic potentiality which would give desirable individuals in subsequent segregating populations. However, specific combining ability (sca) is associated with interaction effects which may be due to dominance and epistatic components of variation that are non-fixable in nature thus it would be worth while for commercial exploitation as hybrids.

Estimates of gca effects showed that it was not possible to pick up a good general combiner for all the characters as the combining ability of the parents was not consistent for all the yield components (Table 2). The male parental line, IET 201108 recorded significant and positive gca effects far grain yield per plant along with eight other characters. IR 52256-9-2-2-1R was found to be good general combiner for days to 50% flowering, panicle bearing tillers plant^{-1}, number of spikelets panicle^{-1}, number of fertile spikelets, grain yield plant^{-1}, biological yield and harvest index but poor general combiner for plant height, pollen viability, panicle length, spikelet fertility and 100- grain weight. IR 60966-29-4-2-2-2R was identified as desirable line for days to 50% flowering, panicle bearing tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, number of fertile spikelets, grain yield plant^{-1} and harvest index but undesirable for plant height, pollen viability, spikelet fertility percent, 100- grain weight and biological yield. The tester IR 35454-18-1-1-2R showed excellent combining ability for all the characters except plant height and pollen fertility percent, where it combined poorly. It was noticed that the best general combiner for grain yield and most of its component traits were often related to late maturity with dwarfness or early maturity with tallness, indicating that these cultivars did not transmit both these characters simultaneously in desirable directions. Among the female parental lines, IR 58025 A was found good general combiner for grain yield and its components except, plant height, pollen viability, panicle bearing tillers plant^{-1} and Spikelet fertility per cent. This line also appeared to be an average combiner for earliness and dwarfness. Remaining two female lines exhibited poor general combining ability for grain yield and most of its components, thereby, indicating the need for transferring the male sterility into genetic background of local elite lines having good general combining ability for yield and its components.

On the basis of overall performance across 12 characters, the male lines, IR 35454-18-1-1-2R followed by IET 201108 and IR 52256-9-2-2-1R were identified as most promising parents having good general combining ability for grain yield and almost all its major components. The association between per se performance of the parents and their gca effects for days to 50% flowering, plant height, number of fertile spikelets and panicle length indicated the effectiveness of choice of parents based on per se performance alone for predicting combining ability of parents for these characters, whereas for rest of the characters, higher

Table 2. Estimates of general combining ability (gca) effects of parents for different characters in rice

Lines/ Testers	Days to 50% flowering	Plant height (cm)	Pollen fertility (%)	Panicle bearing tillers plant^{-1}	Panicle length (cm)	No. of spikelets panicle^{-1}	No. of fertile spikelets	Spikelet fertility (%)	100-grain weight (g)	Grain yield plant^{-1}	Biological yield (g)	Harvest Index (%)
Lines												
IR 58025A	-0.13	0.07	-0.04	-0.72**	0.26	6.13**	2.37**	-0.13	0.05	2.02**	1.38**	2.06**
NMS 4A	-0.23	-0.08	-0.08	0.73**	0.33	-3.37**	-3.71**	0.78**	-0.01	0.21	0.95**	-0.32
PMS 10A	0.37	0.02	0.12	-0.02	0.58**	-2.76**	1.34**	-0.61**	0.06	-2.23**	-2.33**	1.74**
SE (gi) female	0.21	0.28	0.34	0.16	0.21	0.28	0.33	0.2	0.03	0.21	0.29	0.29
SE (gi-gj) male	0.3	0.4	0.49	0.23	0.3	0.39	0.46	0.28	0.04	-0.29	0.41	0.42
Testers												
IR32419-28-3-1-3R	-1.52**	0.56	0.42	-2.71**	0.06	-0.24	0.79	2.3**	-0.01	-0.08	5.09**	-2.97**
IET 201108	-0.52	3.33**	-0.03	0.84*	2.06**	8.64**	8.35**	1.55**	0.34**	1.29**	-2.93**	3.48**
IR 52256-9-2-2-1R	1.7**	0.95	-1.03	1.84**	-0.49	9.42**	6.24**	0.16	-0.43**	4.18**	5.86**	2**
IET 9352	-0.3	6.09**	0.64	-1.49**	1.5**	13.98**	3.46**	-3.38**	0.4**	2.66**	-0.35	4.01**
IR 42686-2-118-6-2R	-1.52**	-0.55	0.42	-1.38**	-0.87	-2.36**	-2.87**	0.71	-0.41**	-3.88**	1.61*	-5.82**
IR 633-76-1R	1.14*	-4.34**	0.53	1.38**	-1.3*	-6.58**	-8.21**	0.39	-0.53**	2.72**	2.26**	2.23**
IR 47310-94-4-3-1R	1.26*	2.35**	-0.03	1.16**	-0.77	12.2**	9.57**	0.41	0.44**	-2.11**	-5.96**	0.7
IR 60966-29-4-2-2-2R	1.48**	-0.43	1.53	1.62**	4.41**	13.76**	3.79**	-3.08**	-0.25**	4.13**	-0.38	5.94**
IR 62030-81-1-3-2R	-1.41*	-2.51**	-0.58	0.18	0.9	-3.47**	-7.76**	-0.78	-0.15*	0.67	3.78**	-1.12
IR-46 R	0.59	-0.12	-0.14	0.29	-1.12*	-1.02	-1.98**	1.44**	-0.45**	0.46	1.6*	-1.36
IR 58110-114-2-2-2R	3.7**	-5.91**	-0.58	-1.71**	-1.45*	-0.47	1.57	2.4**	0.07	-0.2	-2.35**	1.07
IR 48749-53-2-2-2R	-0.52	4.99**	-0.47	-1.27**	-0.29	-7.69**	-9.43**	-0.43	-0.23**	-3.08**	-5.63**	-1.06
IR 19058-170-1R	-0.74	-3.85**	-1.14	-0.82	3.47**	2.09**	-1.54	-0.65	-0.43**	2.23**	-0.14	2.89**
IET 201102	3.14**	1.99**	-3.69**	2.29**	1.49**	1.76*	0.24	0.67	0.24**	0.2	0.54	-0.07
IR 35454-18-1-1-2R	-4.41**	2.02**	0.97	2.62**	1.5**	8.64**	10.91**	3.04**	0.57**	3.94**	1.87*	4.64**
IR 54853-43-1-3R	-0.97	-3.08**	0.31	0.62	-0.92	-6.69**	-9.87**	-1.16*	-0.11	-0.57	2.11**	-2.4**
IR 53480-8-39-3-1-2R	-0.92	-1.64**	1.86*	1.29**	-2.45**	-15.36**	3.91**	-0.86	-0.19*	-7.36**	-9.03**	-5.43**
NDR 6054	-1.97**	-4.54**	0.53	-1.27**	-0.29	-14.58**	6.13**	-2.56**	0.18*	-0.05	1.6*	-1.39
NDR-358	0.92	1.93**	-0.36	1.62**	-2.72**	-3.91**	-4.43**	0.4	-0.17	-3.33**	3.27**	-6.03**
NDR-3008	-0.97	2.76**	0.86	-0.04	-2.71**	8.13**	-8.87**	0.22	0.25**	-0.87	-2.82**	0.33
SE (gi) female	0.55	0.73	0.89	0.42	0.55	0.71	0.84	0.51	0.08	0.53	0.74	0.76
SE (gi-gj) male	0.77	1.03	1.26	0.6	0.78	1.01	1.19	0.72	0.11	0.76	1.05	1.07

per se performance of pollinator lines was not necessarily associated with expression of maximum gca effects. These results are in conformity with the findings of (Peng and Virmani, 1990; Panwar, 2005). The parents, IR 3545H-18-1-1-2R, IET 201108 and IR 52256-9-2-2-1 recorded positively significant gca effect with yield and yield contributing traits parents excelled to others.

In the present investigation, none of the crosses exhibited high specific combining ability (sca) effects for all the characters (Table 3). (Ghosh, 1993) also observed that no specific combination was desirable for all the traits in their study. Out of 60 crosses, about 30% crosses showed significant and desirable sca effects for grain yield along with its three important traits, viz., number of fertile spikelets, number of spikelets panicle^{-1} and biological yield, suggesting that it would be important to give weightage to yield related characters while selecting best combiners for grain yield. On the basis of magnitude, top five crosses were assessed with means and sca effects for all the characters studied (Table 5).

The crosses exhibiting significant and desirable sca effects in order of merit for yield and yield contributing traits were NMS 4A x IR 52256-9-2-2-1R, PMS 10A x IR 633-76-1R, NMS 4A x IR 53480-8-39-3-1- 2R, PMS 10A x NDR 3008. Besides these, the high sca effects for earliness were observed in PMS 10A x IR 633-76-1R, followed by IR 58025A x IR 32419-28-3-1-3R and PMS 10A x NDR 358, while NMS 4A x IR 42686-2-118-6-2R, IR 58025A x NDR 3008 and PMS 10A x IET 201102 possessed considerable sca effects for dwarfness. Therefore, these hybrids are recommended for heterosis breeding. The crosses showing maximum significant sca effects were invariably associated with high per se performance for particular trait, but this behaviour was not always true for plant height, pollen viability, number of spikelets panicle^{-1}, spikelet fertility per cent, 100- grain weight, biological yield and grain yield plant^{-1}, thus suggesting that criteria for the selection of crosses on the basis of either mean performance or sca effects alone would not prove effective.

It is obvious that best cross combinations are not always found between high x high general combiners, but may also occur in other types of parental combinations (Table 5). Parents with highest gca effects do not necessarily generate top specific cross combinations as also reported earlier (Rao *et al.,* 1980). The good specific combinations for different traits involving good general combiners are expected to throw some useful transgressive segregants particularly for developing high yielding pure lines due to additive type of gene action. There are instances where low x low combiners produced the best combination (Amirthadevarathinam, 1983). Maurya and Singh (1977) reported that average x average combinations along with high x low combinations produced the best crosses. The superior cross combinations identified in this study involved high x high, high x low, average x high, average x low, average x average and low x low combining parents indicating all above mentioned types of gene interaction in the F1 combinations studied. Peng and Virmani (1990) also reported the possibility of interaction between positive allels for good combiner and negative allels for poor combiner which suggested for the exploitation of heterosis in F1 generation as their yield potential would be unfixable in succeeding generations. However, those crosses showing better per se performance and desirable sca effects along with either both or at least one parent as a good combiner would be worthful for commercial exploitation.

The higher magnitude of sca than gca variance, greater values of average degree of dominance and lower predictability ratio was observed in 12 characters viz., days to 50% flowering, plant height, Pollen fertility per cent, panicle bearing tillers plant^{-1}, panicle length, number of spikelets panicle^{-1}, number of fertile spikelets, Spikelet fertility per cent, 100-grain weight, grain yield plant^{-1}, biological yield and harvest index (Table 4). This suggested significant role of non-additive gene action which resulted from dominance, epistatic and various other interaction effects. Predominance of non-additive genetic variance indicated the presence of heterozygosity in the population. Breeding methods such as biparental matting followed by recurrent selection may increase the frequency of genetic combinations and break undesirable linkages. Similar gene effects have been reported in rice for different traits by Singh and Nanda (1976), Mohapatra and Mohanty (1985), Sardana and Borthakur (1987), Viraktamath (1987), Dhaliwal and Sharma (1990), Banumathi and Prasad (1991), Ghosh (1993), Chakraborty *et al.* (1994), Verma

Table 3. Estimates of specific combining ability (sca) effects of parents for different characters in rice

Crosses	Days to 50% flowering	Plant height (cm)	Pollen fertility (%)	Panicle bearing tillers $plant^{-1}$	panicle length (cm)	No. of spikelets $panicle^{-1}$	No. of fertile spikelets	Spikelet fertility (%)	100- grain weight (g)	Grain yield $plant^{-1}$ (g)	Biological yield (g)	Harvest index (%)
IR 58025A X IR32419- 28-3-1-3R	-4.64**	1.22	-0.73	1.49*	4.47**	8.76**	8.74**	-1.33	0.1	7.28**	2.39	7.5**
IR 58025A X IET 201108	-2.64**	-7.91**	-0.96	0.27	-1.83	-10.79**	-8.15**	-0.67	-0.17	-0.76	-4.86**	2.03
IR58025A X IR52256-9-2-2-1R	1.13	4.7**	-0.62	-4.06**	-3.02**	3.09*	2.63	-1.31	0.02	1.48	2.15	0.45
IR58025A X IET 9352	4.47**	1.55	-4.29**	-0.06	1.95*	1.79	0.74	-0.07	0.06	-6.86**	-1604**	0.62
IR58025A X IR 42686-2-118-6-2R	-0.31	1.43	1.6	0.49	-0.35	9.21**	13.07**	1.39	-0.04	2.22*	9.09**	-1.6
IR58025A X IR 633-76-1R	1.69	0.45	2.82	-0.51	1.75	-0.91	0.74	-0.53	0.2	-4.32**	-12.01**	1.46
IR58025A X IR 47310-94-4-3-1R	2.24*	2.83*	-1.62	0.94	-3.41**	-9.02**	-8.04**	1.32	-0.04	-2.86**	-10.7**	2.91*
IR58025A X IR 60966-29-4-2-2-2R	-4.31**	6.34**	-2.84	-1.51*	-2.56**	-10.57**	-5.26**	0.55	-0.16	-1.09	-3.11*	0.11
IR58025A X 62030-81-1-3-2R	3.24**	-0.11	-1.73	1.61*	4.82**	-3.02	-4.71**	-1.5	-0.31*	-0.98	3.29*	-3.1*
IR58025A X IR46R	-3.76**	2.23	-0.18	0.16	-0.29	4.54**	5.85**	1.23	0.53**	3.9**	-2.5	6.26**
IR58025A X IR 58110-114-2-2-2R	2.47*	0.69	0.6	-0.51	-3.26**	-22.68**	-16.37**	0.44	-0.35*	-6.16**	2.23	-9.6**
IR58025A X IR 48749-53-2-2-2R	5.02**	5.59**	1.49	-0.28	1.08	0.54	-0.37	-1.98	0.2	7.82**	11.04**	3.81**
IR58025A X IR 19058-170-1R	-1.42	-0.87	-0.18	3.94**	0.85	2.09	6.74**	1.29	0.04	6.71**	9.92**	2.38
IR58025A X IR 54852-129-1-23-1R	-1.64	0.02	6.71**	3.16**	3.7**	11.09**	11.63**	-0.4	0.37**	3.67**	-2.26	6.02**
IR58025A X IR 35454-18-1-1-2R	-3.09**	-6.25**	1.04	-4.17**	-7.38**	-15.46**	-15.71**	-2.73**	-0.06	-10.77	3.84**	-16.17**
IR58025A X IR 54853-43-1-3R	3.47**	3.63**	2.71	-0.51	1.71	8.54**	11.41**	0.9	-0.2	2.24*	-2.74*	4.35**
IR58025A X IR 53480-8-39-3-1-2R	-3.76**	-6.75**	-0.51	-1.51*	-1.72	13.21*	-3.37*	1.94*	-0.07	1.7	13.07**	-4.02**
IR58025A X NDR 6054	0.47	-1.85	-1.84	1.38	2.44*	28.76**	2.07	0.34	0.26*	4.32*	6.27*	2.33
IR58025A X NDR 358	2.58**	1.69	-1.29	-0.17	2.58**	7.76**	13.96**	2.77**	0.29*	-1.97*	-2.8*	-1.35
IR58025A X NDR 3008	-1.2	-8.61**	-0.18	-0.17	-1.53	-23.35**	-15.59**	1.01	-0.68**	-5.56**	-6.27**	-4.27**
NMS 4A X IR 32419-28-3-1-3R	6.46**	-5.16**	2.63	-0.29	-3.17**	-20.07**	-4.51**	6.89**	-0.51**	-5.71**	-1.38	-6.2**
NMS 4A X IET 201108	0.12	2.81*	3.08*	0.16	-0.6	-1.29	-3.07*	-2.1*	0.03	-4.83**	-6.93**	-2.64**
NMS 4A X IR52256-9-2-2-1R	-1.1	1.02	1.41	2.82*	5.81**	3.93**	13.38**	4.3**	0.01	3.89**	0.78	4.59**
NMS 4A X IET 9352	-2.43*	3.37**	4.08*	1.49*	-0.25	-9.63**	-8.18**	-1.43	0.22	5.11**	6.23**	2.62*
NMS 4A X IR 42686-2-118-6-2R	-4.21**	-11.05**	1.3	-1.96*	5.38**	5.29**	-1.18	0.88	0.15	0.39	2.4	-0.54**
NMS 4A X IR 633-76-1R	3.79**	0.17	-1.14	0.04	1.48	10.93**	16.16**	2.84**	0.05	8.05**	10.71**	4.01**
NMS 4A X IR 47310-94-4-3-1R	-2.32*	-1.28	2.41	-1.18	1.95*	10.15**	17.04**	2.78**	0.22	4.71**	13.94**	-1.41
NMS 4A X IR60966-29-4-2-2-2R	2.79**	-5.4**	-3.48*	-1.62*	0.94	7.26**	6.82**	-0.79	-0.01	0.98	7.76**	-3.38*
NMS 4A X IR 62030-81-1-3-2R	-1.99*	-5.46**	0.63	1.49*	3.78**	9.48**	6.38**	-2.91**	0.62**	3.27**	-3.04*	5.91**
NMS 4A X IR46R	2.68**	1.92	2.86	1.04	-3.63**	-16.29**	-12.4**	1.08	-0.26*	-2.61**	-2.93	-1.87
NMS 4A X IR 58110-114-2-2-2R	0.57	-0.56	-2.37	1.38	4.74**	12.15**	5.38**	-4.07**	0.04	6.38**	0.99	8.03**
NMS 4A X IR 48749-53-2-2-2R	-2.21*	-1.06	-1.14	-3.4**	0.44	4.37**	10.04**	2.53**	-0.05	-5.51**	-17.59**	2.95*

Table 3 contd.

Crosses	Days to 50% flowering	Plant height (cm)	Pollen fertility (%)	Panicle bearing tillers $plant^{-1}$	panicle length (cm)	No. of spikelets $panicle^{-1}$	No. of fertile spikelets	Spikelet fertility (%)	100- grain weight (g)	Grain yield $plant^{-1}$ (g)	Biological yield (g)	Harvest index (%)
NMS 4A X IR19058-170-1R	-2.32*	-0.35	-0.81	-1.51*	1.82	4.26**	-0.51	-3.58**	0.16	-5.42**	-2.35	-5.73**
NMS 4A X IET 201102	-0.88	8.17**	-7.59**	-2.96**	-6.04**	-16.74**	-12.96**	-0.54	-0.75**	-6.08**	-3.99**	-5.99**
NMS 4A X IR 35454-18-1-1-2R	0.68	2.28	-1.26	1.71*	4.38**	13.04**	15.38**	0.97	-0.06	5.16**	0.61	5.74**
NMS 4A X IR 54853-43-1-3R	-0.77	-1.82	0.08	-0.29	-5.06**	-19.96**	-14.51**	0.16	-0.65**	-7.72**	-4.94**	-7.63**
NMS 4A X IR 53480-8-39-3-1-2R	2.68**	2.07	-1.14	4.04**	7.24**	25.04**	2.71	-0.05	0.51**	2.26*	-2.46	5.05**
NMS 4A X NDR 6054	-0.77	0.51	-0.48	-0.73	0.54	6.59**	-19.18	-1.23	0.46**	2.09*	0.47	2.92*
NMS 4A X NDR 358	2.01*	2.51*	2.74	0.04	-3.89**	-21.07**	-21.96**	-3.75**	-0.48**	-2.3*	-0.46	-2.55
NMS 4A X NDR 3008	-2.77**	7.31**	-1.81	0.71	-5.1**	3.15*	5.26**	0.17	0.32*	-2.09*	2.19	-3.88**
PMS 10A X IR32419-28-3-1-3R	-1.81	3.94**	-1.9	-1.21	-1.29	11.31**	-4.23**	-5.56**	0.4**	-1.57	-1	-1.3
PMS 10A X IET 201108	2.52**	5.11**	-2.12	-0.43	2.44*	12.09**	11.22**	2.77**	0.15	5.58**	11.79**	0.6
PMS 10A X IR 52256-9-2-2-1R	-0.03	-5.72**	-0.79	2.24**	-2.78**	-7.02**	-16.01**	-2.99**	-0.03	-5.37**	-2.93*	-5.04**
PMS 10A X IET 9352	-2.03*	-4.93**	0.21	-1.43	-1.71	11.42**	7.44**	1.5	-0.28*	1.75	9.81**	-3.24*
PMS 10A X IR42686-2-118-6-2R	4.52**	9.62	-2.9	1.46*	5.73**	-3.91**	-11.89**	-2.27*	-0.1	-2.6**	-11.49**	2.14
PMS 10A X IR 633-76-1R	-5.48**	-0.63	-1.68	0.46	-3.24**	-10.02**	-16.89**	-2.32*	-0.25	-3.74**	1.3	-5.47**
PMS 10A X IR47310-94-4-3-1R	0.08	-1.55	-0.79	0.24	1.46	-1.13	-9.01**	-1.46	-0.18	-1.85*	-3.24*	-1.51
PMS 10A X IR 60966-29-4-2-2-2R	1.52	0.94	6.32**	3.13**	1.62	3.32**	-1.56	0.24	0.17	0.12	-4.65**	3.28*
PMS 10A X IR 62030-81-1-3-2R	-1.26	5.57**	1.1	-3.09**	-8.61**	-6.47**	1.67	4.41*	-0.31*	-2.29*	-0.25	-2.81*
PMS 10A X IR 46R	1.08	-4.15**	-2.68	-1.21	3.92**	11.76**	6.55**	-0.15	-0.26*	-1.3	5.42**	-4.39**
PMS 10A X IR 58110-114-2-2-2R	-3.03**	-0.13	1.77	-0.87	-1.48	10.53**	10.99**	3.63**	0.31*	-0.22	-3.22*	1.58
PMS 10A X IR 48749-53-2-2-2R	-2.81**	4.53**	-0.34	3.68**	-1.52	-4.91**	-9.67**	-0.55	-0.15	-2.3*	6.56**	-6.75**
PMS 10A X IR 19058-170-1R	3.74**	1.22	0.99	-2.43**	-2.67**	-6.36**	-6.23**	2.29*	-0.2	-1.28	-7.57**	3.35*
PMS 10A X IET 201102	2.52**	-8.19**	0.88	-0.21	2.34*	5.64**	1.33	0.94	0.38**	2.41*	6.26**	-0.03
PMS 10A X IR 35454-18-1-1-2R	2.41**	3.98	0.21	2.46**	2.99**	2.42	0.33	1.76*	0.12	5.61**	-4.44**	10.44**
PMS 10A X IR 54853-43-1-3R	-2.7**	-1.82	2.79	0.79	3.35**	11.42**	3.11**	-1.06	0.85**	5.48**	7.68**	3.28**
PMS 10A X IR 53480-8-39-3-1-2R	1.08	4.67**	1.66	-2.54**	-5.52**	-38.24**	0.66	-1.88*	-0.44**	-3.96**	-10.61**	-1.02
PMS 10A X NDR 6054	0.3	1.34	2.32	0.65	-2.98**	-35.36**	17.12**	0.89	-0.72**	-6.4**	-6.74**	-5.15**
PMS 10A X NDR 358	-4.59**	-4.19**	-1.46	0.13	1.32	13.31**	7.99**	0.98	0.19	4.27**	3.26*	3.91**
PMS 10A X NDR 3008	3.97**	1.31	1.99	-0.54	6.64**	20.2**	10.44**	-1.18	0.37**	7.65**	4.08**	8.15**
SE (Sij)	0.95	1.26	1.54	0.73	0.95	1.24	1.46	0.88	0.13	0.93	2.28	1.31
SE (Sij-Skl)	1.34	1.78	2.18	1.03	1.35	1.75	2.07	1.25	0.19	1.31	1.81	1.86

Table 5. Best crosses with their sca effects in relation to per se performance involved for different characters in rice

Characters	Best hybrids on the basis of *per se* performance	Best specific combiners	Best common crosses
Days to 50% flowering	IR 58025A X IR 35454-18-1-1-2R NMS 4A X IR 35454-18-1-1-2R NMS 4A X IET 9352 NMS 4A X IR 42686-2-118-6-2R IR 58025A X IR 32419-28-3-1-3R	PMS 10A X IR 633-76-1R IR 58025A X 32419-28-3-1-3R PMS 10A X NDR 358 IR 58025A X IR 60966-29-4-2-2R IR 58025A X IR 42686-2-118-6-2R	IR 58025 A X IR 32419-28-3-1-3R
Plant height	IR 58025A X NDR 6054 IR 58025A X NDR- 3008 NMS 4A X IR 42686-2-118-6-2R IR 58025A X IR 58110-114-2-2-2R IR 58025A X IET 201108	NMS 4A X IR 42686-2-118-6-2R IR 58025A X NDR 3008 PMS 10A X IET 201102 IR 58025A X IET 201108 IR 58025A X IR 32719-28-3-1-3R	IR 58025 A X IET-201108 NMS 4A X IR 42686-2-118-6-2R IR 58025A X NDR 3008
Pollen fertility percent	PMS 10A X IR 60966-29-4-2-2-2R IR 58025A X IR 35454-18-1-1-2R PMS10A X IR 32419-28-3-1-3R PMS 10A X IR 35454-18-1-1-2R IR 58025A X IR 32419-28-3-1-3R	IR 58025A X IET 201102 PMS 10A X IR 60966-29-4-2-2-2R NMS 4A X IR 53915-43-3-3-3R NMS 4A X IET 201108 NMS 4A X IR 46R	IR 58025A X NDR 3008 PMS 10A X IR 60966-29-4-2-2-2R
Panicle bearing tillers plant^{-1}	PMS 10A X IR 35454-18—1-1-2R PMS 10A X IR 60966-29-4-2-2-2R PMS 10A X IR 52256-9-2-2-1R NMS 4A X IR 32419-28-3-1-3R NMS 4A X IR 35454-18-1-1-2R	NMS 4A X IR 32419-28-3-1-3R IR 58025 A X IR 19058-107-1R PMS 10 A X IR 48749-53-2-2-2R IR 58025A X IET 201102 PMS 10A X IR 60966-29-4-2-2-2R	PMS 10A X IR 60966-29-4-2-2-2R NMS 4A X IR 32419-28-3-1-3R
Panicle length	PMS 10A X IET 201108 PMS 10A X IR 60966-29-4-2-2-2R IR 58025A X IR 32419-28-3-1-3R IR 58025A X IET 201102 PMS 10A X IR 54853-43-3-3-3R	NMS 4A X IR 32419-28-3-1-3R PMS 10A X NDR 3008 NMS 4A X IR 52256-9-2-2-1R PMS 10A X IR 42686-2-118-6-2R IR 58025A X IR 62030-81-1-3-2R	Nil
No. of spikelets panicle^{-1}	NMS 4A X IR 47310-94-4-3-1R NMS 4A X IR 35454-18-1-1-2R IR 58025A X NDR 6054 IR 58025A X IET 201102 IR 58025A X IR 52256-9-2-2-1R	IR 58025A X NDR 6054 NMS 4A X IR 32419-28-3-1-3R PMS 10A X NDR 3008 PMS 10A X NDR 358 IR 58025A X IR 32419-28-3-1-3R	
No. of fertile spikelets	NMS 4A X IR 633-76-1R PMS 10A X IET 201108 NMS 4A X IR 633-76-1R PMS 10 A X NDR 6054 IR 58025A X IR 633-76-1R	PMS 10A X NDR 6054 NMS 4A X IR 47310-94-4-3-1R NMS 4A X IR 633-76-1R NMS 4A X IR 35454-18-1-1-2R IR 58025A X NDR 358	PMS 10A X NDR 6054 NMS 4A X IR 47310-94-4-3-1R NMS 4A X IR 633-76-1R
Spikelets fertility percent	NMS 4A X IR 633-76-1R PMS 10A X IR 62030-81-1-3-2R IR 58025A X IR 633-76-1R PMS 10A X IET 201108 PMS 10A X IR 633-76-1R	NMS 4A X IR 32419-28-3-1-3R PMS 10A X IR 62030-81-1-3-2R NMS 4A X IR 52256-9-2-2-1R PMS 10A X IR 58110-114-2-2-2R NMS 4A X IR 633-76-1R	NMS 4A X IR-633-76-1R PMS 10AX IR-62030-81-1-3-2R
100 Grain weight	PMS 10A X IET 201102 IR 58025A X IET 201102 NMS 4A X IR 53915-43-3-3-3R PMS 10A X IR 54853-43-3-3-3R IR 58025A X IET 9352	PMS 10A X IR 54853-43-1-3R NMS 4A X IR 62030-81-1-3-2R IR 58025A X IR 46R NMS 4A X IR 32419-28-3-1-3R NMS 4A X NDR 6054	PMS 10A X IR 54853-43-1-3R
Grain yield plant^{-1}	IR 58025A X IR 48749-53-2-2-2R NMS 4A X IR 633-76-1R IR 58025A X IR 54853-43-1-3R IR 58025A X IR 19058-170-1R PMS 10A X IR 54853-43-3-3-3R	NMS 4A X IR 633-76-1R IR 58025A X IR 48749-53-2-2-2R PMS 10A X NDR 3008 IR 58025A X IR 48749-53-2-2-2R IR 58025A X IR 19058-170-1R	IR 58025A X IR 48749-53-2-2-2R NMS 4A X IR 633-76-1R IR 58025A X IR 19058-170-1R
Bilogical yield	IR 58025A X IR 42686-2-118-6-2R IR 58025A X IR 19058-170-1R NMS 4A X IR 633-76-1R IR 58025A X IR 52256-9-2-2-1R IR 58025A X NDR 6054	NMS 4A X IR 47310-94-4-3-1R IR 58025A X IR 32419-28-3-1-3R PMS 10A X IET 201108 IR58025A X IR 48749-53-2-2-2R NMS 4A X IR 633-76-1R	NMS 4A X IR 633-76-1R
Harvest index	IR 58025A X IET 201108 IR 58025A X IR 48749-53-2-2-2R NMS 4A X IR 58110-114-2-2-2R IR 58025A X IR 54853-43-1-3R PMS 10A X NDR 358	PMS 10A X IR 35454-18-1-1-2R PMS 10A X NDR 3008 NMS 4A X IR 58110-114-2-2-2R IR 58025A X IR 32419-28-3-1-3R IR 58025A X IR 46R	NMS 4A X IR 58110-114-2-2-2R

et al. (1995), Singh *et al.* (1996) and Sreeramachandra *et al.* (2000). However, contrary to these, the predominant role of additive gene effects have been observed for grain yield and its component traits (Banumathi & Prasad, 1991), (Singh & Singh, 1991), (Ghosh, 1993), (Chakraborty *et al.* 1994).

Results on gene action and combining ability indicated that both general and specific combining ability effects are important but predominance of non-additive genetic variance indicated the presence of heterozygosity in the population. As such this type of genetic variance is non-fixable hence; heterosis breeding is effective for crop improvement. Male lines, IR 35454-18-1-1-2R followed by IET 201108 and IR 52256-9-2-2-1R were identified as most promising parents due to having good general combining ability for grain yield and almost all its major components. The crosses exhibiting significant and desirable sca effects in order of merit for yield and yield contributing traits were NMS 4A x IR 52256-9-2-2-1R, PMS 10A x IR 633-76-1R, NMS 4A x IR 53480-8-39-3-1- 2R, PMS 10A x NDR 3008. Besides these, the high sca effects for earliness were observed in PMS 10A x IR 633-76-1R, followed by IR 58025A x IR 32419-28-3-1-3R and PMS 10A x NDR 358, while NMS 4A x IR 42686-2-118-6-2R, IR 58025A x NDR 3008 and PMS 10A x IET 201102 possessed considerable sca effects for dwarfness. Therefore, these hybrids are recommended for heterosis breeding.

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