"STUDIES OF COMBINING ABILITIES FOR DEVELOPMENT OF NEW HYBRIDS IN RICE (*Oryza sativa* L.)"

THESIS

Submitted to the

Indira Gandhi Agricultural University, Raipur

in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
IN
AGRICULTURE
(Plant Breeding & Genetics)

By

B. S. Sheshgiri

DEPARTMENT OF PLANT BREEDING & GENETICS
INDIRA GANDHI AGRICULTURAL UNIVERSITY
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RAIPUR (M.P.)

1998-99

INDIRA GANDHI AGRICULTURAL UNIVERSITY
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CERTIFICATE - I

This is to certify that the thesis entitled **"STUDIES OF COMBINING ABILITIES FOR DEVELOPMENT OF NEW HYBRIDS IN RICE (*Oryza sativa* L.)"** submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE (Plant Breeding & Genetics)** of the Indira Gandhi Agricultural University, Raipur (M.P.) is a record of the bonafide research work carried out by **Shri B.S. SHESHGIRI** under my guidance and supervision. The subject of the thesis has been approved by Student's Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published. All the assistance and help received during the course of the investigations has been duly acknowledged by him.

Dr. R.K. MISHRA
Chairman of the Advisory Committee

THESIS APPROVED BY STUDENT'S ADVISORY COMMITTEE

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Member	:	Shri G.V. Prasad

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CERTIFICATE - II

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Date......5.6.99

EXTERNAL EXAMINER

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1/7/99

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CHAPTER - I

INTRODUCTION

Rice cultivation probably dates back to the antiquity and has been cultivated in India since ancient times. Vavilov (1926) suggested that India and Burma as the centre of origin of cultivated rice. It is the staple food providing about two-thirds of the calories for more than two billion people in humid and subhumid Asia.

Rice belongs to the family Graminae and genus *oryza*. The genus *oryza* includes 24 species, of which 22 are wild and two namely *O. sativa* and *O. glaberrima* are cultivated. All varieties cultivated in Asia, America and Europe belong to *O.sativa* and varieties grown in West Africa belong to *O. glaberrima*.

In India, rice is the most important and extensively grown food crop with a production of 82.1 million tonnes in the year 1997-98 (Anonymous, 1999). In terms of acreage India ranks first followed by China in the second spot. The productivity of rice in India is approximately 1851 kgs. per hectare (Siddiq, 1999).

At the current rate of population growth of 1.9 per cent in India, the requirement of rice by the turn of the century is estimated to be around 100 million tonnes of paddy. Thus, within the next five years, a production increase of 25 million tonnes has to be achieved to sustain the self sufficiency achieved in the early eighties (Anonymous, 1995).

The task of achieving the target is quite challenging and the options available are very limited in view of plateauing trend of yield in high productivity areas, decreasing and degrading land, water, labour and other inputs. Among the various possible genetic approaches to achieve this target, hybrid rice technology is the most feasible and readily adoptable one, as has been successfully demonstrated in China. Using hybrid rice is one of the strategies to meet this immense challenge. Presently 55 per cent of the 32 million hectares of rice area in China, is under hybrid rice cultivation accounting for more than 66 per cent of the total rice production. Although heterosis in rice has been known since 1926 (Jones, 1926), its commercial exploitation was demonstrated only when chinese rice scientists developed and used commercial rice hybrids which increased rice varietal yields by about 20 per cent over semidwarf varieties (Lin and Yuan, 1980).

Research on hybrid rice in China began in 1964 (Lin and Yuan, 1980) under the initiative and leadership of professor Yuan Long ping. The genetic tools essential for producing F_1 hybrids viz., cytoplasmic male sterile (CMS), maintainer and restorer lines were developed in 1973, and hybrid seed production techniques were established in 1975. For the first time hybrid rice varieties were released commercially in 1976 such as Er-Jin-Nan A/IR24, Zhen Shan 97/IR24 etc. CMS lines with higher outcrossing potential have been developed such as Luon Tepu A and You 1A. yuan *et al*. (1994) observed that during 1976-91 hybrid rice helped china to increase its Production by 200 million tonnes. The ongoing work at present on hybrid rice in China is development of better CMS lines with new cytoplasmic source, development of better hybrids which show advantages in maturity, yield, pest resistance and other aspects.

Convinced by the commercial success and potential of hybrid rice technology in China, the Indian Council of Agricultural Research (ICAR), New Delhi, identified this as a priority area and initiated a network project on hybrid rice since 1989 in collaboration with International Rice Research Institute (IRRI), Philippines. At present this project is being operated as a national research network with twelve centres across the country. Extensive evaluation and research of the experimental hybrids is done at the twelve network centres, so far about 800 experimental hybrids have been evaluated. Very useful information has been collected over the years. The efforts yielded fruit, when for the first time in 1994 four rice hybrid varieties were released for commercial cultivation, these are APHR-1 and APHR-2 for Andhra Pradesh, MGR-1 for Tamil Nadu and KRH-1 for Karnataka. Subsequently CNRH-3 for West Bengal in 1995 and DRRH-1 for Andhra Pradesh were released in 1996 (Siddiq, 1996). Salient features of these Public released hybrids are depicted in Table 1.1.

Table 1.1 : Salient features of released hybrids :

Hybrids/Year of release	Percentage	Duration (days)	Yield (t/ha) Hybrid	Check	%increase over check
APHR-1 (1994)	IR 58025A/ VAJRAM	130-135	7.14	5.27 (Chaitanya)	35.4
APHR-2 (1994)	IR 62829A/ MTU 9992	120-125	7.52	5.21 (Chaitanya)	44.2
MGR-1 (1994)	IR-62829A/ IR 10198	110-115	6.08	5.23 (IR 50)	16.2
KRH-1 (1994)	IR-58025A/ IR 9761	120-125	6.02	4.58 (Mangala)	31.4
CNRH-3 (1995)	IR 62829A/ AJAYA	125-130	7.49	5.45 (Khitish)	37.4
DRRH-1 (1996)	IR-58025A/ IR 40750	125-130	7.30	5.50 (Tella homsa)	32.72

About 1500 test crosses have been evaluated at the twelve research network centres for identification of maintainers and restorers from elite breeding lines and germplasm. On the average for all centres the frequency of restorers was observed to be around 22 per cent and for maintainers was around 14 per cent for WA (Wild abortive) cytoplasm (Siddiq, 1996). More than 60 CMS lines have been developed at the research centres and 50 CMS lines received from IRRI were evaluated for their stability of sterility and other desirable traits. So far only 5 CMS lines, 2 from IRRI viz. IR-58025A and IR 62829A and 3 developed at Kapurthala viz. PMS 2A, PMS 3A and PMS 10 A have been found to be commercially viable for large SCAle hybrid seed production (Siddiq, 1996). Apart from WA cytoplasmic source, some CMS lines with indigenous sources have been developed like CRMS-1, CRMS-2, Krishna A etc. their respective cytoplasmic source are Ratna, Dungahansali and Kalinga-1 (Siddiq, *et al.* 1994).

India was too late in developing and adopting hybrid rice technology in spite of knowing its potential. However, with release of as many as 14 hybrids and with 1.5 lakh hectares under them, India has earned the unique distinction of being the second country after China to make hybrid rice a commercial reality since 1990 (Siddiq, 1999).

Dhamtari district of Chhattisgarh region has the maximum irrigated rice area where hybrid rice varieties can be introduced. The sustenance of this technology will however, be determined by the extent of development of locally adaptable and adoptable rice hybrids and hybrid rice seed technology. At Indira Gandhi Agricultural University, Raipur, research work on hybrid rice has been takenup since 1996-97 to develop a hybrid rice variety as per requirement of this region. Two IRRI male sterile lines viz. IR-58025A and IR 62829A were used to develop hybrids for this region, a thorough screening of elite lines for identification of maintainer lines and restorer lines is in progress, so that some cytoplasmic male sterility can be transferred to our lines and an adapted, acceptable and profitable commercial hybrid can be introduced. This study is mainly aimed to achieve the following objectives :

1. To estimate genetic variability of yield and its components.

2. To estimate GCA of parents and SCA of the hyrbids for yield and yield contributing characters.

3. To determine heterosis and heterobeltiosis of hybrids.

4. To screen suitable maintainers and restorer lines for IR-58025A and IR 62829A male sterile lines.

CHAPTER - II

REVIEW OF LITERATURE

The successful development and utilization of maize hybrids beginning about 1930 was a landmark in crop breeding. It provided impetus to plant breeders to explore commercial exploitation of hybrid vigour or heterosis in other crops. The exploitation of hybrid vigour is widely recognised as the only available means to raise the genetic yield ceiling in areas where yields have already approached potential level. Although heterosis in rice has been known since 1926 (Jones, 1926), its commercial exploitation was demonstrated by Chinese scientists which increased yields by about 20 per cent over semi-dwarf varieties (Lin and Yuan, 1980). Since then, considerable progress has been made in the development and use of this technology world over in this self pollinated crop. Work on various aspects of heterosis by scientists is reviewed below :

1. Heterosis

Days to 50% flowering :

Ponnuthurai and Virmani (1985) observed early flowering in the F_1 hybrids.

Peng and Virmani (1991) observed significant standard heterosis for days to 50% flowering.

Sahai and Chaudhary (1991) observed reduction in days to 50% flowering in most of the hybrids studied.

Manonmani and Ranganathan (1996) reported negative heterosis for flowering duration.

Plant height :

Shrivastava and Seshu (1982) reported high heterosis for plant height.

Kim (1985) evaluated 4 F_1 hybrids and reported heterosis over better parents for plant height.

Peng and Virmani (1991) evaluated 75 F_1 hybrids, of which 31 showed significant standard heterosis for this trait.

Sahai and Chaudhary (1991) observed that hybrids were shorter than their male parents and most of them had more than 20% heterosis over better parent and best commercial varieties.

Number of productive tillers :

Zhang and Xu (1986) reported high heterosis in the hybrids studied for this trait.

Parmasivan and Sree Rangasamy (1988) evaluated 16 hybrids of rice and recorded positive heterosis in five crosses with the maximum of 130.00 per cent. Three crosses exhibited positive and significant heterobeltiosis ranging from 52.70 to 84.68 per cent.

Vivekanandan *et al.* (1992) studied 6 crosses involving TKM6, IR50 and CO29 and found the cross TKM6 x CO29 as heterotic for this trait.

Ramalingam *et al.* (1994) evaluated 15 F_1 rice hybrids along with parents and reported highest standard heterosis for productive tillers per plant followed by other characters.

Mohan Rao *et al.* (1996) reported high heterotic effects for number of productive tillers per plant in the hybrids evaluated.

Panicle length :

Kumar and Saini (1983) reported heterosis of 21.8 per cent for panicle length.

Richharia and Singh (1984) reported positive heterosis for panicle length.

Kim (1985) reported that in 4 F_1 hybrids, heterosis over better parent was seen for panicle length.

Sutaryo (1989) observed significant heterosis for panicle length ranging from 14.6 to 27.7 per cent.

Ramalingam *et al.* (1994) reported positive standard heterosis for panicle length in the 15 F_1 hybrids studied.

Pandey *et al.* (1995) evaluated 36 hybrids and reported significant heterosis for panicle length.

Number of spikelets per panicle :

Virmani *et al.* (1981) reported positive values for all types of heterosis for number of spikelets per panicle.

Shrivastava and Seshu (1982) reported high heterosis for number of spikelets per panicle.

Rao *et al.* (1980) observed standard heterosis ranging from -18.0 to 51.0 per cent for this trait.

Tseng and Huang (1987) reported that heterosis of hybrids over their parents was positive for spikelets per panicle.

Rangaswamy and Natarajamoorthy (1988) reported negative standard heterosis for number of spikelets per panicle.

Pattanaik *et al.* (1990) indicated significant heterosis for spikelets per panicle.

Singh *et al.* (1992) reported positive heterobeltiosis and standard heterosis for this trait.

Fertile spikelets per panicle :

Kumar and Saini (1983) reported 87.6 per cent heterosis for grains per panicle.

Kalaimani and Kadambavanasundaram (1987) reported significant heterosis for grains per panicle.

Suh and Cho (1987) evaluated 11 F_1 rice hybrids and reported significant heterosis over better parent for this trait.

Sutaryo (1989) evaluated three rice hybrids and reported significant heterosis for grains per panicle ranging between 14.6 to 27.7 per cent.

Pandey *et al.* (1995) evaluated 36 hybrids. Most of the crosses showed significant heterosis for grains per panicle.

Spikelet fertility :

Rao *et al.* (1980) reported a negative heterosis for spikelet fertility.

Rangaswamy and Natrajamoorthy (1988) indicated that the 8.0 per cent standard heterosis for grain yield was due to high spikelet fertility.

100 grain weight :

Kumar and Saini (1983) reported 25.4 per cent heterosis for 100 grain weight.

Kalaimani and Kadambavanasundaram (1987) reported significant heterosis for 100 grain weight.

Parmasivan and Sree Rangasamy (1988) evaluated 16 F_1 hybrids, of these three manifested positive and significant heterosis ranging 12.54 to 35.29 per cent. Two crosses recorded heterobeltiosis.

Grain yield :

Hsu *et al.* (1969) in a study of 160 crosses observed heterosis for grain yield in 44 hybrids and was mainly due to higher number of panicles and spikelets per panicle.

Panwar *et al.* (1983) observed high heterotic effects for grain yield in IR8 x Sona, Jhona 349 x Basmati 370, being 42.44% and 56.35% respectively, over the better parent and 42.44% and 31.53% respectively over the best variety, IR-8.

Anandakumar and Rangasamy (1985) worked out heterobeltiosis and standard heterosis of 17 hybrids for grain yield, which ranged from -76.1% to 97.6% and from -15.2% to 42.4%, respectively.

Ponnuthurai and Virmani (1985) observed high yield heterosis in the F_1 hybrid IET 3257 x IR 2797.

Pham and Nguyen (1987) evaluated 89 F_1 hybrids and observed 10-33% positive heterobeltiosis and 11-22% standard heterosis for the promising F_1 hybrids.

Suh and Cho (1987) on evaluation of 11 F_1 hybrids observed average heterosis, heterosis over the better parent and standard heterosis for grain yield was 15.2%, 8.7% and 17.9% respectively.

Bijral *et al.* (1989) observed that the positve standard heterosis for yield ranged from 41.4% to 109.9% in 3 hybrids Zhen Shan 97A/IR31868, V20A/IR 31802 and Zhen Shan 97A/VL15.

Maximum standard heterosis in indica rices of 34% (Virmani *et al.*, 1982) and 41% (Yuan *et al.*, 1987) have been reported. Sivasubramanian *et al.* (1989) reported a standard heterosis ranging from 57 to 78% in rice hybrids.

Leenakumari *et al.* (1993) evaluated 11 hybrids against local checks, the standard heterosis for yield ranged from 20% to 41%.

Nghyen and Bui (1993) have reported heterosis over mid-parents for yield ranging from 23-63.6% and heterosis over better parent ranged from 6.8-62.5% in rice hybrids.

Watanesk (1993) studied heterosis, heterobeltiosis and standard heterosis for yield of 20 F_1 rice hybrids and observed that the F_1 cross of CNTA-10/CNTLR-80140-14-1-1-1 had highest heterosis at 44.5%, CNTA-10/SPLR-77034-PSL-17-11-1 had highest heterobeltiosis at 41.8% and standard heterosis at 51.7%.

Durga and Murthy (1994) evaluated 11 hybrids for yield, MTU 2008 had highest yield (5.9 t/ha) with 38.3% standard heterosis over Prabhat.

Reddy and Nerkar (1995) observed highly significant and positive heterosis for grain yield over MP and BP for four hybrids out of the 8 studied.

Panwar *et al.* (1996) evaluated 22 F_1 hybrids and observed standard heterosis for grain yield/plant in both positive and negative directions ranging from -0.57% to 54.75%.

Ramesha *et al.* (1996) evaluated 8 rice hybrids and observed significant commercial heterosis for grain yield in IR58025A x Swarna, PM33A x PR103 and IR58025A x IR32809. IR 58025A x IR 52256 and IR 62829A x IR 53901 showed negative commercial heterosis.

Ganesan *et al.* (1997) evaluated 28 hybrids and reported that heterosis over mid parent and better parent was positive for grain yield per plant.

Harvest index (%) :

Pattnaik *et al.* (1990) reported significant negative heterosis for harvest index in most of the higher yielding hybrids.

Heterosis over mid parent and better parent was reported to be highly significant and positive for harvest index (Nghyen and Bui, 1993 and Ganesan *et al.*, 1997).

2. Combining ability :

It is the ability of a strain to produce superior genotype upon hybridization with other strains.

The GCA and SCA effects :

GCA or the general combining ability means the average performance of a strain in a series of cross combinations. It is estimated from the crosses. While SCA or specific combining ability is the deviation in performance of a cross combination from that predicted on the basis of the general combining abilities of the parents involved in the cross.

Zhou *et al.* (1982) have reported that general combining ability of parents was more important than the specific combining ability and in the hybrids each character was influenced by the GCA of both male sterile line and restorer and also by SCA of the combinations.

Anandakumar and Rangasamy (1984) by using Line x Tester analysis obtained significant GCA and SCA effects for the traits measured. Cultivars 07414 and 07107 showed good GCA for yield per plant and 06184 did so for stature. Three crosses were superior on the basis of performance and SCA effects.

Jubao (1987) observed that the magnitude of GCA and SCA effects varied with environment. IR-54752A, IR-19661-283-1-3-2A, IR-46 and IR-54 were found good general combiners for yield and hybrid 17492-18-10-2-2-3A x IR-46 as best cross combination with high SCA effects in all environments.

Peng and Virmani (1990) in combining ability studies conducted at IRRI indicated that GCA effects of parents and SCA effects of hybrids for yield were highly significant.

Banumathy and Prasad (1991) in their studies on combining ability analysis by Line x Tester observed that among the parents evaluated IR 62829A was good general combiner for grain yield, plant height and number of filled grains. The cross IR62829A x IR-50 expressed high positive significant SCA effect for plant height.

Mou and Lu (1991) found that GCA and SCA were significant for all the traits of photoperiod sensitive male sterile lines and their hybrids. This indicates that additive and non-additive gene action were important.

Watanesk (1993) studied the GCA of four `A' line and five `R' lines and SCA of 20 hybrids in a Line x Tester design. For `A' lines, CNTA-10 and CNTA-1 were good general combiners for yield, plant height and panicle length. For `R' lines, SPRLR-75055-352-2-1 and SPRLR-77034 and PSL-17-1-1-1 were good general combiners for yield, plant height and panicle length.

Bobby and Nadarajan (1994) observed that the *per se* performance of the hybrids appeared to be not dependent on the SCA effects or heterosis percentage. Therefore, for commercial exploitation, the selection of hybrids should be based on the *per se* performance and standard heterosis.

Kumar and Chanrappa (1994) observed that the variance due to GCA was higher than variance due to SCA, for all the characters studied except productive tiller number, grain yield per panicle and grain yield per plant.

Wenming *et al*. (1996) observed through combining ability studies that to improve cytoplasmic male sterlity restoration, emphasis must be laid on selection of restorers and maintainers with high GCA.

Ramalingam *et al*. (1997) observed that the hybrid combination ZS 97A x IR-24 showed superior SCA effects for all seven traits studied. It was followed by 25 97A x IR-24, IR58025 A x IR-29723 and IR-62829A x IR-54742 with good SCA effects for six characters. Superior GCA effects were produced by involving all kinds of combination viz. high x high, high x low and low x low general combiners.

Gene action :

Khan and Khan (1980) reported additive genetic effects for tillers per plant, plant height and dominance effects for panicle length over dominance was observed for spikelets per panicle and grains per panicle.

Rao *et al.* (1980) reported the preponderence of additive gene action for days to flowering, plant height, ear bearing tillers, panicle length, spikelets per panicle, 100 grain weight, grains per panicle and spikelet sterlity. Non-additive gene action was reported for grain yield.

Singh and Richharia (1980) observed the over dominance for 100 grain weight, ear bearing tillers and panicle length.

Haque *et al.* (1981) reported the predominance of additive gene effects for yield, effective tillers per plant, grains per panicle, while predominance of non-additive gene effects were reported for days to flowering, plant height and spikelet sterlity.

Ghorai and Pande (1982) reported that both additive and dominance effects were important for the inheritance of yield, tillers per plant and spikelets per panicle.

Panwar and Paroda (1983) reported both additive and non-additive gene effects to be significant with additive effects predominating for 100 grain weight.

Devarathinam (1983) reported both additive and non-additive gene actions were important for yield and its related characters.

Kumar and Rangasamy (1984) found non-additive gene action to be important for plant height, panicle length and yield per plant.

Sharma (1985) found that plant height and effective tillers were conditioned by additive gene action, whereas non-additive gene action were important for panicle length, spikelets per panicle, spikelet fertility and yield.

Kuo and Liu (1986) found additive gene effects to be more important than dominance effects for plant height and spikelet number.

Sarathe and Singh (1986) indicated the predominance of non-additive gene action for days to flowering, grains per panicle, sterility per cent, harvest index and grain yield, whereas additive effects were important for panicles per plant and panicle length.

Kalaimani and Sundaram (1987) reported the predominance of additive component of genetic variance for plant height and 100 grain weight. Non-additive gene action was important for days to flowering, productive tillers per plant and grains per panicle.

Cheema *et al.* (1988) indicated that both additive and non-additive gene effects conditioned plant height, days to flowering and spikelets per panicle, whereas the non-additive component alone affected productive tillers per plant.

Manuel and Palanisamy (1989) reported that additive gene action conditioned days to flowering, plant height and panicles per plant, whereas the non-additive component conditioned grains per panicle, spilkelet sterility, 100 grain weight and grain yield per plant, whereas both additive and non-additive gene actions were equally important for panicle length.

Peng and Virmani (1990) found the preponderance of additive gene action for days to flowering and plant height, whereas both additive and non-additive components were equally important for grain yield.

Sarawagi *et al.* (1991) reported the importance of non-additive component for tiller number per plant, fertile spikelets per panicle, spikelet sterility, harvest index and grain yield per plant. Plant height, panicle length, days to 50 per cent flowering and test weight were reported to be governed by additive gene action.

Murthy and Shivashankar (1992) indicated non-additive gene action for grain yield and harvest index.

Ramalingam *et al.* (1993) reported the preponderance of non-additive gene action for days to 50 per cent flowering, productive tillers per plant, panicle length and grain yield per plant, whereas additive gene action was reported for 100 grain weight.

Geetha *et al.* (1994) reported preponderance of additive gene action for plant height and 100 grain weight. Non-additive gene action was reported for grain yield per plant.

Sharma and Koranne (1995) observed preponderance of additive gene action for plant height, while non-additive gene action was reported for number of productive tillers per plant, sterile spikelets and grain yield per plant.

3. Screening for restorers and maintainers :

Rice, being a self pollinated crop, must involve use of an effective male sterlity system to develop and produce F_1 hybrids. The most popular and widely used male sterlity system is the cytoplasmic-genetic male sterlity (CMS). This system is controlled by the interaction of cytoplasmic and nuclear genes and was discovered by Jones and Emsweller (1937) in onion. The role of cytoplasm in causing male sterlity in rice was first reported by Sampath and Mohanty (1954). This phenomenon was also observed by Katsuo and Mizushima (1958) and Kitamura (1962). CMS lines in rice were developed by (Erickson, 1969; Athwal and Virmani, 1972; Yabuno, 1977). But CMS lines for the first time were deployed for developing commercial F_1 rice hybrids in China. For the deployment of CMS lines to develop commercial rice hybrids, it is essential to identify effective restorer and maintainer lines. This section reviews the progress made in the development of genetic tools for hybrid rice breeding.

Yuan (1985) reported that in China, late maturing indica rices showed higher frequency of restorers than the early maturing indica rices.

Rangaswamy *et al.* (1987) pollinated cytoplasmic male sterile lines Zhen Shan 97 A and Erjiu Nan 1 A with pollen from IRRI lines and lines from India, of these Co33 and Co37 were classified as weak maintainers (15% spikelet fertility) and ADT 31 (5-10% spikelet fertility) as effective maintainer.

Li and Zhu (1988) observed that among the three ecotypic rice cultivars, viz. aman, aus and boro (indica rices cultivated in the eastern region of the Indian sub-continent), aman and boro cultivars had a higher frequency of restorers as compared to aus cultivars.

Saran and Mandal (1988) screened 8 standard rice cultivars and identified IR-54, BIET-8549, BIET-1009 and Radha as restorers, Br-9 and Cuttack Basmati as partial restorers and Br-34 and BIET-8550 as maintainers.

Bijral *et al.* (1989) crossed 35 short, medium and long duration indica cultivars with CMS lines Zhen Shan 97 A, IR-48483A and IR-46830A. IR-31802-48-2-2-2 and RR-8585 were identified as restorers of all three CMS lines and China-988, China-1007 and Sattari as maintainers.

Sharma and Mani (1989) crossed four CMS lines with 17 cultivars. Narendra-1, Saket-4 and Basmati-370 were identified as effective restorers and Ratna, N-2 and Rasi as maintainers of IR-46830A. Pant Dhan-4 was maintainer for line IR-46831A. No restorer was identified for Zhen Shan-A and IR-46831A.

Manuel *et al.* (1991) identified Rasi, Co-37, ASD-16 and TM-4309 as maintainers, IR-36 and IR-50 as effective restorers of CMS line V-20A and IR-50 as effective restorer for IR-46830A.

Prasad *et al.* (1992) screened 21 short and medium duration indica cultivars. Co-45, Co-43, IR-50, IET-11752 and IR-62 were identified as potential maintainers, Co-43, Heera and MS-10 as effective restorers.

Chandra *et al.* (1993) crossed V-20A with 89 cultivars. Among the 89 tested, 14 were identified as maintainers, 37 as restorers and 38 as partial restorers.

Pradhan and Jachuk (1995) made 50 test crosses with IR-66707A using high yielding varieties adopted to irrigation and rainfed lowland conditions. 42 of them were found to be effective maintainers, 5 partial restorers, IR-21820-38-2 and Mahsuri were effective restorers.

Leenakumari *et al.* (1996) conducted fertility restoration studies involving four WA CMS lines viz. V20A, IR-58025A, IR-62829A and IR-54752A. This resulted in the identification of 20 restorers.

Padmavathi *et al.* (1997) screened 44 genotypes for restoration ability of different CMS lines derived from WA and 577A cytosteriles. 5 out of 31 genotypes were able to restore fertility of 2 CMS lines derived from WA cytosterile source and 5 were identified as effective maintainers. The frequency of maintainers was high compared to that of restorers for WA cytosteriles.

CHAPTER - III

MATERIAL AND METHODS

Experimental site and situation:

The experiments were conduted in the research farm of Department of Plant Breeding and Genetics, IGAU, Raipur, (M.P.) during the Kharif 1997 and 1998.

i) Geographic location:

Raipur is situated in South Eastern part of Madhya Pradesh and lies between 21.16^{O}N latitude and 81.36^{O}E longitude with an attitude of 289.56 meters above sea level.

ii) Climate :

The climate is dry sub humid with average rainfall of 1000-1350 mm, mainly concentrated from middle of June to September with occassional showers in winter. The maximum temperature goes as high as 46^{O}C during summer months and minimum as low as 6^{O}C during winter months.

Experimental material:

Two cytoplasmic male sterile lines and their maintainer line viz. IR-58025A and IR-62829A and IR-58025B and IR-62829B were procured from Directorate of Rice Research, Hyderabad and were used as lines. Twentyone promising varieties of Chhattisgarh region were selected from crossing block of rice research of Department of Plant Breeding and Genetics, Raipur and used as testers.

The CMS lines IR-58025A and IR-62829A were sown in separate plots at three different dates to match the flowering period for crossing with the male plants.

Crossing programme:

The production of F_1 hybrids involved the following steps :-

i) **Selection and preparation of female plants for hybridization :**

Parent plants of CMS lines IR-58025A and IR-62829A were selected from the CMS plots. The criterion of selection was that the plants should be healthy and vigorous, but above all the CMS plants anthers should be degenerate or sterile. The selected plants were uprooted, labelled and transferred into earthern parts before 8.00 AM. The use of CMS lines in this experiment reduced the task of emasculating the spikelets. All florets in each panicle were cut through lemma and palea in a slanting plane just above the stigma with help of a pair of scissors and care was taken to prevent damage to stigma. This procedure helps in easy entry of desired pollen to fall easily on the respective stigma.

ii) Pollination of CMS lines by tester parents:

The panicles of desired male parents having ripe anthers were collected, labelled and then put in a pot of water and placed in a room where 5 electric bulbs of 200 watts each were lit, this helped in providing high humidity and optimum temeperture. This resulted in complete bursting of anthers which was identified by the yellowish coloured powdery mass in the florets. The pollen from these panicles were dusted on to the female plants on the same day. After pollination the panicles were covered with a butter paper bag to prevent further entry of any foreign pollen and finally tagged and labelled. The crossed plants along with pot were placed into a waterlogged field.

iii) Harvesting of F_1 seeds:

The setting and maturity of seeds was completed approximately in 30 days from the date of pollination. These panicles were harvested, threshed separately and stored in labelled envelopes after sun drying.

Laying of experiment:

Design and details of layout:

Line x tester crossing fashion suggested by Kempthorne (1957) was used. A set of line x tester comprising of 42 (2x21) F_1 hybrids alongwith parents viz.

two CMS lines IR-58025A and IR- 62829A used as lines and 21 promising varieties used as testers were grown.

The sum of sixty seven entries including the 42 F_1s along with male parents (21) females (2) (male sterile A lines) and maintainer lines (2) were grown in randomized complete block design with two replications during kharif 1998. Row to row distance and plant to plant distance was maintained at 20 Cms. apart. All rows comprised of ten plants each. All standard agronomic package and practices were followed.

Recording of observations:

In each treatment, observations were recorded on 5 randomly selected competitive plants of each crosses and parents in each replication. The mean values over five plants was worked out and used for further statistical analysis.

i) **Days to 50 per cent flowering:** Number of days from sowing to the day when 50 per cent plants had flowered was recorded.

ii) **Plant height (cm):** The height of plant was measured from soil surface to the tip of the tallest panicle, excluding awns wherever present at the time of harvest.

iii) **Number of productive tillers per plant:** The total number of panicle bearing tillers in each plant was recorded.

iv) **Panicle length (cm):** The panicle length was measured from panicle base to tip of the panicle.

v) **Number of spikelets per panicle:** The total number of spikelets, both filled and unfilled were counted and recorded.

vi) **Number of filled grains per panicle:** The total number of well filled grains in each panicle was counted and recorded.

vii) **Spikelet fertility per cent :** The ratio of number of filled grains per panicle to the total number of spikelets (filled and unfilled) was calculated and expressed as percentage.

viii) **100 grain weight (g):** Measurements were recorded in grams of 100 well developed whole grains.

ix) **Grain yield per plant(g):** Weight of grains of each plant was measured and expresed in grams.

x) **Harvest index :** The ratio of grain yield to the biological yield (grain yield + straw yield) of each plant was calculated and expressed, as percentage.

$$\text{Harvest index \%} = \frac{\text{Grain yield}}{\text{Biological yield}} \times 100$$

xi) **Pollen sterility(%):** Samples for pollen were collected from five florets from individual plants at heading stage and fixed in 70 per cent alcohol. Two to three anthers were extracted from five of the florets on a glass slide and squeezed out the pollen on a glass slide in a drop of acteocarmine stain. The unstained pollen grains were counted as sterile, whereas the stained pollen grains as fertile. The total count of sterile pollens was seen in relation to the total pollen grains in three microscopic fields. The mean of three fields of sterile and total pollen grains was used for pollen sterility per cent calculation as below:

$$\text{Pollen sterility \%} = \frac{\text{Number of sterile pollen grains (Unstained)}}{\text{Total number of pollen grains (stained + unstained)}} \times 100$$

Cultivars with >95% pollen sterility were classified as potential maintainers, those with 5-95%, as partial restorers; and those with <5%, as effective restorers (Prasad *et al.*, 1993).

Statistical analysis:

Initially, mean values were calculated. These mean values were utilized further for statistical analysis.

I. Analysis of variance:

The mean data were subjected to variance analysis and test of significance as suggested by Panse and Sukhatme (1961).

Table 2.1 : Analysis of variance.

Source of variatión	D.F.	M.S.	Expected M.S.
Replications	r-1	MSr	-
Genotypes	g-1	MSg	$\sigma^2 e + r\sigma^2 g$
Error	(r-1)(g-1)	MSe	$\sigma^2 e$

Where, r = Number of replications, g = number of genotypes.

II. Studies on variability, heritability and genetic advance:

i) Variability:

Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated as suggested by Singh and Chaudhary (1985).

$$\sigma^2 g = \frac{MSv - MSe}{r}$$

Where, $\sigma^2 g$ = Genotypics variance.

MSg = Mean sum of square for genotypes.

MSe = Error mean sum of square.

A) Phenotypic coefficient of variation (PCv)

$$PCV = \frac{\sqrt{\sigma^2 P}}{\bar{x}} \times 100$$

$$\sigma^2 P = \sigma^2 g + \sigma^2 e$$

Where, $\sigma^2 P$ = Phenotypic variance

$\sigma^2 e$ = Error variance

B) Genotypic coefficient of variation (GCV).

$$GCV = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$$

The estimate of pcv and gcv were classified as low, moderate and high according to Sivasubramanian and Madhavamenon (1973).

< 10 per cent = low

10-20 per cent = moderate

and > 20 per cent = high

ii) Heritability:

The broad sense heritability estimates for yield components of hybrids were calculated as suggested by Singh and Chaudhary (1985).

$$H^2 = (\sigma^2 g / \sigma^2 p) \times 100$$

Where,

$\sigma^2 g$ = Variance due to genotype

$\sigma^2 p$ = Variance due to phenotype

The broad sense heritability estiamtes were classified as low, moderate and high as mentioned below:

0 - 30 per cent = low

31 - 60 per cent = moderate

and > 60 per cent = high

iii) Genetic advance:

Genetic advance was estimated by adopting the method suggested by Johnson et al. (1955) as below:

$$GA = KH^2 [\sigma^2 P]^{1/2}$$

Where,

GA = Genetic advance

K = Selection differential (at 5 per cent K = 2.06

H^2 = heritability, and

$\sigma^2 p$ = Phenotypic variance

GA was reported as percentage of mean, which was calculated as follows:

$$\text{GA as percentage of mean} = \frac{GA}{Mean} \times 100$$

The GA was classified as high, moderate and low as mentioned below:

> 20 per cent = high

10-20 per cent = moderate, and

<10 per cent = low

III. Combining ability analysis:

Combining ability analysis was carried out using the method suggested by Kempthorne (1957).

Analysis of variance for Line x Tester analysis.

Source	D.F.	Sum of squares	Mean sum of squares	Expected mean sum of squares
Replication	(r-1)	SS		
Parents	(p-1)	SS(p)	Mp	
Hybrids	(l.t-1)	SS(g)	Mh	
Lines (Female)	(l-1)	SS(l)	Ml	Me+r[Cov(FS)-2 Cov(HS)]+ rt[Cov (HS)]
Testers(Male)	(t-1)	SS(t)	Mt	Me+r[Cov(FS)-2 Cov(HS)]+ rl[Cov (HS)]
Lines x testers	(l-1) (t-1)	SS(lxt)	M(lxt)	Me+r[Cov(FS)-2 Cov(HS)]
Parents Vs Hybrids	1			
Errors	(r-1) (g-1)	SS	Me	

Where,
r = Number of replications
l = number of lines
t = number of testers

and g = number of genotypes (including hybrid + parents) = (lt+p)
p = l+t

Estimates of full sib and half sib covariances were calcualted from mean sums of squares, as below:

$$Cov.(H.S) = \frac{Ml + Mt - 2M\ (lxt)}{r(l+t)}$$

$$Cov.(F.S) = \frac{ML+Mt+M\ (lxt)-3Me+6r\ Cov.(H.S)-r(lt)Cov.(HS)}{r}$$

Cov.(HS) and Cov (FS) were utilized to estimate variances due to general combining ability (GCA) and specific combining ability (SCA) as mentioned below:

Variance GCA = Cov. (HS)

Variance SCA = Cov.(FS) - 2 Cov.(HS)

Estimation of GCA and SCA effects :

The GCA and SCA effects of ijkth observation were estimated by using the following model.

$$yijk = \mu + gi + gj + sij + eijk$$

where,

μ = Population mean

gi = GCA effect of i th line

gj = GCA effect of j th tester

sij = SCA effect of hybrid of i th line with jth tester

eijk = error effect associated with ijkth observation

i = number of lines.

j = number of testers, and

k = number of replications

The individual effects of GCA and SCA were estimated from the data obtained from two way table of lines vs testers. In this table each value was cumulative value over replications.

$$\mu = \frac{x...}{rlt}$$

$$gi = \frac{xi..}{rt} - \frac{x...}{rlt}$$

$$gj = \frac{x.j}{rt} \quad \frac{x...}{rlt}$$

$$sij = \frac{xij}{rt} \quad \frac{x...}{rlt}$$

Where,

x... = total of all hybrid combinations,

xi.. = total of ith line over 't' testers and 'r' replications.

x.j. = total of jth tester over 'l' line and 'r' replications, and

xij. = total of the hybrid between ith line and jth tester over 'r' replications.

The standard errors pertaining to GCA and SCA effects were worked out from the square root of error variance effects, as given below:

i) Standard error for testing the GCA effects of lines

$$SE\ (gi) = \sqrt{\frac{Me}{rt}}$$

ii) Standard error for testing significance of difference between GCA effects of two lines

$$SE\ (gi-gj) = \sqrt{\frac{2\ Me}{rt}}$$

iii) Standard error for testing the GCA effects of testers

$$SE\ (gj) = \sqrt{\frac{Me}{rl}}$$

iv) Standard error for testing significance of difference between GCA effects of two testers

$$SE\ (gj-gi) = \sqrt{\frac{2\ Me}{rl}}$$

v) Standard error for testing the SCA effects of hybrid

$$SE\ (sij) = \sqrt{\frac{Me}{r}}$$

vi) Standard error for testing the significance of difference between SCA effects of two hybrids.

$$SE\ (sij-skl) = \sqrt{\frac{2Me}{r}}$$

IV. Heterosis:

Heterosis for each trait was estimated by utilizing the overall mean of each hybrids over replications for each trait. The mean data of isogenic maintainer lines of (respective CMS lines) were used as values for female parent. Relative heterosis was determined as per cent deviation of hybrid value from its mid parental value. The formula utilized for determining relative heterosis is as below:

$$di = \frac{\overline{F}_1 - \overline{MP}}{\overline{MP}} \times 100$$

where,

di = Heterosis over mid parental value,

F_1 = mean hybrid performance, and

MP = mid parental value

Heterobeltiosis was determined by use of formula as belo

$$dii = \frac{\overline{F}_1 - \overline{BP}}{\overline{BP}} \times 100$$

dii = Heterobeltiosis, and

BP = Average performance of better parent.

Test of significance of heterosis :

Significance of difference was worked out by using 't' test.

S.E (di) = $(2\ Me/r)^{1/2}$

S.E (di) = Standard error of relative heterosis.

Me = Error mean squares, and

r = Number of replications.

't' calculated. (di) = $(F_1 - \overline{MP})/S.E(di)$

S.E. (dii) = $(2Me/r)^{1/2}$

S.E (dii) = Standard error of heterobeltiosis

't' calculated (dii) = $(F_1 - \overline{BP})/S.E(dii)$

This calcualted value of 't' was compared with tabulated value of 't' at error degrees of freedom.

CHAPTER - IV

RESULTS

The results obtained from the present study are depicted under the following sub-headings :-

1. Analysis of variance for combining ability
2. Mean performance :

   a. Mean performance of parents

   b. Mean performance of hybrids
3. Genetic parameters

   a. Genotypic and phenotypic coefficient of variability

   b. Heritability and genetic advance as percentage of mean
4. Combining ability analysis
5. Heterosis
6. Screening for maintainers and restorers

   a. Maintainers

   b. Restorers

1. Analysis of variance for combining ability :

The analysis of variance for combining ability (Table 4.1) revealed that the variance due to lines, testers, parents, hybrids, parents vs. hybrids and line x tester were significant for most of the characters indicating presence of adequate variability in the experimental material.

Table 4.1 : Analysis of variance table for combining ability analysis.

Source	Mean sum of squares											
	d.f.	Days to 50% flowering	Plant Height	No. of productive tillers/ plant	Panicle length	No. of spikelets/panicle	No. of filled grains/ panicle	Spikelet fertility	100 grain weight	Grain yield/plant	Harvest index	Pollen sterility
Parents	22	37.773*	457.165**	23.672**	8.011**	2480.943**	1003.824*	140.422*	0.427**	53.139**	83.289*	1084.612**
Hybrids	41	21.543	451.416**	31.627**	9.131**	4942.421**	3098.439**	1095.976**	0.182**	63.657**	97.081*	1589.970**
Parents vs. hybrids	1	715.000**	2636.375*	188.549	6.666	1104.5	30518.38	13490.780*	0.283	1026.154*	60.785	816.223
Lines	1	29.773	2477.455*	176.026	73.939*	12566.800**	16405.2	689.958	0.078	0.334	320.771	3.311
Testers	20	37.212	721.244**	29.940**	6.101	6490.812**	3751.759**	1127.505**	0.183**	69.104**	84.499*	1455.671**
Lines x Tester	20	5.461**	80.287**	26.094**	8.921**	3012.810**	1779.780*	1084.748**	0.187**	61.375**	98.480*	1803.601**
Error	64	1.439	3.27	1.762	0.215	21.221	197.084	38.32	0.001	0.957	14.15	29.352

* Significant at 5% level

** Significant at 1% level.

Table 4.2 : Mean performance of parents.

Parents	Characters										
	Days to 50% flowering	Plant Height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/ panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR58025A	98.50	77.75	4.40	21.85	118.30	93.75	79.30	1.77	9.61	27.93	96.10
IR62829A	92.00	71.60	22.30	16.65	100.70	85.75	87.11	1.94	20.50	26.81	97.97
Avg. of Female parents	75.25	74.67	13.35	19.25	109.50	89.75	83.20	1.86	15.06	27.37	97.04
Madhuri Sel-A-9	94.00	105.50	7.90	18.10	149.00	119.35	80.18	1.99	14.55	28.44	18.56
Shyamala	96.00	106.60	6.00	20.00	129.95	104.95	80.77	2.59	16.08	34.40	13.51
R-574-11	98.50	118.45	7.80	20.65	143.30	97.80	68.26	2.88	16.07	41.26	28.13
R-671	97.50	102.55	5.40	22.65	161.10	138.70	86.09	1.99	21.19	22.27	8.61
R-405-A-4	93.50	112.95	6.60	19.20	150.25	124.30	82.73	2.09	21.41	23.45	16.32
MW-10	98.00	102.50	6.70	20.75	172.20	127.25	73.90	2.96	25.32	34.74	21.10
R-712-1-6-11-1	97.50	103.55	6.10	19.95	154.30	101.50	65.80	3.05	20.11	39.82	23.81
R-636-405	92.50	138.30	7.70	21.65	126.05	95.45	75.79	2.64	19.71	30.67	23.96
R-635-134	91.50	104.60	9.30	18.55	191.00	147.50	77.24	2.03	17.48	31.96	20.31
IR-72	93.50	92.55	7.60	19.30	159.05	121.90	76.63	2.21	18.82	35.83	48.76
PR-106	106.00	119.40	7.50	20.75	171.85	120.55	70.17	2.03	21.34	37.91	32.12

Cont... Table 4.2

Rajshree	106.00	105.55	5.90	22.45	171.25	132.25	77.22	1.95	16.60	35.91	59.91
R-288-361	92.50	113.55	11.30	20.90	214.05	149.65	69.96	2.31	19.86	21.81	36.81
R-714-2-9	93.00	110.25	9.60	19.65	95.55	67.90	71.10	1.91	14.43	25.29	31.56
Kranti	94.50	115.45	9.50	18.75	132.60	91.85	69.26	2.96	19.83	37.15	30.33
Mahamaya	95.50	114.00	8.40	22.45	218.25	149.30	68.36	3.19	32.68	44.28	30.00
R-703-15-2-1	96.50	115.00	7.40	20.15	125.65	88.95	70.82	3.26	26.64	36.97	24.66
Madhuri-11	104.00	89.65	7.80	19.70	201.00	101.00	50.31	2.18	20.72	42.25	47.44
R-703-23-1-2	101.50	112.45	8.70	21.85	138.25	111.70	80.74	2.39	30.44	34.78	16.11
R-636-382	92.00	135.00	9.70	18.55	214.40	128.95	60.14	2.08	19.37	36.17	49.81
Pusa Basmati	95.00	105.55	7.20	26.35	186.35	132.85	71.24	2.22	15.86	37.15	29.33
Avg. of Male parents	96.62	110.64	7.81	20.59	162.16	116.84	72.70	2.42	20.41	33.93	29.10
Overall parental mean	96.50	107.51	8.30	20.47	157.58	114.48	73.61	2.37	19.94	33.36	35.01

2. Mean performance :

a. Mean performance of parents :

Mean performance of parents is presented in Table 4.2.

Days to 50 per cent flowering :

Among the parents the mean days to 50 per cent flowering ranged from IR62829A and R-636-382 (92.0 days) to PR-106 and Rajshree (106.0 days) and the overall parental mean was 96.5 days. IR-62829A flowered early (92.0 days) while IR 58025A flowered late (98.5 days) as compared to mean of female parents (95.25 days). Amongst the testers, R-635-134 (91.5 days) was earliest to flower while PR-106 (106 days) and Rajshree (106 days) flowered late as compared to testers mean of 96.62 days.

Plant height :

The plant height ranged from IR-62829A (71.60 cms) to R-636-405 (138.30 cm) and the overall parental mean was 107.51 cms. The highest mean value was recorded for IR-58025A (77.75 cms) while the lowest value was recorded for IR-62829A (71.60 cms) amongst lines. The average female parent height was 74.67 cms. R-636-405 (138.30 cms) was the tallest among male parents and Madhuri-11 (89.65 cms) was the shortest, average male parent height was 110.64 cms.

Number of productive tillers per plant :

Among the parents, the mean number of productive tillers per plant ranged from IR-58025A (4.40) to IR-62829A (22.30) with an overall parental mean of 8.30. Highest mean value of IR-62829A (22.20) was recorded for the female parents with lowest value for IR-58025A (4.40). The average number of productive tillers per plant for female parents was 13.35. Among the testers R-288-361 (11.30) recorded highest mean value while R-671 (5.40) recorded the least. The mean value of overall testers was 7.81.

Panicle length :

The mean panicle length among parents ranged from IR-62829A (16.65 cms) to IR-58025A (26.35 cms) with an overall parental mean of 20.47 cms. Among the lines, the mean panicle length ranged from IR-62829A (16.65 cms) to IR-58025A (21.85). The mean of the lines was 19.25 cms. The mean value of testers for panicle length was 20.59 cms. Among testers, the values of this trait ranged from a low of Madhuri Set-A-9 (18.10 cms) to a high of Pusa Basmati (26.35 cms).

Number of spikelets per panicle :

The values for this trait ranged from R-714-2-9 (95.55) to Mahamaya (218.25) with an overall parental mean of 157.58. Among the lines, IR-62829A (100.70) had the highest number of spikelets per panicle while IR-58025A (118.30) had the least. The average of the female parents was 109.50. Tester R-714-2-9 (95.55) had the highest while tester Mahamaya (218.25) had least number of spikelets per panicle. The mean of the male parents was 162.16.

Number of filled grains per panicle :

This trait showed a range of R-714-2-9 (67.90) to R-288-361 (149.65) for parents with overall parental mean of 114.48. Among the females, IR-62829A (85.75) had lowest number of filled grains per panicle while IR-58025A (93.75) had the highest with a mean value of 89.75. The tester R-714-2-9 (67.90) recorded lowest value while the tester R-288-361 (149.65) recorded highest value, with an overall average of 116.84 for testers.

Spikelet fertility per cent :

The mean spikelet fertility among parents ranged from Madhuri-11 (50.31%) to IR-62829A (87.11%), with an overall parental mean of 73.61 per cent. For line IR-58025A, the mean value was 79.30 per cent while for line IR-62829A its value was 87.11 per cent. For testers, the values ranged from Madhuri-11 (50.31%) to R-671 (86.09%) with male parent average of 72.70 per cent.

100 grain weight :

The overall mean of parents for this trait was 2.37 g. The variation ranged from IR-58025A (1.77g) to R-703-15-2-1 (3.26g). For lines the values ranged from IR58025A (1.77g) to IR-62829A (1.94g) with a mean for lines 1.86 g. For tester R-714-2-9 (1.91g), the value for this trait was lowest while, for tester R-706-15-2-1 (3.26g) the value was highest. The male parental mean was 2.42 g.

Grain yield per plant :

The mean grain yield per plant amongst parents ranged from IR-58025A (9.61g) to Mahamaya (32.68g), with an overall parental mean of 19.94 g. The female parent IR58025A (9.61g) showed lowest mean value, whereas IR-62829A (20.50g) recorded highest. The mean value of lines was 15.06 g. The tester R-714-2-9 (14.43g) recorded highest value. The overall mean of male parents was 20.41g.

Harvest index per cent :

This trait showed a range of R-288-361 (21.81%) to Mahamaya (44.28%), with an overall parental average of 33.36 per cent. Among the lines, IR-62829A (26.81%) had lowest harvest index while IR-58025A (27.93%) had highest as compared to the female mean average of 27.37 per cent. Tester R-288-361 (21.81%) had lowest mean value and tester

Mahamaya (44.28%) had highest value for this trait as compared to testers mean of 33.93 per cent.

Pollen sterility per cent :

The mean pollen sterility among parents ranged from IR-62829A (97.97%) to R-671 (8.61%), with an overall mean of 35.01 per cent. Among lines, IR-62829A (97.97%) had highest mean pollen sterlity while line IR-58025A (96.10%) had lowest mean as compared to lines mean of 97.04 per cent. Among testers, Rajshree (59.91%) had highest mean and tester R-671 (8.61%) had lowest mean as compared to testers mean of 29.10 per cent.

b. Mean performance of Hybrids :

Mean performance of hybrids are given in Table 4.3.

Days to 50 per cent flowering :

Among the hybrids, days to 50 per cent flowering ranged from IR-62829A/R-574-11 (85.50 days) to IR-58025A/Rajshree (101 days), with an overall mean of 91.60 days. Early flowering as compared to mean was recorded for twenty one hybrids of which IR-62829A/R-574-11 (85.50 days) was the earliest to flower.

Plant height :

Among the hybrids mean plant height ranged from IR-62829A/R-635-134 (67.65 cms) to IR-58025A/Rajshree (140.40 cms) with an overall average of 98.09 cms. Lowest height

Table 4.3 : Mean performance of hybrids.

Hybrids	Characters										
	Days to 50% flowering	Plant Height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/ panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR58025A x											
Madhuri Sel-A-9	96.50	104.40	9.70	22.35	106.60	38.35	36.05	1.89	8.64	29.08	51.47
Shyamala	92.50	105.50	6.30	22.90	234.20	140.05	59.79	3.17	8.92	30.09	36.60
R-574-11	87.00	98.60	13.50	23.50	240.40	71.00	29.63	2.19	19.69	33.81	65.15
R-671	92.50	99.95	6.20	21.45	149.65	63.85	42.74	2.06	10.34	27.72	35.47
R-405-A-4	95.00	120.00	6.90	25.60	253.50	122.25	48.17	1.97	8.65	30.05	53.81
MW-10	90.50	86.65	8.20	20.90	207.85	148.90	71.60	1.83	11.70	32.24	24.84
R-712-1-6-11-1	92.00	99.70	5.90	22.75	223.90	119.35	53.26	1.98	10.42	36.99	54.65
R-636-405	93.00	125.60	11.20	23.45	202.35	41.15	20.37	2.04	20.07	24.78	76.42
R-635-134	90.50	78.50	11.70	20.45	205.40	90.95	19.02	2.38	7.96	26.80	95.35
IR-72	92.00	91.90	8.60	22.05	184.40	145.85	79.08	2.38	8.71	37.71	27.11
PR-106	88.50	90.40	8.50	22.00	111.25	98.80	88.80	2.09	10.85	35.26	5.84
Rajshree	101.00	140.40	6.00	19.70	172.80	138.65	80.26	2.36	20.07	37.88	16.63

Cont... Table 4.3

R-288-361	95.00	92.05	13.20	21.95	125.00	86.90	69.51	2.01	11.53	36.25	24.60
R-714-2-9	97.50	103.75	4.90	25.15	127.85	93.70	73.29	2.83	20.67	43.90	21.90
Kranti	90.50	103.95	6.50	19.75	151.55	58.35	38.57	2.38	15.03	38.56	43.07
Mahamaya	87.50	92.70	11.90	19.40	108.35	45.80	42.33	2.49	10.31	33.26	51.03
R-703-15-2-1	89.00	105.55	7.30	19.65	101.25	83.30	82.34	2.46	22.12	41.91	11.84
Madhuri-11	91.50	107.75	11.00	22.45	269.60	172.00	63.85	1.92	20.88	45.53	30.81
R-703-23-1-2	92.50	99.00	10.90	21.85	250.55	85.85	34.27	2.05	7.11	22.48	62.44
R-636-382	92.50	125.95	9.90	23.65	168.50	133.90	79.47	2.20	30.38	34.43	14.29
Pusa Basmati	89.00	101.70	18.40	18.60	99.15	45.80	46.27	2.49	12.62	32.81	46.16

Cont... Table 4.3

Hybrids	Characters										
	Days to 50% flowering	Plant Height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/ panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR62829A x											
Madhuri Sel-A-9	91.50	90.20	21.80	20.55	101.80	68.25	67.01	2.13	13.06	25.76	34.67
Shyamala	92.00	83.30	14.90	17.70	181.00	23.65	13.10	2.30	13.12	35.10	93.01
R-574-11	85.50	84.95	12.80	19.30	141.95	36.25	25.78	2.54	8.58	18.93	21.22
R-671	93.00	95.65	16.50	21.60	122.35	88.95	72.79	2.51	17.77	31.65	31.38
R-405-A-4	92.00	103.60	13.70	20.70	161.85	66.50	78.28	2.55	20.46	41.35	21.40
MW-10	90.50	87.20	6.80	20.25	180.45	105.10	58.22	1.85	5.99	23.02	30.94
R-712-1-6-11-1	93.50	84.70	13.50	22.35	191.40	45.00	23.52	1.77	12.01	35.06	1.71
R-636-405	90.50	100.85	11.30	16.35	221.95	51.60	23.17	2.47	6.94	18.01	67.83
R-635-134	90.50	67.65	6.50	18.05	107.00	77.35	72.40	2.26	13.91	31.94	18.12
IR-72	91.00	90.65	10.20	22.15	130.65	119.85	91.78	2.18	19.71	32.81	1.16
PR-106	87.00	77.10	13.00	18.95	128.20	10.60	8.34	2.36	6.39	13.73	98.53
Rajshree	100.00	137.80	11.70	23.25	213.35	147.95	69.35	2.08	20.99	27.55	24.90
R-288-361	92.50	94.30	18.40	20.65	122.80	46.30	37.74	2.45	8.82	28.60	97.37

Cont... Table 4.3

R-714-2-9	93.50	91.15	5.00	22.20	150.75	98.80	65.36	2.29	18.10	25.79	29.29
Kranti	90.50	89.20	14.80	20.80	103.75	75.30	72.39	2.64	21.50	40.00	0.75
Mahamaya	88.00	84.80	7.10	19.85	219.40	49.70	22.72	2.53	12.94	38.42	64.96
R-703-15-2-1	91.00	100.00	10.10	21.20	124.35	40.10	32.38	2.41	9.30	28.42	7.39
Madhuri-11	87.00	88.75	11.90	15.75	187.70	70.80	37.76	2.76	15.91	31.19	43.65
R-703-23-1-2	92.00	107.15	8.50	20.70	157.50	93.90	59.62	2.54	17.52	40.27	30.92
R-636-382	87.00	101.00	15.20	17.45	113.60	89.05	78.41	1.95	19.10	31.71	22.60
Pusa Basmati	92.50	85.90	13.80	20.30	118.60	32.80	28.22	1.90	11.92	30.17	99.29
Average	91.6	98.09	10.81	20.95	163.68	82.44	52.31	2.28	14.06	31.93	40.25

in comparison to mean plant was recorded for twenty one hybrids of which IR-62829A/R-635-134 (67.65 cms) and IR-62829A/PR-106 (77.10 cms) recorded least height.

Number of productive tillers per plant :

Hybrid performance for this trait ranged from IR-58025A/R-714-2-9 (4.90) to IR-62829A/Madhuri Set-A-9 (21.80) with an overall mean of 10.81. Highest number of productive tillers in comparison to mean were recorded for twenty two hybrids. Very high values were recorded for IR-62829A /Madhuri Set-A-9 (21.80), IR-58025A/Pusa Basmati (18.40) and IR-62829A/R-288-361 (18.40).

Panicle length :

Among the hybrids, the mean panicle length ranged from IR-62829A/Madhuri-11 (15.75 cms) to IR-58025A/R-405-A-4 (25.60 cms) with an overall average of 20.95 cms. Longer panicle length in comparison to mean was recorded for 20 hybrids. High panicle length was recorded for IR-58025A/R-405-A-4 (25.60 cms), IR-58025A/R-714-2-9 (25.15 cms) and IR-58025A/R-636-382 (23.65 cms).

Number of spikelets per panicle :

Hybrid performance for this trait ranged from IR-58025A /Pusa Basmati (99.15) to IR-58025A/Madhuri-11 (269.60), with an overall mean of 163.68. Highest mean number of spikelets per panicle in comparison to overall mean was recorded for nineteen hybrids. Of these, hybrids IR-58025A/Madhuri-11 (269.60) and IR-58025A /R-405-A-4 (253.50) recorded higher number of spikelets per panicle.

Number of filled grains per panicle :

Hybrid performance for this trait ranged from IR-62829A/Shyamala (23.65) to IR-58025A/Madhuri-11 (172.00) with an overall hybrid average of 82.44. Higher number of filled grains per panicle in comparison to overall mean was recorded for twenty one hybrids. Of these, hybrids IR-58025A/Madhuri-11 (172.00), IR-58025A/MW-10 (148.90) and IR-62829A/Rajshree (147.95) recorded higher values.

Spikelet fertility :

Among the hybrids, mean value for this trait ranged from (IR-62829A /PR-106 (8.34%) to IR-62829A /IR-72 (91.78%) with an overall hybrid mean of 52.31 per cent. High spikelet fertility in comparison to overall mean was recorded for twenty two hybrids. Of these, hybrids IR-62829A /IR-72 (91.78%), IR-58025A /PR-106 (88.80%) and IR-58025A/R-703-15-2-1 (82.34%) recorded high spikelet fertility per cent.

100 grain weight :

Among the hybrids, 100 grain weight ranged from IR-62829A/R-712-1-6-11-1 (1.77g) to IR-58025A/Shyamala (3.17g) as compared to mean of 2.28 g. Higher values for this trait in comparison to mean value was recorded for 22 hybrids. High values were recorded for IR-58025A/Shyamala (3.17 g), IR-58025A/R-714-2-9 (2.83g) and IR-62829A/Madhuri-11 (2.76g).

Grain yield per plant :

Hybrid performance for this trait ranged from IR-62829A /MW-10 (5.99g) to IR-58025A /R-636-382 (30.38g), with an overall hybrid mean of 14.06 g. Higher values for this trait in comparison to mean value was recorded for 17 hybrids. Of these IR-58025A/R-636-382 (30.38g), IR-58025A/R-703-15-2-1 (22.12g) and IR-62829A/Kranti (21.50g) recorded higher mean grain yield per plant.

Harvest index :

For this trait, the mean values ranged from IR-62829A/R-636-405 (18.01%) to IR-58025A/Madhuri-11 (45.53%) with an overall hybrid mean value of 31.93 per cent. Higher harvest index in comparison to overall mean was recorded for 22 hybrids. Of these, IR-58025A/Madhuri-11 (45.53%), IR-58025A/R-714-2-9 (43.90%) and IR-58025A /R-703-15-2-1 (41.91%) recorded higher mean harvest index.

Pollen sterility :

Among the hybrids, this trait ranged from IR-62829A/Kranti (0.75%) to IR-62829A/Pusa Basmati (99.29%) with an overall hybrid mean of 40.25 per cent. 17 hybrids recorded higher values for this trait in comparison to mean value, whereas 25 hybrids recorded lower values in comparison to mean.

3. Genetic parameters :

a. Genotypic and phenotypic coefficient of variability :

Genotypic coefficient of variability :

The genotypic coefficient of variability is represented in Table 4.4. High genotypic coefficient of variability was observed for pollen sterility (68.28%), number of productive tillers per plant (38.77%), number of filled grains per panicle (38.51%), grain yield per plant (37.72%), spikelet fertility (35.89%) and number of spikelets per panicle (27.74%). It was moderate for the characters viz. 100 grain weight (15.79%), plant height (15.34%) and harvest index (15.27%), whereas the characters panicle length (9.91%) and days to 50 per cent flowering (4.67%) recorded low genotypic coefficient of variability.

Phenotypic coefficient of variability :

The phenotypic coefficient of variability is represented in Table 4.4. None of the characters studied showed high phenotypic coefficient of variability. Moderate phenotypic coefficient of variability was recorded for number of filled grains per panicle (14.97%),

Table 4.4 : Genotypic and phenotypic coefficient of variability (GCV and PCV), heritability (H^2) and genetic advance as percentage of mean (GA as % of X)

Characters	GCV (%)	PCV (%)	Broad sense H^2 (%)	GA as % of $\overline{X}$
Days to 50% flowering	4.67	1.28	92.968	9.282
Plant height (cm)	15.34	1.78	98.667	81.391
No. of productive tillers/plant	38.77	13.38	89.355	75.494
Panicle length (cm)	9.91	2.23	95.180	19.929
No. of spikelets/panicle	27.74	2.85	98.954	56.845
No. of filled grains/panicle	38.51	14.97	86.878	73.960
Spikelet fertility (%)	35.89	10.34	92.332	71.044
100 grain weight (gm)	15.79	1.37	99.254	32.400
Grain yield/plant (gm)	37.72	6.06	97.483	96.716
Harvest index (%)	15.27	11.60	63.411	25.049
Pollen sterility (%)	68.28	14.11	95.905	137.741

Table 4.5 : Genotypic, phenotypic and environmental components of variances.

Characters	Genotypic variance	Phenotypic variance	Environmental variance
Days to 50% flowering	19.024	20.463	1.439
Plant Height (cm)	242.131	245.401	3.270
No. of productive tillers/plant	14.791	16.553	1.762
Panicle length (cm)	4.246	4.461	0.215
No. of spikelets/panicle	2007.549	2028.770	21.221
No. of filled grains/panicle	1304.884	1501.968	197.084
Spikelet fertility (%)	461.426	499.746	38.320
100 grain weight (gm)	0.133	0.134	0.001
Grain yield/plant (gm)	37.061	38.018	0.957
Harvest index (%)	24.523	38.673	14.150
Pollen sterility (%)	687.405	716.757	29.352

pollen sterility (14.11%), number of productive tillers per plant (13.38%), harvest index (11.60%) and spikelet fertility (10.34%). It was low for the characters grain yield per plant (6.06%), number of spikelets per panicle (2.85%), panicle length (2.23%), plant height (1.78%), 100 grain weight (1.37%) and days to 50 per cent flowering (1.28%).

b. Heritability and genetic advance as percentage of mean:

Heritability :

The heritability (broad sense) estimates are represented in Table 4.4. All the characters studied revealed high broad sense heritability. Among the eleven characters, highest heritability (broad sense) estimate was recorded for 100 grain weight (99.254%) followed by number of spikelets per panicle (98.954%), plant height (98.667%), grain yield per plant (97.483%) and pollen sterility (95.905%).

Genetic advance :

Estimates of genetic advance expressed as percentage of mean is represented in Table 4.4. It was high for the characters pollen sterility (137.741%) followed by grain yield per plant (96.716%), number of productive tillers per plant (75.494%), number of filled grains per panicle (73.960%), spikelet fertility (71.044%), number of spikelets per panicle (56.845%), 100 grain weight

(32.400%), plant height (31.391%) and harvest index (25.049%). It was moderate and low for the characters panicle length (19.929%) and days to 50 per cent flowering (9.282%).

4. Combining ability analysis :

The estimates of general combining ability (GCA) effects, specific combining ability (SCA) effects and variances of GCA, SCA and their ratio are depicted in Table 4.6, 4.7 and 4.8. The combining ability effects of the characters studied are presented below :

Days to 50 per cent flowering :

The GCA effects of both lines IR-58025A (0.60) and IR-62829A (-0.60) were significant. The GCA effects of all testers were found to be significant except IR-72 (-0.10) which was non significant.

The SCA effects were found significant for thirty hybrids, which ranged from IR-58025A/Pusa Basmati (-2.35) to IR-62829A/Pusa Basmati (2.35). Out of the thirty hybrids, fifteen showed positive SCA effects, while fifteen showed negative SCA effects.

Plant height :

For this trait, both the lines IR-58025A (5.43) and IR-62829A (-5.43) showed significant GCA effects. Among

Table 4.6 : General combining ability effects of lines and testers for different characters.

Parents	Days to 50% flowering	Plant height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/ panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR-58025A	0.60*	5.43*	-1.45*	0.94*	12.23*	13.97*	2.87*	-0.03*	0.06	1.95*	0.20
IR-62829A	-0.60*	-5.43*	1.45*	0.94*	-12.23*	13.97*	-2.87*	0.03*	-0.06	-1.95*	-0.20
Madhuri Sel-A-9	2.40*	-0.79*	4.94*	0.50*	-59.48*	-29.14*	-0.78*	-0.27*	-3.21*	-4.50*	2.82*
Shyamala	0.65*	-3.69*	-0.21*	-0.65*	43.92*	-0.94	-15.86*	0.46*	-3.04*	0.67*	24.55*
R-574-11	-5.35*	-6.32*	2.34*	0.45*	27.50*	-28.82*	-24.60*	0.09*	0.07	-5.56*	2.94*
R-671	1.15*	-0.29*	0.54*	0.58*	-27.68*	-6.04*	5.45*	0.01*	-0.01	-2.25*	-6.83*
R-405-A-4	1.90*	13.71*	-0.51*	2.20*	44.00*	11.93*	10.92*	-0.02*	0.49*	3.77*	-2.65*
MW-10	-1.10*	-11.17*	-3.31*	-0.37*	30.47*	44.56*	12.60*	-0.44*	-5.22*	-4.30*	-12.36*
R-712-1-6-11-1	1.15*	-5.89*	-1.11*	1.60*	43.97*	-0.27	-13.92*	-0.40*	-2.85*	4.10*	-12.07*
R-636-405	0.15*	15.13*	0.44*	-1.05*	48.47*	-36.07*	-30.54*	-0.02*	-0.56*	-10.54*	31.87*
R-635-134	-1.10*	-25.02*	-1.71*	-1.70*	-7.48*	1.71*	-6.60*	0.04*	-3.13*	-2.56*	16.49*
IR-72	-0.1	-6.82*	-1.41*	1.15*	-6.15*	50.41*	33.12*	0	0.15*	3.33*	-26.12*
PR-106	-3.85*	-14.34*	-0.06	-0.47*	-43.95*	27.74*	-3.73*	-0.05*	-5.44*	-4.73*	11.93*
Rajshree	8.90*	41.01*	-1.96*	0.53*	29.40*	60.86*	22.49*	-0.06*	6.47*	0.78*	-19.49*
R-288-361	2.15*	-4.92*	4.99*	0.35*	-39.78*	-15.84*	1.32*	-0.05*	-3.89*	0.49*	20.73*
R-714-2-9	3.90*	-0.64*	-5.86*	2.73*	-24.38*	13.81*	17.01*	0.28*	5.32*	2.92*	-14.66*
Kranti	-1.10*	-1.52*	-0.16*	-0.65*	-36.03	-15.62*	3.17*	0.23*	4.20*	7.35*	-18.35*
Mahamaya	-3.85*	-9.34*	-1.31*	-1.32*	0.2	-34.69*	-19.78*	0.24*	-2.44*	3.91*	17.74*
R-703-15-2-1	-1.60*	4.68*	-2.11*	-0.52*	-50.88*	-20.74*	5.05*	0.16*	1.65*	3.24*	-30.63*
Madhuri-11	-2.35*	0.16*	0.64*	-1.85*	64.97*	38.96*	-1.50*	0.07*	4.33*	6.44*	-3.02*
R-703-23-1-2	0.65*	4.98*	-1.11*	0.33*	40.35*	7.43*	-5.36*	0.02*	-1.75*	-0.56*	642*
R-636-382	-1.85*	15.38*	1.74*	-0.40*	-22.63*	29.03*	26.63*	-0.21*	10.68*	1.14*	-21.80*
Pusa Basmati	-0.85*	-4.29*	5.29*	-1.50*	-54.80*	-43.14*	-15.07*	-0.08*	-1.79*	-0.44*	32.47*
S.E. Lines	0.33	0.66	0.60	0.18	2.03	6.47	2.71	0.01	0.33	1.61	2.55
S.E. Testers	0.12	0.15	0.13	0.04	0.45	1.45	0.61	0.00	0.07	0.36	0.57

Table 4.7 : Specific combining ability effects of hybrids for different characters.

Hybrids	Days to 50% flowering	Plant height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/ panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR-58025A x											
Madhuri Sel-A-9	1.90*	1.67*	-4.60*	-0.04	-9.83*	-28.92*	-18.34*	-0.09*	-2.27*	-0.29*	8.20*
Shyamala	-0.35	5.67*	-2.85*	1.66*	14.37*	44.22*	20.43*	0.47*	-2.16*	-4.46*	-28.40*
R-574-11	0.15	1.39*	1.80*	1.16*	36.99*	3.4	-0.94	-0.15*	5.49*	5.48*	21.76*
R-671	-0.85*	-3.28*	-3.70*	-1.01*	1.42	-26.52*	-17.89*	-0.19*	-3.78*	-3.92*	1.85
R-405-A-4	0.90*	2.77*	-1.95*	1.51*	33.59*	13.90*	-17.92*	-0.26*	-5.97*	-7.61*	16.00*
MW-10	-0.60*	-5.71*	2.15*	-0.61*	1.47	7.92*	3.83*	0.02*	2.79*	2.66*	-3.25*
R-712-1-6-11-1	-1.35*	2.07*	-2.35*	-0.74*	4.02*	23.20*	12.00*	0.14*	-0.86*	-0.98	26.27*
R-636-405	0.65*	6.94*	1.40*	2.61*	-22.03*	-19.20*	-4.27*	-0.18*	6.50*	1.43	4.09*
R-635-134	-0.60*	-0.01	4.05*	0.26*	36.97*	-7.17*	-29.55*	0.09*	-3.04*	-4.53*	38.42*
IR-72	-0.1	-4.81*	0.65*	-0.99*	14.64*	-0.97	-9.22*	0.13*	-5.56*	0.49	12.77*
PR-106	0.15	1.22*	-0.80*	0.59*	-20.71*	30.13*	37.36*	-0.10*	2.17*	8.82*	-46.54*
Rajshree	-0.1	-4.13*	-1.40*	-2.71*	-32.51*	-18.62*	2.59	0.17*	-0.52*	3.21*	-4.33*
R-288-361	0.65*	-6.56*	-1.15*	-0.29*	-11.13*	6.32	13.02*	-0.19*	1.29*	1.87*	-36.58*
R-714-2-9	1.40*	0.87*	1.40*	0.54*	-23.68*	-16.53*	1.1	0.30*	1.22*	7.10*	-3.90*
Kranti	-0.60*	1.94*	-2.70*	-1.49*	11.67*	-22.45*	-19.77*	-0.10*	-3.30*	-2.67*	-20.96*
Mahamaya	-0.85*	-1.48*	3.85*	-1.16*	-67.76*	-15.92*	6.94*	0.01	-1.38*	-4.53*	-7.17*
R-703-15-2-1	-1.60*	-2.66*	0.05	-1.71*	-23.78*	7.63*	22.11*	0.06*	6.35*	4.79*	2.02
Madhuri-11	1.65*	4.07*	1.00*	2.41*	28.72*	36.62*	10.18*	-0.39*	2.42*	5.22*	-6.62*
R-703-23-1-2	-0.35	-9.51*	2.65*	-0.36*	34.29*	-18.00*	-15.54*	-0.22*	-5.27*	-10.85*	15.56*
R-636-382	2.15*	7.04*	-1.20*	2.16*	15.22*	8.45*	-2.34	0.16*	5.58*	-0.59	-4.36*
Pusa Basmati	-2.35*	2.47*	3.75*	-1.79*	-21.96*	-7.48*	6.16*	0.32*	0.29	-0.63	-26.76*

Cont.. Table 4.7

Hybrids	Days to 50% flowering	Plant height (cm)	No. of productive tillers/ plant	Panicle length (cm)	No. of spikelets/panicle	No. of filled grains/ panicle	Spikelet fertility (%)	100 grain weight (g)	Grain yield/ plant (g)	Harvest index (%)	Pollen sterility (%)
IR-62829A x											
Madhuri Sel-A-9	-1.90*	-1.67*	4.60*	-0.04	9.83*	28.92*	18.34*	0.09*	2.27*	0.29*	-8.20*
Shyamala	0.35	-5.67*	2.85*	1.66*	-14.37*	-44.22*	-20.43*	-0.47*	2.16*	4.46*	28.40*
R-574-11	-0.15	-1.39*	-1.80*	1.16*	-36.99*	-3.4	0.94	0.15*	-5.49*	-5.48*	-21.76*
R-671	0.85*	3.28*	3.70*	-1.01*	-1.42	26.52*	17.89*	0.19*	3.78*	3.92*	-1.85
R-405-A-4	-0.90*	-2.77*	1.95*	1.51*	-33.59*	-13.90*	17.92*	0.26*	5.97*	7.61*	-16.00*
MW-10	0.60*	5.71*	-2.15*	-0.61*	-1.47	-7.92*	-3.83*	-0.02*	-2.79*	-2.66*	3.25*
R-712-1-6-11-1	1.35*	-2.07*	2.35*	-0.74*	-4.02*	-23.20*	-12.00*	-0.14*	0.86*	0.98	-26.27*
R-636-405	-0.65*	-6.94*	-1.40*	2.61*	22.03*	19.20*	4.27*	0.18*	-6.50*	-1.43	-4.09*
R-635-134	0.60*	0.01	-4.05*	0.26*	-36.97*	7.17*	29.55*	-0.09*	3.04*	4.53*	-38.42*
IR-72	0.1	4.81*	-0.65*	-0.99*	-14.64*	0.97	9.22*	-0.13*	5.56*	-0.49	-12.77*
PR-106	-0.15	-1.22*	0.80*	0.59*	20.71*	-30.13*	-37.36*	0.10*	-2.17*	-8.82*	46.54*
Rajshree	0.1	4.13*	1.40*	-2.71*	32.51*	18.62*	-2.59	-0.17*	0.52*	-3.21*	4.33*
R-288-361	-0.65*	6.56*	1.15*	-0.29*	11.13*	-6.32	-13.02*	0.19*	-1.29*	-1.87*	36.58*
R-714-2-9	-1.40*	-0.87*	-1.40*	0.54*	23.68*	16.53*	-1.1	-0.30*	-1.22*	-7.10*	3.90*
Kranti	0.60*	-1.94*	2.70*	-1.49*	-11.67*	22.45*	19.77*	0.10*	3.30*	2.67*	20.96*
Mahamaya	0.85*	1.48*	-3.85*	-1.16*	67.76*	15.92*	-6.94*	-0.01	1.38*	4.53*	7.17*
R-703-15-2-1	1.60*	2.66*	-0.05	-1.71*	23.78*	-7.63*	-22.11*	-0.06*	-6.35*	-4.79*	-2.02
Madhuri-11	-1.65*	-4.07*	-1.00*	2.41*	-28.72*	-36.62*	-10.18*	0.39*	-2.42*	-5.22*	6.62*
R-703-23-1-2	0.35	9.51*	-2.65*	-0.36*	-34.29*	18.00*	15.54*	0.22*	5.27*	10.85*	-15.56*
R-636-382	-2.15*	-7.04*	1.20*	2.16*	-15.22*	-8.45*	2.34	-0.16*	-5.58*	0.59	4.36*
Pusa Basmati	2.35*	-2.47*	-3.75*	-1.79*	21.96*	7.48*	-6.16*	-0.32*	-0.29	0.63	26.76*
S.E. hybrids	0.53	0.66	0.60	0.18	2.03	6.47	2.71	0.01	0.33	1.61	2.55

Table 4.8 : Magnitude of GCA and SCA variances for different characters.

Characters	GCA variance	SCA variance	GCA/SCA ratio
Days to 50% flowering	1.22	1.83	0.67
Plant Height (cm)	66.05	38.71	1.71
No. of productive tillers/plant	3.34	11.89	0.28
Panicle length (cm)	1.35	4.36	0.31
No. of spikelets/panicle	283.30	1493.04	1.9
No. of filled grains/panicle	360.81	753.94	0.48
Spikelet fertility (%)	-7.65	518.52	-0.01
100 grain weight (gm)	-0.024	0.85	-0.03
Grain yield/plant (gm)	-1.16	30.34	-0.04
Harvest index (%)	4.53	40.82	0.11
Pollen sterility (%)	-46.70	880.75	-0.05

the testers, all showed significant GCA effects which ranged from R-635-134 (-25.02) to Rajshree (41.01). Among the twenty one testers, fourteen showed negative GCA effects while seven showed positive GCA effects for this trait.

The SCA effects for this trait was found to be significant for all the hybrids, except for IR-58025A/R-635-134 (-1.01) and IR-62829A/R-635-134 (0.01). The SCA effects ranged from IR-58025A/R-703-23-1-2 (-9.51) to IR-62829A/R-703-23-1-2 (9.51).

Number of productive tillers per plant :

The GCA effects of both lines were significant. All the testers showed significant GCA effects except PR-106 (-0.06) which was non-significant.

Out of the forty two hybrids, forty showed significant SCA effects of which twenty showed positive SCA effects. The SCA effects ranged from IR-58025A/Madhuri Set-A-9 (-4.60) to IR-62829A/Madhuri Set-A-9 (4.60).

Panicle length :

For this trait, GCA effects of both lines were significant viz. IR-58025A (0.94) and IR-62829A (-0.94). Among the testers, all showed significant GCA effects for this trait ranging from Madhuri-11 (-1.85) to R-714-2-9 (2.73).

All the forty two hybrids showed significant SCA effects, except for IR-58025A/Madhuri Set-A-9 and IR-62829A/Madhuri Set-A-9 which showed non-significant SCA effects. Twenty two hybrids showed positive significant SCA effects.

Number of spikelets per panicle :

For this trait, the GCA effects of both lines were significant. Line IR-58025A (12.23) showed a positive GCA effect, whereas line IR-62829A (-12.23) showed negative GCA effect. All the testers showed significant GCA effect, except for Mahamaya. The GCA effects of testers ranged from Madhuri Set-A-9 (-59.48) to Madhuri-11 (64.97).

Thirty eight of the forty two hybrids showed significant SCA effects of which nineteen showed significant positive SCA effects. The SCA effects of hybrids ranged from IR-58025A/Mahamaya (-67.76) to IR-62829A/Mahamaya (67.76).

Number of filled grains per panicle :

For this trait, the GCA effects of both lines were significant. Line IR-58025A (13.97) showed a positive GCA effect, while line IR-62829A (-13.97) showed a negative GCA effect. Nineteen of the twenty one hybrids showed significant GCA effects. The GCA effects of testers ranged from R-636-405 (-36.07) to Rajshree (60.86).

Out of the forty two hybrids, thirty six showed significant SCA effects for number of filled grains per panicle. Positive significant SCA effects were shown by eighteen hybrids. The highest positive significant SCA effect was obtained for IR-58025A/Shyamala (44.22).

Spikelet fertility :

The GCA effects of both lines IR-58025A (2.87) and IR-62829A (-2.87) were significant. All the testers showed significant GCA effects ranging from R-636-405 (-30.54) to IR-72 (33.12). Among the twenty one testers, ten showed positive significant GCA effects.

Among the hybrids, thirty four showed significant GCA effects, of which eighteen showed positive SCA effects for this trait. The SCA effects for hybrids ranged from IR-62829A/PR-106 (-37.36) to IR-58025A/PR-106 (37.36).

100 grain weight :

For this trait, the GCA effects of both lines were significant. Line IR-58025A showed positive significant GCA effect, whereas line IR-62829A showed negative significant GCA effect. All the testers showed significant GCA effects, except tester IR-72 which showed non-significant GCA effect. The GCA effects of testers ranged from MW-10 (-0.44) to Shyamala (0.46).

Among hybrids, forty showed significant SCA effects, of which twenty showed positive significant SCA effects. The highest positive significant SCA effect was obtained for IR-58025A/Shyamala (0.47).

Grain yield per plant :

For this trait, both lines showed non-significant GCA effects. All the testers showed significant GCA effects except R-574-11 and R-671. The significant GCA effects of testers ranged from PR-106 (-5.44) to R-636-382 (10.68).

Among hybrids forty showed significant SCA effects, of which twenty showed positive significant SCA effects.

Harvest index :

For this trait, both lines showed significant GCA effects. Among the testers, all showed significant GCA effects for this trait ranging from R-636-405 (-10.54) to Kranti (7.35).

Among hybrids thirty showed significant SCA effects, of which fifteen showed positive significant SCA effects. The highest positive significant SCA effect was obtained for IR-62829A/R-703-23-1-2 (10.85).

Pollen sterility :

The GCA effects of both lines IR-58025A and IR-62829A were non-significant for this trait. Among the testers, all showed a significant GCA effect for this trait ranging from R-703-15-2-1 (-30.63) to Pusa Basmati (32.47).

Out of the forty two hybrids, thirty eight showed significant SCA effects for pollen sterility, which ranged from IR-58025A/PR-106 (-46.54) to IR-62829A/PR-106 (46.54). Nineteen hybrids showed positive significant SCA effects for this trait.

5. Heterosis:

Relative heterosis (over mid-parent) and heterobeltiosis (over better parent) was determined for all the forty two hybrids for eleven characters, viz. days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, number of spikelets per panicle, number of filled grains per panicle, spikelet fertility per cent, 100 grain weight, grain yield per plant, harvest index per cent and pollen sterility per cent. Relative heterosis and heterobeltiosis estimates have been presented in Table 4.9. The results obtained are discussed as below:

Days to 50 per cent flowering:

For this trait, the value of relative heterosis ranged from IR-58025A/ PR-106(-13.45) to IR-58025A/R-714-2-9 (1.83). Twenty five hybrids showed significant negative heterosis over mid- parent, while none of the hybrids showed significantly positive heterosis.

Table 4.9 : Percent relative heterosis and heterobeltiosis for different characters.

Crosses	Days to 50% flowering		Plant height (cm)		No. of prod. Tillers/plant		Panicle length (cm)		No. of spikelet/panicle	
IR58025A x	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Madhuri Sel-A-9	0.26	-2.03	13.94**	-1.04	57.72**	22.78	11.89**	2.29	20.24**	-28.46**
Shyamala	-4.88**	-6.09**	14.46**	-1.03	21.15	5.00	9.44**	4.80*	88.68**	80.22**
R-574-11	-11.68**	-11.68**	0.51	-16.76**	121.31**	73.08**	10.59**	7.55**	83.79**	62.76
R-671	-5.61**	-6.09**	10.87**	-2.53	16.53	14.81	-3.60	-5.29*	7.12*	7.11*
R-405-A-4	-1.04	-3.55**	25.85**	6.24**	25.45	4.54	24.73**	17.16**	88.79**	68.79**
MW-10	-7.89**	-8.12**	-3.86	-15.46**	47.75	22.39	-1.88	-4.35*	43.10**	20.70**
R-712-1-6-11-1	-6.12**	-6.60**	9.98**	-3.71*	12.38	-3.28	8.85**	4.12	64.27**	45.11**
R-636-405	-6.62*	-5.58**	16.27**	-9.18**	85.12**	45.45*	7.82**	7.32**	65.62**	60.53**
R-635-134	-4.74**	-8.12**	-13.90**	-24.95**	70.80**	25.80	1.24	-6.40**	32.82**	7.54**
IR-72	-4.17**	-6.60**	7.93**	-0.70	43.33	13.16	7.17**	0.91	32.97**	15.94**
PR-106	-13.45**	-16.50**	8.29**	-24.29**	42.86	13.33	3.29	0.69	-23.32**	35.26**
Rajshree	-1.22	-4.71**	53.19**	33.02**	16.50	1.69	-11.06**	-12.25**	19.36**	'0.90
R-288-361	-0.52	-3.55**	3.76*	-18.93**	68.15**	16.81	2.69	0.46	-24.78**	-41.62**
R-714-2-9	1.83	-1.01	10.37**	-5.89**	-30.00	-48.96**	21.20**	15.10**	19.57**	8.07*
Kranti	-6.22**	-8.12**	7.61**	-9.96**	6.47**	31.58*	-2.71	-9.61**	20.81**	14.27**
Mahamaya	-9.79**	-11.17**	-3.31	-18.68**	85.94**	41.66*	-12.42**	-13.59**	-35.61**	50.35**
R-703-15-2-1	-8.72**	-9.64**	9.52**	-8.21**	23.73	-1.35	-6.43**	-10.07**	16.99**	-19.42
Madhuri-11	-9.63**	-12.02**	28.73**	20.12**	80.33**	41.02*	8.06**	5.74	68.87**	34.13**
R-703-23-1-2	-7.50**	-8.87**	4.10**	-11.96**	66.41**	25.29	0.00	0.00	95.32**	81.23**
R-636-382	-2.89**	-6.09**	18.40**	-6.70**	40.43*	2.06	17.08**	8.24**	1.29	-21.41**
Pusa Basmati	-8.01**	-10.61**	10.97**	-3.65*	217.24**	155.55**	-22.82**	-29.41**	-34.91	-46.79**

Cont…. Table 4.9.

Crosses	No. of filled grains/ panicle		Spikelet fertility (%)		100 grain weight (gm)		Grain yield/plant		Harvest index (%)	
IR58025A x	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Madhuri Sel-A-9	-64.01**	-67.45**	-54.79**	-55.03**	0.76	-5.02*	-28.48**	-40.62**	3.19	2.25
Shyamala	40.97**	33.44**	-25.29**	-25.43**	45.45**	22.39**	-30.56**	-44.53**	-3.46	-12.53
R-574-11	25.87	-27.40**	-59.33**	-62.63**	-6.12**	-23.96**	53.35**	22.53**	-2.29	-18.06
R-671	-45.06**	-53.96**	-48.32	-50.35**	9.66**	3.52	-32.86**	-51.20**	10.44	-0.75
R-405-A-4	'12.13	-1.65**	-40.54**	-41.77**	1.93	-5.74**	-44.23**	-59.60**	16.95	7.59
MW-10	34.75**	17.01	-6.53	-9.70	-22.60**	-38.17**	-33.01**	-53.79**	2.9	-7.20
R-712-1-6-11-1	22.25	17.59**	-26.60**	-32.33**	17.78**	-35.08**	-29.88**	-48.18**	9.21	-7.10
R-636-405	-56.50**	-56.89	-73.74**	-74.31**	-7.39**	-22.73**	36.90**	1.83	-15.44	-19.20
R-635-134	24.60**	-38.34**	-75.70	-76.01**	25.30**	17.24**	-41.23**	-54.46**	-10.50	-16.14
IR-72	35.27**	19.65	1.43	-0.28	19.64**	7.69**	-38.73**	-53.72**	18.28	5.25
PR-106	-7.79	-18.04**	18.83*	11.98*	9.74**	2.95	-29.89**	-49.16**	7.12	-6.99
Rajshree	22.7	4.84	2.55	1.21	26.63**	21.02**	53.15**	20.90**	18.66	5.48
R-288-361	-28.59*	-41.93**	-6.86	-12.34	-1.57	-12.99**	-21.76**	-41.94**	15.77**	29.79*
R-714-2-9	15.93	-0.05	-2.54	-7.58	53.34**	48.17**	71.96**	43.24**	64.98**	57.17**
Kranti	-37.12*	-37.76	-48.07**	-51.36**	0.72	-19.59**	2.11	-24.20**	18.49	3.79
Mahamaya	-62.31**	-69.32**	-42.66**	-46.62	0.40	-21.94**	-51.24**	-68.45**	-7.87	-24.89**
R-703-15-2-1	8.81	-11.47**	9.70	3.83	-2.22	-24.54**	22.04**	-16.97**	29.15*	13.36
Madhuri-11	76.64**	70.30**	-1.47	-19.48*	-2.63	-11.93**	37.69**	0.77	29.77**	7.76
R-703-23-1-2	-16.43	-23.14	-57.17**	-57.55**	-1.78	-14.22**	-64.49**	-76.64**	28.32*	-35.36**
R-636-382	20.25	3.84**	13.98	0.21	14.08**	5.77**	109.66**	56.84**	7.43	-4.81
Pusa Basmati	-59.58**	-65.52**	-38.53**	-41.65**	24.56**	12.16**	-0.90	-20.43**	0.84	-11.68

Cont…. Table 4.9.

Crosses	No. of filled grains/ panicle		Spikelet fertility (%)		100 grain weight (gm)		Grain yield/plant		Harvest index (%)	
IR62829A x	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Madhuri Sel-A-9	-33.45*	-42.82**	-19.90**	23.07**	8.28**	7.03**	-25.48**	36.29**	-6.73	9.42
Shyamala	-75.20**	-77.46*	-84.40**	-84.96**	1.59	-11.20**	-28.27**	-36.00**	14.69	2.03
R-574-11	-60.50**	-62.93	-66.81**	-70.40**	3.22**	-11.80**	-53.08**	-58.15**	-44.38**	-54.13**
R-671	-20.74	-35.87**	-15.95**	-16.44	27.40**	26.13**	-4.75**	-16.14	28.95	18.03
R-405-A-4	-36.68**	-46.50	-7.82	-10.14	26.50**	22.00**	-2.36	-4.44	64.54**	54.23**
MW-10	-1.31	-17.41	-27.69**	-33.17**	-24.44**	-37.50**	-73.85**	-76.34**	-25.21*	-33.74**
R-712-1-6-11-1	-51.93**	-55.67	-69.24**	-73.00**	-29.05**	-41.97**	-40.85**	-40.28**	5.22	-11.97
R-636-405	-43.05**	-45.94**	-71.55**	-73.40**	7.52**	-6.44**	-65.48**	-66.15**	-37.55**	-41.29**
R-635-134	-33.68**	-47.56**	-11.90	-16.89*	13.52**	11.33**	-26.75**	-32.15**	8.71	-0.05
IR-72	15.43	-1.68	12.10	5.36	4.84**	-1.36**	0.25	-3.85	4.77	-8.42
PR-106	-89.72**	-91.21	-89.39**	-90.42**	18.65**	16.26**	-69.46**	-70.06**	-57.59**	-63.80**
Rajshree	35.73**	11.87	-15.60*	-20.39**	6.83**	6.67**	13.15*	2.39	-12.17	-23.28**
R-288-361	-60.66**	-69.06**	-51.94**	-56.68**	15.46**	6.06**	-56.30**	-56.97**	17.64	6.66
R-714-2-9	28.60	15.22	-17.37*	-24.97**	18.69**	18.04**	3.64	-11.71*	-1.00	-3.80
Kranti	-15.20	-18.02*	-7.42	-16.90*	7.71**	-10.81**	6.62	4.88	25.07*	7.67
Mahamaya	-15.71**	-66.71**	-70.77**	-73.92**	-1.42	-20.69**	-51.34**	-60.40**	8.08	-13.24
R-703-15-2-1	-54.09**	-54.92	-58.99**	-62.83**	-7.59**	26.07**	-60.54**	-65.09**	-10.88	-23.13*
Madhuri-11	-24.18	-29.90**	-45.05**	-56.66**	33.96**	26.60**	-22.80**	-23.21**	-9.66	-26.17**
R-703-23-1-2	-4.89	-15.94	-28.96**	-31.55**	17.13**	6.28**	-31.21**	-42.44**	30.78*	15.80
R-636-382	-17.05	-30.94	-6.50	-9.99	-3.21	-6.25**	-4.19	-6.83	0.69	-12.33
Pusa Basmati	-69.99**	-75.31**	-64.36**	-67.61**	-8.76**	-14.41**	-34.43**	-41.85**	-5.67	-18.79

* Significant at 5% level, ** Significant at 1% level.

Cont…. Table 4.9.

Crosses	Days to 50% flowering		Plant height (cm)		No. of prod. Tillers/plant		Panicle length (cm)		No. of spikelet/panicle	
IR62829A x	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
Madhuri Sel-A-9	-1.61	2.66*	1.86	-14.50**	44.37**	-2.24	18.27**	13.53**	-18.46**	31.68**
Shyamala	-2.13	-4.17**	-6.51	-21.86**	5.30	-33.18**	-3.41	-11.50**	56.95**	39.28**
R-574-11	-10.24**	-13.20**	-10.68**	-28.23**	-14.5**	-42.60**	3.43*	-6.54**	16.35**	-0.94
R-671	-1.85	-4.61**	9.85**	-6.73**	19.13	-26.01**	9.92**	-4.64*	-6.53	-24.05
R-405-A-4	-0.81	-1.60	12.27**	-8.28**	-5.19	-38.57**	15.48**	7.81**	28.99**	7.72**
MW-10	-4.74**	-7.65**	0.17	-14.93**	-53.10**	-69.51**	8.29**	-2.41	32.25**	4.79
R-712-1-6-11-1	-1.32	-4.10**	-3.28	-18.20**	-4.93	-39.46**	22.13**	12.03**	50.12**	24.04**
R-636-405	-1.90	-2.16	-3.91*	-27.08**	-24.67**	-49.33**	-14.62**	-24.48**	95.77**	76.08**
R-635-134	-1.36	-1.63	-23.21**	-35.33**	-58.86**	-70.85**	2.56	-2.70	-26.64**	-43.98**
IR-72	-1.89	-2.67*	10.45**	-2.05	-31.72**	-54.26**	23.23**	14.77**	0.60	-17.86**
PR-106	-12.12**	-17.92**	-19.27**	-35.43**	-12.75	-41.70**	1.34	-8.67**	-5.92	-25.40**
Rajshree	1.01	-5.66**	55.57**	30.55**	-17.02	-47.53**	18.92**	3.56	56.90**	24.58**
R-288-361	0.27	0.00	1.86	-16.95**	9.52	-17.49**	9.99**	-1.20	-21.97**	-42.63**
R-714-2-9	1.08	0.54	0.25	-17.32**	-68.65**	-77.58**	22.31**	12.98**	53.63**	49.70**
Kranti	-2.95*	-4.23*	-4.62*	-22.74**	-6.92	-33.63**	17.51**	11.20**	-11.06**	-21.76**
Mahamaya	-6.13**	-7.85**	-8.62**	-25.61**	-53.74**	-68.16**	1.53	-11.58**	37.58**	0.53
R-703-15-2-1	-3.45**	-5.70**	7.18**	-13.04**	-31.99**	-54.71**	15.22*	5.21*	9.87*	-1.03
Madhuri-11	-11.22**	-16.35**	10.08**	-1.00	-20.93*	-46.64**	-13.34**	-20.08**	24.43**	-6.62**
R-703-23-1-2	-4.91**	-9.36**	16.43**	-4.71**	-45.16**	-61.88**	7.53**	-5.26*	31.83**	13.92**
R-636-382	-5.43**	-5.43**	-2.23	-25.19**	-5.00	-31.84**	-0.85	5.93*	-27.89**	-47.01**
Pusa Basmati	-1.07	-2.63*	-3.02	-18.62	-6.44	-38.12**	-5.58*	-22.96*	-17.37**	-36.36**

The heterobeltiosis ranged from IR-62829A/PR-106 (-17.92) to IR-62829A/R-714-2-9 (0.54). Thirty five hybrids exhibited significantly negative heterobeltiosis, while none of the hybrids showed positive heterobeltiosis for this trait.

Plant height:

For plant height, relative heterosis ranged from IR-62829A/R-635-134(-23.21) to IR-62829A/Rajshree (55.57). Seven hybrids exhibited significantly negative heterosis, while twenty four hybrids exhibited significantly positive heterosis values.

Heterobeltiosis for this trait ranged from IR-62829A/PR-106(-35.43) to IR-58025A/Rajshree (33.02). Thirty six hybrids exhibited significant heterobeltiosis, while the rest four showed positive heterobeltiosis.

Number of productive tillers per plant:

The relative heterosis for this trait ranged from IR-62829A/R-714-22-9 (-68.65) to IR-58025A Pusa Basmati (217.24). Twenty two hybrids exhibited significant heterosis and of these ten hybrids showed negative heterosis and twelve showed positive heterosis.

For heterobeltiosis, it ranged from IR-62829A/IR-714-2-9 (-77.58) to IR-58025A/ Pusa Basmati (1555.55). Out of the twenty such hybrids which showed significant heterosis over better parent, twenty five showed positive heterobeltiosis and twenty two hybrids showed negative heterobeltiosis.

Panicle length:

The relative heterosis for panicle length ranged from IR-58025A/Pusa Basmati (-22.82) to IR-58Q25A/R-405-A-4 (24.73). Out of the forty two hybrids, twenty two exhibited significant negative heterosis, while seven hybrids exhibited significantly positive relative heterosis.

The heterobeltiosis for this trait ranged from IR-58025A/Pusa Basmati (-29.41) to IR-58025A /R-405-A-4(17.16). Total thirty one hybrids exhibited significant heterobeltiosis and of these eighteen showed negative heterobeltiosis, while rest twelve hybrids exhibited positive heterobeltiosis.

Number of spikelets per panicle:

The range for relative heterosis for this trait was from IR-58025A / Mahamaya (-35.61) to IR-62829A/R-636-405 (95.77). Nine hybrids showed significantly negative relative heterosis and twenty eight showed significantly positive relative heterosis estimates.

The heterobeltiosis for this trait ranged from IR-58025A/ Mahamaya (-50.35) to IR-58025A / R-803-23-1-2 (81.23). Seventeen hybrids showed significantly negative heterobeltiosis, while twenty showed significantly positive heterobeltiosis estimates.

Number of filled grains per panicle:

Relative heterosis for this trait ranged from IR-62829A/PR-106(-89.72) to IR-58025A / Madhuri-11 (76.64). Twenty hybrids exhibited significant negative heterosis, while five hybrids showed significant positive heterosis.

The heterobeltiosis for this trait ranged from IR-62829A/PR-106 (91.21) to IR-58025A /Madhuri-11 (70.30). Twenty five hybrids showed significant heterobeltiosis, and of these, twenty one hybrids exhibited negative heterobeltiosis, while four exhibited positive heterobeltiosis.

Spikelet fertility per cent:

For this trait, the relative heterosis ranged from IR-62829A/PR-106 (-89.39) to IR-58025A/PR-106 (18.83). Out of the twenty nine hybrids which showed significant relative heterosis, twenty eight showed negative relative heterosis, while only one hybrid showed positive relative heterosis.

The heterobeltiosis for this character ranged from IR-62829A/PR-106 (-90.42) to IR-58025A /PR-106 (11.98). Thirty one hybrids exhibited significant negative heterobeltiosis. While only one hybrid showed significant positive heterobeltiosis for this trait.

100 grain weight:

Among forty two hybrids, relative heterosis for this trait ranged from IR-62829A/R-712-1-6-11-1 (-29.05) to IR-58025A/ R-714-2-9 (53.34). Out of the thirty one hybrids which showed significant relative heterosis, twenty three hybrids exhibited negative heterosis while eight hybrids showed positive heterosis for this trait.

The heterobeltiosis ranged from IR-62829A/R-712-1-6-11-1 (-41.97) to IR-58025A/R-714-2-9 (48.17). Thirty nine hybrids showed significant heterobeltiosis. Of these twenty one hybrids showed significant negative heterobeltiosis, while eighteen showed positive heterobeltiosis.

Grain yield per plant :

The relative heterosis for this trait ranged from IR-62829A/MW-10 (-73.85) to IR-58025A/ R-636-382 (109.66). Twenty seven hybrids exhibited significant negative relative heterosis, while eight hybrids exhibited significant positive relative heterosis for this trait.

Table 4.10 : The related combining ability information of the best crosses based on heterosis studies.

Characters	Cross	Mean	RH	HB	Sca effect	GCA status of parent	
						Line	Tester
Days to 50% flowering	IR-62829A/R-574-11	85.50	-10.24**	-13.20**	-0.15	L	H
Plant height (cm)	IR-62829A/R-635-134	140.40	-23.21**	-35.33**	0.01	L	H
No. of productive tillers/plant	IR-62829A/Madhuri-Sel-A-9	21.80	44.37**	-2.24	4.60*	H	H
Panicle length (cm)	IR-58025A/R-405-A-4	25.60	24.73**	17.16**	1.51*	L	L
No. of spikelets/panicle	IR-58025A/Madhui-11	269.60	68.87**	34.13**	28.72*	H	H
No. of filled grains/panicle	IR-58025A/Madhuri-11	172.00	76.64**	70.30*	36.62*	H	H
Spikelet fertility (%)	IR-62829A/IR-72	91.78	12.10	5.36	9.22*	L	H
100 grain weight (gm)	IR-58025A/Shyamala	3.17	45.45**	22.39**	0.47*	L	L
Grain yield/plant (gm)	IR-58025A/R-636-382	30.38	109.66**	56.84**	5.58*	L	H
Harvest index (%)	IR-58025A/Madhuri-11	45.53	29.77**	7.76	5.22*	H	H

The heterobeltiosis ranged from IR-58025A/ R-703-23-1-2(-76.64) to IR-58025A / IR-636-382 (56.84). Thirty five hybrids showed significant heterobeltiosis estimates and of these thirty two hybrids showed negative heterobeltiosis, while three hybrids showed positive heterobeltiosis for this trait.

Harvest index :

For harvest index, the relative heterosis ranged from IR-62829A/PR-106 (-57.59) to IR-62829A/R-405-A-4 (64.54). Four hybrids showed significant negative relative heterosis for this trait, while eight hybrids exhibited significant positive relative heterosis for this trait.

The heterobeltiosis estimates ranged from IR-62829A/PR-106 (-63.8) to IR-58025A/R-714-2-9 (57.17). Twelve hybrids showed significant heterobeltiosis for this trait and of these nine showed negative heterobeltiosis, while three showed positive heterobeltiosis.

The combined effect of GCA, SCA and heterosis in respect to mean performance of various characters is depicted in Table 4.10.

6. Screening for maintainers and restorers

The classification of genotypes into restorers and maintainers for CMS lines IR-58025A and IR-62829A is given in Table 4.11.

Table 4.11 : Classification of genotypes into restores and maintainers for IR-58025A and IR-62829A CMS lines.

Genotypes	Potential maintainers		Partial restorers		Effective restorers	
	IR-58025A	IR-62829A	IR-58025A	IR-62829A	IR-58025A	IR-62829A
Madhuri Sel-A-9	-	-	PR	PR	-	-
Shyamala	-	PM	PR	-	-	-
R-574-11	-	-	PR	PR	-	-
R-671	-	-	PR	PR	-	-
R-405-A-4	-	-	PR	PR	-	-
MW-10	-	-	PR	PR	-	-
R-712-1-6-11-1	-	-	PR	-	-	ER
R-636-405	-	-	PR	PR	-	-
R-635-134	PM	-	-	PR	-	-
IR-72	-	-	PR	-	-	ER
PR-106	-	PM	PR	-	-	-
Rajshree	-	-	PR	PR	-	-
R-288-361	-	PM	PR	-	-	-
R-714-2-9	-	-	PR	-	-	ER
Kranti	-	-	PR	PR	-	-
Mahamaya	-	-	PR	PR	-	-
R-703-15-2-1	-	-	PR	PR	-	-
Madhuri-11	-	-	PR	PR	-	-
R-703-23-1-2	-	-	PR	PR	-	-
R-636-382	-	PM	PR	-	-	-
Pusa Basmati	-	-	PR	PR	-	-

a) Maintainers:

Average per cent pollen sterility (Table 4.3) of F_1 hybrids was used to identify the effective maintainers in the search for maintainers. Varieties showing a very high level of pollen sterility (>90%) are selected.

The results on evaluation of 42 hybrids for average pollen sterility clearly indicated that none of the hybrids showed 100% pollen sterility, however, out of 42 hybrids five hybrids viz. IR-62829A/Pusa Basmati, IR-62829A/PR-106, IR-62829A/R-288-361, IR-58025A/R-635-134, IR-62829A/Shyamala had more than 90% pollen sterility.

b) Restorers:

Test varieties or lines are pollinated to CMS lines. The F_1's are examined for pollen sterility (Table 4.3).

The result on evaluation of 42 hybrids for mean pollen sterility indicated the genotypes, PR-106, R-703-23-1-2, R-636-382, Rajshree, R-714-2-9, R-288-361 and MW-10 were classified as partial restorers (5-95% pollen sterility). Genotype Kranti, IR-72, R-712-16-11-1 were classified as effective restorers (<5% pollen sterility) for CMS line IR-62829A and genotypes R-703-15-2-1, R-635-134, R-574-11, R-405-A-4, R-636-382 and Rajshree were classified as partial restorers (5-95% pollen sterility).

CHAPTER - V

DISCUSSION

The use of hybrid rice is a strategy to lift the yield ceiling of rice to help the world meet the future projected demand, which will increase due to increasing population and rising income.

The parental lines nicknamed as genetic tools, constitute the first and foremost step in a hybrid breeding programme. In fact, the belated success of hybrid rice technology in India was virtually due to the non-availability of a CMS line suited to tropics, so International Rice Research Institute (IRRI) Philippines began collaborations with several tropical rice-growing countries to develop suitable parental lines. In the year 1989, IRRI developed two commercially usable CMS lines IR-58025A and IR-62829A. These lines possess all the essential traits viz., complete and stable male sterility, good combining ability and adaptability. Hence these two lines were used in this investigation. The results were discussed under the following sub headings:-

1. Analysis of variance for combining ability
2. Genetic parameters

   a. Genotypic and Phenotypic coefficient of variability.

   b. Heritability and Genetic advance as percentage of mean

3. Combining ability
   a. Variance of general combining ability and specific combining ability.
   b. General combining ability of lines and testers.
   c. Specific combining ability of hybrids.
4. Heterosis
5. Screening for maintainers and restorers
   a. Maintainers.
   b. Restorers.

In the present investigation two CMS lines, Viz. IR-58025A and IR-62829A, 21 testers and the resulting forty two hybrids were evaluated by their mean performance, estimates of genetic variability, variances, their combining ability and magnitude of heterosis.

1. Analysis of variance for combining ability :

The analysis of variance for combining ability (Table 4.1) revealed that the variance due to lines, testers, parents, hybrids, parents vs. hybrids and line x tester were significant for most of the characters indicating presence of adequate variability in the experimental material.

2. Genetic parameters:

Genetic improvement of rice crop to obtain higher productivity is a prime need, the knowledge on the nature and magnitude of genetic variation governing the inheritance of quantitative charcters like yield and its related characters is essential for effecting genetic improvement.

a. Genotypic and Phenotypic coefficient of variability (GCV and PCV) :

The estimates of genetic parameters (Table 4.4) revealed relatively low magnitude of differences between GCV and PCV for most of the characters except spikelet sterility, pollen sterility and harvest index indicating that these traits were mostly governed by genetic factors or less environmental influence on these characters. However, environment strongly influenced the spikelet fertility, pollen sterility and harvest index. High PCV was observed for number of filled grains per panicle, pollen sterility, number of productive tillers per plant, harvest index and spikelet ferility indicating the presence of ample variation for these charcters in present material. Low PCV was observed for 100 grain weight, panicle length and days to 50 per cent flowering. Grain yield per plant exhibited moderate PCV.

High GCV was observed for number of spikelets per panicle, number of filled grains per panicle, pollen sterility, spikelet fertility and plant height. Lowest GCV were observed for the characters 100 grain weight and panicle length. Moderate to high GCV for several traits suggested the possibility of yield improvement through selection.

The Similar results were obtained by Mehetre *et al.* (1996), Patel and Prajapati (1996) and Borbora and Hazarika (1998).

b. Heritability (H^2) and Genetic advance as percentage of mean (GA as % of mean) :

Heritability estimates were high for all the characters except harvest index and ranged from 63.41 per cent for harvest index to 99.25 per cent for 100 grain weight. The heritability estimates were found to be more than 90 per cent for the traits, pollen sterility and grain yield per plant. Thus, these characters may be used as selection criteria in the breeding programmes. Similar results have also been reported by Borbora and Hazarika (1998).

According to Johnson *et al.* (1955) and Panse (1957) heritability estimate along with genetic advance is more useful than heritability alone in predicting the effectiveness of selection. In the present experiment, high heritability (>90%) with high genetic advance (>30%) was found for the characters 100 grain weight, spikelets per panicle, plant height, grain yield per plant, pollen sterility and spikelet fertility. This indicated that these traits were mostly governed by additve gene action. Simple selection procedures like mass selection and family selection would be effective for improvement of these characters. Similar results have also been reported by Borbora and Hazarika, (1998) and Vivekanandan and Giridharan (1998).

Increased heritability with decrease genetic advance was found in respect to days to 50 per cent flowering. These characters may be under the control of complex inheritance and are sensitive to environmental changes. Evaluation of such characters chould be accomplished through well laid-out experiments in different environments. Similar results have been reported by Borbora and Hazarika (1998) and Vivekanandan and Giridharan (1998).

From the above discussion it can be concluded that the characters like pollen sterility, productive tillers per plant, filled grains per panicle, grain yield per plant, spikelet fertility and spikelets per panicle exhibited high GCV, heritibility and genetic advance. These characters may be considered as important criteria for selection in the segregating population.

3. Combining ability:

a. Variances of general combining ability and specific ability :

GCA variance, SCA variance and their ratio is given in **Table** 4.6, 4.7 and 4.8. The estimates of combining ability showed that the specific combining ability variance was greater than general combining ability variance for all the characters studied viz., days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, number of spikelets per panicle, number of filled grains per panicle, spikelet fertility per cent, 100 grain weight, grain yield per plant, harvest index per cent and pollen sterility per cent, indicating the predominance of non-additive gene action. This is in accordance with the results of Haque *et al.*(1981), Kumar and Rangaswamy (1984), Sharma (1985), Kuo and Liu (1986), Sarathe and Singh (1986), Kalaimani and Sundaram (1987), Cheema *et al.*(1988), Manuel and Palanisamy (1989), Peng and Virmani (1990), Sarawgi *et al.*(1991), Murthy and Shivashankar (1992), Ramalingam *et al.* (1993), Geetha *et al.*(1994) and Sharma and Koranne (1995).

b. General combining ability of lines and testers:

The perusal of the data on GCA effects of the lines indicated that IR-58025A was the best general combiner for grain yield per plant, panicle length, spikelets per panicle, filled grains per panicle, spikelet fertility, harvest index and pollen sterility (Table 4.6). This line can be utilized in evolving high productive hybrids. The significant heterotic crosses for various characters in the study had this line as one of the parent.

For earliness and reduced plant height IR-62829A was best female parent with significant GCA effects.

The GCA effects of the testers (Table 4.6) revealed that R-636-382, Rajshree, and R-714-2-9 for grain yield, Pusa Basmati for productive tillers per plant, R-714-2-9 for Panicle length, Madhuri-11 for spikelet per panicle, Rajshree for filled grains per panicle, Shyamala and R-714-2-9 for 100 grain weight, Kranti, Madhuri-11 and Mahamaya for harvest index are good general combiners. It was revealed that for reduced plant height and earliness testers PR-106 and R-574-11 respectively were good general combiners.

These lines can be utilized in the breeding programme for the above mentioned traits.

c. Specific combining ability of hybrids:

In the present study significant SCA effects (Table 4.7) were exhibited by 21 crosses for grain yield per plant. Among the hybrids IR-58025A/ Pusa Basmati showed significant negative SCA effect for days to 50 per cent flowering. This was reflected in the mean performance of the hybrid, which flowered earlier than both the parents involved. Significant positive SCA effects were also expressed by the hybrids IR-58025A / R-636-382 and IR-58025A / Madhuri sel-A-9, this was reflected in the mean performance as it was late to flower than either one of the parents involved in the respective cross. The hybrid IR-62829A/R-636-382 expressed significant negative SCA effects but was not reflected in its mean performance which might have been due to negative GCA effects of both line and tester.

Highest significant negative GCA effect for plant height was expressed by the hybrid IR-58025A/ R-703-23-1-2 but showed high mean performance in comparison to the parent IR-58025A. This might be due to high significant GCA effects of line IR-58025A and tester R-703-23-1-2. Among the hybrids, IR-62829A/R-635-134 registered the lowest mean plant height but showed significant positive GCA effects. This might be due to very high negative GCA effect of tester R-635-134.

Among the hybrids IR-62829A/ Madhuri Sel-A-9 showed highest significant positive GCA effect for number of productive tillers per plant. This was reflected in the high mean performance of the hybrid. High performance and positive GCA effects was registered for the hybrids IR-58025A / Mahamaya, IR-58025A / Pusa Basmati, IR-58025A /R-703-23-1-2 and IR-58025A / MW-10. The crosses IR-58025A /Mahamaya, IR-58025A / R-703-23-1-2 and IR-58025A / MW-10 expressed high GCA effects, whereas both the parents of respective hybrids showed significant negative GCA effects. This reveals the preponderance of non additive gene action for these crosses which finally results in their high mean performance.

The highest positive significant GCA effect for panicle length was recorded for the hybrid IR-62829A/Rajshree. This hybrid showed a high *per se* performance for this trait. The hybrids IR-58025A / R-636-405, IR-58025A / Madhuri-11 and IR-58025A / R-636-382 showed significant positive GCA effects. This was also reflected in the high mean performance of these hybrids. All these crosses had one parent with high positive GCA effects, while the other parent had negative GCA effects. These crosses also expressed high mean performance for panicle length, thus indicating that high mean performance of the crosses is mainly associated positive GCA effects with the hybrid having one or both the parents showing high GCA effect.

For the trait number of spikelets per panicle, highest positive GCA effect was shown by the hybrid IR-62829A/Mahamaya followed by IR-58025A /R-574-11, IR-58025A /R-635-134 and IR-58025A / R-703-23-1-2. This was reflected in the high mean performance of these hybrids for number of spikelets per panicle. Both the parents involved in each of these hybrids had also shown positive GCA effects.

Among the hybrids IR-58025A / Shyamala showed the highest positive significant GCA effect for number of filled grains per panicle, which was also reflected in its high mean performance. High positive significant GCA effects were also shown by the hybrids IR-58025A / Madhuri-11 followed by IR-58025A/ PR-106, IR-62829A/Madhuri set-A-9 and IR-62829A/R-671. Except for the hybrid IR-58025A/ Madhuri-11, the high positive GCA effects of the other three hybrids was not reflected on their *per se* performance as these hybrids showed low mean values for number of filled grains per panicle. The negative GCA effects of line IR-62829A could have resulted into the low mean performance of hybrids IR-62829A/Madhuri - Sel-A-9 and IR-62829A/R-671.

The hybrid IR-58025A/PR-106 expressed the highest positive GCA effect for spikelet fertility per cent. The high positive GCA effect was also evident from the *per se* performance. The hybrids IR-62829A/R-635-134, IR-58025A/ Shyamala, IR-58025A / R-703-15-2-1 and IR-62829A/ Kranti also showed significant high positive GCA effects but high positive GCA effects in three of these four hybrids (IR-62829 A/R-635-134, IR-58025A/Shyamala and IR-62829A /Kranti) were not reflected in their mean performance, this may be due to significant high negative GCA effects shown by either one or both parents involved in that particular cross.

For 100 grain weight the highest significant positive GCA effect was shown by the hybrid IR-58025A / Shyamala. The positive GCA effects were also reflected in the high mean performance of this hybrid. Positive GCA effects were also shown by the hybrids IR-62829A/ Madhuri-11, IR-58025A/ Pusa Basmati, IR-58025A/ R-714-2-9 and IR-62829A/R-405-A-4. The positive GCA effects were also reflected in their high *per se* mean performance.

Among the hybrids the highest positive significant GCA effect for grain yield per plant was expressed by IR-58025A / R-636-405. High positive GCA effects were also shown by the hybrids IR-58025A/R-703-15-2-1, followed by IR-62829A/IR-72. In two of these hybrids IR-58025A/ R-636-405 and IR-58025A/R-636-382, the mean performance was high, while the hybrids IR-58025A / R-703-15-2-1, IR-

62829A/R-405-A-4 and IR-62829A/ IR-72 showed lower mean performance.

The highest positive significant GCA effect for harvest index was shown by the hybrid IR-62829A/R-703-23-1-2. This was reflected in its high mean *per se* performance. High positive GCA effects were also shown by the hybrids IR-58025A/ PR-106, IR-62829A/R-405-A-4, IR-58025A/R-714-2-9 and IR-58025A/R-574-11, the two hybrids, PR-6289A/R405-A-4 and IR-58025A/R-714-2-9 showed high mean *per se* performance. Low mean performance of the hybrids IR-58025A/ PR-106 and IR-58025A / R-574-11 might be due to very high negative GCA effects of the testers involved in the respective crosses.

The highest positive significant GCA effect for pollen sterility was recorded for IR-62829A/PR-106. The positive GCA effect was reflected in the mean *per se* performance of the hybrid. High positive GCA effect were also registered for the hybrids IR-58025A / R-635-134 followed by IR-62829A/R-288-361, IR-62829A/Shyamala and IR-62829A/Pusa Basmati. The high positive GCA effects were reflected in the high mean pollen sterility percentage expressed by these hybrids. Most of the hybrids showing high positive GCA effects and high mean performance for this trait had one or both parents involved with negative GCA effects thereby confirming the importance of non-additive gene action for this trait.

The SCA effects of the hybrids (Table 4.7) revealed that the top 5 cross combinations viz. IR-58025A/R-635-405, IR-58025A/R-703-15-2-1, IR-58025A/Pusa Basmati, IR-62829A/R-405-A-4 and IR-62829A/IR-72 recorded significantly high positive SCA effects for grain yield per plant. Hybrids like IR-58025A/R-703-23-1-2, IR-58025A/R-288-361, IR-62829A/R-636-382, IR-62829A/R-636-405 and IR-62829A/Shyamala for reduced plant height and hybrids IR-58025A/Pusa Basmati, IR-58025A/R-703-15-2-1, IR-62829A/R-636-382 and IR-62829A/Madhuri Sel-A-9 for earliness were found to possess significant negative SCA effects. These crosses also showed significant relative heterosis and heterobeltiosis for yield and related characters.

Promising crosses based on significant SCA effects and *per se* performance were IR-62829A /R-574-11 for days to 50 per cent flowering; IR-62829A/R-635-134 for plant height; IR-58025A/Madhuri-11 for spikelets per panicle, filled grains per panicle and harvest index; IR-62829A/Madhuri-Sel-A-9 for productive tillers per plant; IR-58025A/R-405-A-4 for panicle length; IR-62829A /IR-72 for spikelet fertility; IR-58025A /Shayamala for 100 grain weight and IR-58025A /R-636-382 for grain yield per plant. These crosses can be directly utilized for the improvement of these characters through the exploitation of heterosis.

Out of 42 cross combinations most of the crosses showed high SCA effects for the different characters. Most of the combination involved atleast one of the parent with good GCA. This indicated the presence of add. x add. or add. x dom. genetic interaction in sizeable amount amongst these crosses. Hence pedigree method of selection should bring an improvement in some of the above cross combination. Remaining crosses involve parents with ave. x ave., ave. x poor or poor x poor GCA effects, it appears that high SCA effects of any cross combinations does not necessarily depend upon GCA effect of parent involved. The superiority of these crosses may be due to complimentary type of gene interaction which can be exploited in subsequent generations.

The results of the present investigation revealed that most of the characters were under the control of non-additive gene action. Nature and magnitude of GCA effects suggested that development of hybrids would be most appropriate breeding strategy to improve grain yield of genotypes under study.

In general these findings were in agreement with the results of Zhou *et al.*(1982), Anandakumar and Rangasamy (1984), Peng and Virmani (1990), Banumathy and Prasad (1991), Mou and Lu (1991), Watanesk (1993), Bobby and

Nadarajan (1994), Wenming *et al.*(1996) and Ramalingam *et al.*(1997).

3. Heterosis:

Relative heterosis and heterobeltiosis for different characters are presented in Table 4.9. For days to 50 per cent flowering the highest significant negative relative heterosis was shown by the hybrrid IR-58025A/ PR-106. This was reflected in its mean performance as it was early than both of its parents but these findings were not in agreement with the GCA effects, which was non-significant and positive. High significant negative relative heterosis was also shown by the hybrids IR-62829A/PR-106, IR-58025A/ R-574-11, IR-62829A/Madhuri-11 and IR-62829A/R-574-11, hybrid IR-62829A/PR-106 registered highest negative heterobeltiosis, rest of the four hybrids also showed high negative heterobeltiosis estimates. Similar results have also been reported by Ponnuthurai and Virmani (1985), Peng and Virmani (1991), Sahai and Chaudhary (1991), Bobby and Nadarajan (1994) and Manomani and Ranganathan (1996).

Negative and significant relative heterosis for plant height was recorded for the hybrid IR-62829A/R-635-134 followed by IR-62829A/PR-106, IR-58025A/R-635-134 and IR-62829A/R-574-11. These hybrids also manifested negative and significant heterobeltiosis. The highest negative and significant heterobeltiosis was recroded for IR-62829A/PR-

106. The relative heterosis and heterobeltiosis results of the hybrids IR-62829A/R-635-134 and IR-58025A/R-635-134 were not in agreement with the results of combining ability which showed non-significant GCA effects for these hybrids, whereas the results of the hybrids IR-62829A/PR-106 and IR-62829A/R-574-11 were in accordance to their mean performances and negative GCA effect estimates. These findings are similar to those reported by Shrivastava and Seshu (1982), Kim (1985), Peng and Virmani (1991), Sahai and Chaudhary (1991) and Bobby and Nadarajan (1994).

The highest positive significant manifestation of relative heterosis for number of productive tillers per plant was in the hybrid IR-58025A/Pusa Basmati. This was reflected in the mean *per se* performance and positive GCA effects of this hybrid.

Highest positive significant heterobeltiosis estimate was recorded for the hybrid IR-58025A/Pusa Basmati. The hybrids which showed high positive significant relative heterosis as well as heterobeltiosis are IR-58025A/R-574-11, IR-58025A/Mahamaya, IR-58025A/R-636-405 and IR-58025/Madhuri-11. These hybrids also showed high mean *per se* performance. Similar results have also been reported by Zhang and Xu (1986), Parmasivan and Sree Rangasamy (1988), Vivekanandan *et al.* (1992), Ramalingam *et al.* (1994) and Mohan Rao *et al.* (1996).

The highest positive and significant relative heterosis and heterobeltiosis for panicle length was registered for the hybrid IR-58025A/R-405-A-4. Significant positive relative heterosis and heterobeltiosis was also shown by the hybrids IR-62829A/R-712-1-6-11-1, IR-58025A/R-714-2-9, IR-62829A/Madhuri Sel-A-9 and IR-62829A/Kranti. The high positive relative heterosis and heterobeltiosis of these hybrids was also reflected in their high mean performance and all the them showed positive GCA effects, except for the hybrid IR-58025A/R-714-2-9 which expressed negative GCA effects. Similar results were reported by Kumar and Saini (1983), Richharia and Singh (1984), Kim (1985), Sutaryo (1989), Ramalingam *et al.* (1994), Pandey *et al.* (1995) and Nilkantapillai (1987).

For the trait number of spikelets per panicle the highest significant positive relative heterosis and heterobeltiosis was shown by the hybrids IR-62829A/R-636-405 and IR-58025A/R-703-23-1-2. This was reflected in their high positive GCA effects and high mean *per se* performance. The hybrids which showed high positive significant relative heterosis and heterobeltiosis are IR-58025A/ R-703-23-1-2 followed by IR-58025A/R-405-A-4, IR-58025A/Shyamala, IR-58025A/R-574-11, IR-58025A/Madhuri-11, IR-58025A/R-636-405 and IR-58025A /R-712-1-6-11-1. Only three out of these seven hybrids showed high *per se* performance for this trait. Similar results have been reported by Pattanaik *et al.* (1990).

The highest positive and significant relative heterosis heterobeltiosis for number of filled grains per panicle was shown by the hybrid IR-58025A /Madhuri-11 and IR-58025A/Shyamala both these hybrids showed high *per se* performance. This was also reflected in their high positive GCA effects. The hybrids IR-58025A/R-636-382 and IR-58025A /R-712-1-6-11-1 showed positive significant heterobeltiosis. These hybrids also showed positive GCA effects. Similar findings were reported by Kumar and Saini (1983), Kalaimani and Kadambavanasundaram (1987), Suh and Cho (1987), Sutaryo (1989) and Pandey *et al.* (1995).

For spikelet fertility the highest positive significant relative heterosis and heterobeltiosis was recorded for IR-58025A /PR-106, this was reflected in the *per se* performance and positive GCA effect. Apart from IR-58025A /PR-106, none of the hybrids showed significant positive relative heterosis and heterobeltiosis. Similar results were reported by Rangaswamy and Natrajamoorthy (1988).

For 100 grain weight the highest positive and significant relative heterosis and heterobeltiosis was shown by the hybrid IR-58025A /R-714-2-9 followed by IR-58025A/Shyamala, IR-62829A/ Madhuri-11, IR-62829A/R-671, IR-62829A/R-405-4-4, IR-58025A/Rajshree, IR-58025A/R-635-134 and IR-58025A/Pusa Basmati. These heterotic hybrids also showed high mean *per se* performance and positive SCA effects. Similar results were obtained by Kumar and Saini (1983), Kalaimani and Kadambavanasundaram (1987) and Parmasivan and Sree Rangasamy (1988).

For grain yield per plant the highest positive and significant relative heterosis and heterobeltiosis was shown by the hybrid IR-58025A/R-636-382 followed by IR-58025A /R-714-2-9, IR-58025A/ R-574-11 and IR-58025A /Rajshree. All these hybrids showed high mean *per se* performance and positive SCA effects, except for the hybrid IR-58025A /Rajshree which showed negative SCA effects. The high mean performance of this hybrid might be due to high positive GCA effects shown by its two parents. Further, it was revealed that twenty seven and thirty two hybrids showed negative relative heterosis and heterobeltiosis respectively for grain yield per plant.

The results were in accordance to the findings of Panwar *et al.* (1983), Anandakumar and Rangasamy (1984), Ponnuthurai and Virmani (1985), Pham and Nghyen (1987), Suh and Cho (1987), Virmani *et al.* (1982), Yuan *et al.*

(1987), Sivasubramanian *et al.* (1989), Nghyen and Bui (1993), Watanesk (1993), Reddy and Nerkar (1995) and Ganesan *et al.* (1997).

For the trait harvest index, the highest positive significant manifestation of relative heterosis and heterobeltiosis was for the hybrid IR-58025A / R-714-2-9 followed by IR-62829A/ R-40-A-4 and IR-58025A/R-288-361. The high relative heterosis and heterobeltiosis of these hybrid was also reflected in their mean *per se* performance. The highest and significant negative heterosis and heterobeltiosis was shown by the hybrid IR-58025A/ PR-106. This was reflected in the low mean performance of this hybrid.

Top ranking hybrids on the basis of heterobeltiosis and relative heterosis alongwith their SCA effects and GCA status of the parents are presented in Table 4.10. Of the 42 hybrids studied SCA effects for all the characters were inconsistent. The best crosses varied with the characters for combining ability studies (Virmani, 1994). In general, any cross which expressed high heterobeltiosis and relative heterosis for particular trait was derived from parent(s) with good GCA for that trait. But, this behaviour was not always true, i.e. the best specific combiner might or might not give the best *per se* performance in the crosses. Similarly good specific combination might or might not have its parent(s) as good general combiner(s). It was observed that one of the parents of the best yielding cross IR-58025A/R-636-382 have good general combiners and exhibited high value of GCA and SCA effects, this finding indicated that both SCA and GCA effects are important considering the performance of hybrid, their heterobeltiosis, relative heterosis, GCA and SCA effects IR-62829A/R-514-11 (Days to 50% flowering), IR-62829A/R-635-134 (Plant height), IR-62829Å/Madhuri Sel-A-9 (productive tillers), IR-58025A/R-405-A-4 (panicle length), IR-58025A/Madhuri-11 (spikelets per panicle, filled grains per panicle and harvest index), IR-62829A/IR-72 (spikelet fertility), IR-58025A/Shyamala (100 grain weight) and IR-58025A/R-636-382 (grain yield per plant) were also considered as promising combiners.

In the present study the best cross IR-58025A/R-636-382 besides showing 56.84 per cent heterobeltiosis and 109.66 per cent relative heterosis also showed high estimates of GCA for one of the parents and SCA for the cross. So, it may be considered for future hybrid breeding programme. Besides these, there were other crosses that produced high heterosis and heterobeltiosis (Table 4.9) which may be considered as crosses having exploitable yield potential. Either of the parents involved in these crosses exhibited high GCA effects. So, in such crosses better transgressive segregants can be expected in F_2 population. It is also indicated that hybrids each giving significant positive relative heterosis and heterobeltiosis for grain yield showed the possibility of achieving economical high yield in rice hybrids. It is suggested that the higher yielding hybrids must be screened for their stability in yield over seasons prior to their multiplication and recommendation to the farmers. Similar findings were reported by Pattnaik *et al.* (1990), Nghuyen and Bui (1993) and Ganesan *et al.* (1997).

4. Screening for maintainers and restorers:

Screening potential maintainers and restorers is a basic operation in hybrid rice breeding programme. Pollen sterility is regularly examined in F_1's in this screening process after crossing CMS lines as female testers. Classfication of genotypes into restorers and maintainers for IR-58025A and IR-62829A are given in Chapter III.

a) Maintainers:

Per cent pollen sterility of F_1 hybrids was used to identify the effective maintainers in the search for maintainers. Varieties showing a very high level of pollen sterility (>90%) are selected.

The results on evaluation of 42 hybrids for average pollen sterility clearly indicated that none of the

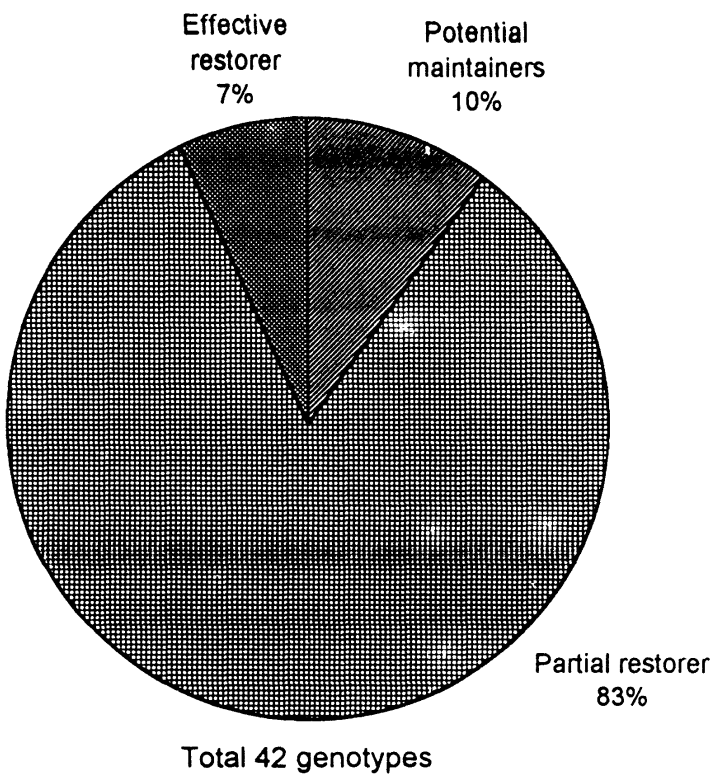

Fig. 1 : Relative frequency of maintainers and restorers among elite genotypes in Chhattisgarh region.

hybrids showed 100% pollen sterility, however, out of 42 hybrids five hybrids viz. IR-62829A/Pusa Basmati, IR-62829A/PR-106, IR-62829A/R-288-361, IR-58025A/R-635-134, IR-62829A/Shyamala had more than 90% pollen sterility, therefore, pollen parents of the above hybrids viz. Pusa Basmati, PR-106, R-288-361 and Shyamala were classified as potential maintainers for CMS line IR-62829A and R-635-134 was identified as potential maintainers for CMS line IR-58025A. It is suggested that these maintainers are being confirmed and converted into CMS lines through recurrent back cross technique for exploitation in the breeding programme. Present investigation is in accordance with studies of Rangaswamy *et al.* (1987), Sharma and Mani (1989), Prasad *et al.* (1992), Chandra *et al.* (1993) and Padmavathi *et al.* (1997).

b) Restorers:

Test varieties or lines are pollinated to CMS lines. The F_1's are examined for pollen sterility. F_1's showing low or very low level of pollen sterility (<5%) were selected as effective restorers, if the F_1 between a tester, CMS line and the tested variety exhibits a clear hybrid pollen sterility, such a variety is rejected from the potential pool of restorers. Thus, the status of hybrid sterility genes of CMS lines determines the range of restorers.

The result on evaluation of 42 hybrids for mean pollen sterility indicated the genotypes, PR-106, R-703-23-1-2, R-636-382, Rajshree, R-714-2-9, R-288-361 and MW-10 were classified as partial restorers (5-95% pollen sterility). Genotype Kranti, IR-72, R-712-16-11-1 were classified as effective restorers (<5% pollen sterility) for CMS line IR-62829A, whereas genotypes R-703-15-2-1, R-635-134, R-574-11, R-405-A-4, R-636-382 and Rajshree were classified as partial restorers (5-95% pollen sterility) for CMS line IR-58025A. It is suggested that these restorers are being confirmed and converted into CMS lines through back cross programme for exploitation in the breeding programme. All studies in this field are in accordance with Yuan (1985), Chandra *et al.* (1993), Leenakumari *et al.* (1996) and Padmavathi *et al.* (1997).

CHAPTER - VI

SUMMARY, CONCLUSION AND SUGGESTION FOR FURTHER WORK

The global requirement for rice by 2020 is expected to be around 800 million tonnes, compared with current production of 520 million tonnes, with shrinking resources particularly arable land area, irrigation water and energy, the only option left is to increase production. Increasing rice production by 300 million tonne during the next 25 years is a challenging task. Of the possible genetic approaches to meet this challenge, hybrid rice technology is an immediate option because it has been a proven technology over the past two decades in China and now has commercial prospects in India.

The present investigation entitled "Studies of combining abilities for development of new hybrids in rice (*Oryza sativa* L.)" was conducted at the research farm of Department of Plant Breeding and Genetics, Indira Gandhi Agricultural University, Raipur (M.P.) during wet season 1997 to 1998 with the following objectives :

1. To estimate genetic variability of yield and its components.
2. To estimate GCA of parents and SCA of the hybrids for yield and yield contributing characters.

3. To determine heterosis and heterobeltiosis of hyrbids.

4. To screen suitable maintainers and restorer lines for IR-58025A and IR-62829A male sterile lines.

Forty two test crosses were made involving two CMS lines (IR-58025A and IR-62829A) and twenty one restorers (Madhuri Sel-A-9, Shyamala, R-574-11,R-671, R-405-A-4, MW-10, R-712-1-6-11-1, R-636-405, R-635-134, IR-72, PR-106, Rajshree, R-288-361, R-714-2-9, Kranti, Mahamaya, R-703-15-2-1, Madhuri-11, R-703-23-1-2, R-636-382 and Pusa Basmati). All the twenty three parents, forty two hybrids and two maintainer lines (`B' lines) were raised in a randomized complete block design with two replications each of two rows consisting of ten plants. Observation were recorded on yield and its related characters on five randomly selected plants from each replication and means were used for statistical analysis. For isolation of maintainers and restorers for CMS lines pollen sterility was determined from florets in the upper third of the panicle before dehisence; pollen grains were stained with aceto-carmine.

The knowledge of the nature and magnitude of genetic variation governing the inheritance of quantitative characters is essential for genetic improvement, the estimates of genetic parameters revealed low magnitude of difference between GCV and PCV for most of the characters like spikelet fertility, pollen sterility and harvest index, days to 50 per cent flowering, plant height, productive tillers per plant, panicle length, spikelets per panicle, filled grains per panicle, 100 grain weight, grain yield per plant indicating less environmental influence on these characters. The estimates of GCV and PCV revealed that the characters, spikelets per panicle, filled grains per panicle, pollen sterility, spikelet sterility and plant height showed high to moderate GCV indicating the presence of ample variation for these character in the present material. In the present experiment high heritability (>90%) with high genetic advance as per cent of mean (>30%) was found for the characters 100 grain weight, spikelet per panicle, plant height, grain yield per plant, pollen sterility and spikelet fertility. Simple selection procedure would be effective for improvement of these characters. High heritability with low genetic advance was found in respect to days to 50 per cent flowering. These characters may be under the control of complex inheritance and are sensitive to environmental changes.

Selection of parents for hybridization assumes greater importance in heterosis breeding programme. The superiority of the parents have to be assessed based on GCA of parents and its ability to produce specific combining hybrids. A knowledge of the combining ability of parents and hybrids will facilitate appropriate choice of parents in breeding programme. Additive and non-additive gene action in the parents estimated through combining ability analysis is useful in determining the possibility for commercial exploitation of heterosis.

The ANOVA for combining ability revealed that the varianc due to lines, testers, parents, hybrid, parent vs hybrid and line x tester were significant for most of the characters indicating the presence of adequate variability in the experimental material.

The estimates of components of variance for SCA were larger in magnitude than GCA variances for all characters indicating the predominance of non-additive gene action. The ratio of GCA to SCA was less than unity for all the characters. However, variance due to lines and testers was significant for most of the characters, indicating that additive variance is also equally important in inheritance of these characters.

Based on GCA among line, IR-58025A was found to be best combiner, which recorded high positive GCA for grain yield per plant. It also had high positive GCA for panicle length, spikelet per panicle, filled grains per panicle, spikelet fertility, harvest index and pollen sterility. CMS line IR-62829A was also found to be the best combiner, which recorded high negative GCA effects for days to 50 per cent flowering and plant height. It also had positive GCA for productive tillers per plant and 100 grain weight. Even though IR-58025A registered positive GCA effects for grain yield per plant, panicle length, spikelet per panicle, filled grains per panicle, spikelet fertility, harvest index and pollen sterility, it cannot be considered best combiner because of its poor fertility restoration in F_1 as comapred to IR-62829A based F_1's. This study suggested that the hybrid between the lines x testers with good GCA for yield and its relative characters will yield high heterotic hybrids.

Based on SCA effects the five cross combination viz. IR-58025A/R-636-405, IR-58025A/R-703-15-2-1, IR-58025A/Pusa Basmati, IR-62829A /R-405-A-4 and IR-62829A /IR-72 showed significant positive SCA effects for grain yield per plant. IR-58025A /R-703-23-1-2, IR-58025A /R-288-361 and IR-62829A /R-636-382 and IR-58025A /R-288-361 and IR-58025A /Shyamala exhibited high negative SCA for reduced plant height and hybrids IR-58025A /Pusa Basmati, IR-58025A /R-703-15-2-1, IR-62829A /R-636-382, IR-62829A /Madhuri-Sel-A-9 for earliness. Whereas, IR-58025A /PR-106 has shown high SCA for spikelet fertility; IR-62829A /Madhuri-Sel-A-9 for productive tillers/plant; IR-62829A /Rajshree for panicle length; IR-62829A /Mahamaya for spikelet per panicle; IR-58025A /Shyamala for filled grains per panicle and 100 grain weight; IR-62829A /R-703-23-1-2 for harvest index and IR-62829A /PR-106 for pollen sterility. These crosses can be utilized in the breeding programme for exploitation of hybrid vigour.

The present study indicated that IR-58025A/R-636-382 is the best heterotic hybrid for grain yield per plant; IR-62829A /R-714-2-9 for productive tillers; IR-58025A /R-405-A-4 for panicle length; IR-58025A /Madhuri-11 for filled grains per panicle, IR-58025A /PR-106 for spikelet fertility and IR-58025A /R-714-2-9 for 100 grain weight. These hybrids manifested the highest significant and positive relative heterosis and heterobeltiosis. The hybrids IR-58025A /PR-106 for days to 50 per cent flowering and IR-62829A /R-635-134 for plant height recorded highest negative relative heterosis and heterobeltiosis. The heterotic hybrids for days to 50 per cent flowering and plant height were IR-58025A /PR-106 and IR-62829A /R-635-134, respectively. In the present study the best cross IR-58025A /R-636-382 besides showing high relative heterosis and heterobeltiosis for grain yield also showed high estiamtes of GCA for one of the parents and SCA for the cross. This finding indicated that both GCA and SCA are important.

Hybrid rice can only be developed if effective fertility restorers for CMS lines are identified and maintainers are isolated to develop new CMS lines. Twenty one genotypes were screened for restoration ability of two CMS lines (IR-58025A and IR-62829A). Three testers (Kranti, IR-72 and R-712-16-11-1) out of 21 were able to restore fertility of CMS line IR-62829A and four testers (Pusa Basmati, PR-106, R-288-361 and Shyamala) were identified as potential maintainers. The frequency of maintainers was high in comparison to restorers for IR-62829A.

Of the 21 genotypes test crossed with IR-58025A cytosterile, none was found to restore the fertility satisfactorily. However, one genotype was identified as potential maintainer (R-635-134).

Conclusion :

From the results obtained from the present investigation, it may be concluded that :-

1. There is presence of adequate variability in the experimental material. It is concluded that the characters like pollen sterility, productive tillers per plant, filled grains per panicle, grain yield per

plant, spikelet fertility and spikelets per panicle exhibited high estimates of GCV, heritability and genetic advance as percentage of mean.

2. Non-additive gene action predominantes for all the characters studied. The high estimates of SCA variance are more desirable in the present context, as female line used in the present investigation are all cytoplasmic male sterile lines.

3. From the study, the line IR-62829A for (earliness and reduced plant height) and the testers R-636-382 and Rajshree were selected as the most suitable parents for exploiting heterosis since, they restored fertility in F_1 which is the most important factor in hybrid rice breeding programme.

4. Among the crosses, the cross IR-58025A/R-636-405 was selected as the best cross for exploitation of hybrid vigour because it had high SCA for grain yield per plant, productive tillers per plant, panicle length, earliness and harvest index. Majority of the crosses showed significant SCA effects which involved good and poor general combiners, indicating add. x dom. type of gene interaction involved in the expression of characters. This also reflects the importance of both GCA and SCA.

5. The cross IR-58025A /R-636-382 was judged the best heterotic hybrid for grain yield as it exhibited significantly high relative heterosis, heterobeltiosis and *per se* performance.

6. The relative frequency of effective restorers, potential maintainers and partial restorers were 7, 10 and 83 per cent, respectively of the 42 genotypes screened of Chhattisgarh region.

Suggestions for further work :

1. It is suggested that the higher yielding hybrids must be screened for their stability in yield over seasons, prior to their development.

2. Characters showing high variability estimates in the present study should be utilized in future hybrid breeding programme.

3. Further evaluation of hybrids involving scented parents such as Madhuri-Sel-A-9, Madhuri-11 and Pusa Basmati should be done for quality attributes.

4. Partial maintainers and restorers identified from this study should be confirmed and converted into CMS lines through recurrent back crossing technique for exploitation in the breeding programme.

5. Crosses showing high SCA effects due to good x poor general combiners can be improved through population improvement i.e. mass selection with concurrent random mating in early segregating generations.

6. The CMS lines IR-58025A and IR-62829A should be screened with more number of genotypes to isolate complete maintainers and restorers.

STUDIES OF COMBINING ABILITIES FOR DEVELOPMENT OF NEW HYBRIDS IN RICE (*Oryza sativa* L.)

By

Mr. B.S. Sheshgiri

ABSTRACT

The investigation was laid-out at the Research Farm, Department of Plant Breeding and Genetics, Indira Gandhi Agricultural University, Raipur (M.P.). The experimental material consisted of two CMS lines viz. IR-58025A and IR-62829A and twenty one testers viz. Madhuri Sel-A-9, Shyamala, R-574-11,R-671, R-405-A-4, MW-10, R-712-1-6-11-1, R-636-405, R-635-134, IR-72, PR-106, Rajshree, R-288-361, R-714-2-9, Kranti, Mahamaya, R-703-15-2-1, Madhuri-11, R-703-23-1-2, R-636-382 and Pusa Basmati. Forty two hybrids were generated by crossing the CMS lines with testers. Forty two hybrids, twenty three parents and two maintainer ('B' lines) were raised in a randomized complete block design with two replications. The data obtained was subjected to line x tester analysis. The objectives of the investigation was to assess genetic variability of yield and its components, GCA of parents and SCA of hybrids, heterosis and heterobeltiosis for various traits and screening of maintainer and restorers.

High GCA was observed for spikelets per panicle, filled grains per panicle, pollen sterility, spikelet fertility plant height and PCV was observed for spikelets per panicle, filled grains per panicle, pollen sterility and spikelet fertility. High heritability coupled with high genetic advance was recorded for the characters 100 grain weight, spikelets per panicle, plant height, grain yield per plant, pollen sterility and spikelet fertility.

The CMS line IR-58025A was found to be the best general combiner for grain yield per plant, panicle length, spikelets per panicle, filled grains per panicle, spikelet fertility, harvest index and pollen sterility, whereas,

line IR-62829A was the best general combiner for days to 50 per cent flowering and plant height. The testers R-636-382 and Rajshree were the best general combiners for grain yield per plant, Madhuri-11 for panicle length, Shyamala for 100 grain weight, Kranti for harvest index and PR-106 for reduced plant height and days to 50 per cent flowering. The hybrid IR-58025A/R-636-405 was the best specific combiner for grain yield/plant, IR-62829A /Madhuri-Sel-A-9 for productive tillers per plant and IR-58025A /Shyamala for 100 grain weight.

The present study indicated that IR-58025A /R-636-382 is the best heterotic hybrid showing high positive relative heterosis and heterobeltiosis.

Three testers Kranti, IR-72 and R-712-16-11-1 were able to restore fertility of CMS line IR-62829A and four testers, viz. Pusa Basmati, PR-106, R-288-361 and Shyamala were identified as potential maintainers. None of the testers restored fertility of IR-58025A. However, one genotype R-635-134 was identified as potential maintainer.

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(Major Advisor)

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* *Originals not seen*