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Prediction of Gene Action, Heterosis and Combining Ability to Identify Superior Rice Hybrids

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Abstract: Nature of gene action and combining ability is valuable in determining whether heterosis is fixable or predictable. Thus, to know the inheritance pattern of some morphological traits sixty F_1 hybrids along with their parents (3 CMS lines and 20 restorer variety) were evaluated to identify best heterotic combinations. The results indicated that the male lines i.e., IR35454-18-1-1-2R, IET201108 and IR52256-9-2-2-1R were identified good general combiner for grain yield and almost all its major components. The higher magnitude of sca than gca variance, greater values of average degree of dominance and lower predictability ratio was observed in all characters studied suggested significant role of non-additive gene action. Out of 60 crosses, about 30% crosses showed significant and desirable sca effects for grain yield along with its important traits, viz., number of fertile spikelets, number of spikelets per panicle and biological yield. High sca effects was observed in the crosses NMS4A×IR633-76-1R, IR58025A×IR19058-107-1R, IR58025A×IR32419-28-3-1-3-3R, NMS4A×IR35454-18-1-1-2R and NMS4A×IR5226-9-2-2-1R. Manifestation of heterobeltiosis for grain yield was significantly superiority of 43 hybrids ranging from 11.63 to 113.04% and 46 hybrids over standard check (Sarjoo-52) ranging from 10.48 to 71.56%. Most of the crosses which exhibited superiority over better parent or standard variety for grain yield also showed significant heterosis for number of fertile spikelets and number of spikelets per panicle. The best cross combination IR58025A×IR48749-53-2-2-2R, NMS4A×IR633-76-1R, IR58025A×IR54853-43-1-3R, IR58025A×IR19058-107-1R and PMS10A×IR54853-43-1-3R, NMS4A×IR52256-9-2-2-1R, NMS4A×IET9352 and IR58025A×IET201102 having more than 50% heterosis in order of merit grain yield and other yield components as well as significant sca effects for major components were most promising combinations and need to be tested on large scale for commercial exploitation of heterosis.

Key words: Rice, gene action, combining ability, line×tester analysis, heterobeltiosis, standard heterosis

INTRODUCTION

Exploitation of heterosis is considered to be one of the outstanding achievements of plant breeding. At the current growth of population rice requirement increases dramatically; hence, it is challenging task to ensuring food and nutritional security to the country. Therefore, enhancing productivity of rice through novel genetic approaches like hybrid rice was felt necessary. It has not only contributed to food security but has also benefited the environment (Duvick, 1999). Hybrid vigour in rice was first reported by Jones (1926). The various crop species in which hybrid varieties are used commercially, rice ranks very high. Since rice is a self-pollinated crop therefore, hybrid seed production must be based on male sterility systems. Currently, the most popular male sterility system for commercial exploitation of hybrid rice technology is the CMS, popularly known as the three-line system. This utilizes three different lines, namely a cytoplasmic male sterile line (A line), a maintainer (B line) and a restorer (R line). Hybrid rice based on Cytoplasmic Male Sterility (CMS) increases grain yield by more than 20% relative to improved inbred rice varieties (Yuan and Virmani, 1994). Rice hybrids were first commercialized in the late 1977 in China (IRRI, 1977). Significant heterosis, heterobeltiosis and standard heterosis in rice have been reported by many earlier workers (Nuruzzaman *et al*., 2002; Faiz *et al*., 2006; Manickavelu *et al*., 2006; Sofi and Trag, 2006; Rashid *et al*., 2007; Bagheri *et al*., 2008; Saleem *et al*., 2008; Bagheri and Jelodar, 2010; Rahimi *et al*., 2010;

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Tiwari *et al*., 2011; Selvaraj *et al*., 2011; Akinwale *et al*., 2011). Hybrids offer opportunity to break through the yield ceilings of semi dwarf rice varieties. The increased yield of rice hybrids alone does not ensure profitability to farmers if their grain quality is not acceptable and if they fetch a low price in the market. The understanding of various characters and identification of superior parents are important prerequisite 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. There are several techniques for the evaluation of varieties for their genetic make-up. Of these, line×tester mating design is a good approach for screening the large number of germplasm on the basis of their gene effects. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desirable parents and crosses for the exploitation of heterosis (Sarker *et al*., 2002; Rashid *et al*., 2007; Selvaraj *et al*., 2011). Heterosis can result from partial to complete dominance, over dominance, epistasis and combinations of these (Comstock and Robinson, 1952). If partial to complete dominance predominates, it is theoretically possible to develop homozygotes with fixed heterosis. If over dominance or over dominant types of epistasis predominate, then the highest yielding lines must be heterozygotes (Sprague and Eberhart, 1977). To exploit maximum heterosis using Cytoplasmic Male Sterile (CMS) technique in the hybrid rice programme, we must know the combining ability of different male sterile and restorer lines. The performance of parent may not necessarily reveal it to be a good or poor combiner. Therefore, gathering information on nature of gene effects and their expression in terms of combining ability is necessary. The information regarding general combining ability (gca) effects of the parents is of prime importance because it helps in successful prediction of genetic potentiality which would give desirable individuals in subsequent segregating populations. However, specific combining ability 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 worthful for commercial exploitation as hybrids. Thus, gene action and combining ability relation to heterosis lies in determining whether heterosis is fixable or predictable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid programme (Pradhan *et al*., 2006). There is need to study various morphological traits to get better understanding of inheritance and select or identify superior genotypes. Heritability values have been variable depending upon the genetic nature of genotypes for different morphological characters (Vivek *et al*., 2000; Mishra and Verma, 2002; Mahto *et al*., 2003; Swati and Ramesh, 2004). Keeping in view the importance of combining ability and heterosis in plant breeding a line×tester analysis employed in rice with following two major objectives: (1) To cram the gene effects for identification of suitable parents for heterosis breeding and (2) To determination of the out yielding effects, adaptability and quality of rice hybrids for various agronomic traits and their possible exploitation for commercial use.

MATERIALS AND METHODS

The parental material comprised 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×tester mating design in 2001-02. Thus, 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 during 2002-03. The experimental site is located at 26.47°N latitude, 82.12°E longitudes and an altitude of 113 m above mean sea level. This site is in the eastern Gangetic plains of India and has sandy loam soil texture. Each genotype was raised in 2.5 m long single row plot keeping 20×15 cm spacing. The recommended agronomic practices followed to raise good crop stand. The data were recorded on 10 randomly selected plants from each replication for various quantitative traits studied were viz., days to 50% flowering, plant height (cm), pollen fertility (%), effective tillers per plant, panicle length (cm), number of spikelets per panicle, number of fertile spikelets, spikelet fertility%, 100 grain weight (g), grain yield per plant (g), biological yield (g) and harvest index (%). The general reference for data collection was standard evaluation system for rice (Anonymous, 2002; Virmani *et al*., 1997). 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). The % increase or decrease of F_1 hybrids over better parent as well as standard check was calculated to estimate possible heterotic effects for above mentioned parameters (Fonseca and Patterson, 1968).

$$Hbt\% = \frac{F_1 - BP}{BP} \times 100$$

$$Hs\% = \frac{F_1 - SV}{SV} \times 100$$

Where:
Hbt = Heterobeltiosis
Hs = Standard heterosis

To estimate significant differences among hybrids and parents, the mean data of each character were subjected to Analysis of Variance (ANOVA) as suggested by Steel and Torrie (1980). The characters showing significant differences were subjected to heterosis calculation. Deviation of F_1 from its either of the parental values was interpreted by Mather and Jink (1977) depicting type of gene action operating for controlling the trait. The t test was applied to determine significant difference of F_1 hybrid means from respective mid parent and better parent values using formulae as reported by Wynne *et al.* (1970).

RESULTS AND DISCUSSION

The analysis of variance (Table 1) revealed that highly significant differences among lines (females) for all the characters under studied 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×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 Janardhanam *et al.* (2000), Satyanarayana *et al.* (2000), Panwar (2005), Saravanan *et al.* (2006), 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×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 in controlling the expression of all the characters.

General combining ability effects: Estimates of gca effects (Table 2) showed that it was not possible to pick up a good general combiner for all the characters because the combining ability of the parents was not consistent for all the yield components. The male parental line, IET201108 recorded significant and positive gca effects far grain yield per plant along with eight other characters viz., plant height, panicle bearing tillers per plant, panicle length, number of spikelets per panicle, number of fertile spikelets, Spikelet fertility per cent, 100 grain weight and harvest index. IR52256-9-2-2-1R was found to be good general combiner for days to 50% flowering, panicle bearing tillers per plant, number of spikelets per panicle, number of fertile spikelets, grain yield per plant, biological yield and harvest index but poor general combiner for plant height, pollen viability, panicle length, Spikelet fertility and 100 grain weight. The IR60966-29-4-2-2-2R was identified as desirable line for days to 50% flowering, panicle bearing tillers per plant, panicle length, number of spikelets per panicle, number of fertile spikelets, grain yield per plant and harvest index but undesirable for plant height, pollen viability, Spikelet fertility percent, 100-grain weight and biological yield. The tester IR35454-18-1-1-2R 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, IR58025A was found good general combiner for grain yield and its components except, plant height, pollen viability, panicle bearing tillers per plant and Spikelet fertility per cent. This line also appeared 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, IR35454-18-1-1-2R followed by IET201108 and IR52256-9-2-2-1R were identified as most promising parents due to having good general combining ability for grain yield and almost all its major components. The 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

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

Source of variation	df	Days to 50% flowering	Plant height(cm)	Pollen fertility (%)	Effective tillers per plant	Panicle length (cm)	No. of spikelets per panicle	No. of fertile spikelets	Spikelet fertility (%)	100-grain weight (g)	Grain yield per plant (g)	Bilogical yield (g)	Harvest index (%)
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**	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 1% probability level of significance, df: degree of freedom

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 per plant	Panicle length (cm)	No. of spikelets per panicle	No. of fertile spikelets	Spikelet fertility (%)	100-grain weight	Grain yield per palnt	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	0.20	0.03	0.21	0.29	0.29
SE (gi-gj) male	0.30	0.40	0.49	0.23	0.30	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	2.30**	-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	1.70**	0.95	-1.03	1.84**	-0.49	9.42**	6.24**	0.16	-0.43**	4.18**	5.86**	2.00**
IET 9352	-0.30	6.09**	0.64	-1.49**	1.50**	13.98**	3.46**	-3.38**	0.40**	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**	-1.30*	-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	12.20**	9.57**	0.41	0.44**	-2.11**	-5.96**	0.70
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	0.90	-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	1.60*	-1.36
IR 58110-114-2-2-2R	3.70**	-5.91**	-0.58	-1.71**	-1.45*	-0.47	1.57	2.40**	0.07	-0.20	-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**	0.20	0.54	-0.07
IR 35454-18-1-1-2R	-4.41**	2.02**	0.97	2.62**	1.50**	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**	-2.40**
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	1.60*	-1.39
NDR-358	0.92	1.93**	-0.36	1.62**	-2.72**	-3.91**	-4.43**	0.40	-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	0.60	0.78	1.01	1.19	0.72	0.11	0.76	1.05	1.07

***Signfiat at 1 and 5% probasility level of significant

characters, higher 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; Hasib *et al*., 2001; Panwar, 2005; Saravanan *et al*., 2006). The parents, IR3545H-18-1-1-2R, IET201108 and IR52256-9-2-2-1 recorded positively significant gca effect with yield and yield contributing traits parents excelled to others. A multiple programme involving all these parents will result in identification of superior genotypes.

Specific combining ability effects: In the present investigation, none of the crosses exhibited high specific combining ability (sca) effects for all the characters (Table 3). (Subramanian and Rathinam, 1984; 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 per panicle 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 6).

The crosses exhibiting significant and desirable sca effects in order of merit for yield and yield contributing traits were NMS4A×IR52256-9-2-2-1R, PMS10A×IR633-76-1R, NMS4A×IR53480-8-39-3-1-2R, PMS10A×NDR3008. Besides these, the high sca effects for earliness were observed in PMS10A×IR 633-76-1R, followed by IR 58025A×IR 32419-28-3-1-3R and PMS10A×NDR358, while NMS4A×IR426862-118-6-2R, IR58025A×NDR3008 and PMS10A×IET201102 possessed considerable sca effects for dwarfness. Therefore, these hybrids are recommended for heterosis breeding. In general, it is also interesting to note that 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 in case of plant height, pollen viability, number of spikelets per panicle, Spikelet fertility percent, 100 grain weight, biological yield and grain yield per plant, 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×high general combiners but may also occur in other types of parental combinations. Parents with highest gca effects will not necessarily generate top specific cross combinations as also reported by Ranganathan *et al.* (1973), Khalique *et al.* (1977), Singh (1977) and 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×low combiners produced the best combinations (Khalique *et al*., 1977; Rahman *et al*., 1981; Arnirthadeverathinam, 1983). Such behaviour has been attributed to over dominance and epistasis (Rahman *et al*., 1981). Maurya and Singh (1977) reported that average×average combinations along with high×low combinations produced the best crosses. The superiority of average×average combinations might be due to the concentration and/or interaction between favourable genes contributed by the parents. The superior cross combinations identified in this study involved high×high, high×low, average×high, average×low, average×average and low×low combining parents indicating all above mentioned types of gene interaction in the F_1 combinations studied. Peng and Virmani (1990) also reported the possibility of interaction between positive alleles for good combiner and negative alleles for poor combiner which suggested for the exploitation of heterosis in F_1 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 %, panicle bearing tillers per plant, panicle length, number of spikelets per panicle, number of fertile spikelets, spikelet fertility (%), 100 grain weight, grain yield per plant, 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. As such this type of genetic variance is non-fixable and thus development of hybrids is an appropriate crop improvement tool. 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 various workers Dhaliwal and Sharma (1990) for 100 grain weight, days to 50% flowering, plant height, panicle length, grain per panicle and grain yield. Banumathi and Prasad (1991) for plant height, number of filled grains, Spikelet fertility (%) and grain yield per plant; Ghosh (1993) for panicle

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 per plant	Panicle length (cm)	No. of spikelets per panicle	No. of fertile spikelets	Spikelet fertility (%)	100 grain weight (g)	Grain yield per plant (g)	Biological yield (g)	Harvest index (%)
IR 58025A×IR32419- 28-3-1-3R	-4.64**	1.22	-0.73	1.49*	4.47**	8.76**	8.74**	-1.33	0.10	7.28**	2.39	7.50**
IR 58025A×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×IR52256-9-2-2-1R	1.13	4.70**	-0.62	-4.06**	-3.02**	3.09*	2.63	-1.31	0.02	1.48	2.15	0.45
IR58025A×IET 9352	4.47**	1.55	-4.29**	-0.06	1.95*	1.79	0.74	-0.07	0.06	-6.86**	-1.604**	0.62
IR58025A×IR 42686-2-118-6-2R	-0.31	1.43	1.60	0.49	-0.35	9.21**	13.07**	1.39	-0.04	2.22*	9.09**	-1.60
IR58025A×IR 633-76-1R	1.69	0.45	2.82	-0.51	1.75	-0.91	0.74	-0.53	0.20	-4.32**	-12.01**	1.46
IR58025A×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**	-10.70**	2.91*
IR58025A×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×62030-81-1-3-2R	3.24**	-0.11	-1.73	1.61*	4.82**	-3.02	-4.71**	-1.50	-0.31*	-0.98	3.29*	-3.10*
IR58025A×IR46R	-3.76**	2.23	-0.18	0.16	-0.29	4.54**	5.85**	1.23	0.53**	3.90**	-2.50	6.26**
IR58025A×IR 58110-114-2-2-2R	2.47*	0.69	0.60	-0.51	-3.26**	-22.68**	-16.37**	0.44	-0.35*	-6.16**	2.23	-9.60**
IR58025A×IR 48749-53-2-2-2R	5.02**	5.59**	1.49	-0.28	1.08	0.54	-0.37	-1.98	0.20	7.82**	11.04**	3.81**
IR58025A×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×IR 54852-129-1-23-1R	-1.64	0.02	6.71**	3.16**	3.70**	11.09**	11.63**	-0.40	0.37**	3.67**	-2.26	6.02**
IR58025A×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×IR 54853-43-1-3R	3.47**	3.63**	2.71	-0.51	1.71	8.54**	11.41**	0.90	-0.20	2.24*	-2.74*	4.35**
IR58025A×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	1.70	13.07**	-4.02**
IR58025A×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×NDR 358	2.58**	1.69	-1.29	-0.17	2.58**	7.76**	13.96**	2.77**	0.29*	-1.97*	-2.80*	-1.35
IR58025A×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×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×IET 201108	0.12	2.81*	3.08*	0.16	-0.60	-1.29	-3.07*	-2.10*	0.03	-4.83**	-6.93**	-2.64**
NMS 4A×IR52256-9-2-2-1R	-1.10	1.02	1.41	2.82*	5.81**	3.93**	13.38**	4.30**	0.01	3.89**	0.78	4.59**
NMS 4A×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×IR 42686-2-118-6-2R	-4.21**	-11.05**	1.30	-1.96*	5.38**	5.29**	-1.18	0.88	0.15	0.39	2.40	-0.54**
NMS 4A×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×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×IR60966-29-4-2-2-2R	2.79**	-5.40**	-3.48*	-1.62*	0.94	7.26**	6.82**	-0.79	-0.01	0.98	7.76**	-3.38*
NMS 4A×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×IR46R	2.68**	1.92	2.86	1.04	-3.63**	-16.29**	-12.40**	1.08	-0.26*	-2.61**	-2.93	-1.87
NMS 4A×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×IR 48749-53-2-2-2R	-2.21*	-1.06	-1.14	-3.40**	0.44	4.37**	10.04**	2.53**	-0.05	-5.51**	-17.59**	2.95*
NMS 4A×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×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×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×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×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×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×NDR 358	2.01*	2.51*	2.74	0.04	-3.89**	-21.07**	-21.96**	-3.75**	-0.48**	-2.30*	-0.46	-2.55
NMS 4A×NDR 3008	-2.77**	7.31**	-1.81	0.71	-5.10**	3.15*	5.26**	0.17	0.32*	-2.09*	2.19	-3.88**
PMS 10A×IR32419-28-3-1-3R	-1.81	3.94**	-1.90	-1.21	-1.29	11.31**	-4.23**	-5.56**	0.40**	-1.57	-1.00	-1.30
PMS 10A×IET 201108	2.52**	5.11**	-2.12	-0.43	2.44*	12.09**	11.22**	2.77**	0.15	5.58**	11.79**	0.60
PMS 10A×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×IET 9352	-2.03*	-4.93**	0.21	-1.43	-1.71	11.42**	7.44**	1.50	-0.28*	1.75	9.81**	-3.24*
PMS 10A×IR42686-2-118-6-2R	4.52**	9.62	-2.90	1.46*	5.73**	-3.91**	-11.89**	-2.27*	-0.10	-2.60**	-11.49**	2.14
PMS 10A×IR 633-76-1R	-5.48**	-0.63	-1.68	0.46	-3.24**	-10.02**	-16.89**	-2.32*	-0.25	-3.74**	1.30	-5.47**
PMS 10A×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×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*

Table 3: Continued

Crosses	Days to 50% flowering	Plant height (cm)	Pollen fertility (%)	Panicle bearing tillers per plant	Panicle length (cm)	No. of spikelets per panicle	No. of fertile spikelets	Spikelet fertility (%)	100 grain weight (g)	Grain yield per plant (g)	Biological yield (g)	Harvest index (%)
PMS 10A×IR 62030-81-1-3-2R	-1.26	5.57**	1.10	-3.09**	-8.61**	-6.47**	1.67	4.41*	-0.31*	-2.29*	-0.25	-2.81*
PMS 10A×IR 46R	1.08	-4.15**	-2.68	-1.21	3.92**	11.76**	6.55**	-0.15	-0.26*	-1.30	5.42**	-4.39**
PMS 10A×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×IR 48749-53-2-2-2R	-2.81**	4.53**	-0.34	3.68**	-1.52	-4.91**	-9.67**	-0.55	-0.15	-2.30*	6.56**	-6.75**
PMS 10A×IR 19058-170-1R	3.74**	1.22	0.99	-2.43**	-2.67**	-6.36**	-6.23**	2.29*	-0.20	-1.28	-7.57**	3.35*
PMS 10A×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×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×IR 54853-43-1-3R	-2.70**	-1.82	2.79	0.79	3.35**	11.42**	3.11**	-1.06	0.85**	5.48**	7.68**	3.28**
PMS 10A×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×NDR 6054	0.30	1.34	2.32	0.65	-2.98**	-35.36**	17.12**	0.89	-0.72**	-6.40**	-6.74**	-5.15**
PMS 10A×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×NDR 3008	3.97**	1.31	1.99	-0.54	6.64**	20.20**	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

***Signfiat at 1 and 5% probasility level of significant

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

Character	Females (Line)	Males (Tester)	Interaction Line×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	4.950	0.075
Pollen fertility	0.102	18.364	81.534	0.603	3.339	3.339	0.152
Panicle bearing tillers per plant	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 per panicle	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 per plant (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

gca: General combining ability, sca: Specific combining ability

number per plant, grains per panicle, spikelets per panicle, 1000-grain weight, harvest index and yield per plant; Chakraborty *et al.* (1994) for plant height, panicles per plant and yield per plant; Verma *et al.* (1995) for biological yield and harvest index and Singh *et al.* (1996) and Sreeramachandra *et al.* (2000) for grain yield and its related characters. However, contrary to these, the predominant role of additive gene effects have been observed for grain yield and its component traits (Hague *et al.*, 1981; Rahman *et al.*, 1981; Singh and Shrivastava, 1982; Sardana and Borthakur, 1987; Kaushik and Sharma, 1986; Wilfred and Prasad, 1992) for days to flowering, plant height, and panicles per plant; (Banumathi and Prasad, 1991) for number of productive tillers and length of panicle. Singh and Singh (1991) for plant height; (Ghosh, 1993) for plant height, panicle length and 100-grain weight; Chakraborty *et al.* (1994) for days to 50% flowering, spikelets per panicle and 100 grain weight.

Estimation of heterosis: Heterosis was computed as percent increase or decrease in F_1 value over better parent (heterobeltiosis) and over best commercial variety (standard heterosis) were presented in Table 5. The nature and magnitude of hybrid vigour differed for different traits in various hybrid combinations.

The grain yield is very complex trait and it is multiplicative end product of several basic components of yield (Grafius, 1959). From practical point of view, heterosis over standard variety is more relevant. Virmani *et al.* (1981) reported as high standard heterosis as 27 and 34% during wet and dry seasons, respectively. They further suggested that a yield advantage of 20-30% over best available standard variety should be sufficient to encourage farmers to take-up hybrid rice cultivation. In the present investigation about 1/3 combinations exhibited standard heterosis more than 30% among these best crosses in order of merit increased grain yield were IR58025A×IR48749-53-2-2-2R, NMS4A×IR633-76-1R, IR58025A×IR54853-43-1-3R, IR58025A×IR19058-107-1R and PMS10A×IR54853-43-1-3R. These findings are in agreement with the earlier workers (Wilfred and Prasad, 1992; Watanesk, 1993; Patel *et al.*, 1994; Zhang *et al.*, 1994; Ali and Khan, 1995; Rao *et al.*, 1996; Mishra and Pandey, 1998; Nuruzzaman *et al.*, 2002; Faiz *et al.*, 2006; Saleem *et al.*, 2008; Bagheri and Jelodar, 2010; Rahimi *et al.*, 2010; Tiwari *et al.*, 2011; Akinwale *et al.*, 2011). In general, F_1 hybrids based on a cytoplasmic genetic male sterile system have shown as much heterosis as F_1 hybrids between conventional cultivars/lines. However, most of the data showed heterosis ranging from about 20% over the mid-parent to 70% over the better parent and heterobeltiosis ranging about 20 to 40%. China has shown 20-30% higher yield potential for hybrids in large-scale production plots, with wider adaptability than conventionally bred varieties (Hunan Provincial Paddy Rice Heterosis Scientific Research Coordination and Cooperation Group, 1978; Li, 1977; Lin and Yuan, 1980; Wu *et al.*, 1980).

Negative heterosis is desirable for days to flowering because this will make the hybrids to mature earlier as compared to parents. Almost all the crosses had either equal or early flowering than the standard variety (Sarjoo-52). When compared to better parent, significant earlier flowering plants were observed in thirty one crosses while; eight crosses were identified for late flowering. The magnitude of heterosis observed over better parent ranged from -16.57% (IR58025A×IR35454-18-1-1-2R) to 7.27% (NMS4A×IR53480-8-39-3-1-2R) with a mean of -3.04% over the better parent, the magnitude of standard heterosis ranged from -4.22% (IR58025A×IR58110-114-2-2-2R) to -16.57% (IR58025A×IR35454-18-1-1-2R) with mean value of -9.67%. In general, all the sixty crosses exhibited early flowering over standard variety (Sarjoo-52), while thirty one crosses exhibited significantly early flowering and eight crosses were late flowering as compared over the better parent. The most promising cross combinations for early flowering were IR58025A×IR32419-28-3-1-3R, NMS4A×IR42686-2-118-6-2R, PMS10A×IR633-76-1 R, PMS10A×IR54853-43-1-3R and PMS10A×NDR358. Heterosis in both negative and positive directions for days to flowering has also been reported by Peng and Virmani (1991) and Murthy and Kulkarni (1996).

Semi-dwarf plant height (80-100 cm) is desirable for recording high yield in rice variety as vigour in plant height may lead to unfavourable grain/straw ratios and below optimum yield due to lodging. The minimum amount of heterosis - 16.99% (IR58025A×NDR6054) and -19.62% (NMS4A×IR42686-2-118-6-2R) was recorded over better parent and standard variety, respectively. However, the maximum significant heterosis observed over the better parent was 8.29% (PMS10A×IR46R), while in case of standard heterosis, it was 0.18% (IR58025A×IR48749-53-2-2-2R) and mean heterosis over better parent and standard variety was 5.98 and -9.26%, respectively. However, 43 and 53 crosses expressed dwarf stature in comparison to both better parent and standard variety. It was obvious from the data that the hybrid combinations have a tendency of dwarfness of trait in most of the cases. The most promising cross combinations for dwarfness were IR58025A×NDR6054, NMS4A×IR42686-2-118-6-2R, IR58025A×NDR3008, IR58025A×IR58110-114-2-2-2R and IR58025A×IET201108. None of the desirable combinations

Table 5: Estimation of heterosis over better parent (BP) and standard variety (SV) for yield and yield components in rice

Crosses	Days to 50% flowering		Plant height (cm)		Pollen fertility (%)		Effective tillers per plant		Panicle length (cm)		No. of spikelets per panicle	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
IR58025A×IR 32419-28-3-1-3R	-11.08**	-15.36**	-9.94**	-7.62**	-11.58**	0.00	-18.75**	8.33	32.68**	17.00**	-0.70	6.60**
IR58025A×IET 201108	-4.61**	-12.65**	-15.44**	-13.26**	-5.30*	-79.00	-4.17	27.78**	17.76**	-1.59	-6.33**	0.57
IR58025A×IR 52256-9-2-2-1R	-4.64**	-7.23**	-3.91*	-4.19**	-8.15**	-1.59	-25.00**	0.00	-1.55	-17.72**	1.41	8.87**
IR58025A×IET 9352	-6.87**	-6.02**	-4.87**	-2.42	-13.26**	-3.97	-20.83**	5.56	12.07**	12.39**	1.23	8.68**
IR58025A×IR 42686-2-118-6-2R	-9.26**	-11.45**	-5.14**	-8.42**	0.00	2.78	-16.67**	11.11**	-21.95**	-7.78	-1.58	5.66**
IR58025A×IR 633-76-1R	-8.06**	-7.23**	-11.12**	-12.64**	-1.87	4.37	-26.00**	2.78	18.97**	-0.58	-9.14**	-2.45*
IR58025A×IR 47310-94-4-3-1R	1.97	-6.63**	-3.27*	-4.61**	-9.16**	-1.59	-20.75**	16.67*	-23.79**	-20.61**	-3.51**	3.58**
IR58025A×IR 60966-29-4-2-2-2R	-9.91**	-12.35**	-1.40	-3.96*	-1.58	-1.19	-10.42	19.44*	23.86**	5.48	-4.85**	3.58**
IR58025A×IR 62030-81-1-3-2R	-0.97	-8.13**	-8.66**	-11.52**	-5.38*	-2.38	0.00	33.33**	24.71**	22.19**	-8.61**	-1.89*
IR58025A×IR 46R	-1.36	-12.65**	-6.36**	-7.33**	-3.08	0.00	-8.33	22.22**	-19.65**	-8.65	-3.34**	3.77**
IR58025A×IR 58110-114-2-2-2R	3.58**	-4.22**	-15.99**	-13.83**	0.40	0.40	-30.77**	0.00	-22.35**	-22.91**	-20.88**	-11.32**
IR58025A×IR 48749-53-2-2-2R	1.29	-5.72**	-2.33	0.18	-1.54	1.59	20.83**	5.56	20.69**	0.86	-8.96**	-2.26*
IR58025A×IR 19058-170-1R	0.00	-11.75**	-3.74*	-13.38**	-8.12**	-1.19	8.33	44.44**	2.41	16.14**	-5.33	4.15**
IR58025A×IET 201102	-3.18*	-8.43**	-2.76	-7.14**	1.55	3.97	15.69**	63.89**	31.23**	19.88**	1.58	9.06**
IR58025A×IR 35454-18-1-1-2R	16.57**	-16.57**	-12.56**	-12.95**	5.28*	2.78	-20.83**	5.56	-30.26**	-27.95**	-8.79**	-2.08*
IR58025A×IR 54853-43-1-3R	-0.65	-7.53**	-4.81**	-8.71**	0.38	3.97	-17.31**	19.44**	20.69**	0.86	-4.22**	2.83**
IR58025A×IR 53480-8-39-3-1-2R	0.69	-12.35**	12.50**	-16.63**	2.39	1.98	-12.50**	16.67**	-13.36**	-20.61**	7.30**	0.57
IR58025A×NDR 6054	-1.34	-11.14**	-16.99**	-14.86**	-9.12**	-1.19	-10.42	19.44**	2.07	6.77	2.28**	9.81**
IR58025A×NDR 358	6.16**	-6.63**	3.28	-6.00**	-4.62	-1.59	-2.08	30.56**	15.86*	-3.17	-3.16**	3.96**
IR58025A×NDR 3008	-5.18**	-11.75**	-16.53**	-14.39**	-8.60**	1.19	-12.50*	16.67*	-24.90**	-20.89**	-21.79**	-16.04**
NMS4A×IR 32419-28-3-1-3R	-0.63	-5.42**	-11.85**	-13.41**	-8.07**	3.97	-24.00**	5.56	-13.08*	-15.71**	-15.41**	-15.09**
NMS4A×IET 201108	-1.97	-10.24**	-2.17	-3.90	-0.76	3.97	0.00	38.89**	7.28	4.03	-2.38*	0.57
NMS4A×IR 52256-9-2-2-1R	-6.81**	-9.34**	-5.92**	-7.59**	-5.93*	0.79	16.00*	61.11**	24.52**	20.75**	-0.72	3.96**
NMS4A×IET 9352	-13.91**	-12.35**	0.84	-0.95	-4.30	5.95**	-6.00	30.56**	2.87	3.17	-1.50	-1.13
NMS4A×IR 42686-2-118-6-2R	-12.96**	-15.05**	-16.74**	-19.62**	-0.39	2.38	-26.00**	2.78	-40.12**	-29.25**	-8.27**	-7.92**
NMS4A×IR 633-76-1R	-6.27**	-5.42**	-11.46**	-13.03**	-6.34**	-0.40	-14.00**	19.44*	1.63	-1.44	-4.73**	-1.13
NMS4A×IR 47310-94-4-3-1R	-2.63**	-10.84**	-6.74**	-8.39**	-4.76*	3.17	-24.53**	11.11	-1.24	2.88	8.65**	9.06**
NMS4A×IR 60966-29-4-2-2-2R	-3.41**	-6.02**	-12.22**	-14.51**	-2.37	-1.98	-6.00	30.56**	24.67**	20.89*	-0.52	8.30**
NMS4A×IR 62030-81-1-3-2R	-6.17**	-12.95**	-13.69**	-16.40**	-2.69	0.40	4.00	44.44**	20.44**	18.01*	-3.64**	-0.19
NMS4A×IR 46R	5.10**	-6.93**	-6.08**	-7.74**	0.38	3.57	2.00	41.67**	-32.07**	-22.77**	-18.62**	-13.40**
NMS4A×IR58110-1-114-2-2-2R	1.63	-6.02**	-13.53**	-15.07**	-3.17	-3.17	-11.54*	27.78**	12.77**	11.96*	-8.08*	3.02**
NMS4A×IR 48749-53-2-2-2R	-5.83**	-12.35**	-4.15*	-5.85**	-4.62	-1.59	-34.00**	-8.33	1.49	-1.59	-5.83**	-5.47**
NMS4A×IR 19058-170-1R	-1.02	12.65**	-3.38*	-13.06**	-8.86**	-1.98	-20.00**	11.11	6.35	20.61**	-9.09**	0.00
NMS4A×IET 201102	-2.55*	-7.83**	4.69**	-0.32	-15.12**	-13.10**	-11.76**	25.00**	-19.47**	-21.90**	-12.41**	12.08**
NMS4A×IR 35454-18-1-1-2R	-13.25**	-13.25**	-3.82*	-5.52**	2.44	0.00	20.00**	66.67**	19.25**	23.20**	6.27**	8.68**
NMS4A×IR 54853-43-1-3R	-4.85**	-11.45**	-9.98**	-13.68**	-2.68	0.79	-7.69	33.33**	-25.85**	-28.10**	-21.35**	-18.68**
NMS4A×IR 53480-8-39-3-1-2R	7.27**	-6.63**	-4.43**	-8.95**	1.59	1.19	26.00**	75.00**	22.14**	18.44**	-6.09**	1.89*
NMS4A×NDR 6054	-2.68*	-12.35**	-11.34**	-12.91**	-7.66**	0.40	-18.00**	13.89	-5.51	-1.15	-8.46**	-8.11**
NMS4A×NDR 358	5.48**	-7.23**	3.93*	-5.41**	0.00	3.17	4.00	44.44**	-28.68**	-30.84**	-20.29**	-17.74**
NMS4A×NDR 3008	-6.80**	-13.25**	1.38	-0.41	-10.39**	-0.79	-2.00	36.11**	-39.26**	-36.02**	-7.98**	-6.42**
PMS10A×IR 32419-28-3-1-3R	7.91**	-12.35**	-0.09	-5.26**	-12.63**	-1.19	-23.26**	-8.33	0.33	-11.53**	-7.61**	3.02**
PMS10A×IET 201108	0.99	-7.53**	3.58*	-1.77	-6.44**	-1.98	-4.17	27.78**	48.30**	13.26**	-2.71**	8.49**
PMS10A×IR 52256-9-2-2-1R	-3.47**	-7.83**	-8.75**	-13.47**	-8.15**	-1.59	32.56**	58.33**	5.74	20.22**	-12.01**	1.89*
PMS10A×IET 9352	-7.26**	-11.45**	-3.21*	-8.21**	-8.24**	1.59	-16.28*	0.00	-7.33	-7.06	-0.34	11.13**
PMS10A×IR 42686-2-118-6-2R	-2.21	-6.63**	4.17*	-1.21	-5.02*	-2.38	4.65	25.00**	-2.80	14.84*	-16.41**	-6.79**
PMS10A×IR 633-76-1R	-9.15**	-13.25**	-8.94**	-13.65**	-6.72*	-0.79	-16.00*	16.67*	-6.02	-25.79**	-21.66**	-12.64**

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Table 5: Continued

Crosses	Days to 50% flowering		Plant height (cm)		Pollen fertility (%)		Effective tillers per plant		Panicle length (cm)		No. of spikelets per panicle	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
PMS10A×IR 47310-94-4-3-1R	0.33	-8.13**	-3.55*	-8.54**	-8.06**	-0.40	-20.75**	16.67*	-7.05	-3.17	-7.61**	3.02**
PMS10A×IR 60966-29-4-2-2-2R	-2.21	-6.63**	-5.58**	-10.46**	9.49**	9.92**	37.21**	63.89**	40.78**	19.88**	-4.57**	6.42**
PMS10A×IR 62030-81-1-3-2R	-4.87**	-11.75**	-1.43	-6.53**	-1.92	1.19	-16.28*	0.00	-38.24**	-39.48**	-18.27**	-8.87**
PMS10A×IR 46R	4.08**	-7.83**	8.29**	-13.03**	-5.77*	-2.78	-2.33	16.67*	-6.84	5.91	-7.78**	2.83**
PMS10A×IR 58110-114-2-2-2R	-1.30	-8.73**	-9.94**	-14.59**	1.98	1.98	-28.85**	2.78	-18.29**	-18.88**	-8.90**	2.45*
PMS10A×IR 48749-53-2-2-2R	-5.83**	-12.35**	-3.86*	-8.83**	-3.46	-0.40	20.93**	44.41**	7.96	-13.98*	-19.63**	-10.38**
PMS10A×IR 19058-170-1R	5.80**	-6.63**	-1.74	-11.58**	-6.64**	0.40	-18.60*	-2.78	-14.23**	-2.74	-15.40**	-5.66**
PMS10A×IET 201102	1.27	-4.42**	-10.09**	-14.74**	-5.04*	-2.78	0.00	41.67**	20.82**	10.37	-9.48**	0.94
PMS10A×IR 35454-18-1-1-2R	-6.94**	-11.14**	1.31	-3.93**	4.47	1.98	39.53**	66.67**	9.62	13.26*	-7.61**	3.02**
PMS10A×IR 54853-43-1-3R	-6.15**	-12.65**	-8.88**	-13.59**	-5.75*	-2.38	-5.77	36.11**	29.52**	4.52	-10.83**	0.57
PMS10A×IR 53480-8-39-3-1-2R	6.23**	-7.53**	-1.46	-6.56**	5.18*	4.76	-14.58**	13.89	-35.22**	-40.63**	-40.44**	-33.58**
PMS10A×NDR 6054	1.00	-10.84**	-7.29**	-12.08**	-4.38	3.97	-9.30	8.33	-23.83**	-20.32**	-38.58**	-31.51**
PMS10A×NDR 358	-0.68	-12.65**	-2.50	-11.26**	-4.62	-1.59	16.28**	38.89**	10.33	-12.25**	-8.46**	2.08*
PMS10A×NDR 3008	0.32	-6.63**	-0.50	-5.64**	-6.09**	3.97	0.00	19.44**	5.20	10.81	-7.11**	3.58**
Mean	-3.04	-9.67	-5.98	-9.26	-4.05	0.43	-6.88	24.44	0.37	-3.65	-8.63	-1.69
No. of hybrids with significant +Ve heterosis	8	0	5	0	3	4	9	41	20	16	3	29
No. of hybrids with significant-Ve heterosis	31	60	43	53	29	1	29	0	19	22	48	22

Crosses	No. of fertile spikelets		Spikelet fertility (%)		100-grain weight (g)		Grain yield per plant (g)		Biological yield (g)		Harvest index (%)	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
IR58025A×IR 32419-28-3-1-3R	25.58**	12.24**	14.68**	5.19**	-3.68	-9.03	48.77**	64.35**	8.33**	27.48**	36.89**	28.85**
IR58025A×IET 201108	28.65**	5.77**	31.78**	5.09**	20.25**	-5.97	37.72**	37.16**	-11.76**	4.25	56.06**	31.50**
IR58025A×IR 52256-9-2-2-1R	11.52**	11.78**	7.29**	2.60	-24.51**	-30.28**	38.83**	58.10**	9.02**	28.29**	-6.63	23.27**
IR58025A×IET 9352	29.48**	8.55**	3.83*	-0.22	51.09**	5.97	23.71**	17.82**	-22.54**	-8.85**	33.19**	29.13**
IR58025A×IR 42686-2-118-6-2R	27.42**	12.70**	10.95**	6.58**	-15.66**	-31.94**	12.68**	28.16**	12.50**	32.38**	-9.21*	-3.19
IR58025A×IR 633-76-1R	31.02**	0.46	39.38**	2.88	-26.94**	-26.94**	35.44**	28.44**	-13.94**	1.27	5.27	26.59**
IR58025A×IR 47310-94-4-3-1R	30.51**	6.70**	10.77**	2.89	22.13**	3.47	5.11	14.69**	-22.89**	-9.26**	11.11**	26.39**
IR58025A×IR 60966-29-4-2-2-2R	12.69**	4.62**	18.46**	0.91	-3.82	-30.14**	47.55**	47.35**	5.86*	10.78**	6.48	32.91**
IR58025A×IR 62030-81-1-3-2R	25.00**	-3.00*	35.23**	1.21	-24.57**	-32.22**	34.45**	33.71**	7.80**	26.86**	18.91**	5.39
IR58025A×IR 46R	8.82**	8.31**	14.38**	7.26**	-0.76	-9.72	57.82**	49.02**	-2.50	14.73**	37.07**	29.84**
IR58025A×IR 58110-114-2-2-2R	-19.02**	-4.62**	2.38	7.48**	-10.38**	-24.44**	-5.02	8.98	-9.00**	15.90**	4.04	-6.16
IR58025A×IR 48749-53-2-2-2R	-2.95*	-1.15	-0.54	1.05	34.79**	-14.44	113.04**	54.29**	5.65*	24.32**	54.08**	24.07**
IR58025A×IR 19058-170-1R	6.05**	9.24**	12.00**	4.79**	-3.40	6.67	74.93**	71.43**	11.29**	30.97**	-2.25	30.84**
IR58025A×IET 201102	16.55**	13.86**	5.27**	4.33**	65.31**	12.50	34.76**	50.75**	-3.58	13.47**	17.26**	32.67**
IR58025A×IR 35454-18-1-1-2R	3.50*	2.31	8.10**	4.38**	7.01	8.19	-0.25	7.07	6.03*	24.78**	-30.18**	-14.22**
IR58025A×IR 54853-43-1-3R	0.43	6.70**	0.99	3.68*	-4.50	-26.25**	78.73**	41.77**	-2.16	15.14**	47.70**	22.90**
IR58025A×IR 53480-8-39-3-1-2R	-4.97**	6.00**	2.53	5.32**	-26.81**	-24.17**	0.12	11.84*	3.88	22.24**	-31.56**	-8.62
IR58025A×NDR 6054	26.84**	11.32**	6.81**	1.29	-7.65	5.56	58.64**	52.38**	8.84**	28.08**	20.46**	18.98**
IR58025A×NDR 358	11.98**	12.24**	11.20**	7.88**	36.49**	-8.06	42.15**	13.33*	-0.73	16.81**	5.37	-3.09
IR58025A×NDR 3008	-20.66**	-11.32**	-3.92**	5.52**	-35.71**	-30.97**	2.32	8.72	-14.61**	2.26	19.74**	6.16
NMS4A×IR 32419-28-3-1-3R	10.59**	-1.15	26.80**	16.31**	-29.12**	-33.06**	-5.91	3.95	-2.21	21.08**	-8.91	-14.26**
NMS4A×IET 201108	27.81**	5.08**	30.91**	4.40**	32.74**	3.79	13.66*	13.20*	-18.89**	0.43	33.61**	12.59*
NMS4A×IR 52256-9-2-2-1R	14.75**	15.01**	15.58**	10.53**	-29.01**	-28.89**	40.98**	60.54**	1.38	25.54**	-3.07	27.98**
NMS4A×IET 9352	17.08**	-1.85	3.21*	-0.81	62.97**	14.31	67.29**	59.32**	0.45	24.37**	32.12**	28.09**
NMS4A×IR 42686-2-118-6-2R	11.49**	-1.39	11.40**	7.02**	-4.13	-22.64**	-0.36	13.33*	-1.84	21.53**	-12.54**	-6.75
NMS4A×IR 633-76-1R	39.46**	6.93**	46.40**	8.07**	-31.53**	-31.53**	80.92**	71.56**	9.18**	35.18**	5.63	27.03**
NMS4A×IR 47310-94-4-3-1R	46.61**	19.86**	17.31**	8.97**	36.56**	15.69*	26.68**	38.23**	3.03	27.57**	-4.70	8.42

Table 5: Continued

Crosses	No. of fertile spikelets		Spikelet fertility (%)		100-grain weight (g)		Grain yield per plant (g)		Biological yield (g)		Harvest index (%)	
	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV	BP	SV
NMS4A×IR 60966-29-4-2-2-2R	17.16**	8.78**	17.80**	0.35	6.50	-22.64**	48.64**	48.44**	2.29	26.65**	-6.13	17.16**
NMS4A×IR 62030-81-1-3-2R	29.46**	0.46	34.36**	0.56	19.78**	7.64	44.46**	43.67**	-5.86**	16.56**	38.96**	23.15**
NMS4A×IR 46R	-8.12**	-8.55**	12.51**	5.51**	-35.42**	41.25**	21.90**	15.10**	-8.40**	13.42**	7.32	1.66
NMS4A×IR58110-1-114-2-2-2R	-9.80**	6.24**	-1.86	3.03*	10.38	6.94	33.20**	52.83**	-10.99**	13.37**	49.35**	34.71**
NMS4A×IR 48749-53-2-2-2R	0.00	1.85	5.95**	7.64**	20.57	-23.47**	27.75**	-7.48	-35.31**	-19.91**	43.26**	15.36**
NMS4A×IR 19058-170-1R	-2.91*	0.00	6.78**	-0.09	2.26	12.92	16.90**	14.56**	-9.83**	11.64**	-23.28**	2.70
NMS4A×IET 201102	-5.20**	-7.39**	6.17**	5.23**	-1.43	-32.92**	-7.41	3.58	-11.02**	10.17**	-16.86**	5.94
NMS4A×IR 35454-18-1-1-2R	21.03**	19.63**	13.88**	9.97**	8.65	9.86	53.49**	64.76**	-3.73	19.20**	12.41**	38.13**
NMS4A×IR 54853-43-1-3R	-20.43**	-15.47**	1.15	3.84*	-26.80**	-43.47**	18.18**	-6.26	-10.24**	11.14**	1.44	-15.59**
NMS4A×IR 53480-8-39-3-1-2R	-4.97**	6.00**	1.20	3.95*	-2.14	1.39	-4.38	6.80	-20.89**	2.05	-18.14**	9.29
NMS4A×NDR 6054	5.26**	-7.62**	5.91**	0.44	0.61	15.00	41.50**	35.92**	-4.22	18.59**	15.86**	14.43**
NMS4A×NDR 358	-17.05**	-16.86**	4.08*	0.97	-9.28	-38.89**	31.23**	4.63	-3.32	19.71**	-5.08	-12.71**
NMS4A×NDR 3008	-11.57**	-1.15	-3.89**	5.55**	3.88	11.53	8.71	15.51**	-7.54**	14.48**	13.71**	0.80
PMS10A×IR 32419-28-3-1-3R	14.73**	2.54	8.41**	-0.55	13.97	7.64	0.37	10.88**	-0.44	16.66**	1.03	-4.91
PMS10A×IET 201108	44.10**	18.48**	36.32**	8.71**	42.63**	11.53	46.31**	45.71**	4.91*	23.93**	39.41**	17.48**
PMS10A×IR 52256-9-2-2-1R	-2.07	1.85	4.53**	-0.04	-21.95**	-27.92**	-0.96	12.79**	-0.18	14.89**	-25.49**	-1.64
PMS10A×IET 9352	34.16**	12.47**	5.22**	1.13	37.23**	-3.75	42.43**	35.65**	8.46**	24.83**	12.02*	8.60
PMS10A×IR 42686-2-118-6-2R	7.05**	-5.31**	5.67**	1.52	-13.43	-30.14**	-19.86**	-8.84	-17.10**	-4.59	-9.35*	-3.34
PMS10A×IR 633-76-1R	14.16**	-12.47**	35.63**	0.11	-41.25**	-41.25**	19.66**	13.47*	0.66	15.85**	-18.63**	-2.15
PMS10A×IR 47310-94-4-3-1R	28.81**	5.31**	9.95**	2.14	20.16*	1.81	-6.98	1.50	-16.22**	-3.58	-8.26	4.36
PMS10A×IR 60966-29-4-2-2-2R	14.68**	6.47**	17.33**	-0.05	20.84*	-12.22**	35.15**	34.97**	-10.70**	2.78	5.13	31.22**
PMS10A×IR 62030-81-1-3-2R	26.79**	-1.62	44.10**	7.86**	-20.09*	-28.19**	11.63*	11.02*	0.62	15.80**	8.30	-4.02
PMS10A×IR 46R	8.58**	8.08**	11.97**	5.00**	-32.37**	-38.47**	17.00**	10.48	5.24*	21.13**	-3.80	-8.87
PMS10A×IR 58110-114-2-2-2R	-3.53*	-13.63**	5.54**	10.80**	26.85**	6.94	1.03	15.92**	-19.95**	1.95	25.97**	13.63**
PMS10A×IR 48749-53-2-2-2R	-9.98**	-8.31**	0.61	2.22	18.16	-25.00**	32.07**	-4.35	-2.82	11.84	6.27	-14.43**
PMS10A×IR 19058-170-1R	-3.36**	-0.46	12.69**	5.43**	-8.55	0.97	23.98**	21.50**	-14.24**	-1.29	-7.93	23.24**
PMS10A×IET 201102	8.51**	6.00**	6.34**	5.39**	71.63**	16.81*	16.69**	28.30**	4.94*	20.77**	-6.09	6.25
PMS10A×IR 35454-18-1-1-2R	14.02**	12.70**	13.18**	9.29**	18.54*	19.86*	45.88**	56.60**	-7.45**	6.52	19.58**	46.93**
PMS10A×IR 54853-43-1-3R	-5.65**	0.23	-1.91	0.70	57.73**	21.81**	73.53**	37.69**	8.90**	25.34**	32.01**	9.85*
PMS10A×IR 53480-8-39-3-1-2R	-3.11*	8.08**	-2.59	0.06	-37.80**	-35.14**	-36.05**	-28.57**	-30.01**	-19.45**	33.17**	-10.77*
PMS10A×NDR 6054	37.89**	21.02**	6.91**	1.39	39.85**	-31.25**	-4.96	-8.71	-10.84**	2.61	-9.90*	-11.01*
PMS10A×NDR 358	7.14**	7.39**	8.34**	5.10**	36.49**	-8.06	52.39**	21.50**	4.58**	20.37**	9.63	0.82
PMS10A×NDR 3008	5.17**	6.00**	-6.89**	2.26	9.06	17.08*	36.75**	45.31**	-6.18**	12.35**	45.82**	29.27**
Mean	10.61	3.99	11.81	4.17	8.15	-11.21	28.05	26.74	-4.53	13.99	8.85	11.18
No. of hybrids with significant+Ve heterosis	40	34	47	35	19	6	43	46	16	45	26	30
No. of hybrids with significant-Ve heterosis	17	12	3	0	16	28	2	1	25	4	12	7

BP: Heterobeltiosis (i.e., heterosis over better parent), SV: Standard heterosis (i.e., heterosis over standard check variety). ***Signficat at 1 and 5% posability level of significant

were common for both the heterosis, suggesting that heterosis for plant height is cross specific. Present observations are in close agreement with earlier report of several workers (Khalique *et al*., 1977; Mallick *et al*., 1978; Arnirthadeverathinam, 1983; Tseng and Huang, 1987; Sharma and Mani, 1990; Peng and Virmani, 1991; Lokaprakash *et al*., 1992; Singh *et al*., 1996); Nuruzzaman *et al*., 2002; Alam *et al*., 2004).

Pollen fertility is one of the constraints in hybrid rice breeding programme which affects the yield considerably. Among 60 crosses studied for pollen fertility %, only three and four hybrids showed significant positive heterosis over pollen parent and standard variety, respectively. The overall range of heterobeltiosis and standard heterosis varied from -15.12 to 9.49%, respectively. However, Pollen fertility in hybrids should be required as in pollen parent and or standard variety this indicates that the pollen parent in hybrid expressed full restoring capacity over a particular CMS line. Therefore, hybrids having non-significant differences over both the parents (BP and SV) either in positive or negative direction would be beneficial for this trait. The seven crosses and twenty eight cross combinations had positive but non-significant differences for both heterobeltiosis and standard heterosis; of these, PMS10A×IR35454-18-1-1-2R,IR58025A×IR53480-8-39-3-1-2R, PMS10A×IR58110-114-2-2-2R, NMS4A×IR46R and NMS4A×IR53480-8-39-3-1-2R were most useful crosses for this trait.

More panicle bearing tillers per plant is believed to be closely associated with high grain yield per plant resulting high productivity. Therefore, the cross combinations with more panicle bearing tillers per plant were to be identified. The significant positive heterosis for this trait was exhibited by 9 and 41 hybrids over better parent and standard variety, respectively. The mean heterosis was observed -6.88% over better parent and 24.44% over standard variety. Further the heterobeltiosis varied from -34.00% (NMS4A×IR48749-53-2-2-2R) to 39.53% (PMS 10×IR35454-18-1-1-2R) and standard heterosis from -8.33 (NMS4A×IR48749-53-2-2-2R) to 66.67% (PMS10A×IR35454-18-1-1-2R). Results for significantly high number of productive tillers per plant are in conformity with those obtained, by Srivastava and Seshu (1982), Govindraj (1983), Sahai *et al*. (1987), Viraktamath (1987) and Manuei and Palanisamy (1989a). However, these findings are in disagreement with the findings of Virmani *et al*. (1981), who reported hybrids posses significantly lower tillers than mid parent, better parent and check variety.

Generally, larger panicle is associated with high number of grains panicle resulting into higher productivity; therefore, hybrids with positive heterosis for panicle length are desirable. The present study revealed that heterosis for panicle length was relatively low as indicated by mean heterosis of 0.37% over better parent and -3.65% over standard variety. Out of 60 crosses 20 and 16 crosses showed higher panicle length over the better parent and standard variety, respectively, whereas 19 crosses possessed significant negative heterobeltiosis and 22 crosses exhibited negative standard heterosis with shorter panicle. The observed heterobeltiosis values ranged between -39.26 (NMS4A×NDR3008) to 48.30% (PMS10A×IET201108) with a mean of 0.37% and standard heterosis between - 40.63 (PMS10A×IR53480-8-39-3-1-2R) to 23.20% (PMS10A×IR35454-18-1-1-2R) in case of standard heterosis with mean of -3.65 percent. Similar findings were also reported by Kumar and Sreerangasamy (1986), Rangaswami and Natarajamoorthy (1988) Vivekanandan (1991), Lokaprakash *et al*. (1992) and Singh *et al*. (1992).

The hybrids with positive heterosis are desirable for number of spikelets per panicle. The lowest estimates of heterosis (-40.44%) over better parent and (-33.58%) standard variety were recorded in the cross PMS10A×IR 53480- 8-39-3-1-2R, while, maximum heterosis over better parent and standard variety was observed in case of cross NMS4A×IR47310-94-4-3-1R (8.65%) and NMS4A×IET201102 (12.08%). Out of 60 crosses studied 3 crosses over better parent and 29 crosses over standard variety exhibited significant higher number of spikelets per panicle. Significantly poor spikelets per panicle over the better parent and standard, variety was observed in 48 and 22 crosses, respectively. Results revealed that three hybrids expressed heterosis in desired direction with significant value when tested against better parent and almost 48 hybrids showed heterobeltiosis negative direction over standard variety. Positive heterosis over better parent and standard, variety was reported by Virmani *et al*. (1981, 1982) they concluded that heterosis in yield was primarily due to increased number of spikelets per panicle.

The number of fertile spikelets directly contributes to the seed yield hence positive heterotic effect would be highly desirable. The successful utilization of CMS in development of hybrids is not possible unless the effective restorer lines are identified. In the present study, more number of fertile spikelets is closely associated with high yield per plant resulting in high productivity. Therefore, the main interest is to find out the cross combinations with more number of long and heavy panicle bearing tillers. Significant and positive heterosis for this trait was exhibited by 47 and 35 hybrids over better parent and standard variety, respectively.

Significant negative heterosis was observed in case of 17 crosses over better parent and in 12 crosses over standard variety with mean heterosis was observed in positive direction for both better parent (10.61%) and standard variety (3.99%). The range of heterosis observed over better parent and standard variety was -20.66% (IR58025A×NDR 3008) to 46.61% (NMS4A×IR47310-94-4-3-1R) and -16.86% (NMS4A×NDR358) to 21.02% (PMS10A×NDR6054), respectively. These observations also corroborate the findings of (Mallick *et al.*, 1978; Mandal, 1982; Sardana and Borthakur, 1985; Kumar and Sreerangasamy, 1986; Viraktamath, 1987; Rangaswami and Natarajamoorthy, 1988; Sharma and Mani, 1989, 1990; Lokaprakash *et al.*, 1992; Bobby and Nadarajan, 1993).

Spikelet fertility percent is very important in hybrid breeding programme. Since this trait has a direct bearing on the yield, hence, manifestation of heterosis in positive direction is desirable for this trait. Out of 60 crosses, 47 expressed positive and significant heterobeltiosis, while 35 crosses expressed this in case of standard heterosis. The range of heterosis over better parent and standard variety varied from -6.89% (PMS10A×NDR3008) to 46.40% (NMS4A×IR633-76-1R) and -0.81% (NMS4A×IET9352) to 16.31% (NMS4A×IR 32419-28-3-1-3R), with mean heterosis of 11.81 and 4.17%, respectively. Results revealed that 40 hybrids expressed heterosis in desired direction with significant value when tested against better parent, and as many as 17 hybrids showed heterosis in negative direction over standard variety. Positive heterosis over better parent and standard variety was reported by Virmani *et al.* (1981) they concluded that heterosis in yield was primarily due to increased fertile spikelets per panicle. These results were in conformity with the results obtained by Srivastava and Seshu (1982), Govindraj (1983), Sahai *et al.* (1987), Viraktamath (1987) and Singh (2000) who reported hybrids posses significantly lower tiller number.

The 100 grain weight is one of the important common traits which influence the yield. The extent of heterosis was -41.25% (PMS 10 A×IR 633-76-1R) to 71.63% (PMS10A×IET201102) over better parent with mean of 8.15% and from - 43.47% (NMS4A×IR54853-43-1-3R) to 21.81% over standard variety. Significantly higher 100 grain weight was observed in case of 19 crosses when tested against their better parents and 6 crosses against the standard variety. Among 60 crosses, 19 and 16 hybrids showed significant heterobeltiosis over better parent in positive and negative direction, respectively, whereas 6 and 28 hybrids exhibited significant heterosis over standard variety in positive and negative direction. Heterosis with respect to 100 grain weight in positive and negative direction have also been reported by Virmani *et al.* (1981), Srivastava and Seshu (1982), Viraktamath (1987), Manuei and Palanisamy (1989b), Wilfred and Prasad (1992), Sharma and Mani (1990) and Lokaprakash *et al.* (1992).

The hybrid, NMS4A×IR48749-53-2-2-2R (-35.31%) and IR58025A×IR42686-2-118-6-2R (12.50%) had expressed heterosis for this trait over their better parent while, NMS4A×IR48749-53-2-2-2R (-19.91%) and NMS4A×IR633-76-1R, (35.18%) recorded heterosis in case of standard variety (Sarjoo-52). In general, out of 60 hybrids only 16 crosses recorded significantly higher heterobeltiosis while 45 crosses exhibited this in case of the standard heterosis. Significant but negative heterosis was exhibited by 25 and 4 hybrids over better parent and standard variety, respectively. These results are in close agreement with Virmani *et al.* (1993) and Peng and Virmani (1991).

Harvest index which indirectly influences the grain yield through controlling the mechanism of distribution of photosynthates to economic and non-economic organs as such is not a yield component. Therefore, it is an important consideration for genetic improvement. The minimum heterosis for harvest index was -31.56 and -15.59% over better parent and standard variety, respectively in cross IR58025A×IR53480-8-39-3-1-2R and NMS4A×IR54853-43-1-3R, however, the maximum heterosis was 56.06% over better parent in cross IR58025A×IET201108 and 46.93% over standard variety in cross PMS10A×IR35454-18-1-1-2R. Among 60 cross combinations 26 crosses showed significant positive and 12 showed significant negative heterobeltiosis while 30 crosses showed significant positive heterosis over standard variety. The positive heterosis was also reported by Virmani *et al.* (1982) and Peng and Virmani (1991). On the other hand, 12 and 7 hybrids exhibited significant and negative estimates for both heterobeltiosis and standard heterosis for this trait. The significant and negative heterosis over better parent for harvest index was also reported by Nijaguna and Mahadevappa (1982) and over standard variety by Sarwagi and Shrivastava (1988).

Heterotic combinations for commercial utilization: A hybrid with the potential of being released for commercial cultivation should significantly surpass the yield level of the best locally adapted variety and its CMS component should have to ensure hybrid seed production in bulk quantities. Swaminathan *et al.* (1972) and Virmani *et al.* (1981) have suggested that about 20-30% standard heterosis may be considered sufficient to offset the extra cost of hybrid seeds in self-pollinated crops. The most heterotic combinations for increased grain yield on the basis of per se performance, their standard heterosis, gca

Table 6: 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	IR58025A×IR 35454-18-1-1-2R	PMS10A×IR 633-76-1R	
	NMS4A×IR 35454-18-1-1-2R	IR58025A×IR32419-28-3-1-3R	
	NMS4A×IET 9352	PMS10A×NDR 358	IR58025A×IR 32419-28-3-1-3R
	NMS4A×IR 42686-2-118-6-2R	IR58025A×IR 60966-29-4-2-2R	
	IR58025A×IR 32419-28-3-1-3R	IR58025A×IR 42686-2-118-6-2R	
Plant height	IR58025A×NDR 6054	NMS4A×IR 42686-2-118-6-2R	
	IR58025A×NDR- 3008	IR58025A×NDR 3008	
	NMS4A×IR 42686-2-118-6-2R	PMS10A×IET 201102	IR58025A×IET-201108
	IR58025A×IR 58110-114-2-2-2R	IR58025A×IET 201108	NMS4A×IR 42686-2-118-6-2R
	IR58025A×IET 201108	IR58025A×IR 32719-28-3-1-3R	IR58025A×NDR 3008
Pollen fertility percent	PMS10A×IR 60966-29-4-2-2-2R	IR58025A×IET 201102	IR58025A×NDR 3008
	IR58025A×IR 35454-18-1-1-2R	PMS10A×IR 60966-29-4-2-2-2R	PMS10A×IR 60966-29-4-2-2-2R
	PMS10A×IR 32419-28-3-1-3R	NMS4A×IR 53915-43-3-3-3R	
	PMS10A×IR 35454-18-1-1-2R	NMS4A×IET 201108	
	IR58025A×IR 32419-28-3-1-3R	NMS4A×IR 46R	
Panicle bearing tillers (Effective tillers) per plant	PMS 10A×IR 35454-18--1-1-2R	NMS4A×IR 32419-28-3-1-3R	
	PMS10A×IR 60966-29-4-2-2-2R	IR58025A×IR 19058-107-1R	PMS10A×IR 60966-29-4-2-2-2R
	PMS10A×IR 52256-9-2-2-1R	PMS 10 A×IR 48749-53-2-2-2R	NMS4A×IR 32419-28-3-1-3R
	NMS4A×IR 32419-28-3-1-3R	IR58025A×IET 201102	
	NMS4A×IR 35454-18-1-1-2R	PMS10A×IR 60966-29-4-2-2-2R	
Panicle length	PMS10A×IET 201108	NMS4A×IR 32419-28-3-1-3R	
	PMS10A×IR 60966-29-4-2-2-2R	PMS10A×NDR 3008	
	IR58025A×IR 32419-28-3-1-3R	NMS4A×IR 52256-9-2-2-1R	Nil
	IR58025A×IET 201102	PMS10A×IR 42686-2-118-6-2R	
	PMS10A×IR 54853-43-3-3-3R	IR58025A×IR 62030-81-1-3-2R	
No. of spikelets per panicle	NMS4A×IR 47310-94-4-3-1R	IR58025A×NDR 6054	
	NMS4A×IR 35454-18-1-1-2R	NMS4A×IR 32419-28-3-1-3R	
	IR58025A×NDR 6054	PMS10A×NDR 3008	
	IR58025A×IET 201102	PMS10A×NDR 358	
	IR58025A×IR 52256-9-2-2-1R	IR58025A×IR 32419-28-3-1-3R	
No. of fertile spikelets	NMS4A×IR 633-76-1R	PMS10A×NDR 6054	PMS10A×NDR 6054
	PMS10A×IET 201108	NMS4A×IR 47310-94-4-3-1R	NMS4A×IR 47310-94-4-3-1R
	NMS4A×IR 633-76-1R	NMS4A×IR 633-76-1R	NMS4A×IR 633-76-1R
	PMS 10 A×NDR 6054	NMS4A×IR 35454-18-1-1-2R	
	IR58025A×IR 633-76-1R	IR58025A×NDR 358	
Spikelets fertility percent	NMS4A×IR 633-76-1R	NMS4A×IR 32419-28-3-1-3R	NMS4A×IR-633-76-1R
	PMS10A×IR 62030-81-1-3-2R	PMS10A×IR 62030-81-1-3-2R	PMS10AX IR-62030-81-1-3-2R
	IR58025A×IR 633-76-1R	NMS4A×IR 52256-9-2-2-1R	
	PMS10A×IET 201108	PMS10A×IR 58110-114-2-2-2R	
	PMS10A×IR 633-76-1R	NMS4A×IR 633-76-1R	
100 grain weight	PMS10A×IET 201102	PMS10A×IR 54853-43-1-3R	
	IR58025A×IET 201102	NMS4A×IR 62030-81-1-3-2R	PMS10A×IR 54853-43-1-3R
	NMS4A×IR 53915-43-3-3-3R	IR58025A×IR 46R	
	PMS10A×IR 54853-43-3-3-3R	NMS4A×IR 32419-28-3-1-3R	
	IR58025A×IET 9352	NMS4A×NDR 6054	

Table 6: Continued

Characters	Best hybrids on the basis of *per se* performance	Best specific combiners	Best common crosses
Grain yield per plant	IR58025A×IR 48749-53-2-2-2R	NMS4A×IR 633-76-1R	IR58025A×IR 48749-53-2-2-2R
	NMS4A×IR 633-76-1R	IR58025A×IR 48749-53-2-2-2R	NMS4A×IR 633-76-1R
	IR58025A×IR 54853-43-1-3R	PMS10A×NDR 3008	IR58025A×IR 19058-170-1R
	IR58025A×IR 19058-170-1R	IR58025A×IR 48749-53-2-2-2R	
	PMS10A×IR 54853-43-3-3-3R	IR58025A×IR 19058-170-1R	
Bilogical yield	IR58025A×IR 42686-2-118-6-2R	NMS4A×IR 47310-94-4-3-1R	NMS4A×IR 633-76-1R
	IR58025A×IR 19058-170-1R	IR58025A×IR 32419-28-3-1-3R	
	NMS4A×IR 633-76-1R	PMS10A×IET 201108	
	IR58025A×IR 52256-9-2-2-1R	IR58025A×IR 48749-53-2-2-2R	
	IR58025A×NDR 6054	NMS4A×IR 633-76-1R	
Harvest index	IR58025A×IET 201108	PMS10A×IR 35454-18-1-1-2R	NMS4A×IR 58110-114-2-2-2R
	IR58025A×IR 48749-53-2-2-2R	PMS10A×NDR 3008	
	NMS4A×IR 58110-114-2-2-2R	NMS4A×IR 58110-114-2-2-2R	
	IR58025A×IR 54853-43-1-3R	IR58025A×IR 32419-28-3-1-3R	
	PMS10A×NDR 358	IR58025A×IR 46R	

and sca effects are presented in Table 6. In the present investigation, about one third of the total hybrids showed more than 20% standard heterosis for grain yield over standard variety (Sarjoo-52). Among these, majority of the combinations expressed significant sca effects except IR58025A×IR52256-9-2-2-1R involving at least one parent with high general combining ability barring few exceptions viz., IR58025A×NDR 6054 and IR58025A×IET 201102. Therefore, it would be better to select at least one parent possessing high general combining ability and the other a low, average or high general combiner to get heterotic F_1 hybrids. Considering the heterosis more than 60% as well as significant sca effects for major components, the NMS4A×IR633-76-1R, IR58025A×IR19058-107-1R and IR 58025A×IR32419-28-3-1-3R were most promising combinations and need to be tested on large scale. Besides these, the some other crosses viz., NMS4A×IR52256-9-2- 2-1R, NMS4A×IET9352 and IR58025A×IET201102, which expressed more than 50% heterosis along with desirable significant sca effects for more than six important yield components may be considered for commercial exploitation.

CONCLUSION

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 that 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. Number of spikelets per panicle, grain yield, number of fertile spikelets, biological yield and harvest index should be taken into consideration either simultaneously or alone for selecting high yielding genotypes of rice. Male lines, IR35454-18-1-1-2R followed by IET201108 and IR52256-9-2-2-1R and CMS line IR58025A 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 NMS4A×IR52256-9-2-2-1R, PMS10A×IR633-76-1R, NMS4A×IR53480-8-39-3-1-2R, PMS10A×NDR3008. Besides these, the high sca effects for earliness were observed in PMS10A×IR633-76-1R, followed by IR58025A×IR32419-28-3-1-3R and PMS10A×NDR358, while NMS4A×IR42686-2-118-6-2R, IR58025A×NDR 3008 and PMS10A×IET201102 possessed considerable sca effects for dwarfness and recommended for heterosis breeding. Therefore, it may be concluded that use of suitable CMS and restorer lines in developing hybrids would be useful for attaining a quantum jump in rice yield.

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