IDENTIFICATION OF STABLE MALE STERILE LINES AND BETTER COMBINERS FOR EXPLOITATION OF HYBRID VIGOUR IN RICE (*Oryza sativa* L.)

By

C. A. ROSAMMA

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 654

1998

DECLARATION

I hereby declare that this thesis entitled "**IDENTIFICATION OF STABLE MALE STERILE LINES AND BETTER COMBINERS FOR EXPLOITATION OF HYBRID VIGOUR IN RICE (*Oryza sativa* L.)**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

C. A. ROSAMMA

Vellanikkara
20-07-1998

CERTIFICATE

Certified that this thesis entitled "**IDENTIFICATION OF STABLE MALE STERILE LINES AND BETTER COMBINERS FOR EXPLOITATION OF HYBRID VIGOUR IN RICE (*Oryza sativa* L.)**" is a record of research work done independently by Ms. **C.A. ROSAMMA** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Vellanikkara

20-07-98

DR. N.K. VIJAYAKUMAR
Chairman, Advisory Committee
Associate Professor
Dept. of Plant Breeding & Genetics
College of Horticulture, KAU, Vellanikkara

CERTIFICATE

We, the undersigned members of the Advisory Committee of Ms. C.A. **ROSAMMA** a candidate for the Degree of **Doctor of Philosophy in Agriculture**, agree that this thesis entitled "**IDENTIFICATION OF STABLE MALE STERILE LINES AND BETTER COMBINERS FOR EXPLOITATION OF HYBRID VIGOUR IN RICE (*Oryza sativa* L.)**" may be submitted by **Ms. C.A ROSAMMA** in partial fulfilment of the requirement for the Degree.

DR. N.K. VIJAYAKUMAR
(Chairman, Advisory Committee)
Associate Professor
Department of Plant Breeding and Genetics
College of Horticulture
Kerala Agricultural University
Vellanikkara, Thrissur

DR. K. PUSHKARAN
(Member, Advisory Committee)
Associate Professor & Head
Dept. of Plant Breeding & Genetics
College of Horticulture
KAU, Vellanikkara

DR. ACHAMMA OOMMEN
(Member, Advisory Committee)
Associate Professor
Dept. of Plant Breeding & Genetics
College of Horticulture
KAU, Vellanikkara

DR. V.K.G. UNNITHAN
(Member, Advisory Committee)
Associate Professor
Department of Agrl. Statistics
College of Horticulture
KAU, Vellanikkara

DR. U. JAIKUMARAN
(Member, Advisory Committee)
Associate Professor & Head
Agricultural Research Station
Kerala Agrl. University, Mannuthy

EXTERNAL EXAMINER

ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude to Dr. N.K. Vijayakumar, Associate Professor, College of Horticulture, Vellanikkara and Chairman of my advisory committee for his valuable guidance, constant encouragement and sustained interest during the course of this investigation and preparation of the thesis. I am highly grateful to him for critically going through the manuscript and for his valuable suggestions for the improvement of the thesis.

I am extremely thankful to Dr. V.K.G. Unnithan, Associate Professor, Department of Agricultural Statistics and member of my advisory committee for his advice and help rendered in the statistical analysis of the data and subsequent interpretations.

I take this opportunity to express my deep sense of gratitude to my advisory committee members, Dr. K. Pushkaran, Associate Professor and Head and Dr. Achamma Oommen, Associate Professor of Department of Plant Breeding and Genetics for their valuable suggestions and critical review of the manuscript.

I gratefully acknowledge Dr. U. Jaikumaran, Associate Professor and Head, Agricultural Research Station, Mannuthy and member of my advisory committee for all the valuable help and suggestions during the course of my research and preparation of the thesis.

I am greatly thankful to Dr. V.V. Radhakrishnan, Associate Professor, Agricultural Research Station, Mannuthy for all the help and suggestions during the period of my thesis work at Mannuthy. My sincere thanks are also due to all my colleagues and friends for their constant help and encouragement during the course of research work.

I am thankful to the staff and workers of Agricultural Research Station, Mannuthy for all the help rendered during the course of my research work at the station. Members and staff of Department of Plant Breeding, College of Horticulture, Vellanikkara are gratefully acknowledged for all the help and suggestions rendered by them for the successful completion of this endeavour.

My sincere thanks are also due to Mr. R. Noel for the prompt and neat typing of the manuscript.

The grant of study leave by the Kerala Agricultural University and Senior Research Fellowship by the Centre for scientific and Industrial Research are gratefully acknowledged.

I owe a great to my husband and children who have endured many difficulties for my sake. My heart felt thanks to them for their remarkable co-operation and forbearance during the period of study.

*Above all, I bow my head before the "**THE ALMIGHTY**" who blessed me with health, strength and confidence to complete this endeavour successfully.*

C.A. ROSAMMA

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Introduction

INTRODUCTION

Rice (*Oryza sativa* L.) is the prime food crop of the world occupying an area of 146.5 million hectares with a total production of 534.7 million tonnes annually. This cater the needs of more than half of the global population. Over 85 per cent of the world's rice is grown in China, India, Japan, Pakistan and South-east Asia. In India, rice occupies an area of 42.0 million hectares with an annual production of 118.4 million tonnes , while China produces 178.3 million tonnes from 30.4 million hectares. Thus the productivity of rice in India is a stunningly low figure of 2817 kg/ha in comparison to 5869 kg per hectare in China. One of the reasons for this remarkable achievement of China in rice production has been the hybrid rice cultivation since 1976. It has been proved that hybrid rice could give more than 30 per cent yield advantage over conventional varieties.

At the present level of population growth and rice consumption, India would require 2.5 million tonnes more of milled rice annually to sustain the present level of self sufficiency (DRR, 1996). Of the major themes and strategies for increasing the yield potential of rice, breaking yield barriers and raising genetic yield ceiling through exploitation of heterosis is of utmost importance. Eventhough efforts for the development and use of this technology started two decades back and few hybrids were released recently, more refinement of the programme is warranted to completely exploit the potential of this technology.

In Kerala where rice is grown in about 4.3 lakh hectares of land, the total production is about 8.7 lakh tonnes which is sufficient to meet only 30 per cent of the requirement. Since the prospects of bringing more area under rice is very remote, increase in production should primarily come through enhanced productivity. Due to plateauing in rice yields even with use of high yielding varieties and improved management practices, modern technologies like exploitation of hybrid vigour seems to be the only possible method that can be effectively adopted to bridge the wide gap between production and demand.

The primary and foremost factor in any viable hybrid rice programme is the availability of male sterile lines, which facilitates natural hybridization and make the programme economically feasible. The methodology presently adopted world over is to exploit the cytoplasmic male sterile (CMS) system in rice and many such lines have been developed starting from the original discovery of the wild abortive (WA) cytoplasm in China as early as 1966. Male sterility in rice has, however, been reported to be highly influenced by the environment in which it is growing (Mishra and Pandey, 1993). This lack of stability in expression of male sterility is one of the serious handicaps in a successful hybrid rice programme since CMS lines which are stable for specific locations and even seasons are to be identified or developed before starting the programme in any place.

Availability of genotypes which can restore fertility and produce hybrids with the CMS lines is another prerequisite for hybrid rice programme. Restorers with high general combining ability are to be identified from the preferred varieties of the location for exploiting maximum possible hybrid vigour. Information regarding the various genetic characteristics including genetic distance among the genotypes is also important in this context to identify the most suitable genotypes that can be made use of in the hybridization programmes. The floral traits and flowering behaviour of the CMS lines as well as the restorers influence out crossing potential which is of great importance in the production of hybrid seeds. Because of these reasons, screening of the popular varieties which are acceptable to the growers of the specific area has to be carried out before taking up the programme. The current understanding of the basis of cytoplasmic male sterility and fertility restoration in rice is very limited. Information in this regard also will greatly help in a successful hybrid rice production programme.

Considering these factors, the present investigation was undertaken with the following objectives:

1) To evaluate CMS lines for sterility, floral traits and agronomic attributes.
2) To identify restorers and maintainers for WA cytosterile lines and *O. perennis* cytosterile lines.
3) To study the inheritance of fertility restoration in WA CMS lines.
4) To evaluate the genetic divergence between restorers and maintainers.
5) To study the various genetic parameters for identifying superior hybrid combinations.
6) To study cytoplasmic influence on agronomic attributes of the hybrids.

Review of Literature

REVIEW OF LITERATURE

Among the various approaches for raising the yield plateau in rice, exploitation of hybrid vigour is having the most potential. The phenomenon of heterosis has been clearly established in several agronomic, physiological and biochemical traits in rice. It is already exploited commercially in China and North Korea. In India also hybrid vigour is being exploited in rice mainly through three line method of breeding involving cytoplasmic genic male sterile (CMS) line, maintainer line and restorer line. Experiences so far indicate that in heterosis breeding programme yields can be increased by 20 to 30 per cent beyond the levels of best inbreds being cultivated, by proper selection of parents based on genetic divergence and combining ability. A knowledge of the restoration ability of different sources of CMS lines will help in developing superior hybrids. Flowering behaviour and floral characters will influence out crossing potential and seed yield in the hybrid seed production programme. A brief review of the literature relevant to the present study is given below:

2.1 Genetic divergence

The importance of genetic diversity in selecting genetically distant parents either to exploit heterosis or to get desirable recombinants has been stressed upon by many workers (Joshi and Dhawan 1966, Anand and Murty 1968). Mahalanobis's D^2 statistics (1936) has been proved as a powerful tool for measuring genetic divergence using the concept of statistical distances utilising multiple measurements.

Maurya and Singh (1977a) discriminated 43 varieties into 16 clusters for use in future breeding programmes and found that Vijaya, Sona, IR 8 and IR 24 which produced high yields but occupied different clusters appear promising for further breeding programmes.

Julfiquar *et al.* (1985) studied genetic divergence among some maintainer and restorer lines in relation to hybrid breeding in rice. One hundred elite lines including maintainers and restorers and 18 improved varieties from five countries were grouped into 13 clusters and there were no indication of relationship between geographical diversity and genetic diversity.

Sasmal (1987) estimated the genetic divergence and hybrid performance of root characters in rice. Significant heterosis was observed for all root character in crosses where the genetic distance of parents was moderate or low.

Zhang *et al.* (1987) conducted study on the application of genetic distance to the selection of Honglian type restorers on hybrid rice and results indicated higher heterosis for crosses when parents had greater genetic distance than those with smaller genetic distance. Sarathe and Perraju (1990) studied genetic divergence and hybrid performance in rice. Genetic diversity was not related with heterosis for grain yield, panicle number, panicle length, number of grains per panicle and 1000 grain weight.

Sarawgi and Shrivastava (1991) studied parental diversity and its relationship with hybrid vigour in rice. Sixteen varieties and their 72 F_1 hybrids were used in the study. Cross IR 52 x Samridhi showed high heterosis for grain yield and both parents were in the same cluster indicating that genetic diversity may not be related to high heterosis.

Peng *et al.* (1991) conducted studies on relationship between heterosis and genetic divergence in rice. The mean heterosis and hetero beltiosis were comparable for hybrids from intermediate divergence class and low divergence class, while hybrids from high divergence class showed lowest mean heterosis and few intra cluster hybrids had highest mean heterosis. Correlation coefficients between magnitude of heterosis and degree of genetic divergence was low and negative. This study did not show a relationship between heterosis and genetic divergence which could be used as a guide line for predicting heterosis in hybrid rice breeding programme.

Patnaik *et al.* (1991) reported that crosses whose parents had moderate genetic divergence showed better performance than the crosses whose parents had extreme genetic divergence. The frequency of heterotic crosses and specific combining ability (sca) effects were found to be higher in crosses between the parents in intermediate genetic divergent classes than the extreme ones.

Sixty six restorers and maintainers of CMS line V 20A were grouped into ten clusters (Pradhan *et al.* 1995). It was suggested that CMS lines developed through conversion by substitution back crossing utilising effective maintainers (for WA cytoplasm) would give high heterotic F_1 hybrids, when crossed with restorers from the clusters having intermediate to high genetic distance.

2.2 Cytoplasmic-genic male sterility in rice

Cytoplasmic-genic male sterility(CMS) is the major system used to breed rice hybrids. This system is controlled by the interaction of cytoplasmic and nuclear genes. Presence of homozygous recessive nuclear gene (s) for fertility restoration in association with sterility inducing genetic factor (s) in cytoplasm make a plant male sterile. The genetic factor (s) present in cytoplasm have been reported to be part of mitochondrial DNA (Levings and Pring 1976; Forde and Leaver 1980; Kadowaki *et al.*. 1986). In the absence of a sterility inducing genetic factor in the cytoplasm, plants become male fertile. In such a cytoplasm if fertility restoring nuclear gene (s) are recessive, the plants will maintain sterility of the male sterile plants and such plants are designated as maintainers. If fertility restoring nuclear gene (s) present in an individual with or without sterility inducing cytoplasm are dominant, the plant will restore fertility in a hybrid derived by crossing with a CMS plant and such a plant is designated as restorer. A CMS line is maintained and multiplied by hybridising it with an isonuclear maintainer line and commercial F_1 hybrids are produced by crossing with appropriate restorer.

One of the earliest reports on cytoplasmically induced male sterility in rice was that of Sampath and Mohanty (1954) and Weeraratne (1954). Later Katsuo and Mizushima (1958) also observed similar phenomenon in the progeny of the first back cross of *Oryza sativa* f. *spontanea* x *O. sativa*. The first CMS line in cultivated rice was developed by Shinjyo and Omura (1966) by substituting the nuclear genes of the ponlai variety Taichung 65 into the cytoplasm of indica variety Chnsurah Boro 11 and designated it as CMS-boro. The first CMS line used to develop commercial F_1 rice hybrids was developed in China in 1973 from a naturally occurring male sterile plant in a wild rice population of *O. sativa* f. *Spontanea* (Lin and Yuan 1980). This was designated as wild abortive (WA) type of male sterility inducing cytoplasm. Since then a number of CMS lines have been developed from various wild and cultivated rice accessions in China and other countries (Virmani and Edwards, 1983; Virmani and Wan, 1988; Pradhan *et al.*, 1990a and 1990b).

2.2.1 **Stability of male sterility**

Stability of male sterility over environments is of great importance in the use of CMS lines to develop commercial hybrids. Among the various sources of cytosterility in rice, CMS lines derived from the WA system have been found to be the most stable one for their complete pollen sterility (Lin and Yuan, 1980). A large number of CMS lines have been developed in China and elsewhere and evaluated in different agroclimatic conditions for their stability of pollen sterility. These research results are reviewed here.

Sarkar and Miah (1983) evaluated five CMS lines and their maintainers for stability for pollen sterility and other characters and found that four of them were stable for pollen sterility. Pankhari 203A was found to have incomplete pollen sterility. Bong *et al.* (1986) evaluated Chinese CMS lines V 20A and Zhen Shan 97A during wet and dry seasons and found that they had high sterility during both the seasons. They also observed a high spikelet sterility during wet season than dry season.

Virmani *et al.* (1986) studied the environmental influence on male sterility by planting a number of CMS lines during different months and studying their pollen sterility. The results indicated that certain CMS lines are stable for complete pollen sterility and remain unaffected by environmental influence, while pollen sterility of some other lines are affected by environmental influence and are unstable for that character.

Sivasubramanian *et al.* (1989) studied the performance of five CMS lines developed at IRRI along with V20 A during 1987. They observed maximum pollen sterility in IR 54753A (99.9%) and minimum in IR 54752A (90%). Pradhan *et al.* (1990c) studied the stability of pollen sterility in 22 cytoplasmic genic male sterile lines of rice derived from five cytoplasmic sources (WA, Gambiaca, TNI, Chinsurah Boro 11 and MS 577A) during wet and dry seasons of 1986 and 1987. They found that six CMS lines viz., V 20A, Zhen Shan 97A, IR 54753A, IR 54754A, IR 54757A and IR 54758A were stable for pollen sterility while IR 54752A was unstable.

Manuel *et al.* (1991) studied the pollen and spikelet sterility in 25 CMS rice lines during wet season of 1989 and found that five CMS lines (V 20A, Zhen Shan 97A, IR 4828A, IR 46830A and IR 58025A) had high levels of pollen and spikelet sterility.

Yogeesha (1991) studied the performance and stability for spikelet sterility of eight CMS lines derived from WA and MS 577A cytosterile sources along with their maintainers under four different agro-climatic zones of Karnataka during 1989 wet season and 1990 dry season. He found that V 20A, Mangala A, Pragathi A and Intan mutant A were highly stable in both the seasons while IR 54752A, Improved Sona A, Madhu A and Pushpa A were found to be unstable exhibiting 6 to 20 per cent seed set.

Pandey *et al.* (1992) evaluated 13 CMS lines for adaptability and stability for pollen sterility under the sub humid tropical conditions of western Uttar Pradesh in northern India. They identified several stable CMS lines with varying duration and plant type. They found that V 20A, IR 58025A, PMS 1A, PMS 2A, PMS 5A, PMS 8A and PMS 10A had complete pollen sterility and almost 100 per cent spikelet sterility. In contrast fertile pollen could be seen in IR 62829A, PMS 3A , PMS 4A, PMS 6A, PMS 7A and PMS 9A. Seed set percentage ranged from 8.2 to 18.5.

Mishra and Pandey (1993) evaluated eight CMS lines with WA cytoplasm during 1990 wet season. Lines IR 46829A, IR 54754A, IR 54758A and V 20A had complete pollen and spikelet sterility where as IR 54752A, IR 54753A Pragathi A and Pushpa A had fertile pollen. They identified V 20A and IR 54758A as most suitable male sterile lines for hybrid rice breeding in subhumid tropics.

2.2.2 Flowering behaviour and floral characteristics of CMS lines

Eventhough rice is a self pollinated crop, out crossing potential of the cytoplasmic-genic male sterile lines is important in hybrid seed production programmes. Extent of natural out crossing on male sterile lines of rice can be attributed to variations in flowering behaviour, floral characteristics of male sterile and pollen parents and variations in environmental factors.

Cultivated rice cultivars show very limited natural out crossing. Among wild rices *O. sativa* f. *spontanea* accessions have shown upto 50 per cent out crossing and *O. longistaminata* and *O. perennis* accessions have shown upto 100 per cent outcrossing (Sakai and Narise, 1959). In cultivated rice outcrossing upto 6.8 per cent has been observed in some varieties under certain conditions (Sahadevan and Namboodiri, 1963).

A wide range (0 - 44 per cent) of natural outcrossing has been observed on male sterile plants/lines (Stansel and Craigmiles, 1966; Athwal and Virmani, 1972; Azzini and Rutger, 1982). Oka (1988) listed out crossing rates estimated in various types of wild and cultivated rices. The Asian forms of the *O. perennis* complex or *O. rufipogon* showed a range from 7 to 56 per cent, tending to be higher in perennial than in annual types. The African annual species *O. breviligulata* appeared to have a lower rate ranging from 3 to 20 per cent. *O. sativa* showed much lower rates.

2.2.2.1 Flowering behaviour in relation to outcrossing

The flowering process in rice has been described by Rodrigo (1925). Grist (1953) stated that duration of blooming depend much on the pace of pollination. Delay or failure of pollination had been reported to prolong blooming interval in rice and wheat. Saran *et al.* (1971) reported positive correlation between duration of floret opening and percentage sterility. Virmani (1994) also reported that at IRRI, several cytoplasmic male sterile lines showing complete pollen sterility were found to bloom longer than their corresponding isogenic maintainer lines possessing normal pollen fertility. Parmar *et al.* (1979a) reported that ethrel induced male sterile plants of rice showed longer duration of blooming than the fertile plants.

CMS lines flowered earlier than their respective maintainers and there was slight reduction in flag leaf length, spikelets per panicle and panicle exsertion compared to maintainers. Extent of natural out crossing ranged from 14.9 to 26.5 per cent (Pradhan and Ratho, 1989; Chauhan *et al.*, 1991).Mallaiah *et al.* (1991) reported a second flush of flower opening in certain varieties which is of importance from the point of view of increasing out crossing.

Nishimaki *et al.* (1992) studied flowering habits of cytoplasmic male sterile lines of rice with different male sterile cytoplasm and nuclei. Delayed flowering and reduced number of bloomed florets compared to the maintainers were identified as the main drawbacks for out crossing and seed set in the male sterile lines. It was also observed that flowering habits of CMS line in rice are decided by the interaction of nuclear and cytoplasmic genes.

Siddiq *et al.* (1994) reported wide variation for flowering behaviour and floral traits in rice. Accessions that could be utilised for improving the floral traits like panicle exsertion, prolonged anthesis and additional flush of flowering, prolonged glume opening, large anther, large stigma surface and good stigma protrusion were also identified.

2.2.2.2 Floral traits influencing out crossing

The most important floral trait influencing out crossing in rice is male sterility. Extent of out crossing in a male sterile line is influenced by its floral traits Viz., stigma size and exsertion, length of style, angle and duration of spikelet opening.

Significant varietal differences have been observed in cultivated and wild rice for the different traits that influence out crossing. Oka and Morishima 1967; Virmani and Athwal, 1973; Parmar *et al.,* 1979b; Virmani *et al.*, 1980; IRRI 1983a). Huang and Huang (1978) found a negative correlation between stigma exsertion and pollen fertility. Parmar *et al.* (1979c) reported a distinct positive correlation between stigma surface and frequency of varieties with exserted stigma. However, stigma surface tended to show a negative correlation with anther size. These results indicate that improvement in floral traits of female and male parents has to be done separately to increase out crossing potential in rice in relation to hybrid rice breeding and seed production programmes.

Hoff and Torre (1981) studied stigma exsertion in rice and its effect on the seed set of male sterile plants. Stigma exsertion in 133 male sterile plants averaged 36.9 per cent (5 - 70%) and seed set 23.7 per cent (1.9-85.2%). Since seed set was significantly correlated with stigma exsertion it was suggested that seed production of suitable hybrid cv. with up to 80 per cent seed set should be possible in USA.

The influence of nine floral traits on out crossing was evaluated for 15 CMS lines grown under dry and wet seasons (Seetharamaiah *et al.*, 1994). Genotypes performed differently in the two environments. Mean values for anther length, anther breadth, anther size, stigma breadth and stigma size were highest in dry season, whereas mean values for stigma length and pollen sterility were highest in wet season. They suggested that hybrid seed production is better during dry season because more floral traits are better expressed than during wet season.

In search of ideal attributes of male and female floral characteristics that would improve cross pollination Jayamani and Rangaswamy (1995) screened fifteen wild species of rice. Species such as *Oryza grandiglumis, O. minuta* and *O. rufipogon* were found to have relatively long and broad anthers with distinct filament elongation; while species like *O. officinalis, O. punctata, O. latifolia* etc. were found to have larger stigma and longer style with stigma well protruded for longer periods. Based on the extent of usable variability available in the wild species for various floral characteristics, there is possibility of restructuring rice flower so as to facilitate increased cross pollination.

2.3 Fertility restoration in cytoplasmic genic male sterility in rice

2.3.1 Identification of restorers and maintainers

Cytoplasmic-genic male sterility system can be used to exploit heterosis in grain crops only when effective restorer lines are available.

Effective restorer lines for the CMS-WA system identified in China in 1970 were selected in 1973 (Lin and Yuan 1980). Since then hundreds of effective restorers have been identified among cultivated rice varieties and elite breeding lines in Japan (Shinjyo 1975), China (Li and Yiao, 1982), IRRI (Virmani *et al.*, 1981; IRRI 1981, 1983a,b 1984, 1986, 1988).

Results of a joint study between IRRI and China aimed at identifying effective restorer lines among elite breeding materials developed at IRRI and other national programmes indicated that about 15 and 24 per cent of these lines were effective restorers in China and at IRRI, respectively, but only 6 per cent were effective restorers at both sites. Restoration ability of remaining restorer lines was site-specific, the frequency of restorer genotypes was higher in a tropical than in a sub tropical or temperate environment (Virmani and Edwards, 1983).

Wang (1983) classified restorer genes for WA MS lines into three different types viz., strong restorer R^s, weak restorer R^w and recessive restorer gene r. Several effective maintainers and restorers were identified for wild abortive cytosterility systems (Hassan and Siddiq, 1983; Mohanty and Sarma, 1983).

Among indica rices, restorer lines have been more frequent among late maturing than early maturing rice cultivars, perhaps because late maturing indicas are primitive and relatively closer to wild rice (Yuan, 1985).

Ratho and Pande (1985) attempted to isolate a number of effective maintainers for three CMS lines viz., V 20A, Wu 10A and Pankhari 203A. No effective restorer was identified for Wu 10A and Pankhari 203A whereas effective restorers were found for V 20A. The results also indicated that cytoplasm of the male sterile lines interact differently with the pollinator varieties used. Effective restorers for WA cytoplasm were also reported by Sahai *et al.,* (1986); Singh and Sinha (1987); Saran and Mandal (1988) and Bijral *et al.* (1989).

Govindaraj and Virmani (1989) studied the progenies of crosses derived from hybridisation between six lines derived from different cytosterility sources viz., WA, BT, TN, Gambiaca, *O. rufipogon* and *O. sativa* f. *spontanea* and a number of indica, japonica and indica-japonica derivative lines developed in Korea, in order to identify effective maintainers and restorers for CMS lines derived from different sources. They found effective maintainers for all the CMS sources used, but restorers were identified only for WA and Gambiaca systems.

Forty rice cultivars were crossed as pollen parents with six CMS lines viz., V 20A, V 97A, Pankhari 203A, IR 46826A, IR 54752A and IR 54753A to identify maintainers and restorers for varying agroclimatic and biotic stresses (Tomar and Virmani, 1990). Effective maintainers and restorers were available for all the CMS lines except Pankhari 203 A. Pande *et al.* (1990) identified several restorers and maintainers for WA cytosterlity system while no restorers could be obtained for Wu 10A and Pankhari 203A. The restoration ability of the restorers identified for WA source was found to be different with different CMS lines in WA cytoplasm. Effective maintainers and restorers for WA CMS lines were reported by several workers (Sutaryo, 1989; Bharaj and Sidhu, 1991, Pradhan *et al.,* 1992, Lara *et al.*, 1992; Bijral *et al.,* 1991, 1993; Sohu *et al.,* 1993 and Jayamani *et al.,* 1994).

Prasad *et al.* (1993) identified restorers and maintainers for eight CMS lines. Restorers could not be identified for IR 54755A and Mangala A and only partial restorers could be identified for IR 46828A and MS 37A.

Restorers and maintainers for cytoplasmic male sterile lines were identified by Manuel and Rangaswamy (1993). CMS lines V 20A, IR 58025A and IR 62829A, all of which had the same wild abortive cytoplasm but different nuclear genotypes differed in maintainer and restorer frequencies. Genetic background of CMS lines influenced their maintaining and restoring abilities. Restoration/maintenance behaviour sometimes differed among pollen parents for CMS lines with the same cytoplasmic source, because of nuclear and cytoplasmic interactions between pollen parents and CMS lines or the heterozygosity of pollen parents.

Variation in the restoration ability of R lines for the same CMS source was reported by Bobby and Nadarajan (1994). Ali and Khan (1995) identified maintainers and restorers from local germplasm in Pakistan for IRRI cytoplasmic male sterile lines. Potential Basmati restorers were identified for Pusa 3A, which has Pusa Basmati I genetic back ground by Zaman *et al.* (1995). Pradhan and Jachuck (1995) identified two effective restorers (IR 21820-38-2 and Mahsuri) for the male sterile line IR 66707A with *O. perennis* cytoplasmic source. Unlike the CMS - wild abortive system, the frequency of maintainers in the CMS *O. perennis* system was very high and frequency of restorers very low.

2.3.2 Genetics of fertility restoration

Kitamura (1962) reported that high fertility in the F_1 hybrids of cytosterile line TA 820 was controlled by a recessive gene combined with modifiers or poly genes. Watanabe *et al.* (1968) reported a restorer gene for a CMS line derived from Burmes variety lead.

Kinoshita *et al.* (1980) reported that pollen fertility in the F_2 population of crosses between male sterile lines and restorers varied depending on the pollen parent and year in which study was carried out. He also pointed out the possibility of a gene or genes other than Rf1 in restoration of pollen fertility.

Tingali *et al.* (1983) found that restoration ability of restorer lines IR 24 and IR 26 was controlled by two dominant genes. Govindaraj and Siddiq (1984) reported monogenic, digenic and trigenic segregation for fertility restoration in WA cytosterile lines.

Huang *et al.* (1986) conducted research on the inheritance of fertility restorer genes for WA type CMS lines and found that fertility restoration in these lines was sporophytic and at least one single dominant gene was involved. Inheritance of fertility restoration in WA cytoplasm was studied by Virmani *et al.* (1986) in three different crosses involving restorers like IR 54, IR 9761-19-1 and IR 42. F_2 and back cross segregation data indicated that pollen fertility restoration ability of these restorers was governed by two independent and dominant genes but the mode of action of the two genes varied in three crosses. Singh and Sinha (1988) studied the genetics and fertility restoration of V20 A in crosses with restorers IR 36, IR 58, IR 60 and found that two major genes are involved.

Govindaraj and Virmani (1988) studied inheritance of fertility restoration in WA type CMS system utilising two CMS lines and five restorers. Results indicated that fertility restoration in all the restorers studied was governed by two independent and dominant genes, and one of the genes appeared to be stronger in action than the other. Allelism test involving six R lines revealed that IR 26, IR 36, IR 54 and IR 9761-19-1 possessed identical restorer genes. Test cross observations involving parental lines in the pedigree of IR 36 and IR 42 revealed that Cina, Latisail, Tadukan, TN1, TKM 6, Ptb 18 and SLO 17 are the probable original sources of R genes in the two restorer lines.

Math *et al.* (1990) studied the inheritance of fertility restoration in 10 segregating F2 families involving CMS lines Zhen Shan 97A and V 20A; and eight complete restorers and two partial restorers. Depending on the type of restorers used, the mode of inheritance was digenic or trigenic and the genes involved were found to inherit in duplicate as well as inhibitory fashion in different restorers.

Inheritance studies conducted by Pande *et al.* (1990) indicated that different CMS lines behaved differently with pollen parents. Anandakumar and Subramanian (1992) made cross combinations involving 14 male sterile lines and different maintainers and found that fertility was restored in certain combinations. Fertility restoration in F_2 segregating population was found to be governed by 3:1, 9:3:3:1 and 12:3:1 ratios due to allelic differences.

Ramalingam *et al.* (1992) reported two independent dominant genes governed fertility restoration and that these genes varied in mode of action among the crosses. Epistasis with dominant type gene interaction, epistasis with recessive gene action and epistasis with incomplete dominance were reported in different cross combinations. The difference in type of reaction was thought to be due to the influence of the female genotype or modifier genes changing the segregation pattern.

Virmani (1994) reported that fertility restoring ability varies according to the number and strength of the two dominant restorer genes and the nature of the modifier complex, which again varies with the nuclear background of CMS lines. It was also observed that penetrance and expressivity of the fertility restorer gene depend mainly on the environment and nature of CMS lines used.

Singh *et al.* (1994) studied genetics of fertility restoration of WA CMS lines in rice. Results indicated that two independent dominant genes govern seed fertility restoration ability of varieties Pankaj and Rajashree, but a single dominant gene govern restoration in Pusa 33.

Ramalingam *et al.* (1995) studied allelic relationship among fertility restoring genes in five restorers which indicated that these alleles differed among the restorers and they possessed different pairs of R genes. A suitable combination of any two of the pairs restore fertility in male sterile lines.

2.4 Heterosis, combining ability and correlation studies

2.4.1 Heterosis

The biological phenomenon in which an F_1 hybrid of two genetically dissimilar parents shows increased vigour over the parental values is referred to as heterosis. Superiority of the F_1 hybrid over the mean parental value is termed as relative heterosis, over the better parent is hetero beltiosis and that over the best commercial variety is standard heterosis. The term heterosis was coined by Shull (1908) and is usually referred to relative heterosis, but heterobeltiosis and standard heterosis are more important in plant breeding programmes.

In rice, heterosis was first reported by Jones (1926) who observed that some F_1 hybrids had more culms and higher yield than their parents. Since then several rice researchers have reported the occurrence of heterosis for yield and yield contributing characters.

Suggestions for development of F_1 hybrids in rice were made in the sixties (Stansel and Craigmiles, 1966 and Yuan, 1966). Before undertaking a hybrid breeding programme it is essential to determine the presence of sufficient heterosis in yield, so that hybrids will significantly out yield the best conventional varieties. Positive heterosis, heterobeltiosis and standard heterosis for grain yield in rice have been reported by several workers (Chang *et al.*, 1971; Davis and Rutger, 1976; Virmani *et al.* 1981; Virmani and Edwards, 1983; Sahai and Chaudhary 1991; Peng and Virmani 1991; Lokaprakash *et al.* 1992; Chauhan and Chauhan 1993; Ramalingam *et al.* 1994). The literature available on heterosis in rice has been reviewed and summarised in Table 1.

2.4.2 Combining ability

The concept of combining ability plays a significant role in crop improvement, since it helps to determine the nature of gene action involved in the expression of quantitative traits of economic importance. The average performance of a particular inbred in a series of hybrid combinations is known as its general combining ability (gca). Specific combining ability(sca) is the performance of two specific inbreds in a particular cross combination (Sprague and Tatum, 1942).

The predominant role of additive gene effects was established for all yield components except panicle number (Chang *et al.*, 1973). Several workers have found high gca effects in the parents to be associated with maximum sca effects and heterosis for yield in the resulting hybrids (Ranganathan *et al.*, 1973; Parmar, 1974;

Table 1 Extent of heterosis, heterobeltiosis and standard heterosis reported for various agronomic characterstics in rice

Character	Number of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)	References
Plant height	4	14.9 to 42.7	-	-	Namboodari (1963)
	20	-17.0 to 35.0	-37.0 to 33.0	-	Karunakaran (1968)
	6	10.8 to 10.2	-2.1 to 1.8	-	Chang *et al.* (1973)
	6	-0.4 to 28.9	-14.9 to 25.1	-	Mallick *et al.* (1978)
	15	-3.53 to 90.67	-25.77 to 82.80	-	Singh *et al.* (1980)
	3	-46.20 to 19.50	-25.77 to 82.80	-	Nijaguna and Mahadevappa (1983)
	5	12.9 to 24.3	1.1 to 10.8	-28.8 to 5.9	Reddy *et al.* (1984)
	7	-1.56 to 16.74	3.33 to 32.24	5.30 to 50.30	Paramasivan (1986)
	21	-6.05 to 32.01	-18.93 to 4.18	-30.26 to 4.18	Kalaimani and Kadambavanasundaram (1987)
	36	-4.1 to 38.64	-29.34 to 28.57	0.33 to 51.74	Nilakanta Pillai (1987)
	50	-34.75 to 48.62	-63.35 to 16.44	-15.22 to 109.19	Balan (1987)
	15	-8.50 to 14.60	-18.90 to 5.90	-46.20 to -8.90	Manuel and Palanisamy (1989)
	140	-23.20 to 28.50	-35.50 to 21.60	-36.00 to 16.10	Young and Virmani (1990a)
	32	-	-	-35.90 to -30.3	Vidyachandra (1991)

Contd....

Table 1 contd...

	7	-	-	-9.33 to 12.36	Yogeesha (1991)
	25	-	-	-40.51 to 16.35	Radhakrishna (1992)
	15	-0.49 to 27.70	-8.27 to 25.27	-14.05 to 87.5	Padmavati (1992)
	51	-21.1 to 24.3	-23.7 to 2.6	-51.8 to -17.0	Manuel (1992)
	10	-	-	-15.53 to 21.35	Patil (1993)
	42	-20.6 to 73.7	-32.4 to 61.6	-49.81 to 19.6	Uma (1994)
Days to flowering	4	0.6 to 10.1	-	-	Namboodari (1963)
	20	-17.0 to 35.5	-37.0 to 27.0	-	Karunakaran (1968)
	6	-11.2 to 9.5	-19.8 to 16.4	-	Chang *et al.* (1973)
	6	-18.5 to 3.1	-19.8 to 4.7	-	Mallick *et al.* (1978)
	15	-33.2 to 9.52	-33.22 to 2.83	-	Singh *et al.* (1980)
	45	-	-15.27 to 51.41	-30.85 to 21.43	Panwar *et al.* (1983b)
	3	-3.47 to 4.81	-9.48 to 4.69	-	Nijaguna and Mahadevappa (1983)
	132	-50.00 to 10.00	-30.00 to 7.00	-5.00 to 42.00	Amrithadevarathinam (1984)
	49	-6.23 to 29.45	-11.85 to 28.28	-	Kaushik and Sharama (1986)
	21	-22.33 to 40.85	-27.83 to 36.84	35.42 to 25.22	Kalaimani and Kadambavanasundaram (1987)

Contd...

Table 1 contd...

50	-30.2 to 41.7	-20.5 to 83.6	-68.9 to 53.09	Balan (1987)
36	2.61 to 52.82	5.84 to 54.09	-3.88 to 30.18	Nilakanta Pillai (1987)
72	-	-3.92 to 4.67	-24.7 to 2.40	Manuel and Palanisamy (1989)
140	-22.00 to 20.70	-26.4 to 9.70	-34.20 to 7.90	Young and Virmani (1990b)
32	-	-	-35.90 to 30.30	Vidyachandra (1991)
7	-	-	-5.63 to 5.64	Yogeesha (1991)
15	-13.11 to 3.30	-18.12 to -4.4	-22.26 to 9.92	Padmavati (1992)
25	-	-	-24.86 to 25.17	Radhakrishna (1992)
51	-9.8 to 26.6	-14.8 to 15.8	-32.4 to -1.6	Manuel (1992)
10	-	-	-9.09 to 19.93	Patil (1993)
42	11.32 to 18.16	-2.32 to 34.33	-32.7 to -6.4	Uma (1994)
4	9.1 to 122.8	-	-	Namboodari (1963)
11	-42.0 to 181.0	-43.0 to 182.0	-	Karunakaran (1968)
19	-	-10.0 to 32.0	-	Carnahan *et al.* (1972)
6	-18.3 to 20.3	-10.2 to -9.6	-	Chang *et al.* (1973)
15	-0.1 to 162.1	-	-	Saini *et al.* (1974)
6	-4.1 to 71.7	-	-	Saini and Kumar (1973)
12	-15.5 to 81.6	-	-	Mohanty and Mahapatra (1973)

Contd...

Table 1 contd...

45	-	-31.0 to 19.0	-	Davis and Rutger (1976)
6	5.8 to 76.9	-23.8 to 64.2	-	Mallick *et al.* (1978)
8	36.80 to 120.00	-88.90 to 100.00	-	Singh and Singh (1978)
15	-44.93 to 78.69	-55.87 to 63.08	-	Singh *et al.* (1980)
7	-	-	-22.90 to -4.90	Virmani *et al.* (1981)
73	-	-	-41.00 to -24.00	Virmani *et al.* (1982)
6	15.60 to 148.70	8.40 to 98.30	11.90 to 84.90	Paramasivan and Chellaiah (1983)
3	-18.47 to 13.13	-22.74 to 28.33	-	Nijguna and Mahadevappa (1983)
45	-	32.70 to 38.80	-0.79 to 77.30	Panwar *et al.* (1983b)
5	41.80 to 69.70	41.10 to 32.70	-10.80 to 31.10	Reddy *et al.* (1984)
32	-56.00 to 165.00	-94.00 to 150.00	-67.00 to 100.00	Amrithadevarathina, (1984)
11	-	-	0.00 to 9.00	Rao *et al.* (1985)
23	147.12 to 424.39	102.74 to 424.39	66.13 to 246.77	Paramasivan (1985)
6	-	-	-5.20 to 38.20	Govindaraj and siddiq (1986)
21	-21.27 to 62.43	28.39 to 46.39	-46.80 to 22.02	Kalaimani and Kadambayanasundaram(1987)
50	-66.96 to 23.72	76.54 to 16.58	-71.82 to 31.93	Balan (1987)
36	-43.23 to 70.75	-60.27 to 54.63	42.62 to 102.7	Nilakanta Pillai (1987)

Contd...

Table 1 contd...

	4	-5.00 to 17.00	-11.00 to 16.00	0.00 to 32.00	Kim and Rutger (1988)
	15	11.00 to 46.00	-20.70 to 43.50	-31.80 to 12.70	Manuel and Palanisamy (1989)
	183	-49.79 to 162.14	-55.45 to 134.38	-65.73 to 40.85	Vishwanath (1989)
	28	-	-40.07 to 43.68	-	Sarathe and Perraju (1990)
	146	-42.8 to 119.0	-51.5 to 100	23.8 to 119.0	Patnaik *et al.* (1991)
	32	-	-	-56.20 to 9.60	Vidyachandra (1991)
	16	-34.04 to 50.34	-42.48 to 39.76	-24.58 to 55.54	Padmavathi (1992)
	25	-	-	-26.58 to 69.40	Radhakrishna (1992)
	10	-	-	-13.88 to 18.51	Patil (1993)
	51	-31.4 to 87.7	-46.1 to 59.8	-62.1 to 59.8	Manuel (1992)
	42	-15.92 to 304.8	-28.47 to 225.5	-27.63 to 44.7	Uma (1994)
No. of grains per panicle	4	3.40 to 20.20	-	-	Namboodari (1963)
	19	-	-45.00 to 44.00	-	Carnahan *et al.* (1972)
	6	-2.30	-17.20	-	Chang *et al.* (1973)
	12	-35.50 to 43.20	-38.10 to 8.80	-	Sivasubramanian and Menon (1973b)
	6	4.60 to 77.80	-	-	Saini and Kumar (1973)
	15	4.60 to 70.00	6.00 to 19.70	-	Saini *et al.* (1974)

Contd...

Table 1 contd...

1	-8.30	-12.30	-	Paramasivan (1975)
22	-	-24.00 to 55.00	-	Davis and Rutger (1976)
15	-39.40 to 73.00	-70.40 to 43.20	-	Khaleque *et al.* (1977)
6	-34.20 to -7.30	-37.70 to -9.50	-	Mallick *et al.* (1978)
15	-37.20 to 91.78	-49.64 to 79.48	-	Singh *et al.* (1980)
45	-	-72.10 to 41.28	-72.84 to 43.41	Panwar *et al.* (1983b)
6	-	-20.50 to 16.80	-53.00 to 16.70	Reddy *et al.* (1984)
132	-56.00 to 127.00	-94.00 to 98.00	-35.00 to 160.00	Amrithadevarathinam (1984)
36	-25.16 to 24.52	-32.24 to 8.14	-37.25 to 8.14	Nilakanta Pillai (1987)
21	-16.23 to 34.72	-32.10 to 8.03	-41.98 to -4.09	Kalaimani and Kadambavanasundaram (1987)
15	60.40 to 28.50	-67.10 to 21.00	-67.10 to 20.30	Manuel and Palanisamy (1989)
9	-	-	-40.46 to 38.81	Bijral *et al.* (1989)
146	-4.1 to 35.38	-8.4 to 22.6	3.7 to 37.7	Patnaik *et al.* (1991)
	-8.00 to 75.00	-12.0 to 53.0	-11.0 to 14.0	Thendapani and Rangaswamy (1992)
	-12.7 to 22.83	-8.21 to 23.12	-	Reddy and Nerkar (1991)
6	-11.16 to 55.55	-14.23 to 31.17	-14.67 to 12.95	Padmavathy (1992)
51	-36.2 to 66.3	-51.9 to 59.9	-54.7 to 2.1	Manuel (1992)
42	-28.68 to 128.02	-54.22 to 46.94	-57.81 to 63.65	Uma (1994)

Contd....

Table 1 contd...

Spikelet sterility (Per cent)	73	-	-	3 to 17	Virmani *et al.* (1982)
	3	-25.81 to 181.97	-51.06 to 178.57	-	Nijaguna and Mahadevappa (1983)
	11	-	-	1.00 to 73.00	Rao *et al.* (1985)
	49	-12.36 to 384.39	-44.96 to 226.99	-	Kaushik and Sharma (1986)
	38	-	7.21 to 908.90	-46.90 to 238.50	Rangaswamy and Natarajamoorty (1988)
	9	-	-	-17.99 to 0.54	Bijral *et al.* (1989)
	15	-47.10 to 446.30	-45.50 to 350.50	-53.90 to 201.00	Manuel and Palaniswamy (1989)
	146	-14.5 to 6.0	-14.0 to -0.3	-18.72 to 2.2	Patnaik *et al.* (1991)
	16	-15.37 to 19.38	-19.22 to 14.27	64.34 to 164.16	Padmavati (1992)
	51	-95.0 to 14.7	-95.3 to 13.6	-95.3 to 3.7	Manuel (1992)
	42	-98.78 to 4.22	-98.86 to 0.66	-98.7 to 12.76	Uma (1994)
1000 grain weight	4	0.60 to 3.80	-	-	Namboodari (1963)
	11	-23.00 to 14.00	-26.00 to 16.00	-	Karunakaran (1968))
	19	-	-25.00 to 3.00	-	Carnahan *et al.* (1972)
	15	-15.9 to 23.70	-	-	Saini *et al.* (1974)
	107	-4.80 to 23.70	-	-	Parmar (1974)

Contd....

Table 1 contd...

22	-	-31.00 to 9.00	-	Davis and Rutger (1976)
8	-11.20 to 21.74	-24.14 to 6.50	-	Singh *et al.* (1980)
73	-	-	15.00 to 19.00	Virmani *et al.* (1982)
3	7.23 to 10.28	-9.36 to 15.15	-	Nijaguna and Madevappa (1983)
6	-12.25 to 8.95	-22.83 to 11.97	-22.54 to -1.41	Paramasivan and chellaiah (1983)
45	-	-27.41 to 9.87	-40.73 to 1.73	Parwar *et al.* (1983b)
132	-33.00 to 46.00	-39.00 to 56.00	-30.00 to 37.00	Amrithadevarathinam (1984)
5	-	-7.20 to 25.90	-20.90 to 7.20	Reddy *et al.* (1984)
23	-29.12 to 37.80	-31.57 to 26.19	-36.61 to -4.80	Paramasivan (1986)
49	-2.80 to 12.87	-35.73 to 8.01	-	Kasushik and Sharma (1986)
12	44.50 to 81.30	8.40 to 45.00	24.00 to 72.00	Sahai *et al.* (1986)
21	-11.40 to 16.51	-14.10 to 29.43	-34.01 to 6.33	Kalaimani and Kadambavanasundaram (1987)
50	-51.06 to 14.59	-58.38 to -1.57	-66.93 to 5.11	Balan (1987)
36	-21.53 to 9.14	-34.22 to 11.93	-13.83 to 18.09	Nilakanta Pillai (1987)
72	-	-11.47 to -4.30	-	Sarawgi and Shrivastava (1988)
38	-	87.27 to 11.11	-81.77 to 7.89	Rangaswamy and Natarajamoorty (1988)
9	-	-	-36.50 to 10.99	Bijral *et al.* (1989)
183	-20.87 to 38.68	-31.38 to 23.42	-27.97 to 27.23	Vishwanatha (1989)

Contd...

Table 1 contd...

	15	-38.50 to 59.20	-53.50 to 45.70	-55.80 to 6.70	Manuel and Palanisamy (1989)
	136	2.00 to 25.30	-11.20 to 15.80	-12.10 to 21.20	Patnaik *et al.* (1991)
	7	-	-	-22.00 to 6.00	Murty *et al.* (1991)
	32	-	-	-23.80 to 11.80	Vidyachandran (1991)
	7	-	-	-15.32 to 17.61	Yogeesha (1991)
	16	-11.90 to 5.34	-15.50 to 7.05	-22.03 to 5.33	Padmavati (1992)
	25	-	-	-26.28 to 51.40	Radhakrishna (1992)
	51	-12.7 to 21.8	-26 to 18.9	-32.2 to 0.3	Manuel (1992)
		-14 to 17	-28.3	-6.41	Thendapani and Rangaswamy (1992)
	10	-	-	-260.79 to 7.45	Patil (1993)
	42	-8.87 to 33.16	-18.97 to 30.28	-30.98 to -5.06	Uma (1994)
	-	-	-	-2.26 to 45.76	Ramalingam *et al.* (1995)
	-	-	-	-59.91 to 4.74	Yolanda and Vijendra Das (1996)
Grain yield	20	-72 to 161	-80 to 57	-	Karunakaran (1968)
	15	-90.7 to 156.70	-91.40 to 136.40	-	Saini *et al.* (1974)
	107	-61.60 to 157.40	-63.70 to 182.70	-	Parmar (1974)
	45	-	-41 to 67	-	Davis and Rutger (1976)
	6	1.9 to 21.90	-1 to 21.10	-	Mallick *et al.* (1978)

Contd....

Table 1 contd...

2	33.50 to 64.30	1.90 to 22	-	Singh and Singh (1978)
15	-28.95 to 69.06	-37.59 to 69.16	-	Singh *et al.* (1980)
75	-	-	0.10 to 34.40	Virmani *et al.* (1982)
105	-	-	28.88 to 35.07	Srivastava and Seshu (1982)
3	-9.97 to 44.29	-12.86 to 36.93	-	Nijaguna and Mahadevappa (1983)
45	-	-50.48 to 56.35	-36.01 to 42.44	Panwar *et al.* (1983b)
66	-	-99 to 204	-98 to 28	Ravikumar (1983)
6	0.01 to 229.41	3.20 to 147.44	-10.23 to 107.44	Paramasivan and Chellaiah (1983)
14	94.47	39.09	-	Anandakumar and Rangaswamy(1984)
132	-70 to 126	-81 to 122	-42 to 148	Amrithadevarathinam (1984)
5	-	-34.20 to 32.30	-57.90 to 34.20	Reddy *et al.* (1984)
23	-21.79 to 203.61	-69.02 to 134.42	-57.87 to 49.58	Paramasivan (1985)
7	-40.23 to 134.77	34.30 to 58.93	-69.10 to 10.77	Paramasivan (1986)
6	-	-	-47.20 to 22.40	Govindaraj and Siddiq (1986)
49	-86 to 60.36	-87.58 to 38.76	-	Kaushik and sharama (1986)
21	-0.76 to 43.51	-20.69 to 26.85	-56.60 to 2.84	Kalaimani and Kadambavanasundaram (1987)
38	-	-87.27 to 11.11	-81.77 to 7.89	Rangaswamy and Natarajamoorthy (1988)
188	-72.96 to 143.59	-75.20 to 84.23	-83.51 to 23.17	Vishwanath (1989)

Contd....

Table 1 contd...

	16	-38.50 to 59.50	-53.50 to 45.70	-53.50 to 6.70	Manuel and Palanisami (1989)
	28	-	81.18 to 73.61	-	Sarathe and Perraju (1990)
	7	-	-	7 to 77	Murthy *et al.* (1991)
	32	-	-	-86.60 to -62.10	Vidyachandra (1991)
	7	-	-	-4.19 to 45.12	Yogeesha (1991)
	16	-21.91 to 34.66	-29.70 to 26.66	-22.28 to 44.91	Padmavati (1992)
	25	-	-	-76.83 to 52.42	Radhakrishna (1992)
	6	-	-	-31.90 to 28.50	Chandra *et al.* (1993)
	10	-	-	-31.76 to 36.69	Patil (1993)
	42	-86.18 to 187.87	-91.4 to 114.16	-95.2 to 85.82	Uma (1994)
		21.24 to 69.21	13.49 to 66.24	6.36 to 65.06	Dhanakodi and Subramanian (1994)
		-	-	-54.23 to 52.79	Ramalingam *et al.* (1994)
Panicle exsertion	51	-21.4 to 6.2	-24.8 to 5.9	-24.8 to 0.0	Manuel (1992)
	42	-28.56 to 7.55	-28.56 to 0.0	-28.56 to 0.0	Uma (1994)
Leaf area index	-	16.9 to 76.5	31.6 to 53.0	-	Lang and Bui (1993)
Total dry matter accumulation	-	-25.0 to 65.0	-42.0 to 60.0	-40.0 to 58.0	Peng and Virmani (1991)
Harvest index	-	-32.0 to 98.0	-35.0 to 31.0	-36.0 to 15.0	Peng and Virmani (1991)
	-	-14.8 to 38.3	-23.3 to 30.0	-	Lang and Bui (1993)

Maurya and Singh, 1977b; Singh, 1977; Khaleque *et al.*, 1977; Rahman *et al.*, 1981). In contrast a number of inheritance studies have suggested dominant gene action for yield and/or yield components (Sivasubramanian and Menon, 1973a; Singh *et al.*, 1979, 1980; Rahman *et al.*, 1981). Some other workers reported little relationship between combining ability effects and manifestation of heterosis in the corresponding hybrids (Mohanty and Mahapatra, 1973; Parmar, 1974; Maurya and Singh, 1977; Rao *et al.*, 1980; Haque *et al.*, 1981; Rahman *et al.*, 1981).

Zhou *et al.* (1982) reported that general combining ability (gca) was more important than specific combining ability (sca) and that there were considerable differences between male sterile and restorer lines in their contributions to the characteristics of the hybrids. Each character was influenced by gca of both male sterile line and restorer and by the sca of the combination, together designated as total combining ability.

Variances in gca were significant for all the traits studied, whereas sca variances were significant only for few traits. Among the two, gca was more important than sca for most of the traits, while sca was more important for three including grain yield per plant (Shrivastava and Seshu, 1983).

Combining ability for grain characters analysed by Panwar and Paroda (1983) revealed that both additive and non additive gene effects were significant with additive effects predominating. Amritadevarathinam (1984) studied heterosis in relation to combining ability and *per se* performance and concluded that specific and general combining ability had a pronounced effect on heterosis. Sasmal and Banerjee (1986) reported that crosses with high sca generally involved high x low general combiners and had a bold grain cultivar as one parent. Koh (1987) analysed combining ability and heterosis of F_1 hybrids using cytoplasmic genic male sterile lines of rice and reported highly significant gca and sca effects for yield and yield related characters. Wang and Tang (1988) reported a close and consistent positive relationship between heterosis and combining ability implying that the heterosis of a hybrid combination could be predicted reliably by combining ability.

Manuel and Palanisamy (1989) conducted Line x Tester analysis of combing ability in rice. The ratio of gca and sca variances revealed the importance of additive gene action for days to flowering, plant height and panicles per plant. Young and Virmani (1990a) and Peng and Virmani (1991) reported high gca and sca effects for days to flowering, plant height and yield per plant. Singh and Singh (1991) studied combining ability for harvest index and other related characters in rice. Both additive and non-additive gene effects were found important for harvest index.

Banumathy and Prasad (1991) studied combining ability for development of new hybrids in rice. The sca variances were higher than gca variances for plant height, number of filled grains, percentage of spikelet sterility and grain, yield per plant indicating the prevalence of nonadditive gene action in the expression of these traits. Among the parents evaluated IR 62829A was found to be a good general combiner and cross IR 62829A x IR 50 expressed high positive significant sca effect for different characters.

Lang and Bui (1993) studied combining ability for leaf area index and reported highly significant mean squares for both gca and sca indicating the importance of both additive and nonadditive gene actions.

2.4.3 Association of characters

Yield being a complex character, is dependent on a number of components. A knowledge of association between yield and yield components will serve to make simultaneous selection for more characters.

Jun (1985) studied inheritance of grain size and shape in rice. Genotypic correlations showed that grain length was positively correlated with grain weight and L/W ratio, grain width was negatively correlated with L/W ratio and positively correlated with thickness and grain thickness was positively correlated with grain weight. Reuben and Kisanga (1989) reported that panicles per m^2, mature grains per panicle, panicle weight and panicle length directly influenced grain yield in a study conducted in upland rice.

Bapu and Soundarapandyan (1992) studied genotypic association and path analysis in F_3 generation of rice crosses and reported that number of productive tillers, panicle length and plant height were positively correlated with grain yield. Mirza *et al.* (1992) suggested panicle length, number of grains per panicle and number of panicles per plant to be used as selection criteria after studying correlation and path analysis in six crosses and their parents.

Correlation studies in 37 genotypes of upland rice indicated that grain yield per plant was positively and significantly correlated with straw yield per plant and filled grains per panicle. Path analysis revealed filled grains per panicle as the most important yield contributing character (Mahajan *et al.,* 1993). Yadav *et al.*, (1995) reported number of panicle bearing tillers having greatest direct effect on yield followed by 1000 seed weight.

Correlation and path analysis in hybrid rice was done by Manuel and Rangaswamy (1993). Among the different characters studied dry matter production exerted maximum direct positive effect on grain yield per plant and it also indirectly nullified negative direct effects of plant height and panicles per plant on grain yield.

Chaubey and Singh (1994) evaluated twenty rice varieties for eight yield related traits. Heritability was highest for total number of spikelets. The greatest direct positive effect on grain yield was recorded for number of ear bearing tillers followed by plant height and 1000 grain weight. Results indicated the importance of ear bearing tillers as a selection criterion for rice hybridisation programmes.

Geetha *et al.* (1994) studied six hybrids for grain characters such as number of panicles, grains per panicle, length and breadth of grains, 100 grain weight and grain yield. The increased yield in hybrids was due to higher number of grains per panicle, which only had strong positive association with grain yield.

According to Chaubey and Richharia (1993) panicle weight made the highest contribution to grain yield. The most important trait affecting grain weight per plant was number of well filled grains per panicle (Yuan *et al.*, 1995). Sawant (1995) reported highest positive direct effect of productive tillers per plant on grain yield followed by filled grains per panicle.

Rajeswari and Nadarajan (1995) conducted path analysis studies in the rice cross Zhen Shan 97A/IR50. Plant height, days to 50 per cent flowering, panicle length and grains per panicle had direct effects on yield. But panicle exertion, productive tillers per plant and 1000 grain weight showed negative effects on yield.

Correlation among nine quantitative traits in 66 diverse genotypes of rice revealed that grain yield was positively and significantly correlated with weight of panicle, number of fertile grains per panicle and 1000 grain weight. Path analysis indicated moderately high direct effect of grains per panicle but the indirect effect via. weight of panicle was quite high (Dash *et al.*, 1996).

2.5 Influence of sterile cytoplasm on agronomic attributes

In hybrid breeding programme based on cytoplasmic male sterility, the effect of sterility inducing cytoplasm on agronomic traits is of considerable importance. In maize, reciprocal differences for yield, maturity and other agronomic traits have been related to the cytoplasmic differences (Kalsy and Sharma, 1972). Bhat and Dhawan (1969) and Kalsy and Sharma (1972) reported large cytoplasm x environment interactions. Hunter and Ganble (1968) found consistent cytoplasmic differences in early maize hybrids evaluated over years and locations.

Effects of sterile cytoplasm (viz., WA, Gam, HL, BT) in rice have been studied in China (Lin and Yuan, 1980; Yang *et al.*, 1980). These results also indicated that sterile cytoplasm reduced the productive capacity of hybrids compared with normal cytoplasms of the maintainers.

Murayama *et al.* (1985) reported reciprocal differences in hybrids. Maternal influence was seen for grain weight and plant height. Wild abortive male sterile cytoplasmic effect on main agronomic characteristics in hybrid rice under different conditions were studied by Lin and Wu (1990). Favourable or unfavourable conditions (nutrient levels, planting densities, solar radiation, temperature etc.) would affect the extent and direction of cytoplasmic effects on grain yield and its components. Because of different nucleo cytoplasmic components in hybrid combinations, their reaction to the environment differed.

Young and Virmani (1990a) reported highly significant reciprocal effects (A/R Vs R/B) for days to flowering, plant height and grain yield. Both positive and negative cytoplasmic effects were observed for the three traits. Heterosis for all the three traits were affected by cytoplasm. However, manifestation of cytoplasmic effects was higher for heterosis for days to flower than the other two characters. Results also implied that cytoplasmic effects were the result of interaction between the cytoplasm and the nuclear genome and it is modified by different environments.

Male sterile cytoplasm exerted negative effects on single plant yield and the chief agronomic characters in the F_1, but significant differences were noted between cytoplasms (Cai, 1995). He has suggested that breeding restorer lines with strong combining ability is important for the development of superior hybrid combinations.

Skikh (1995) reported that the effect of male sterile cytoplasm depend on the recombinant genotype and the trait studied. The cytoplasm affected the correlation between traits in the hybrids relative to the parents. Both WA and Gam male sterile cytoplasms appeared suitable for heterosis breeding but judicious selection of appropriate genotype/cytoplasm combinations are necessary to ensure required heterotic effect for grain yield.

Chunhai and Jun (1995) conducted analysis of seed, cytoplasmic and maternal genetic effects on rice quality traits. Milling quality traits were controlled by seed, cytoplasmic and maternal genetic effects. Cytoplasmic effects accounted for 4.1 to 37.3 per cent of the total genetic variation and were significant for all milling quality traits.

Wenming and Hongcan (1995) identified new cytoplasmic male sterile line with lower negative effects of cytoplasm on some quantitative traits in rice. A new CMS line CMS-K developed in China had a significant positive effect on spikelets per panicle and significant negative effect on seed set percentage. For the other traits, the effects were not significant.

Material and Methods

MATERIALS AND METHODS

The present investigation was conducted at the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara during the period 1994-1998. Field experiments relating to the investigation were laid out at Agricultural Research Station, Mannuthy, which is located at an altitude of 15 m above mean sea level, and is situated between 10°32"N latitude and 76°10"E longitude. The soil type is laterite loam with pH around 5.6. The weather parameters during the period of study are presented in Appendix 1.

Details of the different experiments carried out during the present investigation are given below:

Ten cytoplasmic-gneic male sterile (CMS) lines derived from two cyto sterile sources viz., WA and *Oryza perennis* along with their maintainers and 34 rice genotypes comprising of local strains, high yielding varieties and elite breeding lines formed the material for the study.

3.1 Evaluation of CMS lines

Cytoplasmic-genic male sterile (CMS) lines were evaluated for male sterility characters, morphological attributes, flowering behaviour and floral traits which influence out crossing.

3.1.1 Details of the experiment

Ten CMS lines (both exotic and indigenous) and their isogenic maintainer lines formed the material for this experiment. The genotypes studied and their origin are presented in Table 2. All the CMS lines and their maintainers were evaluated during four seasons, viz., *kharif* and *rabi* seasons of 1995 and 1996. These lines were grown in the field in RCBD with four replications in plots of 4.0 m x 0.6 m with 20 x 15 cm spacing. Before anthesis, the CMS lines were isolated from other adjacent rice fields to prevent out crossing by erecting cloth barriers.

3.1.2 **Observations recorded**

The following observations were recorded from 10 randomly selected plants in each replication and the mean worked out.

1. Pollen sterility

Pollen sterility counts were taken from five randomly selected spikelets of each panicle. The pollen grains were squeezed out from well matured anthers and stained with 2 per cent Iodine-potassium iodide stain and examined under microscope. Round well filled and deeply stained pollen grains were considered as fertile (Plate 1) and unstained or poorly stained and shrivelled pollen grains were counted as sterile (Plate 2). Four microscopic fields were counted for each spikelet and pollen sterility was expressed in percentage.

2. *Spikelet sterility*

Three panicles each, from all the ten plants were bagged at the time of anthesis for selfing. At maturity, seed set was examined by taking the actual count of seeds obtained, and its percentage to the total number of spikelets present in the panicle was calculated.

Table 2 Details of CMS lines used in the study

Sl. No.	CMS lines	Source	Origin
1	IR 58025A	WA	IRRI
2	IR 62829A	WA	"
3	IR 67684A	WA	"
4	IR 68886A	WA	"
5	IR 68890A	WA	"
6	IR 68891A	WA	"
7	PMS 3A	WA	India
8	PMS 10A	WA	"
9	V 20A	WA	China
10	IR 66707A	*O. perennis*	IRRI

3. *Plant height*

Plant height was measured on main culm or tallest tiller from base to the tip of the panicle excluding awn if any, and expressed in cm.

4. *Days to flowering*

The total number of days taken for 50 per cent of the plants to reach flowering from the date of sowing.

5. *Panicle length*

Length of the panicle from the base of first rachis to the tip of the panicle excluding awn if any, was measured from main panicle in each plant, averaged and expressed in cm.

6. *Number of spikelets per panicle*

Total number of spikelets were counted in five panicles selected at random from each plant and averaged.

7. *Panicle exsertion*

Length of the exposed part of the panicle from flag leaf junction to panicle tip was measured and expressed as percentage of exsertion to the total panicle length.

8. *Stigma exsertion*

The percentage of exserted stigma was determined from a sample of bloomed spikelets selected from five panicles in a plant. Percentage of spikelets with exserted stigma to the total number of bloomed spikelets was calculated.

9. *Blooming duration*

Time interval between opening of the first floret in a panicle in a day and closing of the last floret calculated for five panicle and averaged and expressed in minutes.

10. *Number of opened florets per panicle*

Total number of florets opened in a panicle counted from 1st day of blooming till last day of blooming in three panicles of each of the ten plants selected at random.

3.1.3 Statistical analysis

The data obtained from ten CMS lines and their maintainers were subjected to analysis of variance following Panse and Sukatme (1964). For finding out stability in performance of each genotype over seasons, biological concept of stability as explained by Lin *et al.* (1986) in which a genotype is considered to be stable if its among environment variance is small, was adopted. Four seasons were compared for each genotype separately using analysis of variance to assess its stability.

Floral traits of CMS lines and their maintainers were compared based on mean values adopting student's t test.

3.2 Evaluation of source germplasm

Source germplasm consisting of 44 genotypes were evaluated for various agronomic, morphologic and physiologic attributes during *kharif* season of 1995 with a view to find out genetic diversity between genotypes. All the 44 genotypes were planted in Randomised Complete Block Design with three replications in plots of size $5 m^2$(Plate 3). The spacing adopted was 20 x 10 cm. Particulars of the genotypes included in the study are furnished in Table 3.

3.2.1 Observations recorded

Observations on the following characters were recorded from ten plants in each replication and used for estimating D^2.

Table 3 Details of source germplasm evaluated and used for classification into maintainers and restorers for WA and *O. perennis* cytosterile sources

Genotype	Parentage	Source
A. Varieties/cultures		
1. Annapoorna	T(N) 1 / Ptb 10	India
2. Hraswa	IR 8 / T 140	"
3. Jyothi	Ptb 10 / IR 8	"
4. Matta Triveni	Re-Selection from Triveni	"
5. Kairali	IR 36 / Jyothi	"
6. Kanchana	IR 36 / Pavizham	"
7. Jayathi	Triveni / IR 2061	"
8. Bhagya	Thadukan / Jaya	"
9. Onam	Kochuvithu / T(N)1	"
10. Aruna	Jaya / Ptb 33	"
11. Makom	ARC 6650 / Jaya	"
12. IR 36	IR 2042 / CR 94-13	IRRI
13. IR 8	Peta/DGWG	"
14. Jaya	T(N)1 x T141	India
15. Pavizham	IR 8 / Karivennel	"
16. Aathira	BR51-46-1 / KAU23332-2	"
17. Aiswarya	Jyothi / BR51-46-1	"
18. Remya	Jaya / Ptb 33	"
19. Kanakom	IR 1561 / Ptb 33	"
20. Ponmani	Pankaj / Jagannath	"
21. Ptb 1	Pure line selection from Aryan	"
22. Ptb 9	Pure line selection from Thavalakkannan	"

Contd.....

Table 3 contd....

23. Ptb 10	Pure line selection from Thekkancheera	India
24. KAU 10-1-1	[Ptb 10/T(N)1] / T(N)1	"
25. Mahsuri	T 65 / Myang Ebos 6080/2	Malaysia
26. Bharathi	Ptb 10 / IR 8	"
27. Suvarnamodan	Pureline selection from ARC 11775	"
28. Swarnaprabha	Bhavani / Triveni	"
29. M 42-6-3	MO6 / Pokkali 372	"
30. M 45-20-1	Cul.12814 / MO 6	"
31. M 38-4-2	MO4 / Cul.25331	"
32. M 48-11-3	Thonnuran / IR 8	"
33. M 38-4-1	MO4 / Cul 25331	"
34. M 42-6-2	MO6 / Pokkali 372	"

B. Maintainers of selected CMS lines

1. IR 58025B	IRRI
2. IR 62829B	"
3. IR 67684B	"
4. IR 68886B	"
5. IR 68890B	"
6. IR 68891B	IRRI
7. PMS 3B	India
8. PMS 10B	"
9. V 20B	China
10. IR 66707B	IRRI

1. *Plant height*

Plant height was recorded in 3.1.2.

2. *Total number of tillers per plant*

Total number of tillers in each plant was counted at maturity

3. *Number of panicles per plant*

The total number of panicles in each plant was counted at maturity.

4. *Days to flowering*

Number of days from sowing to panicle emergence in 50 per cent of the population was recorded.

5. *Total duration*

Number of days taken from sowing to maturity of each genotype.

6. *Grain yield per plant*

Weight of grains obtained from each plant was taken after drying and was expressed in grams.

7. *Grain yield per m²*

Grains harvested from each plot was dried and weighed and weight expressed in grams per m^2.

8. *Straw yield per m²*

Straw from each plot was weighed after harvest. A portion of it oven dried and weight per plot was converted to oven dry weight and expressed in grams per m^2.

9. *Straw yield per plant*

Plants were uprooted and oven dry weight of straw (excluding root and panicles) was taken and expressed in grams per plant.

10. *Total dry matter*

For estimating total dry matter accumulation of the plant, the entire plant was pulled out at harvesting stage and the plants were dried in 80°C for 24 hours. Total weight was recorded and expressed in grams per plant.

11. *Harvest index*

Harvest index was calculated based on economic yield (grain) in relation to the biological yield as follows:

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

12. *Panicle length*

Length of the panicle from base to the tip of the panicle excluding awn if any was measured from the main panicle of each plant and expressed in cm.

13. *Number of filled spikelets per panicle*

Number of filled spikelets were counted in three panicles selected at random from each plant and averaged.

14. *Spikelet sterility*

Filled and unfilled grains were observed in three randomly selected panicles from each plant and the percentage of spikelet sterility was worked out as:

$$\frac{\text{Number of unfilled spikelets}}{\text{Total number of spikelets}} \times 100$$

15. *100 seed weight*

Weight of one hundred well filled grains was recorded from three random samples in each replication and expressed in grams.

16. *Grain length*

Length of ten randomly selected grains were measured from seed lot of each replication using a seed micrometer and expressed in mm.

17. *Grain breadth*

The width of ten randomly selected grains were measured from seed lot of each replication using a seed micrometer and expressed in mm.

18. *Grain thickness*

Thickness of ten randomly selected grains were measured from seed lot of each replication using a seed micrometer and expressed in mm.

19. *Grain density*

Volume of 100 g of seed was measured by water displacement method and expressed as g/100 ml.

20. *Panicle weight*

Weight of three panicles from a plant was taken, averaged and expressed in grams.

21. *Panicle exsertion*

Percentage exsertion of the panicle was measured as described in 3.1.2.

22. *Flag leaf area*

Area of the flag leaf was calculated by measuring length and maximum width of the flag leaf and using the formula:

Leaf area = K . l . b

where,

K = 0.67, the constant used at maturity stage (IRRI, 1972)

l = length of flag leaf

b = maximum width of flag leaf

23. *Leaf area index*

The length and maximum width of all the leaves of the middle tiller was measured and the corresponding area was calculated for each leaf using the formula, leaf area = K.l.b.

where,

K = 0.75; l and b are the length and maximum width of individual leaf.

Area of all the leaves of this tiller was added to get leaf area of the tiller.

Total leaf area of the plant was calculated by multiplying leaf area of the middle tiller by number of tillers per plant and leaf area index calculated using the formula (Bhan and Pande, 1966).

$$LAI = \frac{\text{Sum of leaf area of six hills } (cm^2)}{\text{Area of land covered by six hills } (cm^2)}$$

3.2.2 Statistical analysis

The data in respect of 23 biometric traits collected from all the 44 genotypes were utilised for finding genetic distance between these genotypes. Clustering of the genotypes was done by iterative algorithm suggested by Suresh and Unnithan (1996).

3.3 Classification of genotypes into maintainers and restorers for different CMS lines

Ten cytoplasmic male sterile lines and 44 rice genotypes were utilised for classifying the genotypes into maintainers and restorers. The study involved source nursery and test cross nursery.

3.3.1 Source nursery

The CMS lines and test varieties were grown in the source nursery during *rabi* 1995 for hybridisation. staggered planting of the CMS lines were done to improve synchronisation of flowering. The CMS lines were planted in twin rows and pollen parents in single rows at a spacing of 20 x 15 cm.

All the plants in the CMS lines were tested for pollen sterility and pollen shedders were removed. Panicles of CMS lines were bagged prior to anthesis. Pollen from male parents were collected at the time of anthesis and dusted separately on the bagged panicles. More than 400 cross combinations were attempted. Mature seeds from each cross were collected, labelled, sun dried and stored separately.

3.3.1.2 Test cross nursery

All the F1 seeds collected from various cross combinations were grown in the field during *kharif* '96, in single rows alternated by the male parents. Before anthesis, three panicles of each F1 plant in each cross were bagged so as to avoid contamination of foreign pollen. Pollen fertility and spikelet fertility with respect to each cross was recorded from bagged panicles and test entries were classified into effective maintainers (pollen fertility <1%); partial/weak maintainers pollen fertility 1-20%); partial restorers (pollen fertility 21-80%) and effective restorers (pollen fertility 81-100%). Reciprocal hybrids of the fertile combinations were produced by hybridisation between restorer as female parent and maintainer as male parent.

3.4 Evaluation of hybrids derived from CMS lines and reciprocal cross combinations

Fertile hybrids identified from the test cross nursery were grown in the retest cross nursery for evaluating heterosis, gca and sca. A total of 24 reciprocal hybrids of the fertile combinations were also included in the study for comparison with A/R hybrids. Material for the study consisted of 58 different sets of hybrids (34 A/R hybrids + 24 reciprocal hybrids) along with their parents and check varieties. These different sets of hybrids were evaluated during *rabi* 1996. Details of the hybrid combinations evaluated are presented in Table 4.

Ten plants each of 25 hybrids and parents along with 4-5 plants of the remaining nine fertile hybrids were planted for evaluating heterosis, combining ability etc. Five plants each of the reciprocal hybrids were also planted for comparing with the direct hybrids. Twenty five day old seedlings were transplanted at the rate of one seedling per hill with a spacing of 20 x 15 cm^2. Recommended package of practices and need based plant protection measures were adopted. Harvesting was done when the crop attained physiological maturity.

3.4.1 Observations recorded

Observations were taken from all the plants on the following characters from sowing to maturity as described in 3.2.1.

Table 4 Fertile hybrids and reciprocals evaluated for heterosis, combining ability and other genetic parameters

A. Direct hybrids

1. IR 58025A / IR 8	18. IR 68891A / Matta Triveni
2. IR 58025A / Jaya	19. IR 68891A / Kanchana
3. IR 58025A / Aiswarya	20. IR 68891A / IR 36
4. IR 62829A / Annapoorna	21. IR 68891A / Aiswarya
5. IR 62829A / Matta Triveni	22. IR 68891A / IR 8
6. IR 62829A / Kanchana	23. IR 68891A / Jaya
7. IR 62829A / IR 36	24. PMS 10A / Annapoorna
8. IR 62829A / Aiswarya	25. PMS 10A / Matta Triveni
9. IR 62829A / Kairali	26. PMS 10A / Kanchana
10. IR 62829A / Aathira	27. PMS 10A / IR 36
11. IR 68890A / Annapoorna	28. PMS 10A / Aiswarya
12. IR 68890A / Matta Triveni	29. PMS 10A / Aruna
13. IR 68890A / Kanchana	30. PMS 10A / Ptb 9
14. IR 68890A / IR 36	31. PMS 10A / Ptb 10
15. IR 68890A / Aiswarya	32. PMS 3A / Jaya
16. IR 68890A / Ptb 10	33. PMS 3A / Aiswarya
17. IR 68891A / Annapoorna	34. IR 67684A / Kanchana

B. Reciprocal hybrids

1. IR 8 / IR 58025B	13. IR 36 / IR 68890B
2. Jaya / IR 58025B	14. Ptb 10 / IR 68890B
3. Aiswarya / IR 58025B	15. Annapoorna / IR 68891B
4. Matta Triveni / IR 62829B	16. IR 36 / IR 68891B
5. Kairali / IR 62829B	17. IR 8 / IR 68891B
6. Kanchana / IR 62829B	18. Jaya / IR 68891B
7. Aathira / IR 62829B	19. Jaya / PMS3B
8. Aiswarya / IR 62829B	20. Aiswarya / PMS 3B
9. Kanchana / IR 67684B	21. Aruna / PMS 10B
10. Annapoorna / IR 68890B	22. IR 36 / PMS 10B
11. Kanchana / IR 68890B	23. Aiswarya / PMS 10B
12. Aiswarya / IR 68890B	24. Ptb 10 / PMS 10B

1. Plant height (cm)
2. Total number of tillers per plant
3. Number of panicles per plant
4. Days to flowering
5. Total duration (days)
6. Grain yield per plant (g)
7. Straw yield per plant (g)
8. Dry matter production (g)
9. Harvest index
10. Panicle length (cm)
11. Panicle weight (g)
12. Panicle exertion (%)
13. Number of filled grains per panicle
14. Spikelet sterility (%)
15. 100 seed weight (g)
16. Grain length (mm)
17. L/B ratio of the grain
18. Grain breadth (mm)
19. Grain thickness (mm)
20. Volume weight (g/100 ml)
21. Flag leaf area (cm^2)
22. Leaf area index

3.4.2 Statistical analysis

All the characters were analysed statistically and tested for significance (Panse and Sukatme, 1964).

3.4.2.1 Combining ability analysis

Analysis of combining ability (gca and sca) was carried out (Kempthorne, 1957). Mean squares due to different sources of variation and their genetic expectations were estimated as indicated in the following ANOVA Table.

Source	df	Mean square	Expected mean square
Replication	(r-1)		
Hybrids	(lt-1)	-	
Lines	(l-1)	M_1	Ems+r [(Cov.(F.S)-2 Cov.(H.S)]+rt[Cov.(H.S.)]
Testers	(t-1)	M_2	Ems+r [(Cov.(F.S)-2 Cov.(H.S)]+rl[Cov.(H.S.)]
Lines x Testers	(l-1) (t-1)	M_3	Ems+r [Cov.(F.S)-2 Cov.(H.S)]
Error	(r-1) (lt-1)	M_4	Ems
Total	(rlt-1)		

Where,

r = number of replications

l = number of lines

t = number of testers

Estimates of covariance of full sibs and half sibs were made by equating genetic expectations to their mean squares as follows:

$$\text{Cov. (F.S)} = \frac{M_1+M_2+M_3-3M_4+6r\text{Cov.(H.S)}-r(l+t)\text{Cov.(H.S.)}}{3r}$$

$$\text{Cov. (H.S)} = \frac{M_1 + M_2 - 2M_3}{r\ (l+t)}$$

From the covariance of full sibs and half sibs, variances due to general combining ability (σ^2 gca) and specific combining ability (σ^2gca) were calculated as follows:

$$\sigma^2\text{gca} = \text{Cov. H.S. and}$$

$$\sigma^2\text{sca} = \text{Cov. F.S. - 2 Cov. H.S.}$$

Proportional contribution by lines, testers and their interaction to total variance was calculated as per Singh and Chaudhary (1985).

$$\text{Contribution of lines} = \frac{ss(l) \times 100}{ss\ (crosses)}$$

$$\text{Contribution of testers} = \frac{ss\ (t) \times 100}{ss\ (crosses)}$$

$$\text{Contribution of hybrids} = \frac{ss\ (l \times t) \times 100}{ss\ (crosses)}$$

where l and t are lines and testers.

3.4.2.2 Estimation of gca and sca effects

The gca and sca effects of parents and hybrids were estimated based on the following model.

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

$$i = 1,2 \ldots l$$
$$j = 1,2 \ldots t$$
$$k = 1,2 \ldots r$$

where,

X_{ijk} = Value of the ijkth observation,

μ = Population mean

g_i = gca effect of the ith line,

g_j = gca effect of the jth tester,

s_{ij} = sca effect of the ijth hybrid

e_{ijk} = error effect associated with ijkth observation,

l = number of lines

t = number of testers

r = number of replications

The effects of gca and sca were obtained from the two way table of lines vs. testers, in which each figure was a total over replications.

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

$$g_i = \frac{xi\ldots}{rt} - \frac{x\ldots}{rlt}$$

$$g_j = \frac{x.j.}{rl} - \frac{x\ldots}{rlt}$$

$$s_{ij} = \frac{xij.}{r} - \frac{xi..}{rt} - \frac{x.j.}{rl} + \frac{x\ldots}{rlt}$$

where,

$x...$ = total of all hybrid combinations

$xi..$ = total of i^{th} line over t testers and r replications,

$x.j.$ = total of j^{th} tester over l lines and r replications,

$xij.$ = total of the hybrid between i^{th} line and j^{th} tester over r replications

The standard errors pertaining to gca and sca effects were calculated from the square root of variance effects as given below:

i) Standard error of the gca effects of lines is given by

$$SE\ (g_i) = \left[\frac{EMS}{rt}\right]^{1/2}$$

ii) Standard error of the difference between gca effects of two lines is given by

$$SE\ (g_i - g_j) = \left[\frac{2EMS}{rt}\right]^{1/2}$$

iii) Standard error of the gca effect of testers is given by

$$SE\ (g_i) = \left[\frac{EMS}{rl}\right]^{1/2}$$

iv) Standard error of the difference between gca effects of two testers is given by

$$SE\ (g_i - g_j) = \left[\frac{2EMS}{rl}\right]^{1/2}$$

v) Standard error of any sca effect of a cross is given by

$$SE(S_{ij}) = \left[\frac{EMS}{r}\right]^{1/2}$$

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

$$SE(s_{ij}-s_{kl}) = \left[\frac{2EMS}{r}\right]^{1/2}$$

3.4.2.3 Heterosis

Heterosis was worked out by utilizing the overall mean of each hybrid for each trait. The values of isogenic maintainer (B) lines were used as values for female parent. Relative heterosis was estimated as per cent deviation of the F1 from its mid-parent values. Heterobeltiosis was estimated as the per cent increase or decrease of F1 value over better parent value. Similarly, standard heterosis for each character was expressed as per cent increase or decrease of F1 value over the standard variety. The heterosis was estimated as follows:

i) Relative heterosis (heterosis over the mid-parent value)

$$di = \frac{F_1 - MP}{MP} \times 100$$

ii) Heterobeltiosis (heterosis over the better parent value)

$$dii = \frac{F_1 - BP}{BP} \times 100$$

iii) Standard heterosis (heterosis over the standard variety)

$$diii = \frac{F_1 - SV}{SV} \times 100$$

where,

F_1 is the average performance of hybrid,

MP is the arithmetic mean of two parents involved in each cross

BP is the average performance of better parent

SV is the average performance of standard variety

The standard variety used in the study was Kanchana(Ptb 50)

The expression of heterosis was tested using the respective CD values.

Test of significance

Test of significance for different estimates of heterosis was carried out by adopting the following formulae.

a) For comparing Heterobeltiosis and standard Heterosis:

$$SE = \left[\frac{2ems}{r}\right]^{1/2}$$ when hybrids and parents have equal number of replications

$$SE = \left[ems\left(\frac{1}{r_1} + \frac{1}{r_2}\right)\right]^{1/2}$$ when hybrids and parents have unequal number of replication

b) For comparing relative heterosis

$$SE = \left[\frac{3/2\ ems}{r}\right]^{1/2}$$ when hybrids and parents have equal number of replications

$$SE = \left[ems \left(\frac{1}{r_1} + \frac{1}{2r} \right) \right]^{1/2}$$ when hybrids and parents have unequal number of replications

ems - error mean square

r_1 - replication for hybrid

r_2 - replication for parents

3.4.2.4 Estimation of correlation co-efficients

The estimates of inter component correlations (r) were calculated by Goulden's (1959) method.

3.4.2.5 Student's `t' test

Student's t test was conducted to compare the performance of hybrids derived from cytoplasmic male sterile lines (AxR) and their reciprocal crosses (RxB).

3.5 Inheritance of fertility restoration in WA cytoplasmic male sterile lines

F2 population of eight fertile cross combinations were evaluated during summer 1996. Number of plants in each F2 population varied from 100-200 single plants and were planted at 20 x 15 cm spacing. The F3 population of two partially fertile and two fully fertile cross combinations were studied during *kharif*, 1997. Number of plants in F3 population varied from 100-200 in each cross and were planted at 20 x 15 cm spacing.

3.5.1 Observation recorded

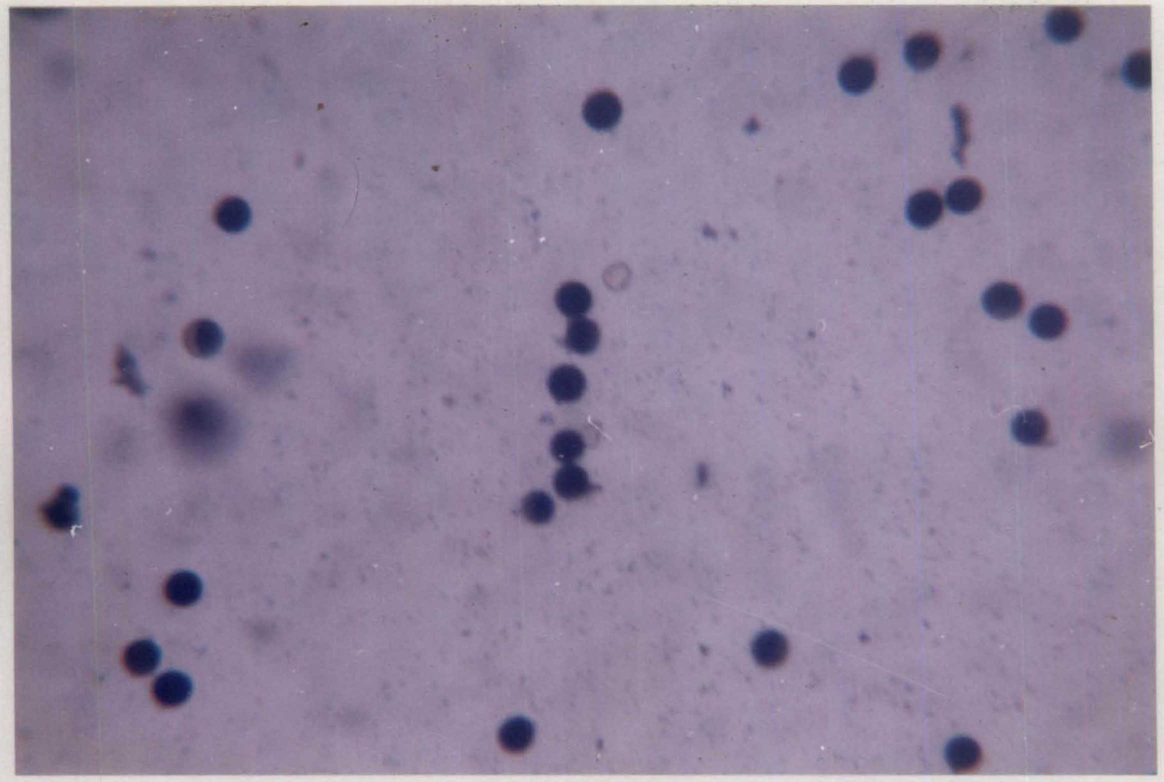
Pollen and spikelet sterility of each plant was monitored from three bagged panicles as described in 3.1.2.

3.5.2 Statistical analysis

Frequency distribution of plants in different fertility classes were found and analysed for studying inheritance of fertility restoration.

Plate 1 Fertile pollen grains of maintainer lines

Plate 2 Sterile pollen grains of CMS lines



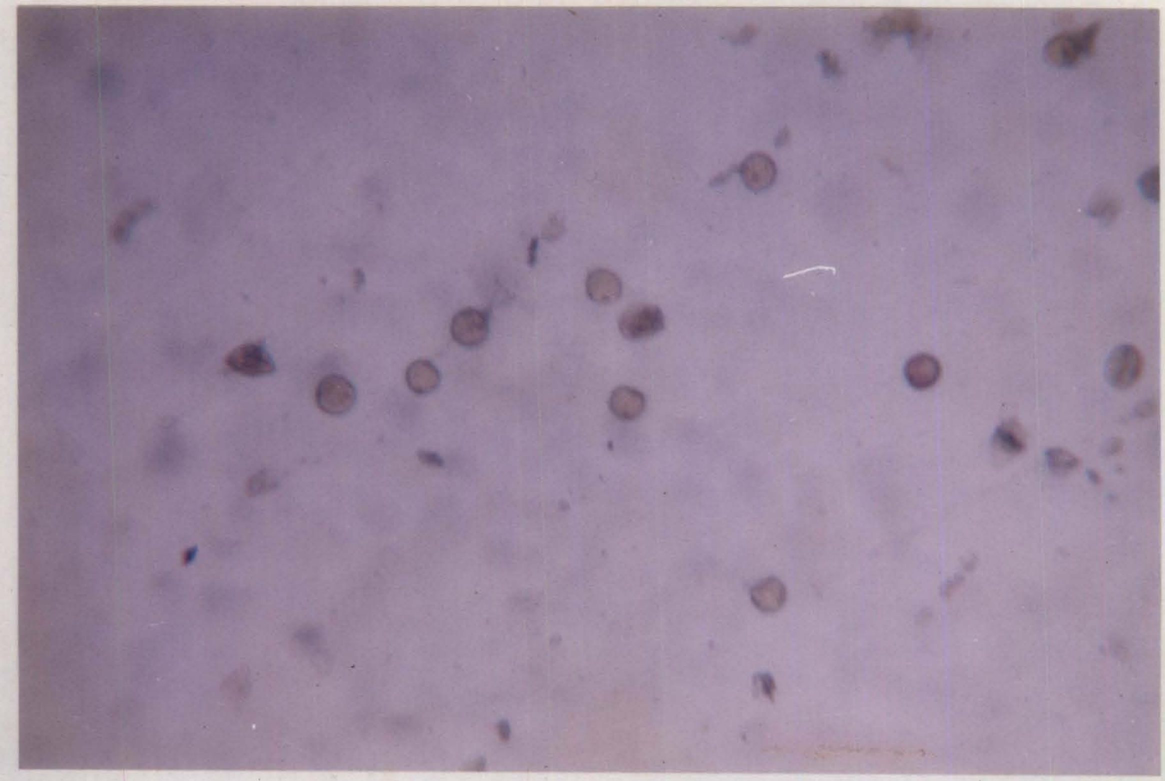


Plate 3 Field view of the source germplasm


SOURCE NURSERY FOR
HYBRID RICE PROGRAMME
No. of entries - 30
Spacing - 20x15cm Plot size - 4.5m²
Sown on - 18.6.96 Planted on - 15.7.96

Results

RESULTS

The results obtained from various experiments conducted in the study are presented in this chapter.

4.1 Evaluation of cytoplasmic - genic male sterile lines

Ten CMS lines and their isogenic maintainers were analysed for stability in male sterility characters, agronomic attributes and floral traits.

4.1.1 Stability in male sterility and agronomic attributes

The data on pollen and spikelet sterility along with other agronomic attributes recorded from ten CMS lines during four seasons were analysed to find out differences among genotypes. Highly significant differences were observed among genotypes during all the four seasons for all the characters under study. Analysis over seasons for each variety separately, taking seasons as treatments revealed that some varieties performed uniformly during all the seasons, while certain other varieties exhibited variation between seasons.

4.1.1.1 Pollen sterility

Among the ten CMS lines tested, IR 66707A with *O. perennis* cytoplasmic source recorded 100 per cent pollen sterility during all the seasons. Among the CMS lines with WA cytoplasmic source IR 58025A, IR 62829A, IR 68890A, IR 68891A and PMS 10A recorded high pollen sterility of more than 99.5 per cent during all the four seasons. IR 68886A and V 20A exhibited significantly low pollen sterility compared to other CMS lines. All the CMS lines except IR 68886A and V 20A were on par for pollen sterility behaviour during all the four seasons (Table 5).

Analysis of CMS lines for stability over four seasons revealed that all genotypes except IR 68886A, PMS 3A and V 20A had no significant differences between seasons for pollen sterility behaviour indicating stable performance of these varieties for pollen sterility. IR 68886A and V 20A exhibited significant difference between seasons. IR 68886A recorded high pollen sterility during *kharif* season whereas V 20A recorded the same during *rabi* season. Coefficient of variation was also high for these two varieties (5.16% and 5.96%).

4.1.1.2 Spikelet sterility

CMS lines IR 68890A and IR 66707A recorded 100 per cent spikelet sterility during all the four seasons under study. All the other CMS lines except IR 68886A and V 20A recorded above 99 per cent mean spikelet sterility and were on par with fully sterile CMS lines. IR 68886A and V 20A recorded significantly lower values (96.1% and 92.6%) of mean spikelet sterility.

Analysis over seasons indicated no significant difference between seasons for IR 58025A, IR 62829A, IR 67684A, IR 68890A, IR 68891A, PMS 10A and IR 66707A. All these CMS lines exhibited high spikelet sterility behaviour during *rabi* season. IR 68886A, PMS 3A and V 20A exhibited significant difference between seasons with high level of sterility during *rabi* seasons (Table 6).

Table 5 Pollen sterility behaviour of 10 CMS lines during four seasons

CMS lines	Mean pollen sterility (%)						Overall mean	CD for comparison between seasons		CV (%)
	Kharif			*Rabi*						
	95-96	96-97	Mean	95-96	96-97	Mean		0.05	0.01	
IR 58025A	99.41[a]	99.79[a]	99.60[a]	99.05[a]	99.53[a]	99.29[a]	99.44[a]	NS	NS	0.52
IR 62829A	99.82[a]	99.78[a]	99.80[a]	99.37[a]	99.74[a]	99.56[a]	99.68[a]	NS	NS	0.38
IR 67684A	98.39[a]	98.86[a]	98.63[a]	98.08[a]	99.23[a]	98.65[a]	98.64[a]	NS	NS	1.35
IR 68886A	94.59[b]	94.13[b]	94.37[b]	90.19[b]	90.65[b]	90.42[b]	92.39[b]	2.95	3.88	5.16
IR 68890A	99.94[a]	99.94[a]	99.94[a]	99.78[a]	99.92[a]	99.86[a]	99.90[a]	NS	NS	0.19
IR 68891A	99.85[a]	99.86[a]	99.86[a]	99.54[a]	99.83[a]	99.68[a]	99.77[a]	NS	NS	0.34
PMS 3A	98.50[a]	99.44[a]	98.97[a]	98.02[a]	98.48[a]	98.25[a]	98.61[a]	0.94	1.26	1.54
PMS 10A	99.75[a]	99.73[a]	99.74[a]	98.95[a]	99.78[a]	99.37[a]	99.55[a]	NS	NS	0.47
V 20	86.21[c]	88.42[c]	87.20[c]	97.48[a]	97.98[a]	97.74[a]	92.47[b]	3.31	3.35	5.96
IR 66707A	100.0[a]	100.0[a]	100.0[a]	100.0[a]	100.0[a]	100.0[a]	100.0[a]	NS	NS	0.00

Genotypes with same alphabets do not differ significantly

Table 6 Spikelet sterility behaviour of 10 CMS lines during four seasons

CMS lines	Mean spikelt sterility (%)						Overall mean	CD for comparison between seasons		CV (%)
	Kharif			*Rabi*						
	95-96	96-97	Mean	95-96	96-97	Mean		0.05	0.01	
IR 58025A	99.83^{a}	99.87^{a}	99.85^{a}	99.96^{a}	99.87^{a}	99.92^{a}	99.88^{4}	NS	NS	0.28
IR 62829A	99.92^{a}	99.90^{a}	99.91^{a}	99.97^{a}	99.88^{a}	99.93^{a}	99.92^{a}	NS	NS	0.21
IR 67684A	98.71^{a}	99.37^{a}	99.04^{a}	99.91^{a}	99.73^{a}	99.82^{a}	99.43^{a}	NS	NS	1.17
IR 68886A	94.78^{b}	95.36^{b}	95.07^{b}	98.76^{b}	95.58^{b}	97.17^{b}	96.12^{b}	2.13	2.80	3.58
IR 68890A	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	NS	NS	0.00
IR 68891A	99.90^{a}	99.86^{a}	99.88^{a}	100.0^{a}	100.0^{a}	100.0^{a}	99.94^{a}	NS	NS	0.18
PMS 3A	98.39^{a}	99.45^{a}	98.92^{a}	99.78^{a}	99.85^{a}	99.81^{a}	99.37^{a}	0.89	1.18	1.45
PMS 10A	99.90^{a}	99.97^{a}	99.94^{a}	99.81^{a}	99.87^{a}	99.84^{a}	99.89^{a}	NS	NS	0.26
V 20A	84.94^{c}	88.42^{c}	86.68^{c}	98.84^{b}	98.20^{b}	98.52^{b}	92.60^{c}	5.12	6.74	5.64
IR 66707A	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	100.0^{a}	NS	NS	0.00

Genotypes with same alphabets do not differ significantly

4.1.1.3 Plant height

There was significant difference between genotypes tested for plant height with overall mean ranging from 60.2 cm (V 20A) to 96.2 cm (IR 68890A). Analysis of stability of genotypes between seasons indicated significant difference between seasons for all genotypes. Comparison of mean performance during *kharif* and *rabi* seasons revealed higher values for plant height during *kharif* season for all the genotypes studied (Table 7).

4.1.1.4 Days to flowering

Mean performance of 10 CMS lines during four seasons for days to flowering are presented in Table 8. In CMS lines, the range was from 65.3 days (V 20A) to 92.3 days (IR 68890A). Analysis for stability over seasons indicated non-significant difference for IR 67684A, IR 68890A and V 20A. All the other genotypes exhibited significant difference in duration between seasons. A reduction in duration during *rabi* season was expressed by all genotypes.

4.1.1.5 Panicle length

There was significant difference between genotypes for panicle length and their mean values ranged from 18.32 cm (V 20A) to 25.15 cm (PMS 3A). PMS 3A and PMS 10A were on par and they were significantly superior to other varieties (Table 9). Out of the 10 CMS lines tested, six were stable over environments exhibiting non-significant difference between seasons. IR 68886A, IR 68890A, PMS 10A and V 20A showed significant difference between seasons.

Table 7 Mean performance of 10 CMS lines during four seasons for plant height

CMS lines	Plant height (cm)						Overall mean	CD for comparison between seasons		CV (%)
	Kharif			*Rabi*						
	95-96	96-97	Mean	95-96	96-97	Mean		0.05	0.01	
IR 58025A	75.02[f]	74.41[g]	74.72[e]	69.70[g]	71.70[dg]	70.7[de]	72.71[e]	2.61	3.44	4.15
IR 62829A	73.31[g]	71.13[h]	71.72[f]	68.0[h]	67.25[h]	67.62[e]	69.67[f]	2.21	2.91	3.44
IR 67684A	79.02[e]	79.13[f]	79.07[d]	76.45[d]	78.05[e]	77.25[cd]	78.16[d]	1.51	1.99	3.12
IR 68886A	80.15[e]	79.98[f]	80.07[d]	75.05[e]	75.75[f]	75.40[cde]	77.73[d]	2.94	3.87	8.70
IR 68890A	99.77[a]	100.02[a]	99.89[a]	89.75[a]	95.10[a]	92.43[a]	96.16[a]	3.01	3.97	3.20
IR 68891A	85.24[d]	85.48[d]	85.36[c]	81.00[c]	80.35[cd]	80.67[bc]	83.02[c]	2.73	3.59	4.03
PMS 3A	79.09[e]	82.80[e]	80.94[d]	74.40[ef]	79.45[d]	76.93[cd]	78.93[d]	3.09	4.05	4.29
PMS 10A	87.95[c]	87.95[c]	87.95[c]	73.25[f]	81.10[c]	77.18[cd]	82.56[c]	3.33	4.40	4.55
V 20A	61.23[h]	61.62[i]	61.43[g]	59.65[i]	58.35[i]	59.00[f]	60.21[g]	2.03	2.67	5.43
IR 66707A	91.84[b]	95.30[b]	93.57[b]	83.90[b]	90.45[b]	87.18[ab]	90.37[b]	4.30	5.66	4.43

Genotypes with same alphabets do not differ significantly

Table 8 Mean performance of 10 CMS lines during four seasons for days to flowering

CMS lines	Days to flowering						Overall mean	CD for comparison between seasons		CV (%)
	Kharif			*Rabi*				0.05	0.01	
	95-96	96-97	Mean	95-96	96-97	Mean				
IR 58025A	83.20^{bc}	85.80^{c}	84.50^{b}	74.2^{d}	76.55^{d}	75.38^{d}	79.94^{e}	1.337	1.754	1.82
IR 62829A	81.60^{cd}	81.55^{d}	81.58^{c}	76.4^{d}	78.30^{d}	77.35^{d}	79.46^{e}	1.36	1.79	1.99
IR 67684A	92.75^{a}	92.50^{a}	92.63^{a}	92.15^{a}	91.10^{ab}	91.63^{a}	92.13^{a}	NS	NS	1.78
IR 68886A	79.0^{d}	80.40^{d}	79.70^{c}	74.45^{d}	75.50^{d}	74.98^{d}	77.34^{f}	1.08	1.53	1.84
IR 68890A	92.40^{a}	92.25^{a}	92.33^{a}	91.60^{a}	92.75^{a}	92.18^{a}	92.25^{a}	NS	NS	2.84
IR 68891A	79.35^{d}	80.20^{d}	79.78^{c}	75.00^{d}	75.25^{d}	75.13^{d}	77.45^{f}	1.09	1.43	1.47
PMS 3A	89.45^{a}	90.30^{b}	89.88^{a}	87.35^{b}	87.25^{bc}	87.30^{b}	88.59^{c}	1.17	1.49	1.44
PMS 10A	91.5^{a}	93.30^{a}	92.40^{a}	90.70^{a}	90.70^{ab}	90.70^{a}	91.6^{b}	1.31	1.71	1.35
V 20A	66.80^{e}	64.80^{e}	65.80^{d}	65.00^{e}	64.60^{e}	64.80^{e}	65.30^{g}	NS	NS	4.63
IR 66707A	85.95^{b}	86.75^{c}	86.35^{b}	82.95^{c}	85.35^{c}	84.15^{c}	85.25^{d}	1.28	1.68	1.82

Genotypes with same alphabets do not differ significantly

Table 9 Mean performance of 10 CMS lines during four seasons for panicle length

CMS lines	Panicle length (cm)						Overall mean	CD for comparison between seasons		CV (%)
	Kharif			*Rabi*						
	95-96	96-97	Mean	95-96	96-97	Mean		0.05	0.01	
IR 58025A	24.33^{abc}	24.28^{cd}	24.31^{abcd}	23.40^{a}	24.15^{ab}	23.78^{ab}	24.04^{b}	NS	NS	5.00
IR 62829A	22.87^{c}	22.93^{e}	22.90^{d}	21.60^{b}	22.87^{c}	22.23^{cd}	22.56^{d}	NS	NS	8.21
IR 67684A	23.02^{bc}	22.93^{e}	22.97^{cd}	23.15^{a}	22.92^{c}	23.04^{bc}	23.00^{cd}	NS	NS	5.64
IR 68886A	23.31^{bc}	24.07^{d}	23.69^{bcd}	23.35^{a}	21.26^{d}	22.31^{cd}	23.00^{cd}	1.05	1.39	5.98
IR 68890A	24.92^{ab}	25.05^{bc}	24.98^{ab}	23.79^{a}	24.36^{ab}	24.08^{ab}	24.53^{ab}	0.96	1.26	4.39
IR 68891A	21.03^{d}	21.63^{f}	21.33^{e}	21.46^{b}	21.32^{d}	21.39^{d}	21.36^{e}	NS	NS	6.00
PMS 3A	24.76^{abc}	26.39^{a}	25.58^{bcd}	24.21^{a}	25.24^{a}	24.73^{a}	25.15^{a}	NS	NS	12.22
PMS 10A	25.67^{a}	25.71^{ab}	25.69^{a}	24.17^{a}	24.38^{ab}	24.28^{ab}	24.98^{a}	1.03	1.36	4.05
V 20A	17.76^{e}	19.74^{g}	18.75^{f}	17.85^{c}	17.95^{e}	17.90^{e}	18.32^{f}	1.30	1.72	7.77
IR 66707A	24.42^{abc}	24.28^{cd}	24.35^{abc}	23.22^{a}	23.48^{bc}	23.35^{bc}	23.85^{bc}	NS	NS	4.09

Genotypes with same alphabets do not differ significantly

4.1.2 Evaluation of flowering behaviour and floral traits

Ten CMS lines and their isogenic maintainers were evaluated for their floral characteristics during *kharif* and *rabi* seasons.

4.1.2.1 Panicle exsertion

Data presented in Table 10 indicated significant difference between genotypes for panicle exsertion. All the CMS lines exhibited low degree of panicle exsertion than their corresponding maintainer lines. IR 68890A had the highest level of panicle exsertion (79.14%) followed by IR 62829A. The lowest panicle exsertion per cent was recorded in IR 68886A (53.25). All the maintainer lines exhibited panicle exsertion above 88 per cent. The highest level of exsertion being shown by IR 66707B (102.89%) followed by IR 68890B (101.61%).

4.1.2.2 Stigma exsertion

Percentage of florets with exserted stigma was found to vary widely between male sterile lines and maintainers (Table 11). In CMS lines mean values ranged, between 38.46 per cent (V 20A) and 48.75 per cent (IR 66707A). In maintainer lines which are isogenic to CMS lines, variation for the character was from 1.33 per cent (IR 58025B) to 5.30 per cent (IR 68891B). In all CMS lines, stigma exsertion was higher during *rabi* season, whereas in the maintainer lines only IR 62829B, IR 68886B, IR 68890B, PMS 3B, PMS 10B and V 20B expressed higher values during *rabi* season.

Table 10 Mean performance of 10 CMS lines and their maintainers during *kharif* and *rabi* seasons for panicle exsertion

Sl. No.	Genotypes	Panicle exsertion (%)		
		Kharif	*Rabi*	Mean
1	IR 58025A	64.67^{hijia}	62.50^{fg}	63.58^{d}
2	IR 58025B	93.67^{d}	83.95^{c}	88.81^{b}
3	IR 62829A	78.97^{e}	76.84^{cd}	77.91^{c}
4	IR 62829B	99.00^{bcd}	91.75^{b}	95.37^{ab}
5	IR 67684A	62.13^{ej}	59.40^{gh}	60.76^{de}
6	IR 67684B	103.00^{ab}	97.4^{ab}	100.20^{a}
7	IR 68886A	52.79^{k}	53.72^{h}	53.25^{e}
8	IR 68886B	96.37^{cd}	91.78^{b}	94.07^{ab}
9	IR 68890A	77.00^{ef}	81.27^{c}	79.14^{c}
10	IR 68890B	103.57^{ab}	99.90^{a}	101.61^{a}
11	IR 68891A	59.06^{j}	62.96^{fg}	61.01^{de}
12	IR 68891B	103.45^{ab}	97.20^{ab}	100.33^{a}
13	PMS 3A	72.53^{fg}	68.05^{ef}	70.29^{cd}
14	PMS 3B	101.63^{abc}	96.85^{ab}	99.24^{a}
15	PMS 10A	69.45^{gh}	70.75^{dc}	70.10^{cd}
16	PMS 10B	103.25^{ab}	97.23^{ab}	100.24^{a}
17	V 20A	66.67^{ghi}	55.67^{gh}	60.99^{de}
18	V 20B	95.05^{d}	94.85^{ab}	94.95^{ab}
19	IR 66707A	69.06^{gh}	70.91^{dc}	69.98^{cd}
20	IR 66707B	105.27^{a}	100.50^{a}	102.89^{a}

Genotypes with same alphabets do not differ significantly

Table 11 Mean performance of 10 CMS lines and their maintainers during *kharif* and *rabi* seasons for stigma exsertion

Sl. No.	Genotypes	Stigma exsertion (%)		
		Kharif	*Rabi*	Mean
1	IR 58025A	43.38^{ab}	43.63^{b}	43.50^{ab}
2	IR 58025B	1.463^{d}	1.200^{d}	1.33^{c}
3	IR 62829A	34.38^{b}	45.38^{b}	39.87^{b}
4	IR 62829B	3.15^{c}	3.85^{c}	3.50^{c}
5	IR 67684A	46.62^{a}	47.25^{a}	46.94^{a}
6	IR 67684B	4.02^{c}	2.88^{d}	3.45^{c}
7	IR 68886A	41.63^{ab}	46.63^{a}	44.13^{ab}
8	IR 68886B	3.20^{c}	4.15^{c}	3.68^{c}
9	IR 68890A	47.38^{a}	48.50^{a}	47.94^{a}
10	IR 68890B	2.75^{d}	3.40^{c}	3.07^{c}
11	IR 68891A	44.88^{a}	47.88^{a}	46.38^{a}
12	IR 68891B	6.23^{c}	4.38^{c}	5.30^{c}
13	PMS 3A	44.63^{a}	48.63^{a}	46.63^{a}
14	PMS 3B	4.70^{c}	5.33^{c}	5.01^{c}
15	PMS 10A	43.50^{ab}	47.50^{a}	45.50^{a}
16	PMS 10B	3.45^{c}	4.90^{c}	4.18^{c}
17	V 20A	33.80^{b}	43.13^{b}	38.46^{b}
18	V 20B	1.00^{d}	2.78^{d}	1.88^{c}
19	IR 66707A	48.87^{a}	48.63^{a}	48.75^{a}
20	IR 66707B	6.68^{c}	2.95^{d}	4.81^{c}

Genotypes with same alphabets do not differ significantly

4.1.2.3 Blooming duration

The time interval between opening and closing of florets varied highly between CMS lines (87 to 189 minutes). In the maintainer lines blooming duration was much lower and it varied from 34 to 68 minutes. All the CMS lines exhibited higher duration of blooming than the corresponding maintainer lines. Male sterile line PMS 10A had highest duration of blooming and among the maintainer lines highest blooming duration was shown by PMS 10B (Table 12). All the CMS lines exhibited higher duration of blooming during *rabi* season. Among the maintainer lines such a trend was not seen and different maintainer lines behaved differently between seasons.

4.1.2.4 Frequency of floret opening and number of opened florets

Flowering behaviour in CMS lines and their maintainers are presented in Fig. 1 and 2. In CMS lines IR 58025A, IR 62829A, IR 68891A and IR 66707A the peak period of floret opening was between 10 AM and 11 AM and there was synchronisation in floret opening between maintainers and CMS lines(Fig.1). In PMS 3 A and PMS 10 A anthesis took place after 12 noon and the corresponding B lines bloomed between 10 and 11 AM. In all the B lines anthesis started by 10 AM or earlier irrespective of the flower opening in A lines.

Frequency of floret opening in blooming phase from first to last day of anthesis is presented in Fig.2, which revealed a clear difference in the pattern of anthesis in male sterile and maintainer lines. In CMS lines anthesis was for a short period of 3 to 4 days and in maintainer lines it prolonged upto 7 or 8 days. There was significant difference in the number of florets opened on one day as well as total

Table 12 Mean performance of 10 CMS line and their maintainers during *kharif* and *rabi* seasons for blooming duration

Sl. No.	Genotypes	Blooming duration (minutes)		
		Kharif	*Rabi*	Mean
1	IR 58025A	109.25^{c}	118.25^{c}	113.75^{c}
2	IR 58025B	32.50^{h}	35.00^{h}	33.75^{h}
3	IR 62829A	80.25^{d}	93.75^{d}	87.00^{de}
4	IR 62829B	36.25^{gh}	41.25^{gh}	38.75^{h}
5	IR 67684A	219.25^{b}	239.65^{b}	229.45^{b}
6	IR 67684B	36.25^{gh}	60.00^{f}	48.13^{fgh}
7	IR 68886A	114.25^{c}	119.25^{c}	116.75^{c}
8	IR 68886B	43.75^{fgh}	38.75^{h}	41.25^{h}
9	IR 68890A	220.25^{b}	243.00^{b}	231.63^{b}
10	IR 68890B	52.50^{f}	48.75^{g}	50.63^{fgh}
11	IR 68891A	87.75^{d}	94.00^{d}	90.88^{d}
12	IR 68891B	48.75^{fg}	41.25^{h}	45.00^{gh}
13	PMS 3A	276.90^{a}	295.25^{a}	286.07^{a}
14	PMS 3B	67.50^{e}	66.25^{ef}	66.88^{efg}
15	PMS 10A	283.50^{a}	294.25^{a}	288.88^{a}
16	PMS 10B	66.25^{e}	68.75^{e}	67.50^{ef}
17	V 20A	112.00^{c}	113.50^{c}	113.00^{c}
18	V 20B	42.50^{fgh}	38.75^{h}	40.63^{h}
19	IR 66707A	114.00^{c}	119.75^{c}	116.88^{c}
20	IR 66707B	46.25^{fg}	40.00^{h}	43.13^{h}

Genotypes with same alphabets do not differ significantly

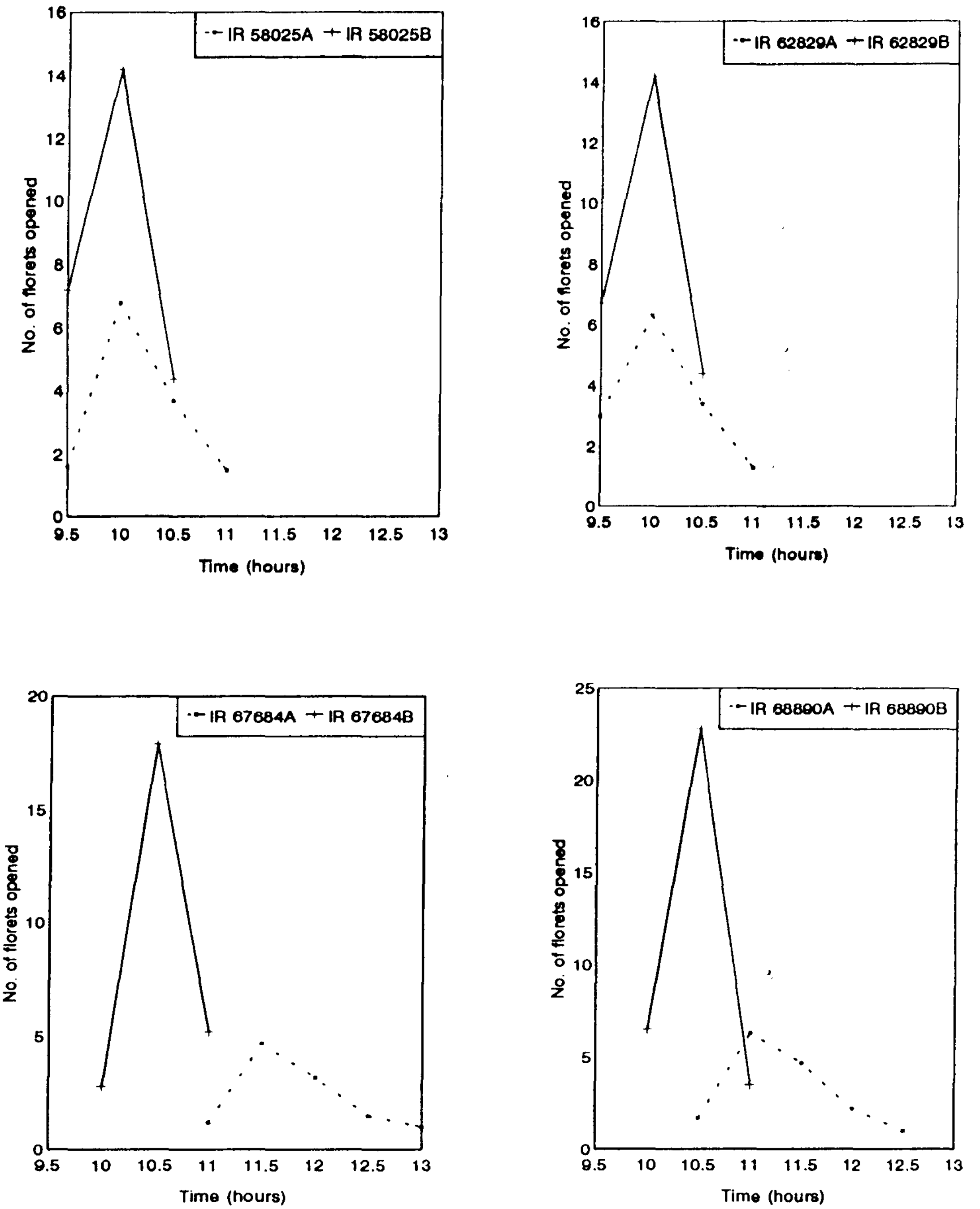


Fig.1a Frequency of floret opening in different CMS lines and their maintainers

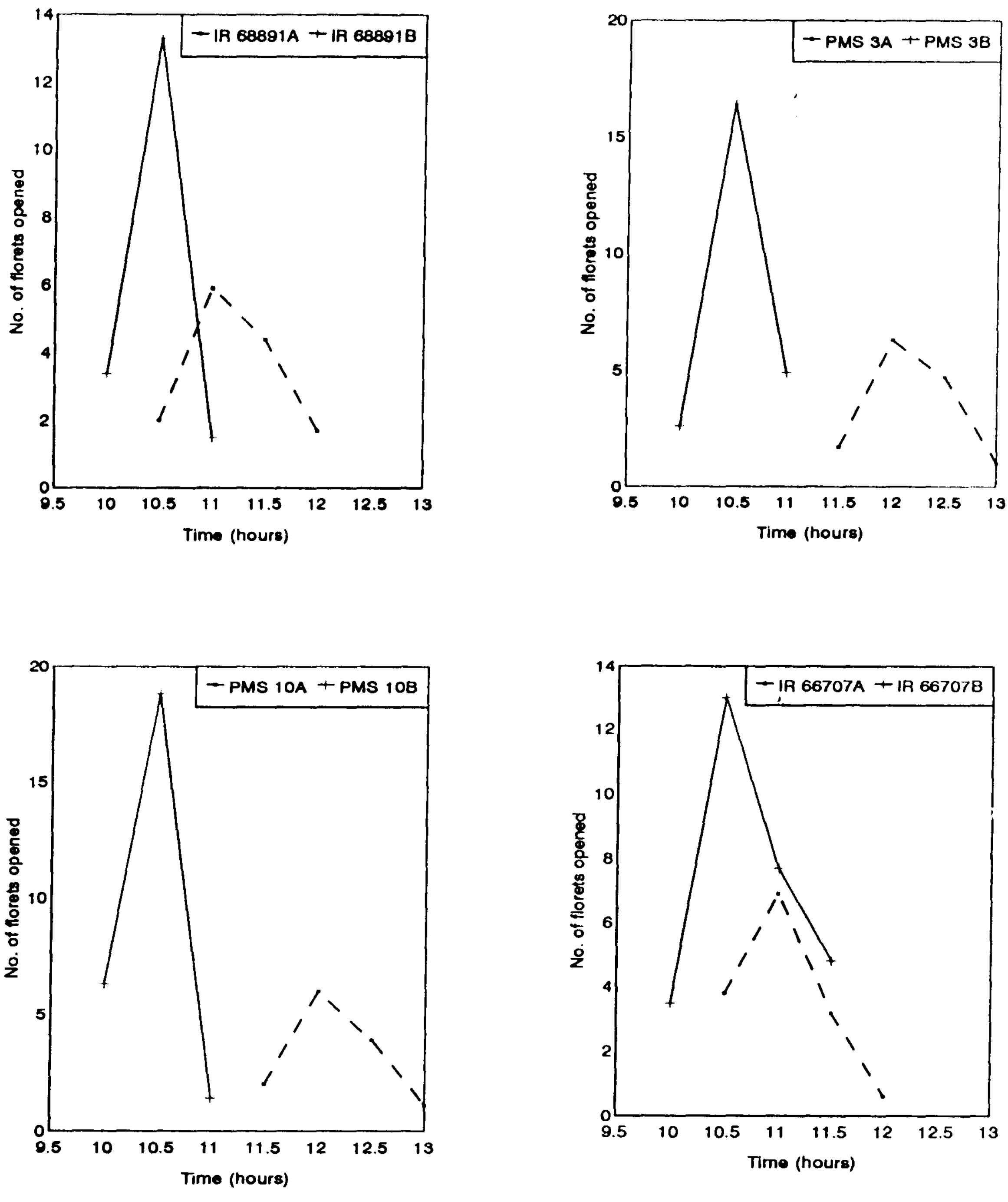


Fig.1b Frequency of floret opening in different CMS lines and their maintainers

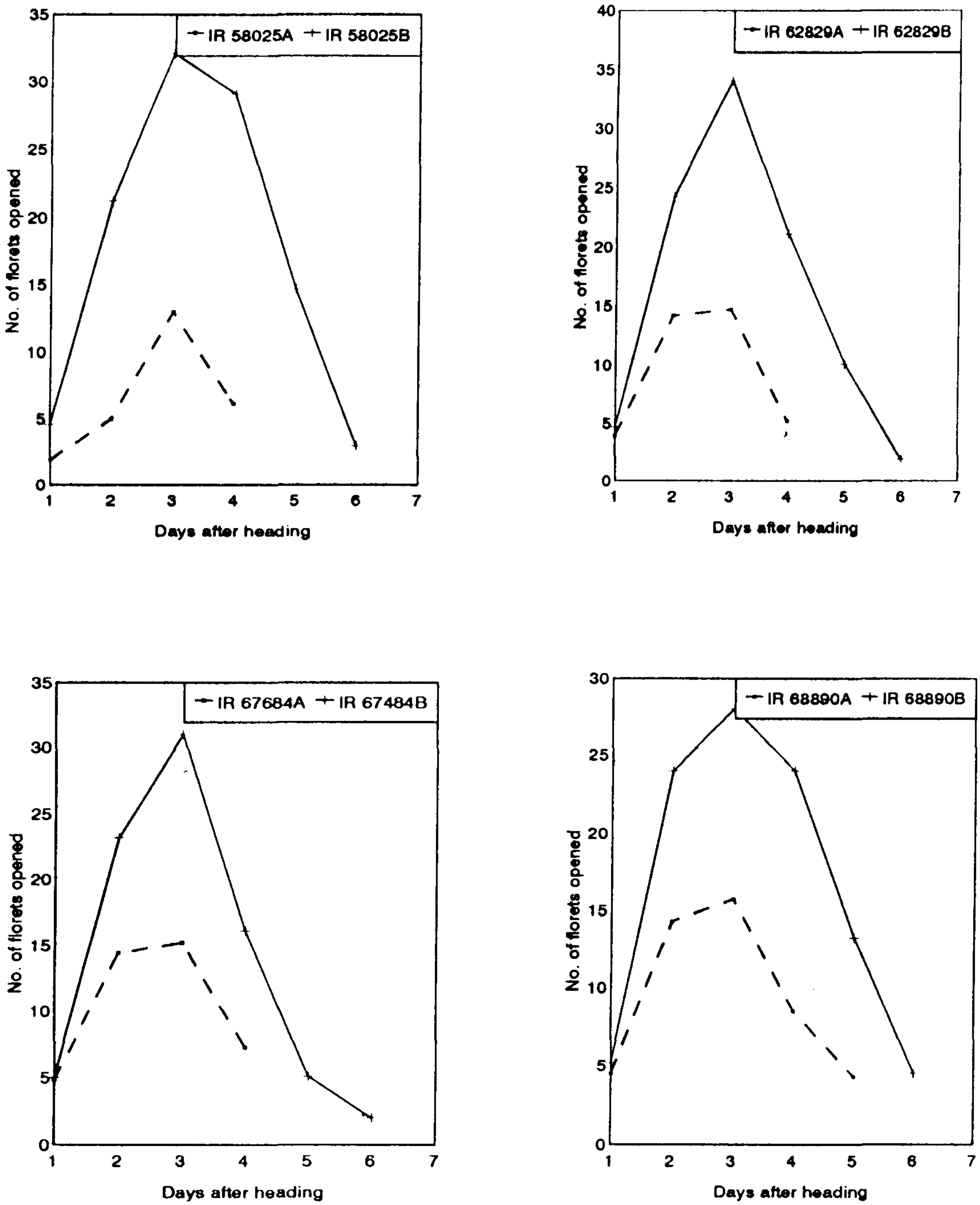


Fig.2a Sequence of blooming in a panicle in CMS lines and their maintainers

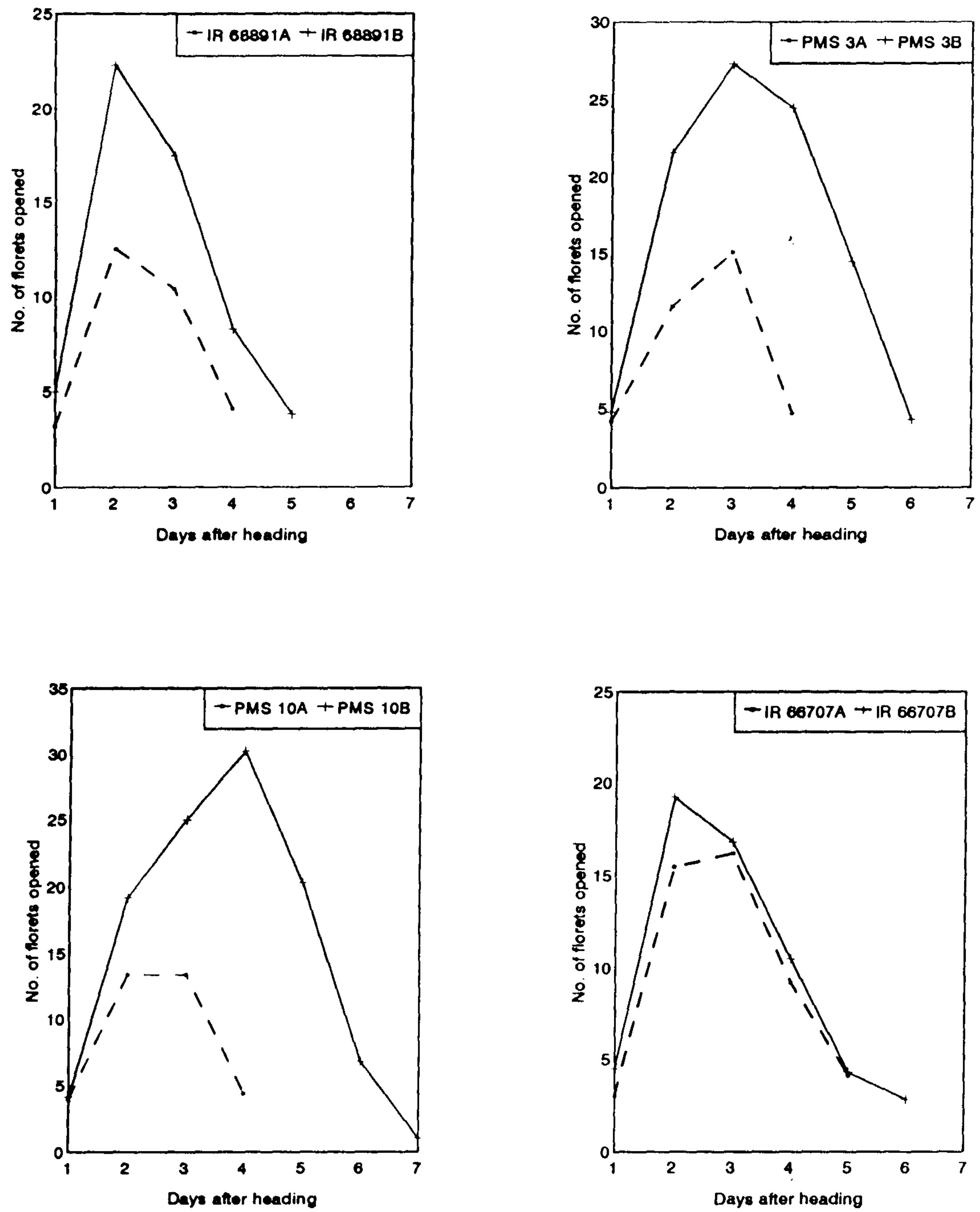


Fig.2b Sequence of blooming in a panicle in CMS lines and their maintainers

number of florets opened in a panicle. Both these traits were low in CMS lines compared to their corresponding maintainers (Tables 13 and 14). Number of florets opened on the 2nd day of blooming ranged from 10.67 (V 20A) to 16.03 (IR 66707A) in CMS lines whereas number of florets opened in the maintainer lines on the corresponding day ranged between 17.38 and 27.0.

Results of pooled analysis showed significant genotype x environment interaction for all the floral characters indicating difference in performance of genotypes during different seasons (Table 15).

4.1.3 Comparison between CMS lines and maintainers for agronomic and morphological attributes.

Comparison of CMS lines and their isogenic maintainers for various agronomic and floral traits using `t' test revealed significant difference between A and B lines for all the characters under study except panicle length. Characters like plant height, flowering duration, panicle exsertion, stigma exsertion, blooming duration and number of florets opened per day as well as total number of spikelets opened in a panicle expressed significant difference between male sterile line and their isogenic maintainers (Table 16).

4.2 Fertility restoration studies

4.2.1 Classification of genotypes into restorers (R), Maintainers (M), Partial restorers (PR) and Partial maintainers (PM) for WA and *Oryza perennis* cytosterile lines

Thirty four rice genotypes including exotic varieties, high yielding varieties, elite cultivars and local lines were crossed with seven WA CMS lines (IR 58025,

Table 13 Mean performance of 10 CMS line and their maintainers during *kharif* and *rabi* seasons for number of opened florets per day per panicle

Sl. No.	Genotypes	Number of opened florets/day/panicle		
		Kharif	*Rabi*	Mean
1	IR 58025A	13.50^{def}	12.70^{fg}	13.10^{def}
2	IR 58025B	27.50^{b}	25.25^{a}	26.37^{a}
3	IR 62829A	12.80^{def}	13.00^{efg}	12.90^{def}
4	IR 62829B	25.50^{b}	23.25^{ab}	24.37^{abc}
5	IR 67684A	11.30^{ef}	12.50^{fg}	11.90^{ef}
6	IR 67684B	27.25^{b}	19.75^{abcd}	23.50^{abcd}
7	IR 68886A	15.45^{de}	14.10^{defg}	14.78^{bcdef}
8	IR 68886B	26.25^{b}	24.00^{ab}	25.13^{ab}
9	IR 68890A	15.80^{d}	16.20^{cdefg}	16.00^{bcdef}
10	IR 68890B	33.50^{a}	20.50^{abc}	27.00^{a}
11	IR 68891A	12.00^{def}	12.60^{fg}	12.30^{ef}
12	IR 68891B	16.25^{d}	13.75^{efg}	15.00^{bcdef}
13	PMS 3A	12.85^{def}	15.40^{cdefg}	14.13^{cdef}
14	PMS 3B	21.75^{c}	20.50^{abc}	21.13^{abcdef}
15	PMS 10A	15.50^{de}	15.80^{cdefg}	15.65^{bcdef}
16	PMS 10B	26.75^{b}	17.50^{cdef}	22.13^{abcdef}
17	V 20A	10.80^{f}	10.65^{g}	10.67^{f}
18	V 20B	21.00^{c}	13.75^{efg}	17.38^{abcdef}
19	IR 66707A	13.30^{def}	18.75^{bcde}	16.03^{bcdef}
20	IR 66707B	21.25^{c}	23.50^{ab}	22.38^{abcde}

Genotypes with same alphabets do not differ significantly

Table 14 Mean performance of 10 CMS line and their maintainers during *kharif* and *rabi* seasons for number of opened florets per panicle

Sl. No.	Genotypes	Number of opened florets per panicle		
		Kharif	*Rabi*	Mean
1	IR 58025A	28.8^{fg}	29.10^{ef}	28.95^{f}
2	IR 58025B	96.75^{a}	108.75^{a}	102.75^{ab}
3	IR 62829A	39.35^{def}	29.30^{ef}	34.33^{ef}
4	IR 62829B	99.25^{a}	102.25^{a}	100.75^{ab}
5	IR 67684A	37.90^{def}	29.00^{ef}	33.45^{ef}
6	IR 67684B	81.50^{b}	108.25^{a}	94.88^{ab}
7	IR 68886A	36.60^{efg}	28.45^{ef}	32.53^{ef}
8	IR 68886B	66.50^{c}	106.75^{a}	86.63^{abc}
9	IR 68890A	48.00^{de}	52.55^{cd}	50.28^{def}
10	IR 68890B	100.00^{a}	116.00^{a}	108.00^{a}
11	IR 68891A	30.05^{fg}	27.05^{f}	28.55^{f}
12	IR 68891B	59.50^{c}	60.50^{bc}	60.50^{cde}
13	PMS 3A	34.35^{fg}	32.00^{ef}	33.18^{ef}
14	PMS 3B	95.75^{a}	100.75^{a}	98.25^{ab}
15	PMS 10A	35.25^{fg}	35.65^{ef}	35.45^{ef}
16	PMS 10B	106.50^{a}	103.00^{a}	104.75^{ab}
17	V 20A	25.50^{g}	26.30^{f}	26.00^{f}
18	V 20B	48.75^{d}	57.75^{bc}	53.25^{def}
19	IR 66707A	29.50^{fg}	43.10^{de}	36.30^{ef}
20	IR 66707B	83.00^{b}	70.00^{b}	76.50^{bcd}

Genotypes with same alphabets do not differ significantly

Table 15 Two way ANOVA for interaction in 10 CMS lines and their isogenic maintainers over kharif and rabi seasons

Source	df	Mean square							
		Plant height	Days to flowering	Panicle length	Stigma exsertion	Blooming duration	Opened florets per day per panicle	Total number of opened florets	Panicle exsertion
Replication	3	22.94	2.09	2.40	8.39	19.59	7.49	55.01	5.18
Genotype	19	705.12**	521.04**	43.46**	3696.89**	56038.75**	227.47**	7863.38**	2358.58**
Environment	1	732.28	122.73	2.07	74.18	1416.10	134.96	713.89	391.23
Genotype x environment	19	82.41**	39.85**	2.39	15.24**	188.52**	38.39**	331.20**	34.33**
Error	117	12.32	1.03	1.19	2.76	46.69	9.84	72.22	19.70

* Significant at 5% level
** Significant at 1% level

Table 16 Comparison of male sterile lines and maintainer lines using `t' test

Characters	Mean value		`t' value	Probability
	CMS line	Maintainer line		
Plant height(cm)	78.13	80.91	3.04*	0.00
Days to flowering	82.59	83.81	2.07*	0.04
Panicle length(cm)	22.92	22.77	0.68	0.49
Panicle exsertion(%)	66.70	97.77	27.57*	0.00
Stigma exsertion(%)	45.31	3.62	95.66*	0.00
Blooming duration (minutes)	167.43	47.56	15.42*	0.00
Number of opened florets per panicle	33.90	88.63	24.46*	0.00

*Significant at 1% level

IR 62829A, IR 67684A, IR 68890A, IR 68891A, PMS 3A and PMS 10A) and one *Oryza perennis* CMS line (IR 66707A) to identify maintainers and restorers. The results are presented in Table 17.

Out of a total of 200 F_1 hybrids of the seven CMS lines of WA cytoplasmic source and the selected genotypes, 36 were completely fertile and 47 completely sterile. The remaining 117 hybrids expressed different degrees of fertility. Sixty of them were partial maintainers and the remaining 57 were partial restorers. Among the genotypes tested, Jyothi expressed complete sterility when hybridised with all the CMS lines. Out of the seven CMS lines, 5 produced sterile hybrids when crossed with Aruna, Pavizham and Ptb 10. More number of fertile hybrid combinations were produced by Annapoorna, Matta Triveni, Kanchana, IR 36 and Aiswarya. Most of the genotypes expressed differential fertility reactions when crossed with different CMS lines having WA cytoplasm.

Cytoplasmic male sterile line IR 66707A having *O. Perennis* cytoplasmic source was hybridised with 31 rice genotypes to identify restorers if any, for this new source of cytoplasmic male sterility. All the 31 hybrids evaluated expressed complete sterility reaction and hence restorers were not identified (Table 17 and 18).

4.2.2 Inheritance of fertility restoration in WA cytoplasmic male sterile lines

F2 and F3 population of eight fertile hybrids produced by Aiswarya, Matta Triveni, Kanchana and IR 36 in combination with IR 62829A and IR 68890A were evaluated for fertility/sterility behaviour. Results of these studies on inheritance of fertility restoration are presented in Table 19 and 20.

Table 17 Pollen and spikelet fertility (%) of hybrids developed utilising WA and *Oryza perennis* cytosterile sources

Sl. No.	Genotypes	WA cytosterile lines							*O. perennis* cytosterile line IR 66707 A
		IR 58025A	IR 62829A	IR 67684A	IR 68890A	IR 68891A	PMS 3 A	PMS 10A	
1	Annapoorna	9.1 (10.3)	80.8 (85.6)	0.4 (1.2)	84.7 (85.9)	84.3 (88.2)	21.5 (24.8)	81.1 (83.5)	0
2	Hraswa	15.3 (18.5)	62.8 (69.3)	-	-	45.6 (52.9)	-	-	0
3	Jyothi	0.3 (0.0)	0.2 (0.0)	0 (0)	0.2 (0.0)	0 (0)	0 (0)	0 (0)	0 (0)
4	Matta Triveni	0.4 (1.2)	87.5 (90.3)	5.1 (7.8)	84.8 (86.3)	80.9 (82.5)	23.2 (43.6)	80.6 (84.6)	0.2 (0.0)
5	Kairali	13.4 (22.9)	80.1 (82.7)	0.1 (0.0)	12.8 (24.5)	21.5 (34.8)	18.8 (26.3)	0.2 (0.0)	0 (0)
6	Kanchana	7.7 (16.5)	87.5 (86.3)	83.4 (88.2)	84.5 (86.9)	83.8 (84.6)	48.9 (62.3)	83.4 (85.9)	0 (0)
7	Jayathi	27.3 (32.7)	37.1 (49.8)	11.5 (20.5)	40.5 (48.2)	3.4 (10.6)	16.8 (23.4)	36.3 (49.8)	0 (0)
8	Bhagya	2.7 (4.5)	2.5 (3.8)	21.5 (32.3)	0.2 (0.0)	37.1 (49.3)	12.6 (20.4)	0 (0)	0 (0)
9	Onam	0.2 (0.0)	0.4 (0.5)	11.4 (8.9)	1.6 (4.5)	2.2 (10.3)	46.7 (60.8)	4.0 (16.5)	0 (0)
10	Aruna	0.2 (2.8)	0 (0)	0.3 (6.2)	0.4 (4.1)	0.7 (2.8)	3.9 (10.6)	88.5 (86.7)	0 (0)

Contd....

Table 17 contd...

11	Makom	13.7	5.2	9.9	6.2	22.5	0.4	25.4	0
		(22.4)	(10.3)	(8.6)	(14.8)	(39.7)	(9.6)	(32.5)	(0)
12	IR 36	11.7	82.2	4.1	85.4	88.9	1.0	87.8	0.8
		(12.8)	(85.6)	(10.3)	(88.9)	(92.3)	(4.6)	(90.4)	(1.0)
13	IR 8	90.7	0.3	45.9	4.0	86.2	0.2	37.6	0.1
		(92.1)	(2.8)	(59.7)	(12.3)	(91.5)	(2.8	(48.2)	(0.0)
14	Jaya	90.5	10.7	49.6	0.8	84.6	85.2	0	0
		(88.6)	(23.4)	(62.3)	(1.2)	(90.3)	(88.6)	(0)	(0)
15	Pavizham	39.5	10.7	0	0.4	0	0	0.2	0
		(42.6)	(23.1)	(0)	(0.8)	(0)	(0)	(0.0)	(0)
16	Aathira	15.5	86.5	4.9	4.7	39.3	28.8	29.3	0
		(20.3)	(88.9)	(10.2)	(8.2)	(40.5)	(36.9)	(34.5)	(0)
17	Aiswarya	90.4	87.2	0.7	87.8	80.7	84.6	81.5	0
		(92.7)	(90.3)	(1.8)	(89.6)	(82.4)	(89.3)	(83.4)	(0)
18	Remya	2.1	40.4	1.1	5.6	20.8	22.8	11.2	0
		(4.3)	(46.9)	(3.4)	(7.3)	(24.6)	(20.9)	(13.6)	(0)
19	Kanakom	24.2	20.3	0	2.9	1.2	0.1	47.4	0.6
		(28.9)	(22.8)	(0)	(3.8)	(2.5)	(0.0)	(50.2)	(0.0)
20	Ponmani	-	-	10.5	62.3	-	-	58.5	0.9
				(15.3)	(67.8)			(60.2)	(1.0)
21	Ptb 1	-	-	8.3	26.4	-	-	58.5	0.9
				(10.2)	(29.7)			(60.2)	(1.0)
22	Ptb 9	9.6	8.5	0.4	25.7	0.2	0	80.7	0.0
		(10.4)	(10.2)	(1.2)	(30.9)	(0.0)	(0)	(82.5)	(0.0)

Contd....

Table 17 contd...

23	Ptb 10	0.1 (0.0)	0.4 (0.0)	0.2 (0.0)	85.0 (92.3)	0 (0)	0.1 (0.0)	84.6 (88.6)	0.0 (0.0)
24	KAU 10-1-1	28.4 (32.6)	56.5 (64.9)	-	-	32.7 (48.3)	-	-	-
25	Mahsuri	-	-	10.2 (14.6)	38.6 (42.7)	49.2 (53.8)	-	-	-
26	Bharathi	10.3 (12.2)	42.6 (50.7)	-	8.6 (9.4)	38.1 (44.6)	-	12.2 (14.8)	0 (0)
27	Suvarnamodan	60.5 (67.5)	-	14.5 (22.1)	54.8 (58.3)	63.4 (64.8)	18.2 (23.9)	0.6 (1.0)	-
28	Swarnaprabha	-	63.4 (66.7)	69.2 (73.1)	-	-	49.6 (52.8)	-	9 (0)
29	M 42-6-3	0.8 (1.0)	0.2 (0.8)	12.6 (20.3)	-	10.4 (11.6)	-	-	0 (0)
30	M 45-20-1	18.3 (20.9)	46.3 (52.4)	68.1 (72.6)	0.3 (0.0)	12.4 (16.5)	60.3 (62.8)	18.9 (20.5)	0 (0)
31	M 38-4-2	8.6 (12.5)	0.6 (0.0)	11.3 (18.6)	48.2 (66.7)	56.9 (52.7)	12.9 (20.3)	63.2 (67.8)	0 (0)
32	M 48-11-3	-	82.1 (80.8)	-	8.5 (10.3)	42.6 (49.7)	0.2 (0.0)	-	0.3 (0.0)
33	M 38-4-1	-	-	42.5 (49.3)	36.7 (42.5)	7.2 (12.6)	61.4 (70.9)	-	0 (0)
34	M 42-6-2	-	80.4 (82.6)	16.2 (24.5)	26.4 (32.1)	-	-	15.9 (20.1)	0 (0)

Figures in paranthesis indicate spikelet fertility

Table 18 Classification of genotypes into restorers (R) maintainers (M), partial restorers (PR) and partial maintainers (PM) for WA and *Oryza perennis* cytosterile lines

Sl. No.	Genotypes	WA cytosterile lines							*O. perennis* cytosterile line
		IR 58025A	IR 62829A	IR 67684A	IR 68890A	IR 68891A	PMS 3 A	PMS 10 A	IR 66707A
1	Annapoorna	PM	R	M	R	R	PR	R	M
2	Hraswa	PM	PR	-	-	PR	-	-	M
3	Jyothi	M	M	M	M	M	M	M	M
4	Matta Triveni	M	R	PM	R	R	PR	R	M
5	Kairali	PM	R	M	PM	PR	PM	M	M
6	Kanchana	PM	R	R	R	R	PR	R	M
7	Jayathi	PR	PR	PM	PR	PM	PM	PR	M
8	Bhagya	PM	PM	PR	M	PR	PM	M	M
9	Onam	M	M	PM	PM	PM	PR	PM	M
10	Aruna	M	M	M	M	M	PM	R	M
11	Makom	PM	PM	PM	PM	PR	M	PR	M
12	IR 36	PM	R	PM	R	R	M	R	M
13	IR 8	R	M	PR	PM	R	M	PR	M
14	Jaya	R	PM	PR	M	R	R	M	M
15	Pavizham	PR	PM	M	M	M	M	M	M

Contd.....

Table 18 contd...

16	Aathira	PM	R	PM	PM	PR	PR	PR	M
17	Aiswarya	R	R	PM	R	R	R	R	M
18	Remya	PM	PR	PM	PM	PR	PR	PM	M
19	Kanakom	PR	PR	M	PM	PM	M	PR	M
20	Ponmani	-	-	PM	PR	-	-	PR	M
21	Ptb 1	-	-	PM	PR	PM	PM	PM	M
22	Ptb 9	PM	PM	M	PR	M	M	R	M
23	Ptb 10	M	M	M	R	M	M	R	M
24	KAU 10-1-1	PR	PR	-	-	PR	-	-	-
25	Mahsuri	-	-	PM	PR	PR	-	-	-
26	Bharathi	PM	PR	-	PM	PR	-	PM	M
27	Suvarnamodan	PR	-	PM	PR	PR	PM	M	-
28	Swarnaprabha	-	PR	PR	-	-	PR	-	M
29	M 42-6-3	M	M	PM	-	PM	-	-	M
30	M 45-20-1	PM	PR	PR	M	PM	PR	PM	M
31	M 38-4-2	PR	M	PM	PR	PR	PM	PR	M
32	M 48-11-3	-	R	-	PM	PR	M	-	M
33	M 38-4-1	-	-	PR	PR	PM	PR	-	M
34	M 42-6-2	-	R	PM	PR	-	-	PM	M

Fertility of plants in F_2 generation varied considerably and frequency distribution of fertility showed a broader range (Table 19). F_2 plants exhibited fertility range from 0 to 100 per cent and these were grouped into 11 classes with class interval of 10. Fully sterile plants with 0 per cent fertility restoration were taken as one class. Different number of plants were present in each class and distribution was not discrete. Frequency distribution of fertile plants in the F2 generation did not show perfect normal distribution. Presence of plants in each of the classes indicate polygenic inheritance of the character. Deviation from a perfect normal distribution along with more number of plants in certain classes also suggest involvement of two or three genes along with modifiers.

F_3 progeny of partially fertile and fully fertile F_2 plants indicated different segregation patterns. F_3 progeny of partially fertile plants exhibited difference in frequency of fertile plants in each class (Table 20) and the distribution was also normal. F_3 progeny from the fully fertile plants have fertile plants in classes above 40 per cent fertility level and the distribution was skewed with median towards higher classes of fertility.

4.3 Genetic divergence among selected rice genotypes

Forty four rice genotypes included in the source germplasm for hybrid rice breeding were found to fall into nine clusters, each one having different number of genotypes (Table 21). The results revealed that 12 genotypes constituted Cluster I. There were six genotypes in Cluster II, five genotypes in Cluster III, and four genotypes in Cluster IV. Cluster V was constituted by nine genotypes and Cluster VI

Table 19 Distribution of pollen fertility in the F2 generation of eight crosses involving four restorers

Sl. No.	Cross combination	Number of plants in each fertility class											
		0	10	20	30	40	50	60	70	80	90	100	Total
1	IR 62829A / Aiswarya	1	5	9	20	19	20	15	18	25	11	5	148
2	IR 68890A / Aiswarya	6	8	16	17	26	17	17	22	16	17	4	166
3	IR 62829A / Matta Triveni	1	3	1	3	5	5	16	30	41	43	15	163
4	IR 68890A / Matta Triveni	15	21	21	17	19	25	34	48	44	35	8	287
5	IR 62829A / Kanchana	2	25	5	7	13	18	23	46	67	46	22	274
6	IR 68890A / Kanchana	2	2	1	8	12	7	16	6	25	15	11	105
7	IR 62829A / IR 36	8	9	14	12	15	18	14	8	13	8	2	121
8	IR 68890A / IR 36	2	9	1	8	8	16	9	14	16	13	3	99

Table 20 Distribution of pollen fertility in the F3 generation from partially fertile and fully fertile F2 plants

Sl. No.	Cross combination	0	10	20	30	40	50	60	70	80	90	100	Total
	F3 generation from partially fertile (50%) plants												
1	IR 62829A / Kanchana	-	2	5	9	9	17	12	10	9	3	1	77
2	IR 68890A / Kanchana	-	2	5	8	9	10	12	6	5	5	-	62
	F3 generation from fertile (100%) plants												
1	IR 62829A / Kanchana	-	-	-	-	-	5	20	37	53	10	2	127
2	IR 68890 A / Kanchana	-	-	-	-	-	7	18	40	38	8	3	114

Table 21 Rice genotypes included in different clusters

Cluster No.	Number of genotypes	Genotypes included in each cluster
I	12	Aruna, Makom, IR 8, Jaya, Remya, Kanakom, Bharathi, M 42-6-3, M 45-20-1, M 38-4-2, M 48-11-3, M 38-4-1
II	6	IR 36, IR 58025B, IR 67684B, IR 68886B, PMS 3B, PMS 10B
III	5	Kairali, Kanchana, Pavizham, Aathira, Aiswarya
IV	4	Ptb 1, Ptb 9, Mahsuri, M 42-6-2
V	9	Jyothi, Jayathi, Bhagya, Ptb 10, KAU 10-1-1, Suvarnamodan, Swarnaparabha, IR 68890B, IR 66707B
VI	5	Annapoorna, Matta Triveni, Onam, IR 62829B, IR 68891B
VII	1	Ponmani
VIII	1	Hraswa
IX	1	V 20B

by five genotypes. Three Clusters (Cluster VII, VIII and IX) consisted of single genotype each.

Intra and inter-cluster D^2 values of nine clusters are presented in Table 22. Intracluster D^2 values were lower than the corresponding inter cluster D^2 values. Intra Cluster D^2 value was highest in Cluster No. IV. Maintainers of CMS lines were distributed in Cluster No. II, V, VI and IX. All the Clusters consisted of genotypes from different sources.

Mean values for the different characters of each cluster are presented in Table 23. Cluster No. VII which is represented by a single genotype recorded highest mean values for 14 out of 23 characters studied. Highest value for plant height was recorded by Cluster No. IV and that for harvest index by Cluster No. III. Cluster No. VIII manifested highest values for the seed characters such as hundred seed weight, grain breadth and grain thickness. Cluster No. IX recorded lower values than grand mean for most of the characters and it also recorded highest value for spikelet sterility. Cluster No. VII which recorded highest mean value for most of the characters exhibited high genetic distance with Clusters II, III, V, VI, VIII and IX.

4.4 Genetic analysis of hybrids

Results of genetic analysis of 34 fertile hybrids developed by hybridisation between seven cytoplasmic male sterile lines and 12 genetically divergent genotypes are presented under this head.

Table 22 Average intra and inter D^2 values for nine different clusters of rice genotypes

Cluster No.	1	2	3	4	5	6	7	8	9
1	441.62								
2	2323.75	491.52							
3	1183.66	2272.58	564.99						
4	960.33	4249.23	1912.47	805.18					
5	1216.55	1249.79	1070.29	2383.88	475.52				
6	2336.96	1106.76	1426.35	4122.80	834.91	482.52			
7	4338.56	10927.44	6520.64	2367.24	7713.91	11117.38	0.00		
8	6854.82	3273.24	4649.55	9813.88	3508.31	1800.21	19869.12	0.00	
9	6380.83	4175.11	3568.79	8702.13	3776.89	1983.87	17965.68	1060.60	0.00

Table 23 Mean values for different characters in nine clusters of rice genotypes

Characters	I	II	III	IV	V	VI	VII	VIII	IX	Grand Mean
Plant height (cm)	104.45	92.3	106.93	148.2	102.48	92.7	132.7	71.1	66.9	112.15
Tillers per plant	9.68	11.85	8.8	8.65	9.69	9.39	12.13	7.73	8.0	9.73
Panicles per plant	7.94	9.89	6.32	6.96	7.96	6.66	10.53	6.53	4.46	8.01
Flowering duration (days)	99.47	85.59	88.26	106.66	86.00	78.79	125.66	62.33	64.33	90.87
Total duration (days)	128.05	112.83	117.59	136.75	113.60	104.66	158.00	80.66	89.33	118.69
Grain yield/ m^2 (g)	400.41	235.55	425.00	383.75	342.59	269.66	470.0	146.66	130.0	342.20
Grain yield/ plant (g)	15.44	11.76	20.55	15.83	15.89	12.88	29.16	7.21	3.98	15.23
Straw yield/plant (g)	22.9	21.26	22.75	28.59	21.38	15.47	44.24	10.66	15.42	22.60
Straw yield /m^2 (g)	339.24	178.32	378.99	466.66	367.03	240.66	741.66	93.33	100.0	326.01
Total dry matter (g)	38.71	32.86	43.31	42.76	39.78	29.69	73.38	17.99	19.40	37.88
Harvest index	0.395	0.35	0.468	0.35	0.465	0.422	0.397	0.400	0.203	0.42
Earhead length (cm)	23.64	24.00	24.78	26.50	25.5	24.19	29.63	17.26	17.33	24.38

Contd...

Table 23 Contd...

Characters	I	II	III	IV	V	VI	VII	VIII	IX	Grand Mean
Grains per panicle	106.1	97.00	122.58	183.28	121.05	89.58	258.46	68.5	60.66	118.51
Chaff per cent	28.42	28.71	23.61	24.29	24.36	26.1	22.96	28.56	31.76	26.41
100 seed weight (g)	2.72	2.11	2.50	2.46	2.63	2.45	2.49	2.83	2.68	2.54
Grain length (mm)	8.28	10.35	6.13	6.95	8.9	8.56	5.71	9.5	5.79	8.27
Grain breadth (mm)	2.68	2.42	2.82	2.90	2.48	2.7	2.89	3.06	2.71	2.65
Grain thickness (mm)	2.04	2.05	2.14	2.07	2.06	2.0	2.20	2.22	2.10	2.07
Grain density (g/100ml)	56.92	50.87	56.23	58.15	55.44	55.31	62.73	51.33	55.5	55.66
Flag leaf area (cm^2)	32.69	34.57	38.05	37.29	34.72	29.91	43.3	28.17	24.68	34.04
Panicle weight (g)	3.2	2.41	3.76	3.91	2.93	2.55	5.07	1.41	1.12	3.05
Leaf area index	9.75	8.72	10.26	10.41	11.33	9.35	8.39	7.50	5.94	9.85
Panicle exsertion	102.63	100.25	104.74	107.74	105.46	102.8	107.4	98.4	97.03	103.50

4.4.1 Heterosis in direct and reciprocal hybrids

Mean performance and results on estimation of heterosis in direct and reciprocal hybrids are presented in Tables 24 to 37. There was difference in performance between hybrids for the different characters under study and performance of direct and reciprocal hybrids also varied for most of the characters (Tables 24 and 25).

4.4.1.1 Plant height

In hybrids mean plant height ranged from 85.3 cm (IR 62829A/Annapoorna) to 145.1 cm (PMS 10A/Ptb 9). In reciprocal hybrids, the range was between 86.6 cm in Annapoorna/IR 68891B and 106 cm in Kanchana/IR 68890B (Table 24).

Studies on heterosis for plant height presented in Table 26 revealed significant positive heterosis over mid parent for 13 hybrids and significant negative heterosis for six hybrids with the range between -10.5 (IR 58025A/IR 8) and 26.5 (PMS 10A/ Ptb 10) per cent. Heterobeltiosis was significant and positive for two hybrids while it was significant and negative for 13 hybrids. The range was from -16.8 (IR 62829A/Aiswarya) to 9.2 (PMS 10A/Ptb 10) per cent. Significant positive standard heterosis over Kanchana was recorded by nine hybrids, while for seven hybrids it was significantly negative.

Among the 24 reciprocal hybrids evaluated eight recorded significant relative heterosis showing a range between - 9.9 (Aiswarya/IR 58025B) and 6.7 (Kanchana/ IR 68890B) per cent. Thirteen hybrids exhibited significant negative heterobeltios

Table 24 Mean performance of hybrids and parents in rice for plant and economic characters

Sl. No.	Cross combination	Plant height (cm)	Panicle per plant	Days to flowering	Leaf area index	Grain yield per plant (g)	Straw yield per plant (g)	Harvest index
Hybrids								
1	IR 62829A/Annapoorna	85.3	9.7	75.3	6.9	12.8	16.1	0.4
2	IR 62829A/ Matta Triveni	98.0 (87.8)	9.2 (8.8)	78.3 (76.4)	9.7 (5.4)	19.7 (23.1)	22.9 (19.2)	0.5 (0.6)
3	IR 62829A/ Kanchana	98.0 (88.0)	15.7 (8.4)	79.0 (77.6)	11.5 (7.5)	23.4 (27.2)	15.8 (19.5)	0.6 (0.6)
4	IR 62829A/ IR 36	95.5	9.5	81.2	7.4	12.5	17.1	0.4
5	IR 62829A/ Aiswarya	94.0 (98.0)	13.7 (9.8)	81.5 (82.4)	12.1 (7.2)	17.2 (23.4)	27.9 (20.1)	0.4 (0.5)
6	IR 68890A/ Annapoorna	98.8 (91.6)	10.8 (6.2)	84.0 (79.6)	11.4 (6.5)	20.1 (28.2)	18.8 (22.0)	0.5 (0.6)
7	IR 68890A/ Matta Triveni	94.3	14.5	80.0	7.4	14.0	17.7	0.4
8	IR 68890A/ Kanchana	105.5 (106.0)	14.8 (9.6)	85.0 (85.8)	9.8 (6.2)	24.8 (18.0)	21.7 (18.1)	0.5 (0.5)
9	IR 68890A/ IR 36	96.0 (99.6)	8.5 (10.6)	86.5 (86.8)	9.4 (6.0)	17.9 (18.9)	24.9 (19.1)	0.4 (0.5)
10	IR 68890A/ Aiswarya	105.7 (98.8)	10.8 (8.4)	87.0 (87.0)	9.3 (6.7)	29.9 (28.8)	25.8 (25.0)	0.5 (0.5)

Contd...

Table 24 Contd...

11	IR 68891A/Annapoorna	92.5 (86.6)	8.3 (8.8)	82.5 (79.8)	7.1 (6.2)	21.2 (15.4)	20.8 (15.9)	0.5 (0.5)
12	IR 68891A/ Matta Triveni	97.5	12.8	81.7	6.1	16.6	19.8	0.5
13	IR 68891A/ Kanchana	93.2	13.3	84.5	8.9	18.2	20.1	0.5
14	IR 68891A/ IR 36	93.5 (96.8)	9.8 (8.8)	84.0 (81.4)	7.8 (6.4)	24.5 (21.4)	19.1 (17.9)	0.6 (0.5)
15	IR 68891A/ Aiswarya	98.0	13.3	89.0	6.9	16.8	19.2	0.5
16	PMS 10A / Annapoorna	86.0	9.0	80.0	7.2	14.7	19.0	0.4
17	PMS 10A / Matta Triveni	90.5	10.0	80.0	7.5	16.9	20.0	0.5
18	PMS 10A/ Kanchana	97.5	11.0	81.2	6.4	17.6	20.3	0.5
19	PMS 10A/IR 36	94.0 (93.4)	10.8 (8.6)	81.2 (85.0)	8.2 (5.7)	20.2 (23.6)	21.2 (22.2)	0.5 (0.5)
20	PMS 10A/ Aiswarya	110.8 (101.2)	9.0 (8.6)	90.0 (90.2)	8.4 (6.5)	21.5 (20.6)	20.2 (21.0)	0.5 (0.5)
21	IR 58025A/ IR 8	86.3 (95.8)	9.5 (8.2)	88.7 (86.4)	7.4 (6.4)	20.6 (25.9)	17.4 (18.8)	0.5 (0.6)
22	IR 58025A/ Jaya	88.8 (93.0)	6.0 (9.0)	87.9 (87.0)	7.4 (5.0)	12.2 (26.3)	21.8 (19.9)	0.4 (0.6)
23	IR 58025A/ Aiswarya	117.3 (96.6)	5.9 (8.2)	88.8 (90.0)	6.6 (5.1)	12.3 (25.3)	23.4 (21.0)	0.3 (0.5)

Contd..

Table 24 Contd...

24	IR 62829A/ Kairali	95.5 (85.4)	16.4 (8.4)	82.6 (80.8)	10.0 (6.9)	17.7 (21.5)	22.3 (20.2)	0.4 (0.5)
25	IR 62829A/ Aathira	111.7 (95.4)	13.2 (8.0)	80.2 (87.4)	11.6 (7.6)	24.3 (24.4)	23.3 (19.1)	0.5 (0.6)
26	IR 67684A/ Kanchana	91.9 (95.0)	13.0 (8.0)	84.3 (83.2)	11.6 (6.3)	15.3 (23.4)	19.7 (19.0)	0.4 (0.5)
27	IR 68890A/ Ptb10	124.10 (104.0)	7.3 (8.8)	81.7 (84.0)	9.3 (5.6)	22.13 (20.7)	24.6 (24.9)	0.5 (0.5)
28	IR 68891A/ IR 8	87.6 (95.4)	16.7 (11.0)	86.9 (86.6)	9.3 (6.4)	16.7 (20.6)	24.4 (21.6)	0.4 (0.5)
29	IR 68891A/ Jaya	90.6 (92.6)	15.6 (9.2)	85.9 (91.2)	9.0 (6.5)	18.1 (18.2)	21.5 (19.3)	0.5 (0.5)
30	PMS 3A/Jaya	97.5 (92.0)	10.0 (8.8)	96.7 (93.2)	9.2 (5.3)	17.2 (22.5)	21.5 (19.0)	0.4 (0.5)
31	PMS 3A/ Aiswarya	104.2 (97.8)	7.6 (8.6)	92.3 (98.0)	9.8 (6.1)	17.9 (22.6)	22.5 (26.9)	0.4 (0.5)
32	PMS 10A/Aruna	93.5 (92.6)	10.1 (8.6)	88.1 (90.4)	9.1 (5.3)	22.2 (25.3)	18.8 (20.6)	0.5 (0.6)
33	PMS 10A/ Ptb 9	145.1	9.1	91.5	9.3	22.6	23.6	0.5
34	PMS 10A/ Ptb 10	130.0 (101.2)	9.7 (8.0)	85.4 (84.0)	9.1 (6.5)	22.8 (24.2)	23.5 (27.0)	0.5 (0.5)

Figures in parentheses indicate performance of reciprocal hybrids

Table 24 contd.......

Parents								
1	IR 58025B	97.80	5.40	86.60	6.00	9.34	17.11	0.35
2	IR 62829B	85.90	5.30	83.10	4.91	10.55	17.51	0.38
3	IR 67684B	93.10	6.80	83.90	6.39	8.12	13.13	0.38
4	IR 68890B	102.00	7.00	91.20	5.97	10.75	20.70	0.35
5	IR 68891B	96.00	7.30	83.90	5.82	7.50	17.84	0.30
6	PMS 3B	89.70	7.20	91.10	6.34	11.67	18.28	0.39
7	PMS 10B	86.60	7.70	93.90	6.24	11.74	17.11	0.41
8	Annapoorna	84.50	6.40	74.70	5.01	13.17	13.63	0.49
9	Matta Triveni	96.40	6.60	79.20	5.65	15.21	16.43	0.49
10	Kairali	94.80	6.70	87.40	5.48	15.77	16.42	0.49
11	Kanchana	96.70	7.20	85.10	5.38	19.72	16.63	0.54
12	Aruna	95.90	7.50	99.00	5.99	15.65	16.87	0.48
13	IR36	93.90	7.40	88.90	5.69	16.28	15.72	0.52
14	IR8	95.10	6.90	99.30	4.79	16.20	16.47	0.50
15	Jaya	97.60	6.60	100.90	5.91	17.53	16.51	0.52
16	Aathira	116.70	6.60	96.20	6.53	16.54	20.25	0.45
17	Aiswarya	113.20	6.20	89.70	4.93	16.69	18.27	0.48
18	Thavalakkannan (Ptb9)	156.80	5.00	101.20	5.94	14.46	22.19	0.40
19	Thekkancheera (Ptb10)	119.00	5.50	85.30	5.62	14.65	21.96	0.40

Table 25 Mean performance of hybrids and parents in rice for grain and earhead characters

Sl. No.	Cross combination	Grains per panicle	Spikelet sterility (%)	Panicle exsertion (%)	100 seed weight (g)	Grain density (g/100 ml)
Hybrids						
1	IR 62829A/Annapoorna	103.0	16.9	78.5	2.3	52.5
2	IR 62829A/ Matta Triveni	93.5 (115.8)	16.5 (19.6)	58.1 (105.4)	2.4 (2.3)	52.7 (55.8)
3	IR 62829A/ Kanchana	119.2 (124.2)	16.2 (9.1)	86.4 (107.7)	2.5 (2.2)	54.0 (56.2)
4	IR 62829A/ IR 36	118.0	15.1	75.7	2.6	52.7
5	IR 62829A/ Aiswarya	128.2 (137.0)	14.1 (12.2)	64.4 (107.3)	2.6 (2.4)	52.9 (56.5)
6	IR 68890A/ Annapoorna	96.0 (131.6)	16.4 (11.4)	93.8 (108.8)	2.6 (2.7)	54.7 (56.0)
7	IR 68890A/ Matta Triveni	103.2	24.2	78.9	2.5	54.5
8	IR 68890A/ Kanchana	128.5 (130.0)	14.3 (9.3)	85.1 (107.8)	2.4 (2.3)	56.4 (55.7)
9	IR 68890A/ IR 36	104.2 (115.2)	16.2 (14.5)	70.8 (103.4)	2.6 (2.4)	54.8 (52.7)
10	IR 68890A/ Aiswarya	107.5 (140.0)	20.7 (10.7)	86.9 (110.6)	3.0 (2.7)	55.9 (58.1)

Contd....

Table 25 Contd...

11	IR 68891A/ Annapoorna	98.5 (121.4)	21.8 (11.7)	106.4 (102.0)	2.0 (2.4)	53.4 (53.5)
12	IR 68891A/ Matta Triveni	107.0	20.4	80.6	2.1	53.0
13	IR 68891A/ Kanchana	102.5	21.7	71.3	2.3	54.3
14	IR 68891A/ IR 36	156.2 (153.2)	14.8 (9.8)	101.0 (105.7)	2.0 (2.3)	51.8 (52.4)
15	IR 68891A/ Aiswarya	109.7	24.3	69.1	2.3	54.1
16	PMS 10A / Annapoorna	118.2	18.7	74.6	2.1	52.5
17	PMS 10A /Matta Triveni	110.0	16.8	84.4	2.2	55.22
18	PMS 10A/ Kanchana	114.0	20.8	81.2	2.2	57.2
19	PMS 10A/IR 36	124.7 (136.0)	15.4 (13.7)	106.5 (99.6)	1.9 (2.3)	54.6 (54.4)
20	PMS 10A/ Aiswarya	120.5 (145.0)	15.1 (11.7)	85.6 (99.7)	2.3 (2.6)	54.4 (58.9)
21	IR 58025A/ IR 8	108.9 (112.6)	17.3 (11.1)	76.0 (90.9)	2.4 (2.4)	53.8 (55.1)
22	IR 58025A/ Jaya	86.0 (122.0)	22.9 (11.0)	84.3 (100.2)	2.2 (2.4)	54.3 (55.9)
23	IR 58025A/ Aiswarya	91.8 (105.4)	20.5 (11.2)	70.8 (104.0)	2.4 (2.8)	54.2 (56.5)

Contd...

Table 25 Contd...

24	IR 62829A/ Kairali	95.4 (133.4)	17.9 (12.7)	71.7 (104.9)	1.9 (2.2)	52.8 (53.2)
25	IR 62829A/ Aathira	115.3 (119.0)	13.8 (10.9)	83.5 (107.5)	2.3 (2.4)	54.3 (55.7)
26	IR 67684A/ Kanchana	100.4 (124.0)	17.5 (18.3)	71.3 (99.3)	2.2 (2.5)	53.0 (54.7)
27	IR 68890A/ Ptb10	127.2 (134.4)	14.0 (11.4)	101.9 (109.1)	2.5 (2.5)	56.5 (56.2)
28	IR 68891A/ IR 8	96.2 (143.2)	24.9 (12.0)	93.3 (104.6)	2.5 (2.4)	52.7 (57.7)
29	IR 68891A/ Jaya	96.2 (124.8)	24.2 (12.1)	93.2 (104.3)	2.5 (2.2)	53.1 (54.9)
30	PMS 3A/Jaya	126.3 (124.8)	21.9 (14.6)	100.3 (101.4)	2.4 (2.3)	54.3 (57.0)
31	PMS 3A/ Aiswarya	100.0 (159.2)	20.5 (8.3)	102.0 (104.9)	2.2 (2.5)	53.3 (58.7)
32	PMS 10A/Aruna	123.1 (146.0)	15.2 (13.9)	103.9 (108.9)	1.9 (2.5)	57.9 (57.3)
33	PMS 10A/Ptb 9	173.0	16.0	103.3	2.0	59.4
34	PMS 10A/ Ptb 10	169.6 (126.8)	13.2 (12.4)	96.9 (102.1)	2.4 (2.5)	59.0 (57.7)

Figures in paranthesis indicate performance of reciprocal hybrids

Table 25 contd.....

Parents						
1	IR 58025B	96.40	20.60	97.30	2.16	51.60
2	IR 62829B	75.40	20.52	101.81	2.20	52.73
3	IR 67684B	89.80	17.99	101.00	2.03	51.03
4	IR 68890B	118.40	12.56	101.60	2.62	55.33
5	IR 68891B	79.80	16.48	100.60	2.51	53.26
6	PMS 3B	115.60	15.74	105.55	2.06	50.13
7	PMS 10B	119.00	16.61	105.46	2.11	52.18
8	Annapoorna	83.40	15.51	103.62	2.42	54.66
9	Matta Triveni	426.60	14.20	102.34	2.56	55.83
10	Kairali	115.20	14.38	101.32	2.36	55.18
11	Kanchana	115.30	12.29	91.80	2.65	57.14
12	Aruna	106.20	14.08	102.18	2.48	56.72
13	IR 36	132.60	13.38	109.02	2.29	52.89
14	IR 8	105.00	12.92	100.57	2.65	54.53
15	Jaya	98.20	19.03	101.91	2.82	54.32
16	Aathira	128.80	15.14	101.41	2.62	54.53
17	Aiswarya	128.60	14.09	101.25	2.66	56.15
18	Thavalakannan (Ptb9)	143.60	13.00	107.31	2.50	57.67
19	Thekkancheera (Ptb10)	84.50	15.12	107.81	2.60	57.42

Table 26 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for plant height

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	0.4	-1.4	-10.7**	-	-	-
2	IR 62829A/Matta Triveni	7.1**	1.8	2.3	-3.6	-10.2**	-9.2**
3	IR 62829A/Kanchana	6.5**	1.5	1.5	-3.6	-8.9**	-8.9**
4	IR 62829A/IR 36	5.2	0.5	1.5	-	-	-
5	IR 62829A/Aiswarya	-5.7**	-16.8**	-1.5	-7.1**	-13.4**	-1.3
6	IR 68890A/Annapoorna	6.3**	-3.6	3.40	-1.7	-10.2**	-5.2
7	IR 68890A/Matta Triveni	-5.0	-8.1**	-1.30	-	-	-
8	IR 68890A/Kanchana	6.5**	2.9	10.4**	6.7*	3.9	9.6**
9	IR 68890A/IR 36	-2.7	-6.3**	0.5	1.7	-2.3	2.9
10	IR 68890A/Aiswarya	-1.8	-6.4**	10.5**	-8.1**	-12.7**	-2.1
11	IR 68891A/Annapoorna	3.7	-2.6	-3.1	-4.0	-9.8**	7.6**
12	IR 68891A/Matta Triveni	2.1	1.5	2.1	-	-	-
13	IR 68891A/Kanchana	-2.1	-2.3	-2.3	-	-	-
14	IR 68891A/IR 36	-1.5	-1.5	-2.1	2.1	0.8	10.4**
15	IR 68891A/Aiswarya	-5.7*	-13.2**	2.6	-	-	-
16	PMS 10A/Annapoorna	0.2	-2.5	-9.9**	-	-	-
17	PMS 10A/Matta Triveni	-1.7	-5.7*	-5.2	-	-	-
18	PMS 10A/Kanchana	6.1*	2.1	2.1	-	-	-
19	PMS 10A/IR 36	2.5	-1.1	-1.5	0.0	-3.9	-6.7*
20	PMS 10A/Aiswarya	10.1**	-1.9	15.9**	-5.8*	-17.5**	-3.4
21	IR 58025A/IR 8	-10.5**	-11.7**	-10.7**	0.0	-2.0	-0.9
22	IR 58025A/Jaya	-9.1**	-9.2**	-11.2**	-4.8	-4.9	-3.8
23	IR 58025A/Aiswarya	11.2**	3.6	21.3**	-9.9**	-14.6**	0.7
24	IR 62829A/Kairali	5.7**	0.7	-1.2	5.4*	-9.9**	-11.7**
25	IR 62829A/Aathira	10.2**	-4.3	15.5**	-5.8*	-18.2**	-1.3
26	IR 67684A/Kanchana	-3.2	-5.0**	-5.0*	0.0	-1.7	-1.7
27	IR 68890A/Ptb 10	12.3**	4.3*	28.3**	-5.8*	-12.6**	2.1
28	IR 68891A/IR 8	-8.3**	-8.7**	-9.4**	0.1	0.6	0.1
29	IR 68891A/Jaya	-6.2**	-7.2**	-6.3**	-4.3	-5.1	-4.2
30	PMS 3A/Jaya	4.3*	-0.1	0.8	-1.7	-5.7	-4.8
31	PMS 3A/Aiswarya	2.6	-7.9**	7.8**	-3.8	-13.6**	1.1
32	PMS 10A/Aruna	2.4	-2.5	-3.3	1.4	-3.4	-4.2
33	PMS 10A/Ptb 9	19.2**	-7.5**	50.1**	-	-	-
34	PMS 10A/Ptb 10	26.5**	9.2**	34.4**	-1.5	-14.9**	-4.6

* Significant at 5% level   di - Relative heterosis
** Significant at 1% level   dii - Heterobeltiosis
diii - Standard heterosis

(-18.2 to -8.9%). Standard heterosis over Kanchana ranged from -11.7 (Kairali/ IR 62829B) to 10.4 (IR 36/IR 68891B) per cent. Three hybrids were significant and positively heterotic, while four hybrids expressed significant negative standard heterosis.

4.4.1.2 Panicles per plant

Hybrids had a better expression of the character than their parents with mean values ranging from 5.9 (IR 58025A/Aiswarya) to 16.7 (IR 68891A/IR 8) in direct hybrids (Table 24). In reciprocal hybrids the mean values ranged between 6.2 (Annapoorna/IR 68890B) and 11.0 (IR 8/IR 68891B).

Results presented in Table 27 indicated significant positive relative heterosis for all the hybrids with the range between 0.0 (IR 58025A/Jaya) and 173.3 (IR 62829 A/Kairali) per cent. Twenty one hybrids showed significant positive heterobeltiosis and 26 hybrids recorded significant positive standard heterosis. Significant negative heterosis was not observed in both the cases. Highest heterobeltiosis for panicle number was exhibited by the hybrid IR 62829A/ Kairali (144.8%) and the highest standard heterosis was recorded by IR 68891A/ IR 8 (131.9%).

Relative heterosis in reciprocal hybrids ranged from -7.4 (Annapoorna/ IR 6889B) to 70.4 (Aiswarya/IR 62829B) per cent and 19 hybrids had significant positive relative heterosis. Twelve hybrids recorded significant positive heterobeltiosis and nine recorded significant positive standard heterosis. Aiswarya/IR 62829B had

Table 27 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for panicles per plant

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	73.3**	56.0**	34.4**	-	-	-
2	IR 62829A/Matta Triveni	57.4**	37.0*	27.5**	46.6**	33.3**	22.2*
3	IR 62829A/Kanchana	157.1**	117.2**	117.2**	34.4**	16.6	16.6
4	IR 62829A/IR 36	49.0**	22.5	31.0**	-	-	-
5	IR 62829A/Aiswarya	120.0**	83.3**	89.6**	70.4**	58.0**	36.1**
6	IR 68890A/Annapoorna	62.2**	53.5**	48.2**	-7.4	-11.4	-13.8
7	IR 68890A/Matta Triveni	110.9**	107.1**	100.0**	-	-	-
8	IR 68890A/Kanchana	107.0**	103.4**	103.4**	32.4**	33.3**	33.3**
9	IR 68890A/IR 36	15.2	9.6	17.2	47.2**	43.2**	47.2**
10	IR 68890A/Aiswarya	48.2**	43.3*	48.2**	27.2**	20.0	16.6
11	IR 68891A/Annapoorna	13.7	0.0	13.7	28.4**	20.5	22.2*
12	IR 68891A/Matta Triveni	70.0**	54.5**	75.8**	-	-	-
13	IR 68891A/Kanchana	70.9**	60.6**	82.7**	-	-	-
14	IR 68891A/IR 36	21.8	18.1	34.4*	33.3**	32.4**	36.1**
15	IR 68891A/Aiswarya	68.2**	60.6**	82.7**	-	-	-
16	PMS 10A/Annapoorna	28.5	16.1	24.1	-	-	-
17	PMS 10A/Matta Triveni	37.9*	29.0*	37.9**	-	-	-
18	PMS 10A/Kanchana	46.6**	41.9*	51.7**	-	-	-
19	PMS 10A/IR 36	38.7*	38.7*	48.2**	14.6	11.7	19.4
20	PMS 10A/Aiswarya	18.0	16.1	24.1	24.6*	11.7	19.4
21	IR 58025A/IR 8	54.4**	43.9**	31.9*	33.3**	18.8	13.9
22	IR 58025A/Jaya	0.0	-9.1	-16.6	50.0**	36.3**	25.0
23	IR 58025A/Aiswarya	1.7	-4.8	-18.1	41.3**	32.2**	13.8
24	IR 62829A/Kairali	173.3**	144.8**	127.8**	40.0**	25.3*	16.6
25	IR 62829A/Aathira	121.8**	100.0**	83.3**	50.0**	21.2	11.1
26	IR 67684A/Kanchana	85.7**	80.5**	80.5**	14.2	11.1	11.1
27	IR 68890A/Ptb 10	18.70	4.2	1.39	39.8**	22.8*	19.4
28	IR 68891A/IR 8	135.2**	128.7**	131.9**	23.9*	20.5	22.2
29	IR 68891A/Jaya	124.5**	113.7**	116.7**	-	-	-
30	PMS 3A/Jaya	44.9**	38.8**	38.8**	59.4**	52.7**	52.7**
31	PMS 3A/Aiswarya	13.4	5.5	5.5	37.3**	27.7*	27.7*
32	PMS 10A/Aruna	32.9**	31.2*	40.3**	42.1**	44.0**	50.0**
33	PMS 10A/Ptb 9	43.3**	18.2	26.4*	-	-	-
34	PMS 10A/Ptb 10	46.9**	25.9*	34.7**	21.2	3.9	11.1

* Significant at 5% level
** Significant at 1% level

di - Relative heterosis
dii - Heterobeltiosis
diii - Standard heterosis

the highest heterobeltiosis (58.0), whereas the highest level of standard heterosis was exhibited by Aruna/PMS 10B (50.0%).

4.4.1.3 Grain yield per plant

Among the female parents grain yield per plant varied from 7.5 g (IR 68891A) to 11.7 g (PMS 10 A) and in the male parents the range was between 13.2 g (Annapoorna) and 19.7 g (Kanchana). In direct hybrids the range was from 12.2 g (IR 580 25 A/Jaya) to 29.9 g (IR 688 90 A/Aiswarya). In reciprocal hybrids the values were high and the range was between 15.4 g (Annapoorna/IR 688 91B) and 28.8 g (Aiswarya/IR 688 90 B) (Table 24).

Results of the studies on heterosis (Table 28) indicated significant positive relative heterosis for 23 hybrids and significant positive heterobeltiosis for 12 hybrids. Two hybrids had significant negative heterobeltiosis. Standard heterosis in comparison with Kanchana, the highest yielding variety, showed a range between -38.3 (IR 58025A/Jaya) and 70.6 (IR 68890A/Aiswarya) per cent. Five hybrids had significant positive standard heterosis and three hybrids exhibited significant negative standard heterosis. Hybrid IR 68890A/Aiswarya manifested maximum hybrid vigour with highest values of relative heterosis (125.8%), heterobeltiosis (81.7%) and standard heterosis (70.6%).

Among the 24 reciprocal hybrids studied, 23 recorded highly significant and positive relative heterosis and 18 recorded significant positive heterobeltiosis. Twelve hybrids had significant positive standard heterosis and one recorded significant

Table 28 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for grain yield per plant

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	15.5	-2.1	-27.1	-	-	-
2	IR 62829A/Matta Triveni	64.3**	32.2	12.2	94.4**	51.6**	16.9
3	IR 62829A/Kanchana	75.7**	33.3*	33.3*	79.7**	37.9**	37.9**
4	IR 62829A/IR 36	2.6	-18.3	-28.4	-	-	-
5	IR 62829A/Aiswarya	34.2	4.1	-2.2	72.1**	40.2**	18.8*
6	IR 68890A/Annapoorna	73.6**	53.5**	14.4	135.7**	114.1**	43.0**
7	IR 68890A/Matta Triveni	12.2	-6.1	-20.2	-	-	-
8	IR 68890A/Kanchana	79.8**	41.4**	21.7**	18.4	8.5	8.5
9	IR 68890A/IR 36	40.8*	16.4	1.9	40.1**	16.3	-3.9
10	IR 68890A/Aiswarya	125.8**	81.7**	70.6**	109.7**	72.4**	45.9**
11	IR 68891A/Annapoorna	106.1**	62.1**	20.7	48.6**	16.6	-22.1*
12	IR 68891A/Matta Triveni	48.2*	11.4	-5.4	-	-	-
13	IR 68891A/Kanchana	45.5*	3.8	3.7	-	-	-
14	IR 68891A/IR 36	114.2**	59.3**	39.6**	80.4**	31.8**	8.8
15	IR 68891A/Aiswarya	40.5*	2.2	-3.9	-	-	-
16	PMS 10A/Annapoorna	23.4	12.2	16.2	-	-	-
17	PMS 10A/Matta Triveni	31.8	13.2	-3.82	-	-	-
18	PMS 10A/Kanchana	24.6	0.2	0.28	-	-	-
19	PMS 10A/IR 36	54.7**	31.2	14.9	68.7**	45.2**	19.8*
20	PMS 10A/Aiswarya	58.4**	30.6	22.6	44.9**	23.4	4.4
21	IR 58025A/IR 8	61.7**	27.6*	4.8	102.9**	60.0**	31.4**
22	IR 58025A/Jaya	-9.4	-30.5*	-38.3**	95.6**	49.9**	33.2**
23	IR 58025A/Aiswarya	-5.6	-26.4*	-37.7**	94.6**	51.5**	28.2**
24	IR 62829A/Kairali	34.8**	12.5	10.0	63.5**	36.4**	9.1
25	IR 62829A/Aathira	79.6**	47.0**	23.3*	80.6**	47.8**	24.0**
26	IR 67684A/Kanchana	10.2	-22.1	-22.1*	67.8**	18.4*	18.4*
27	IR 68890A/Ptb 10	74.2**	51.0**	12.2	62.9**	41.2**	4.9
28	IR 68891A/IR 8	40.7**	-2.5	-15.5	74.1**	27.2*	4.5
29	IR 68891A/Jaya	45.0**	3.4	-8.0	45.9**	4.1	-7.5
30	PMS 3A/Jaya	17.8	-1.8	-12.7	53.9**	28.2**	13.9
31	PMS 3A/ Aiswarya	26.5**	7.5	-8.9	59.2**	35.2**	14.4
32	PMS 10A/Aruna	62.2**	41.8**	12.6	84.8**	61.6**	28.2**
33	PMS 10A/Ptb 9	72.7**	56.5**	14.8	-	-	-
34	PMS 10A/Ptb 10	72.5**	55.5**	15.5	83.3**	65.1**	22.7*

* Significant at 5% level di - Relative heterosis
** Significant at 1% level dii - Heterobeltiosis
diii - Standard heterosis

negative standard heterosis. Among the reciprocal hybrids highest values of relative heterosis and heterobeltiosis were recorded by Annapoorna/IR 68890B (135.7% and 114.1%) whereas highest standard heterosis was exhibited by Aiswarya/IR 68890B (45.9%).

4.4.1.4 Straw yield per plant

Among hybrids straw yield varied from 15.8 g (IR 62829A/Kanchana) to 27.9 g (IR 62829A/Aiswarya). Reciprocal hybrids exhibited a range from 15.9 g (Annapoorna/IR 68891B) to 27.0 g (Ptb 10/PMS 10B) (Table 24).

Magnitude of relative heterosis for straw yield per plant varied from -14.3 (IR 68890A/Matta Triveni) to 55.3 (IR 62829A/Aiswarya) per cent. Eighteen hybrids recorded significant positive relative heterosis. Heterobeltiosis was significant and positive for 10 hybrids, while it was significant and negative for two hybrids. Significant positive standard heterosis was exhibited by 21 hybrids with the range from 18.6 (IR 67684A/Kanchana) to 71.8 (IR 62829A/Aiswarya).

In reciprocal hybrids, seven recorded significant positive relative heterosis, five recorded significant positive heterobeltiosis and eleven recorded significant positive standard heterosis. Significant negative heterosis was not observed in any of these cases. Highest value for relative heterosis and heterobeltiosis was recorded by Aiswarya/PMS 3B (47.6% and 47.5%) whereas Ptb 10/PMS 10B (62.3%) had highest standard heterosis (Table 29).

Table 29 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for straw yield per plant

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	0.0	-12.4	-1.2	-	-	-
2	IR 62829A/Matta Triveni	29.5**	25.2*	41.1**	13.2	9.7	15.5
3	IR 62829A/Kanchana	-8.8	-14.0	-3.1	14.2	11.3	17.2
4	IR 62829A/IR 36	-11.8	-16.5	5.3	-	-	-
5	IR 62829A/Aiswarya	55.3**	52.4**	71.8**	12.4	10.1	20.9*
6	IR 68890A/Annapoorna	-1.3	-22.6**	15.2	28.3*	6.3	32.4**
7	IR 68890A/Matta Triveni	-14.3	-26.9**	8.9	-	-	-
8	IR 68890A/Kanchana	7.1	-10.5	33.4**	-0.2	-12.1	9.3
9	IR 68890A/IR 36	11.1	2.5	52.9**	4.2	7.7	14.8
10	IR 68890A/Aiswarya	23.1*	6.3	58.6**	28.4**	20.9**	50.5**
11	IR 68891A/Annapoorna	28.1*	11.3	27.7*	1.2	-10.7	-4.2
12	IR 68891A/Matta Triveni	10.4	5.8	21.4	-	-	-
13	IR 68891A/Kanchana	15.4	8.0	23.8	-	-	-
14	IR 68891A/IR 36	-2.4	-6.9	17.4	7.1	0.7	8.1
15	IR 68891A/Aiswarya	5.9	3.1	18.2	-	-	-
16	PMS 10A/Annapoorna	24.4*	13.6	16.7	-	-	-
17	PMS 10A/Matta Triveni	18.1	16.7	22.8	-	-	-
18	PMS 10A/Kanchana	22.8*	21.2	22.5*	-	-	-
19	PMS 10A/IR 36	14.0	3.4	30.5*	35.8**	30.2**	33.9**
20	PMS 10A/Aiswarya	17.8	14.7	22.5*	18.9	15.1	26.5**
21	IR 58025A/IR 8	3.9	-0.3	4.9	12.2	10.1	13.2
22	IR 58025A/Jaya	29.9**	32.2**	31.3**	18.2	16.1	19.5
23	IR 58025A/Aiswarya	32.2**	27.9**	40.5**	19.5	14.9	26.2**
24	IR 62829A/Kairali	31.5**	27.4**	34.2**	19.0	15.3	21.4
25	IR 62829A/Aathira	23.5**	15.2	40.2**	1.1	-5.6	14.8
26	IR 67684A/Kanchana	33.3**	18.6*	18.6*	28.5*	14.3	14.3
27	IR 68890A/Ptb 10	15.4**	12.3	48.1**	17.1	13.7	50.2**
28	IR 68891A/IR 8	42.0**	36.5**	46.4**	25.9*	21.1**	29.8**
29	IR 68891A/Jaya	25.2**	20.6**	29.4**	12.1	7.9	15.8
30	PMS 3A/Jaya	25.2**	22.2**	31.0**	9.6	4.3	14.7
31	PMS 3A/Aiswarya	23.1**	23.0**	35.2**	47.6**	47.5**	62.2**
32	PMS 10A/Aruna	12.2	9.9	13.1	23.1	20.6	24.1*
33	PMS 10A/Ptb 9	19.9**	6.1	41.7**	-	-	-
34	PMS 10A/Ptb 10	20.1**	6.8	41.0**	38.4**	23.1*	62.3**

* Significant at 5% level
** Significant at 1% level

di - Relative heterosis
dii - Heterobeltiosis
diii - Standard heterosis

4.4.1.5 **Days to flowering**

Days to flowering in hybrids varied between 75.3 days (IR 62829A/ Annapoorna) and 96.7 days (PMS 3A/Jaya). Reciprocal hybrids had variation between 76.4 days (Matta Triveni/IR 62829B) and 98 days (Aiswarya/ PMS 3B) (Table 24).

Out of 34 hybrids evaluated 23 had significant negative relative heterosis and five recorded significant positive heterotic vigour (Table 30). Magnitude of relative heterosis for days to flowering ranged from -10.8 (PMS 10A/IR 36) to 8.6 (PMS 10A/Aruna) per cent. Significant negative heterobeltiosis was recorded by 34 hybrids with overall range between -16.6 (IR 62829A/Aathira) and -2.6 (IR 68891A/Matta Triveni) per cent. Standard heterosis in comparison with Kanchana ranged from -11.7 (IR 62829A/Annapoorna) to 13.6 (PMS 3A/Jaya) per cent. Eighteen hybrids recorded significant negative standard heterosis and 11 hybrids exhibited significant positive standard heterosis.

Among reciprocal hybrids 15 recorded significant negative relative heterosis and three recorded significant positive relative heterosis. The range was from -11.9 (IR 36/PMS 10B) to 6.2 (Ptb 10/PMS 10B). Significant negative hetero beltiosis was exhibited by 23 hybrids and eight hybrids recorded significant negative standard heterosis. Standard heterosis in comparison with Kanchana was positive for another eight hybrids.

Table 30 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for days to flowering

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	-4.2**	-9.3**	-11.7**	-	-	-
2	IR 62829A/Matta Triveni	-3.5**	-5.7**	-8.2**	-5.9**	-8.0**	-10.2**
3	IR 62829A/Kanchana	-6.1**	-7.3**	-7.3**	-7.7**	-8.8**	-8.8**
4	IR 62829A/IR 36	-5.2**	-8.1**	-4.6**	-	-	-
5	IR 62829A/Aiswarya	-5.5**	-8.9**	-4.3**	-4.6**	-8.1**	-3.1**
6	IR 68890A/Annapoorna	1.8*	-7.4**	-1.4	-7.4**	-12.7**	-6.4**
7	IR 68890A/Matta Triveni	-5.8**	-11.8**	-6.1**	-	-	-
8	IR 68890A/Kanchana	-3.4**	-6.3**	-2.9**	-2.7**	-5.9**	0.8
9	IR 68890A/IR 36	-3.4**	-4.6**	1.4	-5.3**	-4.8**	2.0
10	IR 68890A/Aiswarya	-3.4**	-4.1**	2.1*	-3.3**	-4.6**	2.2*
11	IR 68891A/Annapoorna	4.2**	-1.7	-3.2**	-5.6**	-4.9**	-6.2**
12	IR 68891A/Matta Triveni	0.1	-2.6**	-4.1**	-	-	-
13	IR 68891A/Kanchana	-0.1	-0.8	-0.8	-	-	-
14	IR 68891A/IR 36	-2.6**	-5.0**	-1.4	2.6**	-8.4**	-4.3**
15	IR 68891A/Aiswarya	2.5**	-0.5	4.4**	-	-	-
16	PMS 10A/Annapoorna	-4.7**	-14.6**	-6.1**	-	-	-
17	PMS 10A/Matta Triveni	-7.5**	-14.6**	-6.1**	-	-	-
18	PMS 10A/Kanchana	-9.2**	-13.3**	-4.6**	-	-	-
19	PMS 10A/IR 36	-10.8**	-13.3**	-4.6**	-11.9**	-9.4**	0.0
20	PMS 10A/Aiswarya	-1.7*	-4.0**	5.5**	-1.7	-3.9**	5.6**
21	IR 58025A/IR 8	-4.5**	-0.2	4.2**	-6.6**	-13.0**	1.5
22	IR 58025A/Jaya	-6.2**	-12.8**	3.3**	-7.1**	-7.2**	2.2*
23	IR 58025A/Aiswarya	0.6	-1.0	4.3**	2.20*	0.50	6.0**
24	IR 62829A/Kairali	-3.1**	-5.5**	-2.9**	-5.1**	-7.5**	-5.0**
25	IR 62829A/Aathira	-10.5**	-16.6**	-5.7**	-2.4**	-9.1**	2.7**
26	IR 67684A/Kanchana	-0.2	-0.9	-0.9	-1.5	-2.2*	-2.2*
27	IR 68890A/Ptb 10	-3.5**	-10.5**	-4.1**	-7.1**	-7.9**	-1.3
28	IR 68891A/IR 8	-0.5	-12.5**	2.1*	0.0	-12.8**	1.7
29	IR 68891A/Jaya	-7.0**	-14.8**	0.9	-1.3	-9.6**	7.1**
30	PMS 3A/Jaya	0.7	-4.2**	13.6**	-8.3**	-7.6**	7.1**
31	PMS 3A/ Aiswarya	2.1*	1.3	8.5**	-2.2*	-1.9	3.4**
32	PMS 10A/Aruna	8.6**	-11.0**	3.5**	-6.2**	-8.6**	6.2**
33	PMS 10A/Ptb 9	-6.2**	-9.5**	7.5**	-	-	-
34	PMS 10A/Ptb 10	-4.6**	-9.1**	0.3	6.2**	-10.5**	-1.3

* Significant at 5% level di - Relative heterosis
** Significant at 1% level dii - Heterobeltiosis
diii - Standard heterosis

4.4.1.6 Harvest index

Among female parents harvest index ranged from 0.3 (IR-688 91 A) to 0.4 (PMS 10A) and that among male parents was from 0.4 (Ptb 9 and Ptb 10) to 0.5 (IR 36 and Jaya). Harvest index exhibited a range from 0.3 (IR 58025 A/Aiswarya) to 0.6 (IR 628 29A/Kanchana) among the hybrids. Reciprocal hybrids exhibited higher harvest index and the range was from 0.5 to 0.6 (Table 24).

Estimation of hybrid vigour over mid parent values revealed significant positive relative heterosis for 15 hybrids and significant negative relative heterosis for three hybrids (Table 31). Heterosis over better parent was positive and significant for five hybrids, while it was negative and significant for another five hybrids. Standard heterosis was significant and positive for only one hybrid whereas 14 hybrids had significant negative standard heterosis.

All the 24 reciprocal hybrids exhibited positive relative heterosis with 16 of then showing significant values. The range was from 0.8 (IR 8/IR 68891B) to 37.5 (IR 8/IR 58025B) per cent. Heterobeltiosis was significant and positive for 10 hybrids whereas none of the hybrids had significant standard heterosis.

4.4.1.7 Filled grains per panicle

Direct hybrids originated from A/R combinations recorded a range from 86.0 (IR 58025A/Jaya) to 173.0 (PMS 10A/Ptb 9) and in reciprocal hybrids the range was from 105.4 (Aiswarya/IR 58025B) to 159.2 (Aiswarya/PMS 3B (Table 25).

Table 31 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for harvest index

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	8.8	-8.7	-11.7	-	-	-
2	IR 62829A/Matta Triveni	13.0	-4.2	-11.7	26.6**	12.3*	1.1
3	IR 62829A/Kanchana	40.2**	15.1*	15.6*	27.7**	8.1	8.1
4	IR 62829A/IR 36	11.2	-1.1	-17.6*	-	-	-
5	IR 62829A/Aiswarya	-7.4	-21.8**	-25.4**	26.2**	13.2*	-0.5
6	IR 68890A/Annapoorna	31.1**	4.6	0.0	34.9**	14.8*	4.2
7	IR 68890A/Matta Triveni	14.3	-7.8	-13.7*	-	-	-
8	IR 68890A/Kanchana	31.1**	2.4	3.9	11.9	-8.3	-8.3
9	IR 68890A/IR 36	13.2	-4.7	-19.6**	15.5*	-3.4	-8.3
10	IR 68890A/Aiswarya	39.6**	11.9	5.8	30.2**	12.4*	-1.2
11	IR 68891A/Annapoorna	28.6**	2.5	-1.9	24.6**	0.0	-9.2
12	IR 68891A/Matta Triveni	18.3*	-4.7	-11.7	-	-	-
13	IR 68891A/Kanchana	18.0*	-7.7	-5.8	-	-	-
14	IR 68891A/IR 36	55.9**	31.1**	9.8	33.9**	5.6	0.5
15	IR 68891A/Aiswarya	21.4*	-2.6	-7.8	-	-	-
16	PMS 10A/Annapoorna	-1.1	-10.7	-13.7*	-	-	-
17	PMS 10A/Matta Triveni	4.9	-4.2	-9.8	-	-	-
18	PMS 10A/Kanchana	2.4	-9.7	-7.8	11.2	-0.1	-4.9
19	PMS 10A/IR 36	19.8*	15.2*	-3.9	12.4	-3.4	-8.3
20	PMS 10A/Aiswarya	16.9*	6.2	0.0	-	-	-
21	IR 58025A/IR 8	25.2**	8.2	-2.0	37.5**	17.3**	7.5
22	IR 58025A/Jaya	-28.2**	-32.4**	-35.6**	17.1*	10.0	4.9
23	IR 58025A/Aiswarya	-17.1**	-28.0**	-36.7**	31.9**	14.7*	0.7
24	IR 62829A/Kairali	-7.8	-11.2	-19.3**	8.6	4.6	-4.9
25	IR 62829A/Aathira	12.1	11.6	-6.3	24.5**	24.8**	4.1
26	IR 67684A/Kanchana	-6.8	-11.2	-19.4**	17.3**	1.4	1.4
27	IR 68890A/Ptb 10	9.3	2.2	-12.9*	4.6	12.6*	-1[illegible].2
28	IR 68891A/IR 8	-15.8**	-18.3**	-25.1**	0.8	-2.0	-10.1
29	IR 68891A/Jaya	-7.8	-12.2	-16.2**	19.6**	-5.6	-10.1
30	PMS 3A/Jaya	-11.0	-15.3*	-19.2**	18.8**	5.0	0.1
31	PMS 3A/ Aiswarya	2.5	-7.1	-18.5**	5.5	-4.0	-15.7
32	PMS 10A/Aruna	21.3**	12.3	-0.3	23.8**	14.7*	1.8
33	PMS 10A/Ptb 9	20.6**	18.6*	-10.3	-	-	-
34	PMS 10A/Ptb 10	21.2**	20.0**	-9.2	16.5	17.6**	-12.5

* Significant at 5% level
** Significant at 1% level

di - Relative heterosis
dii - Heterobeltiosis
diii - Standard heterosis

Studies on heterosis in 34 hybrids revealed significant positive relative heterosis for 10 hybrids and significant negative relative heterosis for six hybrids with an overall range from -18.79 (IR-688 90 A/Aiswarya) to 66.8 (PMS 10 A/Ptb 10) per cent (Table 32). Heterobeltiosis was significant and positive for five hybrids while it was negative and significant for eleven hybrids. Three hybrids recorded significant positive standard heterosis and five hybrids exhibited significant negative standard heterosis over the check variety, Kanchana.

Relative heterosis was significant and positive in 12 out of the 24 reciprocal hybrids. Three hybrids recorded significant positive heterobeltiosis and six hybrids exhibited significant positive standard heterosis. Significant negative heterosis was not observed in any of the reciprocal hybrids.

4.4.1.8 Spikelet sterility

In direct hybrids spikelet sterility varied between 13.2 (PMS 10A/Ptb 10) and 24.9 (IR 68891A/IR 8) per cent. Reciprocal hybrids registered low values of spikelet sterility and the range was between 8.3 (Aiswarya/PMS 10B) and 19.6 (Matta Triveni/IR 62829B).

Studies on heterosis in 34 hybrids revealed significant positive relative heterosis in 13 hybrids and significant negative relative heterosis in one hybrid (Table 33). Hetero beltiosis ranged from -33.9 (IR 62829 A/Aiswarya) to 71.5 (IR 68890A/Matta Triveni). Eight hybrids manifested significant positive heterobeltiosis and four hybrids recorded significant negative heterobeltiosis.

Table 32 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for filled grains per panicle

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	29.7*	28.3*	-5.7	-	-	-
2	IR 62829A/Matta Triveni	-8.7	-25.1**	-14.4	14.6	-8.5	0.4
3	IR 62829A/Kanchana	25.8*	9.1	9.1	30.1**	7.7	7.7
4	IR 62829A/IR 36	18.1*	-1.2	8.0	-	-	-
5	IR 62829A/Aiswarya	18.1	-6.3	17.3	34.3**	6.5	18.8
6	IR 68890A/Annapoorna	-6.9	-24.8*	-12.1	30.4**	10.9	14.1
7	IR 68890A/Matta Triveni	-18.2*	-19.1*	-5.4	-	-	-
8	IR 68890A/Kanchana	8.4	0.5	17.6	11.3	9.7	12.7
9	IR 68890A/IR 36	-15.6*	-18.4*	-4.5	-8.2	-13.1	0.0
10	IR 68890A/Aiswarya	-18.7*	-21.5**	-1.6	13.3	8.8	21.4*
11	IR 68891A/Annapoorna	24.6	23.9*	-9.8	48.7**	45.5**	5.2
12	IR 68891A/Matta Triveni	4.7	-4.2	-2.1	-	-	-
13	IR 68891A/Kanchana	8.6	-6.1	-6.1	-	-	-
14	IR 68891A/IR 36	57.0**	30.7**	43.0**	44.2**	15.5	32.8**
15	IR 68891A/Aiswarya	1.3	-19.8**	0.4	-	-	-
16	PMS 10A/Annapoorna	11.6	-11.2	7.6	-	-	-
17	PMS 10A/Matta Triveni	-14.7*	-17.4*	0.6	-	-	-
18	PMS 10A/Kanchana	-5.9	-14.4	4.3	-	-	-
19	PMS 10A/IR 36	-1.2	-6.3	14.1	8.1	2.7	17.9
20	PMS 10A/Aiswarya	-10.8	-12.0	10.2	17.1	12.7	25.7*
21	IR 58025A/IR 8	8.1	3.7	-5.5	11.8	7.2	-2.3
22	IR 58025 A/Jaya	-11.6	-12.4*	-25.5**	25.3	24.2*	5.8
23	IR 58025A/Aiswarya	-18.4**	-28.6**	-20.4**	-6.3	-16.7	-8.5
24	IR 62829A/Kairali	0.0	-17.2**	-17.1*	39.9**	15.7	15.7
25	IR 62829A/Aathira	13.0*	-10.8	0.0	16.5	-7.6	3.2
26	IR 67684A/Kanchana	-1.9	-13.0	-13.0	20.9	7.5	7.5
27	IR 68890A/Ptb 10	25.3**	7.4	10.3	32.4**	13.1	16.5
28	IR 68891A/IR 8	4.1	-8.3	-16.5*	54.9**	36.3**	24.1*
29	IR 68891A/Jaya	8.0	-2.0	-16.5*	40.2**	27.1	8.2
30	PMS 3A/Jaya	18.0**	9.2	9.5	16.7	7.9	8.2
31	PMS 3A/Aiswarya	-18.1**	-22.4**	-13.3	30.3**	23.7	38.1**
32	PMS 10A/Aruna	9.2	3.4	6.7	29.6*	22.6	26.6*
33	PMS 10A/Ptb 9	32.0**	20.5**	50.0**	-	-	-
34	PMS 10A/Ptb 10	66.8**	42.0**	47.0**	24.5*	6.5	9.9

* Significant at 5% level di - Relative heterosis
** Significant at 1% level dii - Heterobeltiosis
diii - Standard heterosis

Table 33 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for spikelet sterility

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	-13.7	-20.5	60.8**	-	-	-
2	IR 62829A/Matta Triveni	-6.9	-22.8	56.3**	-44.7**	-53.2**	-21.8
3	IR 62829A/Kanchana	1.6	-24.1	53.8**	-44.5**	-55.6**	-25.9*
4	IR 62829A/IR 36	-11.0	-29.2**	43.3*	-	-	-
5	IR 62829A/Aiswarya	-19.2	-33.9**	33.8*	-29.4**	-40.4**	-0.5
6	IR 68890A/Annapoorna	9.4	-9.0	55.2**	-18.7	-26.4**	-7.2
7	IR 68890A/Matta Triveni	85.7**	71.5**	128.9**	-	-	-
8	IR 68890A/Kanchana	28.8	21.3	37.1**	-25.1*	-25.9*	-24.3*
9	IR 68890A/IR 36	31.7	28.1	53.2**	11.9	8.4	18.6
10	IR 68890A/Aiswarya	62.1**	52.2*	96.2**	-20.4	-24.3*	-12.2
11	IR 68891A/Annapoorna	24.9	21.3	107.1**	-26.4*	-28.6*	-4.3
12	IR 68891A/Matta Triveni	31.7*	20.4	93.8**	-	-	-
13	IR 68891A/Kanchana	57.8**	27.9	105.9**	-	-	-
14	IR 68891A/IR 36	0.0	-12.8	40.2**	-34.5**	-40.6**	-20.4
15	IR 68891A/Aiswarya	59.1**	43.3**	130.5**	-	-	-
16	PMS 10A/Annapoorna	14.7	3.7	77.1**	-	-	-
17	PMS 10A/Matta Triveni	17.3	15.4	59.7**	-	-	-
18	PMS 10A/Kanchana	66.1**	43.3**	97.6**	-	-	-
19	PMS 10A/IR 36	13.5	6.0	46.1**	-8.8	-17.7	9.0
20	PMS 10A/Aiswarya	7.1	3.6	42.8**	-23.7*	-29.5*	-4.8
21	IR 58025A/IR 8	3.3	-16.0	40.6**	-33.9**	-46.2**	-9.8
22	IR 58025A/Jaya	15.7*	11.1	87.0**	-44.2**	-46.4**	-11.3
23	IR 58025A/Aiswarya	18.5*	-0.5	66.7**	-35.4**	-45.7**	-9.0
24	IR 62829A/Kairali	2.8	-12.7	45.5**	-26.7**	-37.8**	3.8
25	IR 62829A/Aathira	-22.4**	-32.7**	12.2	-38.3**	-46.4**	-10.6
26	IR 67684A/Kanchana	15.9*	-2.2	42.3**	-12.1	-26.2**	7.8
27	IR 68890A/Ptb 10	1.4	-7.30	13.8	-17.2	-24.4**	-7.1
28	IR 68891A/IR 8	70.0**	51.5**	103.3**	-18.1	-26.9**	-2.0
29	IR 68891A/Jaya	35.9**	46.5**	96.70**	-32.2**	-36.0**	-1.9
30	PMS 3A/Jaya	27.2**	15.8*	78.9**	-15.6	-23.2*	-18.7
31	PMS 3A/Aiswarya	37.6**	25.5**	66.6**	-44.2**	-47.1**	-32.3**
32	PMS 10A/Aruna	-0.6	-8.4	23.0	-9.0	-16.1	-13.2
33	PMS 10A/Ptb 9	8.1	-3.6	30.0*	-	-	-
34	PMS 10A/Ptb 10	-14.5	-20.5**	8.1	-17.3	-25.3**	0.8

* Significant at 5% level di - Relative heterosis
** Significant at 1% level dii - Heterobeltiosis
diii - Standard heterosis

All the hybrids exhibited positive standard heterosis over Kanchana out of which 30 were significant.

All the reciprocal hybrids, except one registered negative heterosis over mid parent with a range from -44.7 (Matta Triveni/IR 62829B) to 11.9 (IR 36/ IR 68890B) per cent. Out of the 24 hybrids evaluated 14 exhibited significant negative relative heterosis and 21 recorded significant negative heterobeltiosis. Twenty hybrids registered negative standard heterosis when compared with Kanchana.

4.4.1.9. Panicle exsertion

Percentage of panicle exsertion of hybrids ranged from 64.4 to 106.5 (Table 25). Eight hybrids expressed panicle exsertion above 100 per cent. In reciprocal hybrids, extent of panicle exsertion ranged from 90.9 per cent to 110.6 per cent.

All the hybrids except two expressed negative heterosis over mid parent. Among them 24 were significant and heterosis was between -36.3 (IR 62829A/ Aiswarya) and 3.7 (IR 68891A/Annapoorna) per cent. Heterobeltiosis was negative for all the hybrids except one. Significant positive standard heterosis was expressed by five hybrids and significant negative standard heterosis by 23 hybrids (Table 34).

Among reciprocal hybrids heterosis for panicle exsertion was significant and positive over mid parent for five hybrids, whereas negative and significant only for one hybrid. Heterobeltiosis was significant for only two hybrids; one being positive and the other negative. Standard heterosis was significant and positive for 18 hybrids

Table 34 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for panicle exsertion

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	-22.8**	-24.0**	-23.0**	-	-	-
2	IR 62829A/Matta Triveni	-12.8**	-13.4**	-13.6**	3.3	3.0	14.8**
3	IR 62829A/Kanchana	-14.5**	-15.3**	-15.3**	11.3**	5.7	17.3**
4	IR 62829A/IR 36	-28.1**	-31.5**	-25.7**	-	-	-
5	IR 62829A/Aiswarya	-36.3**	-36.9**	-36.9**	6.3	6.0	17.0**
6	IR 68890A/Annapoorna	-9.0*	-9.1**	-8.0*	6.0	2.7	18.5**
7	IR 68890A/Matta Triveni	-22.8**	-22.4**	-22.6**	-	-	-
8	IR 68890A/Kanchana	-17.0**	-17.3**	-16.6**	11.4**	6.1	17.4**
9	IR 68890A/IR 36	-33.7**	-36.0**	-30.6**	-1.8	-5.1	12.6*
10	IR 68890A/Aiswarya	-15.2**	-15.6**	-14.8**	9.0*	9.1*	20.4**
11	IR 68891A/Annapoorna	3.7	3.08	4.34	0.0	-1.5	11.1
12	IR 68891A/Matta Triveni	-20.9**	-20.9**	-26.5**	-	-	-
13	IR 68891A/Kanchana	-30.3**	-30.0**	-30.0**	-	-	-
14	IR 68891A/IR 36	-4.9	-8.6*	-0.9	0.8	-3.0	15.1**
15	IR 68891A/Aiswarya	-32.3**	-32.3**	-32.3**	-	-	-
16	PMS 10A/Annapoorna	-29.0**	-30.3**	-26.9**	-	-	-
17	PMS 10A/Matta Triveni	-19.1**	-21.0**	-17.3**	-	-	--
18	PMS 10A/Kanchana	-22.3**	-24.0**	-20.4**	-	-	-
19	PMS 10A/IR 36	-2.0	-3.60	4.4	-7.2	-5.6	8.4
20	PMS 10A/Aiswarya	-18.0**	-19.9**	-16.0**	-6.3	-5.5	8.6
21	IR 58025A/IR 8	-23.1**	-24.4**	-17.2**	-8.0*	-9.6*	-0.9
22	IR 58025A/Jaya	-15.3**	-17.3**	-8.1*	0.6	-1.6	9.1
23	IR 58025A/Aiswarya	-28.6**	-30.0**	-22.9**	4.7	2.7	13.3**
24	IR 62829A/Kairali	-21.4**	-29.2**	-21.9**	3.2	3.0	14.3**
25	IR 62829A/Aathira	-17.8**	-18.0**	-9.0**	5.8	5.6	17.1**
26	IR 67684A/Kanchana	-17.2**	-29.7**	-22.3**	15.3**	-1.6	8.1
27	IR 68890A/Ptb 10	-2.6	-5.5	11.0**	4.1	9.1	20.4**
28	IR 68891A/IR 8	-7.1	-7.2	1.6	3.9	3.9	13.9**
29	IR 68891A/Jaya	-7.9	-8.5*	1.5	7.9*	7.3	19.0**
30	PMS 3A/Jaya	-3.1	-4.8	9.4**	2.2	3.9	10.4*
31	PMS 3A/ Aiswarya	-1.3	-3.3	11.1**	1.4	3.5	14.2**
32	PMS 10A/Aruna	0.2	-1.4	13.2**	4.9	6.5	18.6**
33	PMS 10A/Ptb 9	-2.9	-3.7	12.5**	-	-	-
34	PMS 10A/Ptb 10	-9.0**	-10.1**	5.5	-4.2	-5.3	11.2*

* Significant at 5% level   di - Relative heterosis
** Significant at 1% level   dii - Heterobeltiosis
diii - Standard heterosis

ranging from -0.9 (IR 8/IR 58025B) to 20.4 (Aiswarya/IR 68890B and Ptb 10/ IR 68890B) per cent.

4.4.1.10 Hundred seed weight

Female parents recorded low values for 100 seed weight which ranged from 2.0 g (IR 67684A) to 2.6 g (IR 68890A), whereas male parents manifested a higher expression of the character ranging from 2.3 (IR 36) to 2.8 g (Jaya). Among hybrids the range was from 1.9 g (IR 62829A/Kairali) to 3.0 g (IR 68890A/Aiswarya). Reciprocal hybrids expressed higher values for 100 seed weight and the range was between 2.2 g (Kairali/IR 62829B) and 2.8 g (Aiswarya/ IR 58025B).

Heterosis over mid parent was positive and significant for three hybrids, while it was significant and negative for 17 hybrids with the range being -20.5 (IR 68891 A/Annapoorna) to 12.9 (IR 68890 A/Aiswarya) per cent. All hybrids, except two recorded negative heterosis over better parent and it was significant for 28 of them. Standard heterosis over Kanchana was significant and negative for 31 hybrids. Only IR 68890 A/Aiswarya exhibited significant positive heterobeltiosis and standard heterosis for 100 seed weight (Table 35).

Among the 24 reciprocal hybrids, six exhibited significant negative relative heterosis and seven recorded significant positive heterosis over mid parent. Heterobeltiosis ranged from -17.0 (Kanchana/IR 62829 B) to 7.1 (Aiswarya/ IR 58025 B) and 14 hybrids had significant negative heterobeltiosis. Only one hybrid exhibited highly significant positive heterobeltiosis and standard heterosis. Twenty hybrids had significant negative standard heterosis.

Table 35 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for 100 seed weight

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	-0.4	-6.1*	-12.1**	-	-	-
2	IR 62829A/Matta Triveni	-2.5	-10.5**	-11.3**	-5.2*	-11.7**	-14.9**
3	IR 62829A/Kanchana	5.2*	-3.8	-3.8	-9.3**	-17.0**	-17.1**
4	IR 62829A/IR 36	-9.9**	-12.0**	-23.4**	-	-	-
5	IR 62829A/Aiswarya	7.3**	-2.8	-1.1	2.5	-6.4**	-6.0*
6	IR 68890A/Annapoorna	3.5	0.9	-0.7	5.1*	1.5	0.00
7	IR 68890A/Matta Triveni	-5.4*	-5.7*	-6.8**	-	-	-
8	IR 68890A/Kanchana	-9.6**	-10.4**	-10.2**	-12.1**	-12.5**	-12.5**
9	IR 68890A/IR 36	-18.5**	-13.0**	-24.5**	-1.6	-7.3**	-8.8**
10	IR 68890A/Aiswarya	12.9**	10.9**	12.8**	1.14	0.3	0.7
11	IR 68891A/Annapoorna	-20.5**	-21.3**	-24.9**	-1.6	-3.6	-8.7**
12	IR 68891A/Matta Triveni	-18.5**	-20.0**	-20.8**	-	-	-
13	IR 68891A/Kanchana	-11.1**	-13.2**	-13.2**	-	-	-
14	IR 68891A/IR 36	-17.1**	-20.8**	-24.5**	-3.3	-7.6**	-12.5**
15	IR 68891A/Aiswarya	-12.0**	-14.8**	-13.2**	-	-	-
16	PMS 10A/Annapoorna	-8.2**	-15.7**	-21.1**	-	-	-
17	PMS 10A/Matta Triveni	-6.4**	-16.2**	-17.0**	-	-	-
18	PMS 10A/Kanchana	-8.0**	-18.0**	-18.1**	-	-	-
19	PMS 10A/IR 36	-9.7**	-14.1**	-25.7**	3.6	0.0	-13.6**
20	PMS 10A/Aiswarya	-2.6	-13.9**	-12.0**	7.6**	-3.8	-3.4
21	IR 58025A/IR 8	-1.2	-3.2	-13.2**	3.6	-6.2**	-6.2*
22	IR 58025A/Jaya	-9.6	-20.2**	-15.0**	-2.0	-14.4**	-8.0**
23	IR 58025A/Aiswarya	0.4	-9.0	-8.7**	18.3**	7.1**	7.6**
24	IR 62829A/Kairali	-18.0**	-20.8**	-29.4**	-5.3*	-8.5**	-18.5**
25	IR 62829A/Aathira	-2.9	-10.7**	-11.7**	0.9	-7.3**	-8.3**
26	IR 67684A/Kanchana	-4.2	-15.5**	-15.5**	6.0*	-6.4*	-6.4*
27	IR 68890A/Ptb 10	-3.4	-3.8	-4.9**	-5.4*	-5.7	-6.8*
28	IR 68891A/IR 8	-4.4	-7.1**	-7.1**	-4.7	-7.5**	-7.6**
29	IR 68891A/Jaya	-6.3	-11.7**	-6.0**	-15.8**	-15.5**	-15.5**
30	PMS 3A/Jaya	3.0	-8.6**	-8.6**	0.4	-16.3**	-10.9**
31	PMS 3A/Aiswarya	-6.1	-16.9**	-16.6**	7.7**	-4.9	-4.5
32	PMS 10A/Aruna	-17.2**	-23.4**	-28.3**	7.9**	-0.4	-6.8*
33	PMS 10A/Ptb 9	-9.7**	-16.8**	-23.7**	-	-	-
34	PMS 10A/Ptb 10	2.5	-7.3**	-9.0**	6.4**	-3.8	-5.7*

* Significant at 5% level   di - Relative heterosis
** Significant at 1% level   dii - Heterobeltiosis
diii - Standard heterosis

4.4.1.11 Grain density

Seven hybrids had significant positive heterosis over mid parent and four recorded significant negative heterosis. Heterobeltiosis was significant and negative for 13 hybrids whereas it was significant and positive for three hybrids. Three hybrids exhibited significant positive standard heterosis and all the others recorded negative heterosis of which 30 were significant (Table 36).

Among reciprocal hybrids, significant positive heterosis over mid parent was recorded by 16 hybrids and significant negative heterosis was manifested in one hybrid. Significant positive heterobeltiosis was shown by eight hybrids. Standard heterosis over Kanchana was positive and significant for two hybrids while it was significant and negative for 11 hybrids.

4.4.1.12 Leaf area index

Among parents, leaf area index varied between 4.8 (IR 8) and 6.5 (Aathira). Higher leaf area indices than parents were expressed by hybrids, which ranged from 6.1 (IR 68891 A/Matta Triveni) to 12.1 (IR 62829 A/Aiswarya) (Table 25). Among reciprocal hybrids the range was from 5.0 (Jaya/IR 58025B) to 7.6 (Aathira/ IR 62829B).

Significant positive relative heterosis was expressed by 29 hybrids with a range from 21.4 (IR 68891A/Aiswarya) to 146.0 (IR 62829A/Aiswarya) per cent. Twenty four hybrids expressed significant positive heterobeltiosis and 31 hybrids exhibited significant positive standard heterosis (Table 37).

Table 36 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for grain density

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	-1.4	-2.6	-9.3**	-	-	-
2	IR 62829A/Matta Triveni	-2.5*	-5.0**	-9.1**	2.8**	0.0	-2.2
3	IR 62829A/Kanchana	-2.4*	-6.9**	-6.8**	2.2*	-1.6	-1.6
4	IR 62829A/IR 36	-0.2	-0.5	-9.0**	-	-	-
5	IR 62829A/Aiswarya	-2.6*	-5.4**	-8.7**	3.9**	0.7	-1.0
6	IR 68890A/Annapoorna	0.2	-1.0	-5.6**	1.8	1.2	-1.9
7	IR 68890A/Matta Triveni	-1.6	-1.8	-6.0**	-	-	-
8	IR 68890A/Kanchana	-0.5	-2.8	-2.7*	-0.8	-2.5*	-2.5*
9	IR 68890A/IR 36	1.2	-0.8	-5.3**	-2.5*	-4.6**	-7.7**
10	IR 68890A/Aiswarya	0.4	-0.1	-3.6**	4.1**	3.4**	1.6
11	IR 68891A/Annapoorna	-0.1	-0.9	-6.3**	-0.9	-2.1	-6.3**
12	IR 68891A/Matta Triveni	-2.3	-4.5**	-8.6**	-	-	-
13	IR 68891A/Kanchana	-2.1	-6.2**	-6.2**	-	-	-
14	IR 68891A/IR 36	-2.3	-2.3	-10.6**	-1.2	-1.5	-8.2**
15	IR 68891A/Aiswarya	-0.6	-3.2*	-6.6**	-	-	-
16	PMS 10A/Annapoorna	-0.7	-2.5	-9.3**	-	-	-
17	PMS 10A/Matta Triveni	2.7*	-0.5	-4.7**	-	-	-
18	PMS 10A/Kanchana	4.0**	-1.3	-1.3	-	-	-
19	PMS 10A/IR 36	4.0**	2.9*	-5.7**	3.5**	2.9*	-4.7**
20	PMS 10A/Aiswarya	0.8	-2.7*	-6.1**	8.7**	4.9**	3.1**
21	IR 58025A/IR 8	1.6	-1.2	-5.7**	4.0**	1.08	-3.5**
22	IR 58025A/Jaya	2.8**	0.1	-4.7**	5.6**	2.8*	-2.2*
23	IR 58025A/Aiswarya	0.7	-4.9**	-4.9**	4.9**	0.5	-1.1
24	IR 62829A/Kairali	2.1	-5.8**	-7.5**	2.4	0.0	-3.4**
25	IR 62829A/Aathira	1.3	-0.3	-4.9**	4.1**	2.2*	-2.4**
26	IR 67684A/Kanchana	0.0	-7.1**	-7.1**	3.1*	-4.2**	-4.2**
27	IR 68890A/Ptb 10	0.5	-1.4	-0.8	-0.2	-2.1	-1.6
28	IR 68891A/IR 8	-2.0	-3.3	-7.7**	7.1**	5.8**	1.1
29	IR 68891A/Jaya	-2.0	-2.0	-6.8**	2.2	1.2	-3.7**
30	PMS 3A/Jaya	4.0**	0.0	-4.9**	9.3**	5.0**	-0.1
31	PMS 3A/Aiswarya	0.4	-5.0**	-6.6**	10.5**	4.5**	2.7*
32	PMS 10A/Aruna	-4.6**	-8.4**	-9.1**	5.2**	0.9	0.2
33	PMS 10A/Ptb 9	8.3**	3.1**	4.2**	-	-	-
34	PMS 10A/Ptb 10	7.6**	2.7**	3.3**	5.3**	0.5	1.0

* Significant at 5% level
** Significant at 1% level

di - Relative heterosis
dii - Heterobeltiosis
diii - Standard heterosis

Table 37 Expression of heterosis in 34 F1 hybrids and their reciprocal crosses in rice for leaf area index

Sl. No.	Cross combination	Direct hybrids			Reciprocal hybrids		
		di	dii	diii	di	dii	diii
1	IR 62829A/Annapoorna	38.4**	33.1*	24.8*	-	-	-
2	IR 62829A/Matta Triveni	73.6**	51.5**	76.0**	9.8	-3.7	1.1
3	IR 62829A/Kanchana	122.1**	107.2**	107.2**	47.1**	39.4**	39.4**
4	IR 62829A/IR 36	24.0*	3.8	33.3**	-	-	-
5	IR 62829A/Aiswarya	146.0**	140.1**	118.4**	46.1**	45.8**	33.6**
6	IR 68890A/Annapoorna	99.6**	82.8**	106.0**	18.0*	9.0	20.5*
7	IR 68890A/Matta Triveni	16.1	14.3	33.0**	-	-	-
8	IR 68890A/Kanchana	66.5**	57.2**	77.0**	9.5	5.5	15.4
9	IR 68890A/IR 36	39.8**	31.2**	68.5**	3.0	0.5	11.5
10	IR 68890A/Aiswarya	63.7**	48.0**	66.7**	22.8**	12.0	24.4**
11	IR 68891A/Annapoorna	22.4*	11.0	28.0*	13.4	6.0	14.7
12	IR 68891A/Matta Triveni	-4.3	-4.0	10.8	-	-	-
13	IR 68891A/Kanchana	49.8**	39.9**	60.5**	-	-	-
14	IR 68891A/IR 36	16.0	10.2	41.4**	12.2	11.0	20.0*
15	IR 68891A/Aiswarya	21.4*	8.6	25.2*	-	-	-
16	PMS 10A/Annapoorna	31.5**	25.2*	29.8**	-	-	-
17	PMS 10A/Matta Triveni	23.8*	17.0	36.0**	-	-	-
18	PMS 10A/Kanchana	14.2	12.2	16.2	-	-	-
19	PMS 10A/IR 36	26.6**	14.4	46.9**	-5.2	-9.3	5.2
20	PMS 10A/Aiswarya	56.5**	46.9**	52.3**	16.3	-4.2	20.9*
21	IR 58025A/IR 8	37.4**	23.3**	37.0**	18.9*	7.00	19.1
22	IR 58025A/Jaya	26.0**	25.0**	38.8**	-16.1	-16.7*	-7.0
23	IR 58025A/Aiswarya	20.7**	9.6	22.3	-6.6	-15.2*	-5.4
24	IR 62829A/Kairali	92.3**	81.8**	85.8**	33.5**	26.2**	29.0**
25	IR 62829A/Aathira	43.0**	56.1**	88.7**	33.3**	16.4	41.3**
26	IR 67684A/Kanchana	94.9**	113.7**	113.7**	6.8	-1.4	17.1*
27	IR 68890A/Ptb 10	60.3**	55.0**	72.8**	3.9	-6.7	3.5
28	IR 68891A/IR 8	59.1**	58.7**	74.0**	8.1	9.3	18.2*
29	IR 68891A/Jaya	57.0**	54.7**	67.2**	14.2	10.5	21.4**
30	PMS 3A/Jaya	50.8**	46.3**	71.0**	-12.8	-16.0	-1.1
31	PMS 3A/Aiswarya	75.3**	55.2**	82.9**	8.5	-3.8	13.4
32	PMS 10A/Aruna	49.2**	46.7**	68.5**	-13.0	-15.0	-1.5
33	PMS 10A/Ptb 9	52.4**	50.0**	22.2**	-	-	-
34	PMS 10A/Ptb 10	54.2**	46.7**	68.5**	9.8	3.8	20.4*

* Significant at 5% level
** Significant at 1% level

di - Relative heterosis
dii - Heterobeltiosis
diii - Standard heterosis

Seven reciprocal hybrids recorded significant positive heterosis over mid parent and only three hybrids exhibited significant positive heterobeltiosis. Two hybrids recorded significant negative heterobeltiosis. Significant positive standard heterosis was exhibited by 10 hybrids with overall range from -7.0 (Jaya/IR 58025B) to 41.2 (Aathira/IR 62829B) per cent.

4.4.2 Studies on combining ability in parents and hybrids

4.4.2.1 Analysis of variance for combining ability

Line x tester analysis was conducted with four CMS lines (IR 62829A, IR 68890A, IR 68891A and PMS 10A) as female parents and 5 varieties (Annapoorna, Matta Triveni, Kanchana, IR 36 and Aiswarya) as testers. Results of the analysis of variance are presented in Table 38 and 39. These results revealed that the variance due to lines were significant for all the characters except panicles per plant, straw yield, grains per panicle and panicle weight. Variance due to testers were significant for all the characters except spikelet sterility percentage and flag leaf area whereas variance due to line x tester interaction was significant for all the characters. Variance due to parents were significant for 17 characters. It was not significant for tillers and panicles per plant, total dry matter production, panicle exsertion and flag leaf area. Variance due to hybrids were highly significant for all the characters.

Magnitude of gca variance was more than the variance due to sca for days to flowering, total duration, harvest index, 100 seed weight, grain length, grain breadth, grain thickness, grain density and l/b ratio, whereas sca variance was more for plant height, tillers per plant, total dry matter production per plant panicle length, filled grains per panicle, spikelet sterility, panicle exsertion, flag leaf area, leaf area index, panicles per plant, grain yield per plant and straw yield per plant.

Table 38 Analysis of variance for combining ability in rice for plant and economic characters

Source	df	Mean square										
		Mean plant height	Tillers per plant	Panicles per plant	Days to flowering	Total duration	Flag leaf area	Leaf area index	Grain yield per plant	Straw yield per plant	Total dry matter	Harvest Index
Parents	8	289.4**	11.3	3.8	147.3**	232.44**	92.8	2.4*	50.6**	34.7**	60.0	0.031**
Hybrids	19	149.3**	90.1**	21.0**	54.1**	102.42**	260.5**	12.2**	76.5**	38.4**	154.8**	0.011**
Parents vs. hybrids	1	46.3	589.0**	429.0**	189.3**	291.00**	11099.1**	173.7**	980.4**	129.0**	1821.0**	0.108**
Lines	3	138.6**	105.6**	14.7	128.6**	113.73**	735.3**	27.2**	66.5**	16.6	135.8**	0.004**
Testers	4	300.6**	178.0**	48.8**	120.6**	327.28**	49.2	7.1**	71.4**	50.2**	192.2**	0.009**
Lines x Testers	12	101.5**	57.0**	13.5**	11.4**	24.64**	212.3**	10.0**	80.8**	39.9**	147.0**	0.014**
Error	57	10.8	7.4	4.6	1.7	2.14	98.3	1.3	18.5	7.8	37.3	0.003
^{2}gca		6.6	4.7	1.0	6.2	10.88	10.0	0.39	0.65	0.36	0.9	
^{2}sca		22.7	12.4	2.2	2.9	5.61	28.5	2.21	15.56	8.01	27.4	

* Significant at 5% level
** Significant at 1% level

Table 39 Analysis of variance for combining ability in rice for grain and earhead characters

Source	df	Mean square										
		Panicle length	Grains per panicle	Spikelet sterility (%)	Panicle exsertion	100 seed weight	Grain length	Grain bredth	Grain thickness	Panicle weight	Grain density	L/B ratio
Parents	8	4.9*	2350.3**	45.6**	40.8	0.2**	6.2**	0.3**	0.039**	0.60**	14.9**	2.37**
Hybrids	19	12.5**	837.3**	42.8**	547.7**	0.3**	1.0**	0.2**	0.021**	0.44**	7.9**	0.83**
Parents vs. hybrids	1	1.0	250.7	254.2**	9958.4**	0.8**	0.3**	0.0*	0.044**	5.38**	2.0	0.00
Lines	3	24.4**	331.8	82.3*	250.0*	0.6**	1.5**	1.3**	0.032**	0.01	24.4**	3.22**
Testers	4	8.3*	1437.0**	38.6	416.8**	0.7**	2.9**	0.0**	0.022*	0.01**	11.8**	1.06**
Lines x Testers	12	10.8**	763.7**	34.4*	665.8**	0.1**	0.3**	0.0**	0.017**	0.01**	2.4*	0.15**
Error	57	2.5	256.2	16.7	53.2	0.01	0.09	0.01	0.005	0.00	0.98	0.04
^{2}gca		0.3	6.7	1.5	18.5	0.03	0.11	0.04		0.03	0.87	0.11
^{2}sca		2.1	126.9	4.4	153.1	0.02	0.04	0.01		0.03	0.36	0.03

* Significant at 5% level ** Significant at 1% level

Proportional contribution of lines, testers and hybrids to total genetic variance is presented in Table 40. Out of 22 characters studied, contribution of l x t interaction was higher for 13 characters. Contribution of females were higher only for three characters viz., grain breadth, grain density and l/b ratio. Contribution of male parents were higher with respect to six characters.

4.4.2.2 Combining ability effects

4.4.2.2.1 Plant height

The general combining ability effects (gca) ranged from -2.26 (IR 62829A) to 3.89 (IR 68890A) for the lines and from -5.54 (Annapoorna) to 5.96 (Aiswarya) for the testers. Among the four CMS lines tested, IR 68890A recorded significant positive gca effect and among the testers Kanchana and Aiswarya recorded significant positive gca effects. Annapoorna, Matta Triveni and IR 36 recorded significant negative gca effects.

Specific combining ability effects of hybrid combinations ranged from -5.86 to (IR 62829A/Aiswarya) to 9.04 (PMS 10A/Aiswarya). Eight crosses recorded significant positive sca effects and 10 combinations recorded significant negative effects. Eventhough Aiswarya and IR 68890A recorded positive gca effects, their hybrid combination recorded significant negative sca effect (Table 41).

4.4.2.2.2 Number of panicles per plant

Among the lines tested, IR68890A recorded significant positive gca effect (0.66) and PMS 10A recorded significant negative gca effect (-1.26). Of the testers

Table 40 Proportional contribution to total variance by parents and hybrids

Sl. No.	Character	Proportional contribution (%)			Total
		Female	Male	LxT	
1	Plant height	14.66	42.40	42.94	100
2	Tillers per plant	18.50	41.57	39.93	100
3	Panicles per plant	11.02	48.69	40.29	100
4	Days to flowering	37.49	46.91	15.60	100
5	Total duration	17.53	67.27	15.20	100
6	Grain yield per plant	13.72	19.64	66.64	100
7	Straw yield per plant	6.81	27.55	65.64	100
8	Total dry matter per plant	13.85	26.14	60.01	100
9	Harvest index	5.97	15.92	77.97	100
10	Panicle length	30.97	14.11	54.92	100
11	Filled grains per panicle	6.26	36.13	57.61	100
12	Spikelet sterility	30.34	18.99	50.67	100
13	Panicle exsertion	7.21	16.02	76.77	100
14	1oo seed weight	33.41	47.50	19.09	100
15	Grain length	23.26	60.76	15.98	100
16	Grain breadth	85.66	5.25	9.09	100
17	Grain thickness	24.64	22.68	52.68	100
18	Panicle weight	31.24	31.83	36.93	100
19	Grain density	48.97	31.61	19.42	100
20	Flag leaf area	44.56	3.97	51.47	100
21	Leaf area index	35.31	12.31	52.38	100
22	L/B ratio	61.65	27.13	11.22	100

Table 41 Combining ability effects of parents and hybrids for plant height

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-3.11**	5.01**	0.95	3.01**	-5.86**	-2.26**
IR 68890A	4.24**	-4.64**	3.30**	-2.64*	-0.26	3.89**
IR 68891A	3.09**	3.71**	-3.85**	-0.04	-2.91**	-1.21*
PMS 10A	-4.21**	-4.09**	-0.40	-0.34	9.04**	-0.41
GCA of males	-5.54**	-1.16*	2.15**	-1.41*	5.96**	

SE (Females) 0.54
SE (Males) 0.62
SE (hybrids) 1.07

* Significant at 5% level
** Significant at 1% level

Table 42 Combining ability effects of parents and hybrids for number of panicles per plant

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-0.08	-2.76**	1.67*	-0.51	1.67*	0.39
IR 68890A	0.67	2.24**	0.42	-1.76*	-1.58*	0.66*
IR 68891A	-1.43*	0.89	-0.68	-0.11	1.32	0.24
PMS 10A	0.82	-0.36	-1.43*	2.39**	-1.43*	-1.26**
GCA of males	-1.77**	0.41	2.48**	-1.59**	0.48	

SE (Females) 0.34
SE (Males) 0.40
SE (Hybrids) 0.69

* Significant at 5% level
** Significant at 1% level

studied, Kanchana recorded significant positive gca effect (2.48) Annapoorna and IR36 recorded significant negative gca effect (Table 42).

Specific combining ability effects of the hybrid combinations ranged between -2.76 (IR 62829A/Matta Triveni) and 2.39 (PMS 10A/IR 36). Out of the 20 hybrid combinations tested, 10 recorded significant sca effects of which four were positive and six were negative. Highest positive gca effect was recorded by PMS 10A/IR 36 (2.39) followed by IR 68890A/Matta Triveni.

4.4.2.2.3 Days to flowering

General combining ability effects of the females ranged from -3.55 (IR 62829A) to 1.90 (IR 68890A). Among the testers, Annapoorna and Matta Triveni had significant negative gca effect (-2.16 and -2.60), whereas IR 36 and Aiswarya recorded significant positive gca effects (0.65 and 4.28). Highest positive gca effect was recorded by Aiswarya (4.28) and highest negative gca effect was recorded by Matta Triveni (-2.60).

Specific combining ability effects ranged from -1.90 (IR68890A/Matta Triveni and PMS10A/IR36) to 3.22 (PMS10A/Aiswarya). Seven hybrid combinations recorded significant negative sca effect and five exhibited significant positive sca effects (Table 43).

4.4.2.2.4 Grain yield per plant

The gca effect ranged from -1.91 (IR 62829A) to 2.32 (IR 68890A) among the lines and from -2.23 (Matta Triveni) to 2.34 (Aiswarya) among the testers.

Table 43 Combining ability effects of parents and hybrids for days to flowering

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-1.64**	1.80**	0.11	1.55**	-1.83**	-3.55**
IR 68890A	1.66**	-1.90**	0.66	1.35**	-1.78**	1.90**
IR 68891A	0.31	0.00	0.31	-1.00*	0.38	1.75**
PMS 10A	-0.34	0.10	-1.09**	-1.90**	3.22**	-0.10
GCA of males	-2.16**	-2.60**	-0.16	0.65**	4.28**	

SE (Females) 0.21
SE (Males) 0.24
SE (Hybrids) 0.42

* Significant at 5% level
** Significant at 1% level

Table 44 Combining ability effects of parents and hybrids for grain yield per plant

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-2.48	4.82**	4.30**	-4.32**	-2.31	-1.91**
IR 68890A	0.57	-5.12**	1.49	-3.20*	6.26**	2.32**
IR 68891A	3.57**	-0.64	-3.23*	5.27**	-4.96**	0.45
PMS 10A	-1.65	0.94	-2.55	2.25	1.02	-0.86
GCA of males	-1.84*	-2.23**	1.98*	-0.25	2.34**	

SE (Females) 0.69
SE (Males) 0.80
SE (Hybrids) 1.38

* Significant at 5% level
** Significant at 1% level

Aiswarya and Kanchana showed significant positive gca effect (1.98 and 2.34 respectively), whereas Annapoorna and Matta Triveni recorded significant negative gca effects of -1.84 and -2.23 respectively (Table 44).

Specific combining ability effects of hybrids ranged from -5.12 (IR 68890A/ Matta Triveni) to 6.26 (IR 68890A/ Aiswarya). Five hybrid combinations viz. IR 68891A/ Annapoorna (3.57), IR 62829A/Matta Triveni (4.82), IR 68891A/IR36 (5.27), IR 68890A/Aiswarya (6.26) and IR 62829A/Kanchana (4.30) recorded significant positive sca effect and another five combinations viz. IR 68890A/ Matta Triveni (-5.12), IR68891A/Kanchana (-3.23), IR 62829A/IR 36 (-4.32), IR 68890A /IR 36 (-3.20) and IR 68891A/Aiswarya (-4.96) had significant negative sca effect.

4.4.2.2.5 Straw yield per plant

Out of the four lines tested, only IR68890A manifested significant gca effect (1.35). The other three lines exhibited negative gca effect. Among the testers Annapoorna recorded significant negative gca effect (-1.78) and Aiswarya had significant positive effect (2.89) (Table 45).

The variation for sca effect was from -3.74 in IR 68890A/Matta Triveni to 5.09 in IR 62829A/Aiswarya. Six hybrid combinations recorded significant negative sca effect while four had significant positive sca effects.

4.4.2.2.6 Total dry matter

The gca effects of lines ranged between -2.36 in IR 62829A and 3.67 in IR 68890A. The variation was from -3.62 in Annapoorna to 5.23 in Aiswarya among the testers. Results presented in Table 46 indicated significant negative gca effect

Table 45 Combining ability effects of parents and hybrids for straw yield per plant

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-2.14*	3.31**	-3.26**	-3.01**	5.09**	-0.45
IR 68890A	-1.24	-3.74**	0.89	2.95**	1.15	1.35**
IR 68891A	2.75**	0.27	1.30	-0.87	-3.47**	-0.62
PMS 10A	0.62	0.16	1.07	0.92	-2.78**	-0.28
GCA of males	-1.78**	-0.32	-0.95	0.17	2.89**	

SE (Females) 0.45
SE (Males) 0.52
SE (Hybrids) 0.90

* Significant at 5% level
** Significant at 1% level

Table 46 Combining ability effects of parents and hybrids for total drymatter

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-4.61*	8.12**	1.04	-7.33*	2.78	-2.36**
IR 68890A	-0.67	-8.86**	2.38	-0.26	7.41**	3.67**
IR 68891A	6.32**	-0.37	-1.93	4.41*	-8.43**	-0.17
PMS 10A	-1.04	1.10	-1.49	3.18	-1.76	-1.14
GCA of males	-3.62**	-2.56*	1.03	-0.08	5.23**	

SE (Females) 0.98
SE (Males) 1.13
SE(Hybrids) 1.96

* Significant at 5% level
** Significant at 1% level

for IR 62829A and significant positive gca effect for IR 68890A. Among the testers, Annapoorna and Matta Triveni exhibited significant negative gca effects whereas Aiswarya recorded significant positive gca effect.

Among the hybrids tested, the sca effects ranged from -8.86 (IR 68890A/ Matta Triveni) to 8.12 (IR 62829A/Matta Triveni). Four hybrids exhibited significant negative sca effects and another four hybrids recorded significant positive sca effect.

4.4.2.2.7 Harvest index

Among the females, gca effect was between -0.02 (IR 62829A) and 0.01 (IR 68890A and IR 68891A). IR 62829A recorded significant negative gca effect (-0.02) and for the other CMS lines gca effect was positive though not significant (Table 47). Among the testers, Annapoorna, IR36 and Aiswarya recorded negative gca effect whereas Matta Triveni and Kanchana had positive effect with the range between -0.08 (Aiswarya) and 0.10 (Kanchana). The specific combining ability of the hybrid combinations ranged between -0.08 (IR 62829A/Aiswarya) and 0.10 (IR 62829A/ Kanchana). IR 62829A/Aiswarya (-0.08), IR 68890A/IR 36 (-0.07), IR 68891A/Kanchana (-0.05) exhibited significant negative sca effect while IR 68891A/IR 36 (0.07), IR 68890A/Aiswarya and PMS 10A/Aiswarya showed significant positive sca effect for this character.

4.4.2.2.8 Filled grains per panicle

Among the four female parents, two CMS lines recorded positive gca effect and the other two recorded negative effect with the range between -5.25 (IR 68890A) and 4.35 (PMS 10A). Out of five male parents, two had negative gca effect while

Table 47 Combining ability effects of parents and hybrids for harvest index

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-0.01	0.02	0.10	-0.03	-0.08**	-0.02**
IR 68890A	0.03	-0.02	0.00	-0.07**	0.06**	0.01
IR 68891A	0.01	-0.01	-0.05**	0.07**	-0.02	0.01
PMS 10A	-0.03	0.01	-0.05**	0.03	0.04*	0.00
GCA of males	-0.01	0.02**	0.10**	-0.03**	-0.08**	

SE (Females) 0.01   * Significant at 5% level
SE (Males) 0.01   ** Significant at 1% level
SE(Hybrids) 0.02

Table 48 Combining ability effects of parents and hybrids for number of filled grains per panicle

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-0.19	-9.19	3.94	-7.06	12.50*	-0.75
IR 68890A	-2.69	5.06	17.69**	-16.31**	-3.75	-5.25*
IR 68891A	-7.09	1.91	-15.21**	28.79**	-8.40	1.65
PMS 10A	9.96	2.21	-6.41	-5.41	-0.35	4.35
GCA of males	-9.21**	-9.71**	2.91	12.66**	3.35	

SE (Females) 2.57   * Significant at 5% level
SE (Males) 2.97   ** Significant at 1% level
SE (Hybrids) 5.15

the other three recorded positive effect with the overall range between -9.71 (Matta Triveni) and 12.6 (IR36).

Five hybrid combinations recorded significant sca effects of which IR 68890A/Kanchana (17.69), IR 68891A/IR 36 (28.79) and IR 62829A/Aiswarya (12.5) exhibited significant positive effect while IR 68891A/Kanchana and IR 68890A/IR 36 recorded significant negative effects (Table 48).

4.4.2.2.9 Spikelet sterility

The general combining ability effects of the lines ranged from -2.25 (IR 62829A) to 2.59 (IR 68891A). Among the testers, Matta Triveni had significant positive gca effect (1.44) whereas IR36 recorded significant negative gca effect (-2.66) with the range between -2.66 and 1.44 (Table 49).

Specific combining ability effects of the hybrid combinations ranged from -4.18 (IR 68890A/Kanchana) to 4.34 (IR 68890A/Matta Triveni). Out of the 20 hybrid combinations tested eight combinations recorded negative sca effect and 12 recorded positive sca effect. Combination with significant negative effects were IR 68890A/Kanchana (-4.18) PMS 10A/Aiswarya (-2.81) and IR 68891A/IR 36 (-3.17).

4.4.2.2.10 Panicle exsertion

General combining ability effects of the female parents exhibited a range between -4.84 (IR 62829A) and 2.99 (PMS 10A). Among the testers, Annapoorna (4.87) and IR 36 (5.04) had significant positive gca effect whereas Kanchana (-2.46) and Aiswarya (6.99) recorded significant negative effect (Table 50).

Table 49 Combining ability effects of parents and hybrids for spikelet sterility

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	0.76	-0.73	0.16	1.99	-2.18	-2.25**
IR 68890A	-2.43	4.34**	-4.18**	0.46	1.81	0.34
IR 68891A	0.79	-1.62	0.82	-3.17*	3.18*	2.59**
PMS 10A	0.88	-2.00	3.21*	0.72	-2.81*	-0.67
GCA of males	0.43	1.44*	0.28	-2.66**	0.52	

SE (Females) 0.66
SE (Males) 0.76
SE (Hybrids) 1.32

* Significant at 5% level
** Significant at 1% level

Table 50 Combining ability effects of parents and hybrids for panicle exsertion

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-4.98*	9.92**	10.27**	-7.93**	-7.27**	-4.84**
IR 68890A	5.87*	-3.68	4.44*	-17.38**	10.75**	-0.37
IR 68891A	15.85**	-4.62*	-11.90**	10.30**	-9.64**	2.22
PMS 10A	-16.74**	-1.62	-2.82	15.01**	6.16**	2.99*
GCA of males	4.87**	-0.46	-2.46*	5.04**	-6.99**	

SE (Females) 1.35
SE (Males) 1.17
SE (Hybrids) 2.35

* Significant at 5% level
** Significant at 1% level

Seventeen hybrid combinations had significant sca effect of which nine were positive and eight negative. The sca effects ranged between -17.38 (IR 68890A/ IR 36) and 15.85 (IR 68891A/Annapoorna).

4.4.2.2.11 100 seed weight

Among the four female parents, two (IR 62829A and IR 68890A) had significant positive gca effect and the other two (IR 68891A and PMS 10A) recorded significant negative gca effect with the range between -0.14 and 0.20. The gca effect of the male parents ranged between -0.29 (IR 36) and 0.27 (Aiswarya). Significant positive gca effect was recorded by Kanchana (0.06) and Aiswarya (0.27) while significant negative effect was exhibited by IR 36(-0.29).

Specific combining ability effects of the hybrid combinations ranged between -0.20 (IR 68890A/IR 36) and 0.23 (IR 68890A/Aiswarya). Among the 20 hybrid combinations tested, seven recorded significant positive sca effects and six recorded significant negative sca effect (Table 51).

4.4.2.2.12 Grain density

IR 68890A and PMS 10A recorded significate positive gca effect whereas IR 62829A and IR 68891A had significant negative gca effect (Table 52). Among testers Kanchana recorded significant positive gca effect (1.38).

Specific combining ability effects of hybrid combinations ranged between -1.45 (PMS 10A/Annapoorna) and 1.01 (PMS 10A/Kanchana). Six hybrid combinations recorded significant sca effect of which three were positive and three negative.

Table 51 Combining ability effects of parents and hybrids for 100 seed weight

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-0.02	-0.02	0.11**	-0.06*	-0.02	0.09**
IR 68890A	0.17**	-0.01	-0.18**	-0.20**	0.23**	0.20**
IR 68891A	-0.12**	-0.03	0.10**	0.15**	-0.11**	-0.15**
PMS 10A	-0.03	0.06*	-0.04	0.11**	-0.10**	-0.14**
GCA of males	-0.03	-0.01	0.06**	-0.29**	0.27**	

SE (Females) 0.02
SE (Males) 0.02
SE (Hybrids) 0.03

* Significant at 5% level
** Significant at 1% level

Table 52 Combining ability effects of parents and hybrids for grain density

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	0.34	0.00	-0.37	0.35	-0.32	-1.12**
IR 68890A	0.26	-0.53	-0.28	0.17	0.37	1.16**
IR 68891A	0.85*	-0.12	-0.36	-0.94**	0.56	-0.75**
PMS 10A	-1.45**	0.65*	1.01**	0.41	-0.62*	0.70**
GCA of males	-0.79**	-0.24	1.38**	-0.57**	0.23	

SE (Females) 0.16
SE (Males) 0.18
SE (Hybrids) 0.32

* Significant at 5% level
** Significant at 1% level

4.4.2.2.13 Leaf area index

Among the four female parents tested for gca, three recorded significant negative gca effect and only one recorded significant positive gca effect. Among the testers, Matta Triveni recorded significant negative gca effect, whereas Kanchana and Aiswarya recorded significant positive gca effect (Table 53).

Specific combining ability of seven hybrid combinations were significant and positive and that of six combinations were significant and negative.

4.4.3 Association of characters in hybrids

Results of the studies on correlation of 21 morphologic and agronomic attributes on grain yield are presented in Table 54. Out of the 21 characters studied only 10 characters had significant correlation with yield and of these two were negative. Highest positive correlation on yield was recorded by total dry matter production by the plant followed by harvest index. Chaff per cent and grain length exhibited significant negative correlation with yield. Other characters having significant positive correlation were number of filled grains per panicle, grain breadth, panicle weight, grain density, flag leaf area and leaf area index at 60 DAS.

Genotypic and phenotypic correlations of the selected characters between themselves and with yield also revealed the same pattern of association between characters (Table 55). Total dry matter produced by the plant had higher phenotypic correlation with grain yield than genotypic correlation. All the other characters under study recorded higher genotypic correlation. Harvest index, number of grains per

Table 53 Combining ability effects of parents and hybrids for leaf area index

Female parents	SCA of hybrids with each male parent					GCA of females
	Anna-poorna	Matta Triveni	Kanchana	IR 36	Aiswarya	
IR 62829A	-2.30**	1.00**	1.26**	-1.85**	1.87**	-1.06**
IR 68890A	2.30**	-1.30**	-0.31	0.20	-0.90*	0.96**
IR 68891A	0.02	-0.48	0.86*	0.75*	-1.16**	-1.09**
PMS 10A	-0.04	0.76*	-1.80**	0.89*	0.18	-0.93**
GCA of males	-0.32	-0.77**	0.69**	-0.30	0.71**	

SE (Females) 0.18
SE (Males) 0.21
SE (Hybrids) 0.36

* Significant at 5% level
** Significant at 1% level

Table 54 Correlation between grain yield and different plant characters

Sl. No.	Characters	Correlation with grain yield
1	Plant height	0.173
2	Total number of tillers	0.061
3	Productive tillers	0.083
4	Days to flowering	-0.140
5	Total duration	-0.136
6	Straw yield per plant	0.054
7	Total drymatter per plant	0.868**
8	Harvest index	0.866**
9	Panicle length	-0.018
10	Grains per panicle	0.231*
11	Sterility	-0.222*
12	Panicle exsertion	0.189
13	100 seed weight	0.146
14	Grain length	-0.200*
15	Grain breadth	0.217*
16	Grain thickness	-0.017
17	Panicle weight	0.286**
18	Grain density	0.212*
19	Flag leaf area	0.241*
20	Leaf area index (60 DAS)	0.217*
21	L/B ratio	-0.186

* Significant at 5% level   ** Significant at 1% level

Table 55 Genotypic and phenotypic correlation coefficients of hybrids for selected characters

Sl. No.	Grain yield/ plant	Total dry matter/ plant	Harvest index	Number of grains/ panicle	Grain length	Grain breadth	Panicle weight	Flag leaf area	Volume weight	Leaf area index	l/b ratio	Straw yieldper plant
1	1.000 (1.000)											
2	0.682** (0.825**)	1.000 (1.00)										
3	0.860** (0.829**)	0.210 (0.380**)	1.000 (1.000)									
4	0.436** (0.234)	0.539** (0.228)	0.251 (0.168)	1.000 (1.000)								
5	-0.391** (-0.150)	-0.546** (-0.214)	-0.182 (-0.043)	-0.226 (-.150)	1.000 (1.000)							
6	0.427** (0.236)	0.637** (0.270**)	0.136 (0.093)	0.096 (0.085)	-0.83** (-0.66**)	1.000 (1.000)						
7	0.660** (0.153)	0.840** (0.042)	0.358** (0.213)	0.695** (.392**)	-0.176 (-0.110)	-0.069 (-0.003)	1.000 (1.000)					
8	0.936** (0.276**)	0.826** (0.114)	0.925** (0.348**)	0.619** (.423**)	-0.359** (-0.205)	0.252 (0.184)	0.971** (0.442**)	1.000 (1.000)				
9	0.315** (0.137)	0.660** (0.192)	-0.012 (0.046)	0.661** (.504**)	-0.557** (-.449**)	0.679** (0.507**)	0.519** (0.370**)	0.486** (0.348**)	1.000 (1.000)			
10	-0.233 (-0.022)	-0.509** (-0.019)	0.088 (0.019)	0.156 (0.130)	-0.132 (-0.141)	0.032 (-0.032)	-0.113 (-0.161)	0.137 (0.103)	-0.072 (-0.172)	1.000 (1.000)		
11	-0.341** (-0.169)	-0.531** (-0.231)	-0.105 (-0.033)	-0.132 (-.101)	0.949** (0.883**)	-0.939** (-.905**)	0.017 (-0.003)	-0.270** (-0.165)	-0.627** (-.493**)	-0.092 (-0.048)	1.000 (1.00)	
12	-0.375** (0.046)	0.422** (0.602**)	-0.800** (-.499**)	0.143 (0.073)	-0.207 (-0.166)	0.278** (0.143)	0.247 (-0.142)	-0.316** (-0.188)	0.446** (0.146)	-0.356** (-0.002)	-0.250 (-.17)	1.000 (1.0)

Figures in parentheses indicate phenotypic correlation * Significant at 5% level ** Significant at 1% level panicle, grain breadth, panicle weight, flag leaf area and grain density had significant positive genotypic correlation with yield, whereas grain length, l/b ratio and straw yield per plant had significant negative genotypic correlation with yield.

Correlation of total dry matter per plant with harvest index was significant and positive only at phenotypic level. All the other characters had significant genotypic correlation with total dry matter of which correlation of grain length, leaf area index and l/b ratio were negative. Harvest index had significant positive genotypic correlation with panicle weight and flag leaf area; but correlation with straw yield was negative. Number of grains per panicle recorded significant and positive genotypic correlation with panicle weight, flag leaf area and grain density. Grain length exhibited negative correlation with all the characters under study except l/b ratio. Grain breadth exhibited significant positive genotypic correlation with grain density and straw yield per plant, whereas correlation with l/b ratio was significant and negative both at genotypic and phenotypic level. Panicle weight had significant and positive genotypic correlation with flag leaf area and grain density.

4.4.4 Cytoplasmic influence on agronomic attributes

Inorder to study the influence of cytoplasm, 24 fertile hybrids evolved by hybridisation between CMS lines as females and popular rice varieties as pollen parents (AxR) were compared with reciprocal hybrids evolved by hybridisation between popular rice varieties as females and maintainers of CMS lines as pollen parents (RxB). Observations on 21 agronomic attributes were subjected to `t' test and the results are presented in Table 56. Results indicated significant values of `t' for

Table 56 Comparison of direct and reciprocal hybrids using `t' test

Characters	Mean values		`t' value	Probability
	Direct hybrids (AxR)	Reciprocal hybrids (RxB)		
Plant height (cm)	100.26	94.73	5.54*	0.00
Total no. of tillers	15.03	10.90	9.61*	0.00
Productive tillers	10.73	8.86	6.38*	0.00
Days to flowering	85.35	85.18	0.33	0.75
Total duration (days)	112.58	114.34	3.24	0.00
Grain yield per plant (g)	20.74	22.90	3.72*	0.00
Straw yield per plant (g)	22.23	20.75	3.38*	0.00
Total dry matter (g)	42.97	43.65	0.88	0.38
Harvest index	0.47	0.52	6.10*	0.00
Panicle length (cm)	24.47	24.59	0.43	0.67
No. of grains per panicle	111.40	130.21	6.46*	0.00
Spikelet sterility (%)	17.69	11.62	14.31*	0.00
Panicle exsertion (%)	89.34	104.38	15.17*	0.00
100 seed weight (g)	2.33	2.44	4.30	0.00
Panicle weight (g)	2.91	3.58	11.24*	0.00
Grain density (g/100 ml)	54.37	55.97	7.22*	0.00
Leaf area index	9.57	6.22	21.77*	0.00

*Significant at 1% level

all the characters except days to flowering , total duration, total drymatter, panicle length, 100 seed weight and grain length indicating that there was no reciprocal difference for these characters. Characters like tillering pattern, spikelet sterility , grains per panicle, panicle exsertion, grain thickness, panicle weight and leaf area index exhibited significant difference between direct and reciprocal hybrids.

Discussion

DISCUSSION

Among the various possible genetic approaches for increasing rice production to cater the growing needs of rice consumers all over the world, hybrid rice technology is identified to be the most readily adaptable technique. The feasibility of this techniques has been demonstrated in the Peoples' Republic of China, during the last two decades.

Essential pre-requisite for commercial exploitation of heterosis in any self pollinated crop is the availability of an effective and economically viable seed production technique. Male sterility system is being widely used for this purpose, and in rice, various types of male sterility systems are being utilised. Among these, cytoplasmic genic male sterility (CMS) system has been recognised as the most effective and practical one for development of hybrids under tropical conditions. A number of CMS lines have been developed in China, IRRI, India, Indonesia, Thailand etc., but only a few have been useful in developing commercial rice hybrids. This is because, use of a CMS line for commercial production of hybrids depends on its stability over environments for pollen sterility, adaptability, ease of pollen fertility restoration, genetic diversity from restorer parents, outcrossing potential and combining ability. Information on these aspects are very limited especially under the humid tropical conditions and hence, the present investigation was undertaken as per the objectives mentioned earlier and the results are discussed under the following heads.

1. Evaluation of CMS lines for sterility, agronomic attributes and floral traits
2. Identification of restorers and maintainers
3. Inheritance of fertility restoration
4. Genetic distance among maintainers and restorers
5. Genetic analysis of the hybrids
6. Association of characters in hybrids
7. Cytoplasmic influence on agronomic attributes

5.1 Evaluation of CMS lines for sterility, agronomic attributes and floral traits

5.1.1 Pollen and spikelet sterility

The first CMS line used to develop commercial F1 rice hybrid was developed in China in 1973 from a naturally occurring male sterile plant in a wild rice population and it was designated as WA cytosterile line (Yuan, 1977). Since then a number of cytosterile lines have been developed in various countries by substituting the cytoplasm in indica or japonica cultivars as well as by distant hybridisation techniques (Virmani and Edwards, 1983; Pradhan *et al.*, 1990a).

The most important attribute for a CMS line to be used in hybrid rice production programme is complete pollen sterility and stability over environments. In the present study, ten CMS lines, evaluated for pollen and spikelet sterility during four seasons from *kharif* 1995 to *rabi* 1996 exhibited significant difference between the genotypes during all the four seasons. Eight CMS lines viz., IR 58025A, IR 62829A, IR 67684A, IR 68890A, IR 68891A, PMS 3A, PMS 10A and IR 66707A recorded high pollen and spikelet sterility during all the four seasons. All these CMS lines except PMS 3A recorded non significant difference between seasons for pollen as well as spikelet sterility indicating that these genotypes are stable over environments. Genotypes IR 68886A and V 20A recorded pollen fertility ranging from 13.79 per cent to 8.02 per cent in V 20A and from 9.81 per cent to 4.41 per cent in IR 68886A. V 20A recorded higher spikelet fertility during *kharif* seasons whereas IR 68886A exhibited higher fertility during *rabi* seasons. Spikelet sterility behaviour of different genotypes followed the same pattern as that of pollen sterility. Among genotypes exhibiting significant difference between seasons both V 20A and IR 68886A exhibited higher spikelet fertility during *kharif* season.

V 20A was identified as stable male sterile line by Bong *et al.* (1986), Pradhan *et al.* (1990c), Manuel *et al.* (1991), Yogeesha (1991), Pande *et al.* (1992) and Mishra and Pandey (1993). Pande *et al.* (1992) reported IR 62829A as unstable. In the present study V 20A expressed unstable performance whereas IR 62829A had stable pollen sterility. This difference in the performance of male sterile lines for sterility can be the result of expression of nucleo cytoplasmic interactions under certain environmental conditions as reported by Wang *et al.* (1991). Lack of sterility of a genotype may be due to the presence of minor genes for fertility restoration in the maintainer genotype, due to incomplete sterilisation or due to breakdown of male sterility in different environments as reported by Virmani and Wan (1988).

IR 68886A and PMS 3A expressed high level of pollen fertility during *rabi* season whereas V 20A had high level of pollen fertility during *kharif* season which clearly indicate environmental influence. High temperature and low relative humidity prevailing during *rabi* seasons favoured pollen fertility in CMS lines IR 68886A and PMS 3A, whereas the peculiar climatic condition of *kharif* season in Kerala might have made V 20A pollen fertile during that season and almost sterile during *rabi* seasons. All CMS lines expressed higher spikelet sterility during *rabi* season. This is in agreement with the findings of Bong *et al.* (1986) and Yogeesha (1991) in which the CMS lines recorded lower spikelet sterility during wet season than dry season. Virmani *et al.* (1986) and Pradhan *et al.* (1990c) reported that pollen sterility of some CMS lines varied with environment, while some others are stable for complete pollen sterility and remained unaffected by environmental influence.

Environment influence sterility behaviour of many plants. Temperature was found to interact strongly with fertility restoring mechanism and the influence of photoperiod and relative humidity also are of importance. In brassica, high temperature promoted better development of anthers and increased stamen length whereas at low temperature plants remained sterile (Fan and Stefanson, 1986). The influence of temperature on breakdown of male sterility was reported for other crops like sorghum (Duvick, 1965), cotton (Meyer, 1969), wheat (Ingold, 1968 and Saini and Aspinall, 1982), sunflower (Seetharam and Sathyanarayana, 1982) and tomato (Sawhney, 1983). In some cases fertility was enhanced at higher temperature while in some other cases lower temperature favoured male fertility.

From the present study it may be inferred that higher temperature and low relative humidity during the months (February and March) could convert the CMS anthers of IR 68886A and PMS 3A to partially fertile, while the peculiar temperature and humidity prevailing during the month of July-August converted V 20A to partially fertile. Further studies under controlled conditions are necessary to confirm this.

Stable CMS lines identified from the present study like IR 58025A, IR 62829A, IR 67684A, IR 68890A, IR 68891A, PMS 10A and IR 66707A may be utilised in further breeding programmes for the development of rice hybrids.

Lin and Yuan (1980) reported that among the various sources of cytosterility in rice, CMS lines derived from the WA system is the most stable one for their complete pollen sterility. In the present study unstable CMS lines were observed in the WA source and *O. perennis* source was found to be stable.

5.1.2 Agronomic attributes

Agronomic attributes like plant height, days to flowering and panicle length of the CMS lines were evaluated to study the stability in performance for these attributes. Since fertilisation and seed yield depend much on synchronisation in flowering of male sterile and restorer lines, stability in plant height and days to flowering is important in hybrid seed production programme.

All the CMS lines exhibited a reduction in plant height and flowering duration during *rabi* season. Reduction in plant height was only 2 to 4 cm whereas difference in flowering duration was upto 8 days. IR 68890 A, which had medium plant height of 96 cm can be well utilised in the production of semi tall hybrids. V 20A, the most commonly used CMS line had duration of only 65 days for flowering and while using this in hybrid seed production programme, staggered planting and adjustment of planting dates were indispensable. But by using CMS line like IR 67684 A, IR 68890 A, PMS 10 A etc., restorers with medium duration can be used. Hence these CMS lines will be of high value in the production of hybrids with semi tall plant stature as well as with medium duration. When floral traits and sterility behaviour along with agronomic attributes were considered IR 68890A was identified as an ideal CMS line for the humid tropical conditions and Plate 4 depicts the isogenic maintainer of the same.

5.1.3 Floral characters and flowering behaviour

Rice is a self pollinated crop, although outcrossing upto 6.8 per cent has been observed in some varieties and under certain conditions (Sahadevan and Namboodiri, 1963). However, a wide range (0 - 44%) of natural outcrossing has been observed on male sterile plants. In large scale hybrid seed production plots in China, natural outcrossing in male sterile lines have been reported upto 74 per cent with median value of 25 to 35 per cent. The degree of outcrossing in cytosterile lines has been reported to vary from 0.5 to 74 per cent (Virmani *et al.*, 1981). Variability in the extent of natural outcrossing on male sterile lines of rice can be attributed to variations in flowering behaviour, floral characteristics and environmental factors.

In the present study, flowering behaviour and floral characters of CMS lines and their isogenic maintainers were studied during *kharif* and *rabi* seasons. Good panicle exsertion in a male sterile parent would expose higher number of spikelets for out crossing compared to a male sterile line showing incomplete panicle exsertion (Plate 5). All the ten CMS lines in the present study exhibited lower level of panicle exsertion than their maintainers. Among them the highest level of panicle exsertion was shown by IR 68890A followed by IR 62829A. Chauhan *et al.* (1991) reported poor panicle exsertion in most of the CMS lines they have studied, which is in agreement with the results of the present study. Comparison between seasons for the expression of this character revealed significant difference between seasons indicating environmental influence for the character (Fig.3). Environmental influence in the expression of the character was also reported by Virmani *et al.* (1981).

Extent of outcrossing in a male sterile line is influenced by its floral traits and stigma exsertion is of prime importance among them (Plate 6). Percentage of florets with protruding stigma were highest in PMS 10A (49.46%) followed by IR 68890A (48.13) and IR 66707A (47.84). Compared to *kharif* season, the trait was more expressed during *rabi* season in all the CMS line (Fig.4). In the maintainer lines stigma exsertion was very low and ranged between 1.33 and 5.3 per cent. This is in conformity with the negative correlation between stigma exsertion and pollen fertility reported by Huang and Huang (1978). Hoff and Torre (1981) reported significant correlation between seed set and stigma exsertion. In wild rices, where cross pollination is the general rule, stigma exsertion is very high (75 - 100%), but with domestication and shift from vegetative to sexual mode of reproduction, cultivated rice became adapted to self pollination in which exserted stigma is not a desirable trait. Hence in male sterile lines where cross pollination should occur these floral traits can be improved by using wild species.

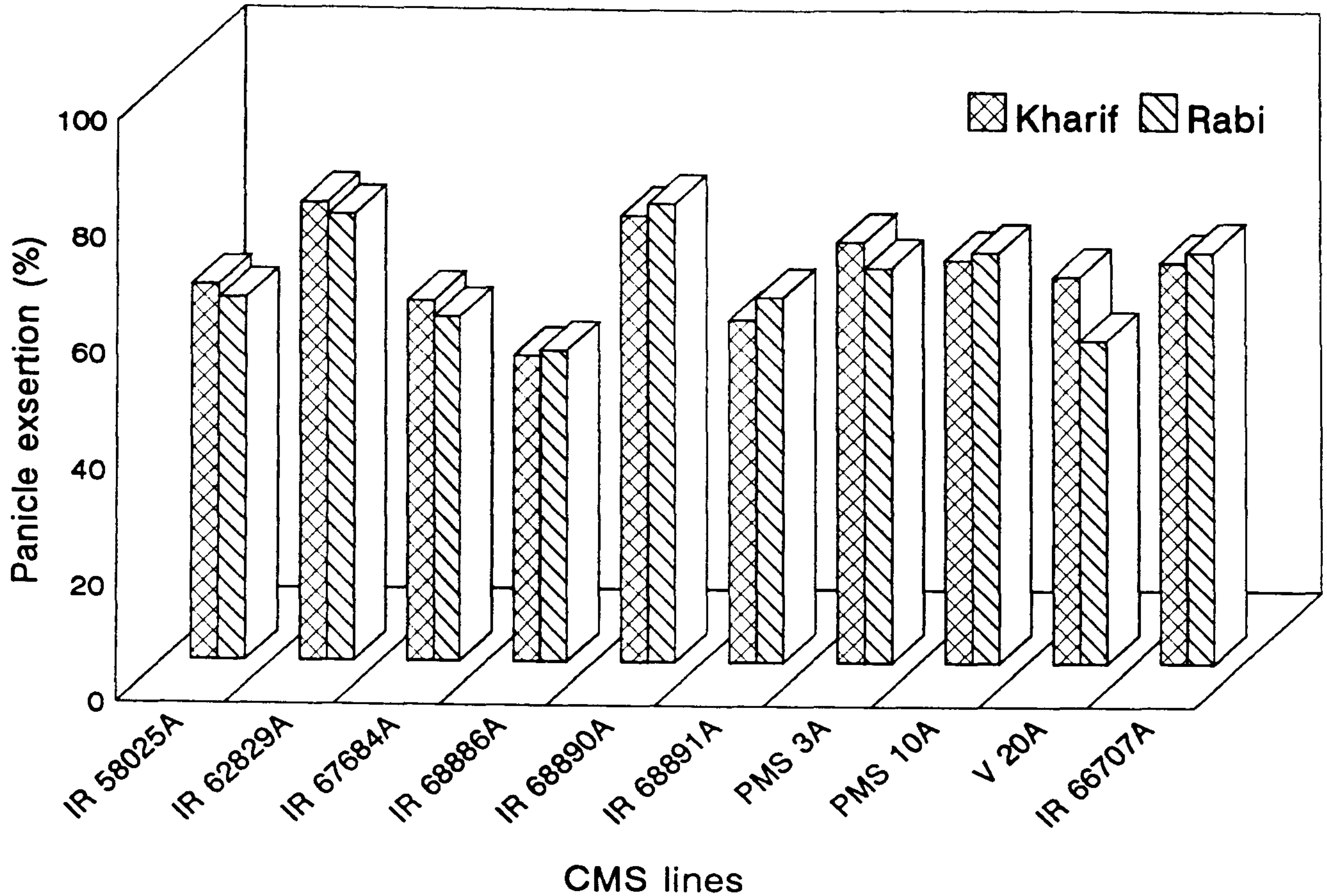


Fig.3 Panicle exsertion of 10 CMS lines during *kharif* and *rabi* seasons

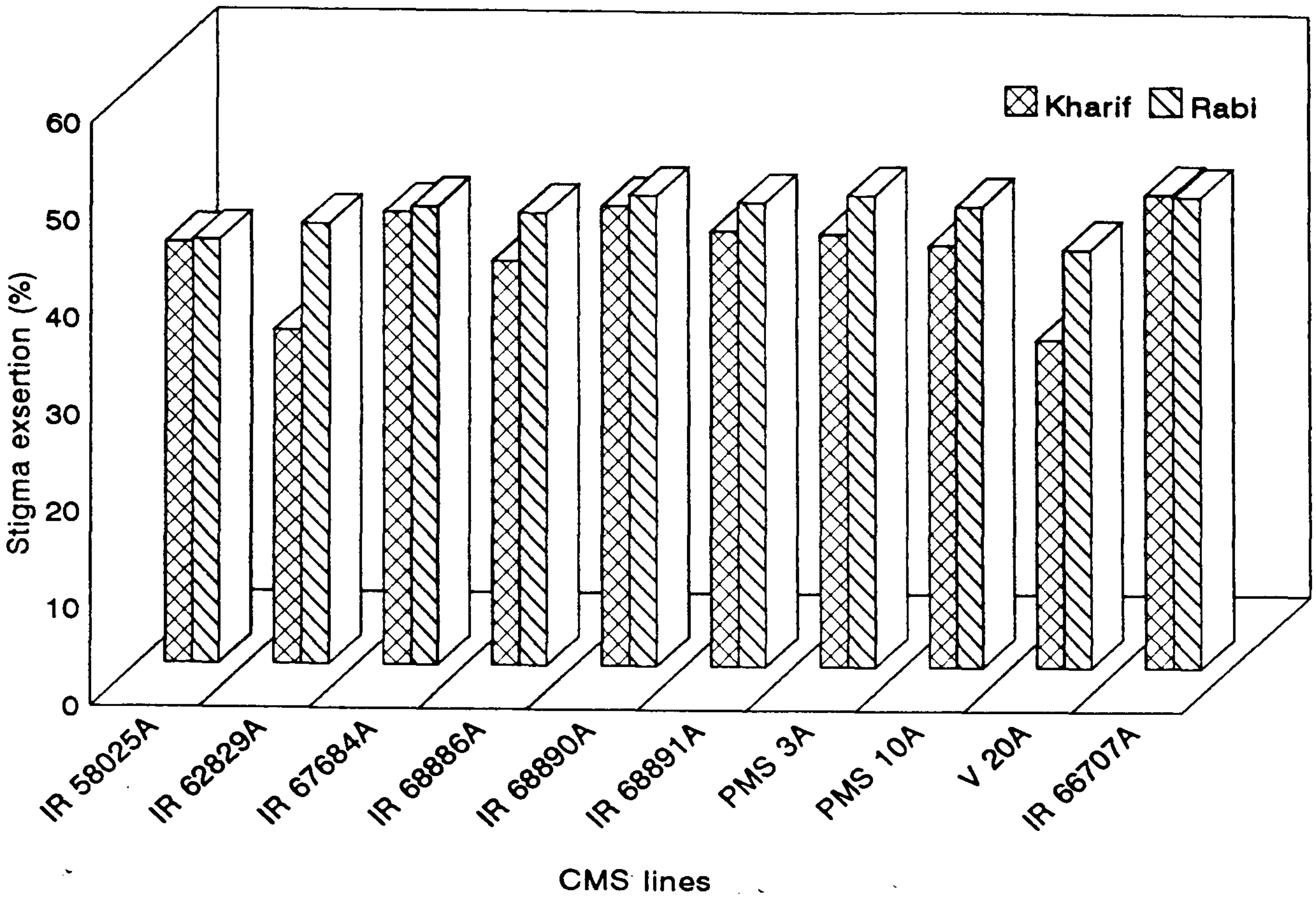


Fig.4 Stigma exsertion of 10 CMS lines during *kharif* and *rabi* seasons

Plate 4 IR 68890B - Maintainer of the most promising CMS line identified from the present study

Plate 5 Well exserted and partially enclosed panicles of rice


90 B

The period from opening to closing of florets, designated as blooming duration, varied highly between CMS lines (Fig.5). In the CMS lines studied, it varied from 86 to 290 minutes and in their isogenic maintainers blooming duration varied from 33 to 67 minutes.

Varietal differences in the duration of flower opening from 28 to 93 minutes have been reported in cultivated rice (Virmani and Athwal, 1973; Parmar *et al.*, 1979a) whereas in CMS rice plants it ranged from 105 to 280 minutes (IRRI, 1983a). Delay or failure in pollination was found to prolong blooming period (Grist, 1953) and consequently CMS plants have a longer duration of floret opening than fertile plants (Saran *et al.*, 1971). Results of the present study are in conformity with these reports.

All the CMS lines expressed higher duration of blooming during *rabi* seasons. This can be attributed to the high temperature. Works at IRRI had revealed that high temperature delayed anthesis and slightly increased the period of floret opening (IRRI, 1983b).

In addition to duration of floret opening, synchronisation of anthesis of female and male parents is extremely important. Synchronisation of anthesis in A and B lines was observed only in few CMS lines, viz., IR 58025A and IR 62829A (Fig.1a and 1b). In all the other cases maintainer lines flowered between 10 and 11 AM, whereas CMS lines started flowering only later. IR 67684A, PMS 3A and PMS 10A initiated blooming after 11.30 AM. Virmani (1994) also reported similar

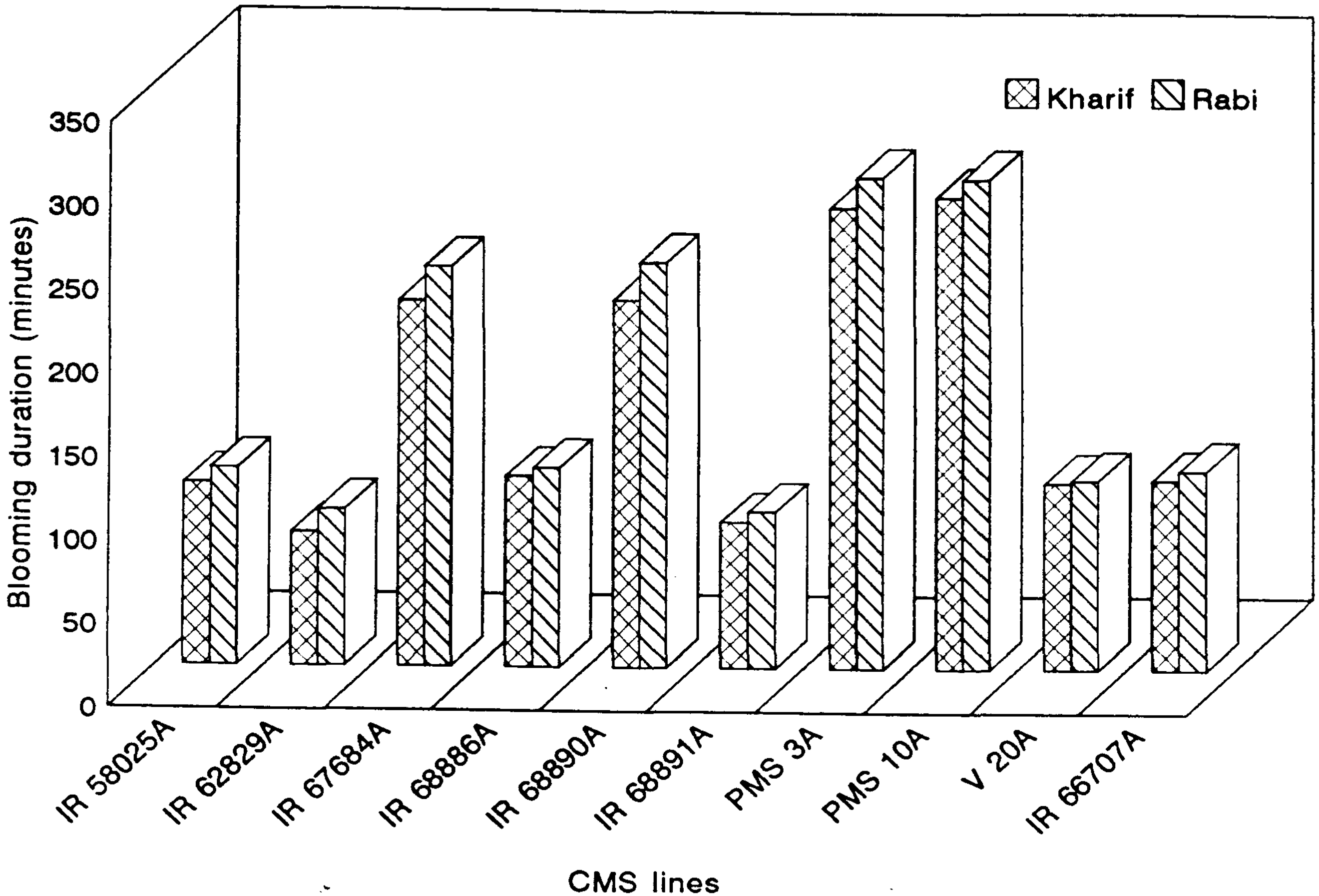


Fig.5 Blooming duration of 10 CMS lines during *kharif* and *rabi* seasons

phenomenon in anthesis of A and B lines at IRRI. Since pollen parents have a shorter period of anthesis, contrary to the opinions of Parmar *et al.* (1979b), the longer period of opening of female flowers may not necessarily increase seed setting. The prolonged period may be useful only in exceptional cases where there are two flushes of flower opening in pollen parents as reported by Mallaiah *et al.* (1991). Hence studies on pollen viability period and stigma receptivity in different lines will also be useful. Singh and Mahadevappa (1990) observed that in A lines only a few spikelets remained open at a particular time whereas in B lines all the spikelets opened and closed almost simultaneously.

Comparison of flowering behaviour during *kharif* and *rabi* seasons indicated the same trend during both seasons with the difference that anthesis started slightly earlier during *rabi* season in the B lines. This can be attributed to the slightly higher day temperature during this season.

Number of florets opened in a panicle was very low in CMS lines compared to their maintainers. Maximum number of florets opened in IR 68890A (50.28) and this was less than 50 per cent of the florets opened in corresponding B line. Floret opened in CMS lines varied from 26.00 (V 20A) to 50 (Fig.6). Low panicle exsertion can be attributed as one of the reasons for the low floret opening and hence low seed set. Nishimaki *et al.* (1992) opined that the disadvantages of CMS lines for outcrossing are delayed flowering and reduced number of bloomed florets. In CMS lines anthesis was over within three or four days and peak blooming was only for one or two days. In maintainer lines anthesis was for seven or eight days with peak

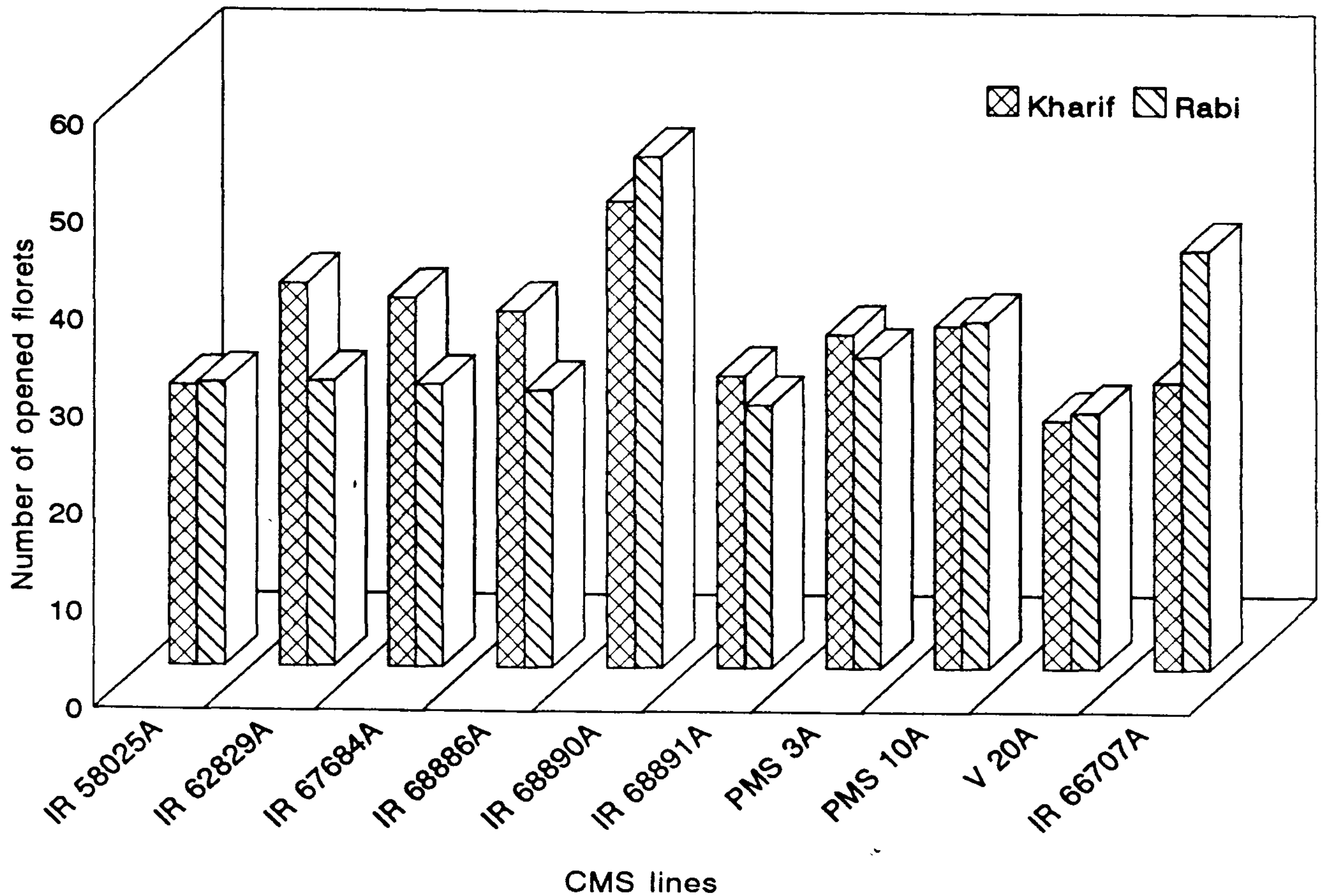


Fig. 6 Number of opened florets of 10 CMS lines during *kharif* and *rabi* seasons

blooming for three to four days (Fig.2a and 2b). Identification or development of CMS lines having longer blooming phase with more number of florets opening only can lead to increased seed production in hybrid rice programme. Singh and Mahadevappa (1990) also opined that, since A lines have low number of spikelets per panicle, conversion of non restorers with high number of spikelets into CMS lines may be useful in obtaining a distinct flush of sterile flowers.

Comparison between *kharif* and *rabi* seasons for the various parameters that influence outcrossing revealed that all these attributes are well expressed during *rabi* season than the *kharif* season. All the CMS lines had higher stigma exsertion and blooming duration during *rabi* season. Regarding panicle exsertion and number of opened florets also most genotypes expressed higher values during *rabi* season eventhough some others performed well during *kharif* season. It was seen that CMS lines viz., IR 68890A, PMS 10A and IR 66707A with higher panicle exsertion during *rabi* season had higher number of bloomed florets also during the same season. All these results reveal that hybrid seed production can be undertaken with more ease during *rabi* season, when all the floral traits favouring cross pollination are well expressed. Seetharamaiah *et al.* (1994) after evaluating male sterile lines during dry and wet seasons suggested that it is advantageous to produce hybrid rice seed during dry season, which is in conformity with the results of the present study.

5.2 Identification of restorers and maintainers

In any heterosis breeding programme using CMS system, identification of restorers and maintainers is the most important step. For developing commercial rice hybrids elite restorers with wide genetic base are to be identified and identification of genetically diverse maintainers are important for developing new CMS lines. For this locally adapted and elite breeding lines are to be screened for their fertility behaviour when crossed with CMS lines and grouped into maintainers and restorers based on pollen and spikelet sterility behaviour. Identification of restorers for different cytosterile sources will increase the cytoplasmic diversification which in turn can prevent genetic vulnerability due to the use of a single CMS source.

In the present study 34 rice genotypes were evaluated for fertility restoration when crossed with CMS lines derived from WA and *O. perennis* cytoplasm and were classified as effective restorers, partial restorers, partial maintainers and effective maintainers (Plate 7).

A large number of restorers and maintainers have been identified for WA CMS lines, in China (Li and Yiao, 1982; Wang, 1983; Yuan, 1985) at IRRI in Philippines (Virmani and Edwards, 1983; Govindaraj and Virmani, 1989; Tomar and Virmani, 1990) and in India (Pande *et al.*, 1990; Bharaj and Sidhu, 1991; Pradhan and Jachuck, 1991; Pradhan *et al.*, 1992; Misra and Pandey, 1993; Sohu *et al.*, 1993; Bijral *et al.*, 1991, 1993; Manuel and Rangaswamy , 1993a ; Prasad *et al.*, 1993; Jayamani *et al.*, 1994). Effective restorers for *O. perennis* source have not been identified so far.

Out of a total of 200 cross combinations attempted, 36 were fertile. Annapoorna, Kanchana, IR36, Matta Triveni and Aiswarya were considered as

Plate 6 Panicle of CMS lines with exserted stigma

Plate 7 Panicles from effective maintainers, partial maintainers, partial restorers and effective restorers (from left to right)

effective restorers for WA cytoplasmic male sterile lines. From among a total of seven CMS lines tested with WA sterile cytoplasm, these varieties were able to restore fertility of four to six CMS lines. Some of these varieties have been identified as effective restorers by previous workers also (Leenakumary *et al.*, 1998). Some of the results of the present study, however, differ from their observations. Annapoorna and Aiswarya were identified as maintainers by the previous workers, but they were found to restore fertility in the present study. Annapoorna, Matta Triveni, Kanchana, IR 36 and Aiswarya restored fertility of more number of WA cytosterile lines (Fig.7a; Plates 8 and 9).

These results suggest that environment influence fertility restoring genes as well as the sterile cytoplasm. Results of a joint study between IRRI and China, aimed at identifying effective restorer lines among elite breeding material developed at IRRI and other national programmes indicated that about 15 and 24 per cent of these lines were effective restorers in China and at the IRRI, respectively, but only 6 per cent were effective restorers at both sites. The restoration ability of the remaining restorer lines was site specific (Virmani and Edwards, 1983). They also described environmental influence on fertility restoration in wheat. Various environmental factors influence the penetrance and expressivity of Rf genes in wheat and in some cases the interaction of cytoplasmic male sterile lines with restoring genes in different environments have been highly unstable (Siddiq *et al.*, 1994).

Four varieties viz., Jyothi, Aruna, Pavizham and Ptb10 were identified as effective maintainers for more than five of the CMS lines tested

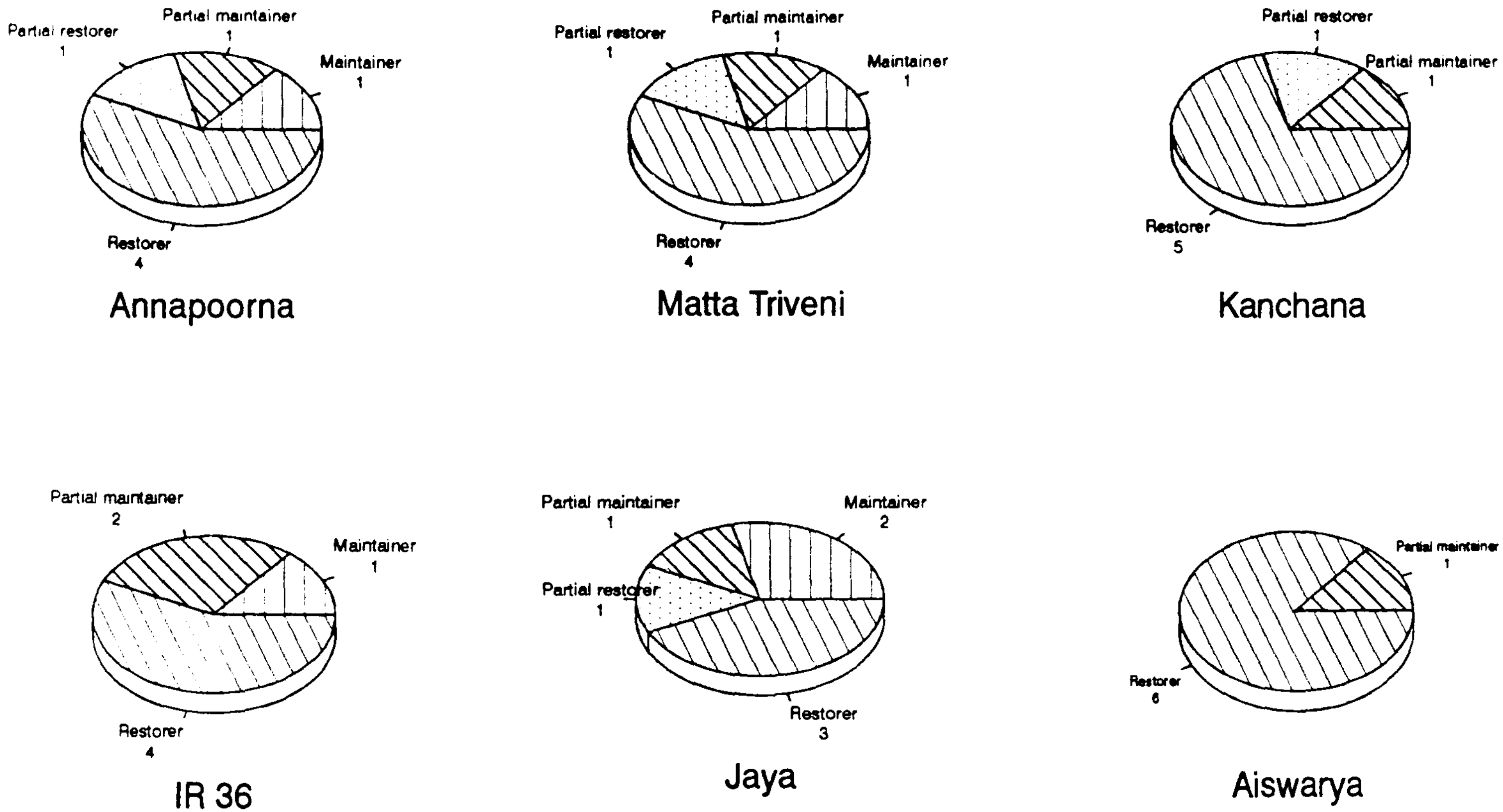
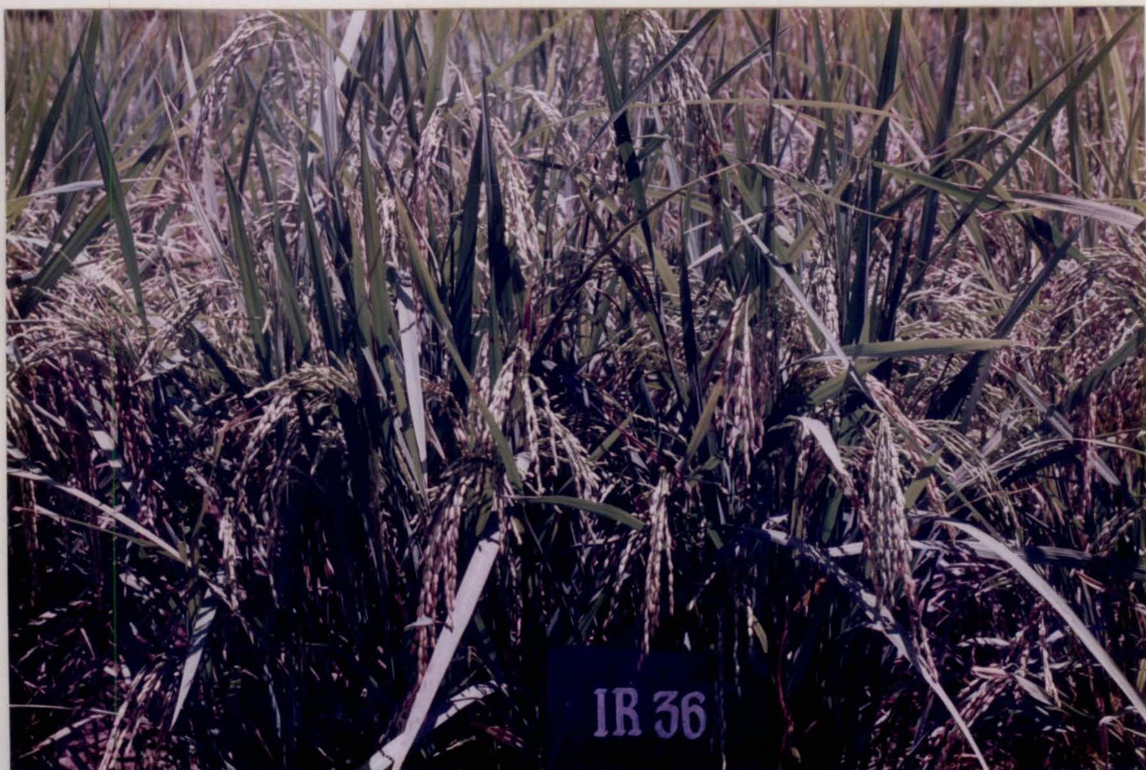


Fig.7a Restoration/Maintenance behaviour of selected rice genotypes

Plate 8 Kanchana - a promising restorer

Plate 9 IR 36 - a promising restorer


KANCHANA


IR 36

(Fig.7b; Plates 10 and 11). Jyothi was maintainer for all the seven CMS lines and could be effectively utilised in back cross breeding programme for development of location specific male sterile lines. Jyothi, being the most popular and well adapted variety of Kerala, conversion of the same into CMS line can be of great use to the humid tropical conditions, where stable CMS lines like V 20A expressed fertility to a certain extend. Aruna, Pavizham and Ptb10 were maintainers for five CMS lines. It is interesting to note that eventhough Aruna and Ptb 10 were maintainers for five CMS lines, they restored fertility of certain CMS lines. Aruna restored fertility of one CMS line and Ptb 10 restored fertility of two CMS lines with WA sterile cytoplasm. This type of differential reaction to fertility restoration was exhibited by other varieties also.

Prasad *et al.* (1993) reported CO 43 as a maintainer for IR 62829A and as restorer for V 20A. It was partial restorer for IR 58025A and TNAU 1A. This kind of behaviour of some rice genotypes with different CMS lines of the same cytoplasmic source has been reported by many workers (Govindaraj *et al.*, 1984; Bijral *et al.*, 1989; Tomar and Virmani, 1990; Bijral *et al.*, 1993; Chandra *et al.*, 1993). Oka (1953, 1964, 1974) suggested that the genetic background of the female parents could influence the pollen and spikelet fertility of F1 hybrids in intervarietal rice hybrids. Ingold (1968) also suggested that the restoration mechanism could be partly influenced by the genetic background of a variety. In wheat variation in the ease of restoration of a number of genotypes in *Triticum timopheevi* cytoplasm has been reported by several workers. Wilson (1968) interpreted this phenomenon as being the result of

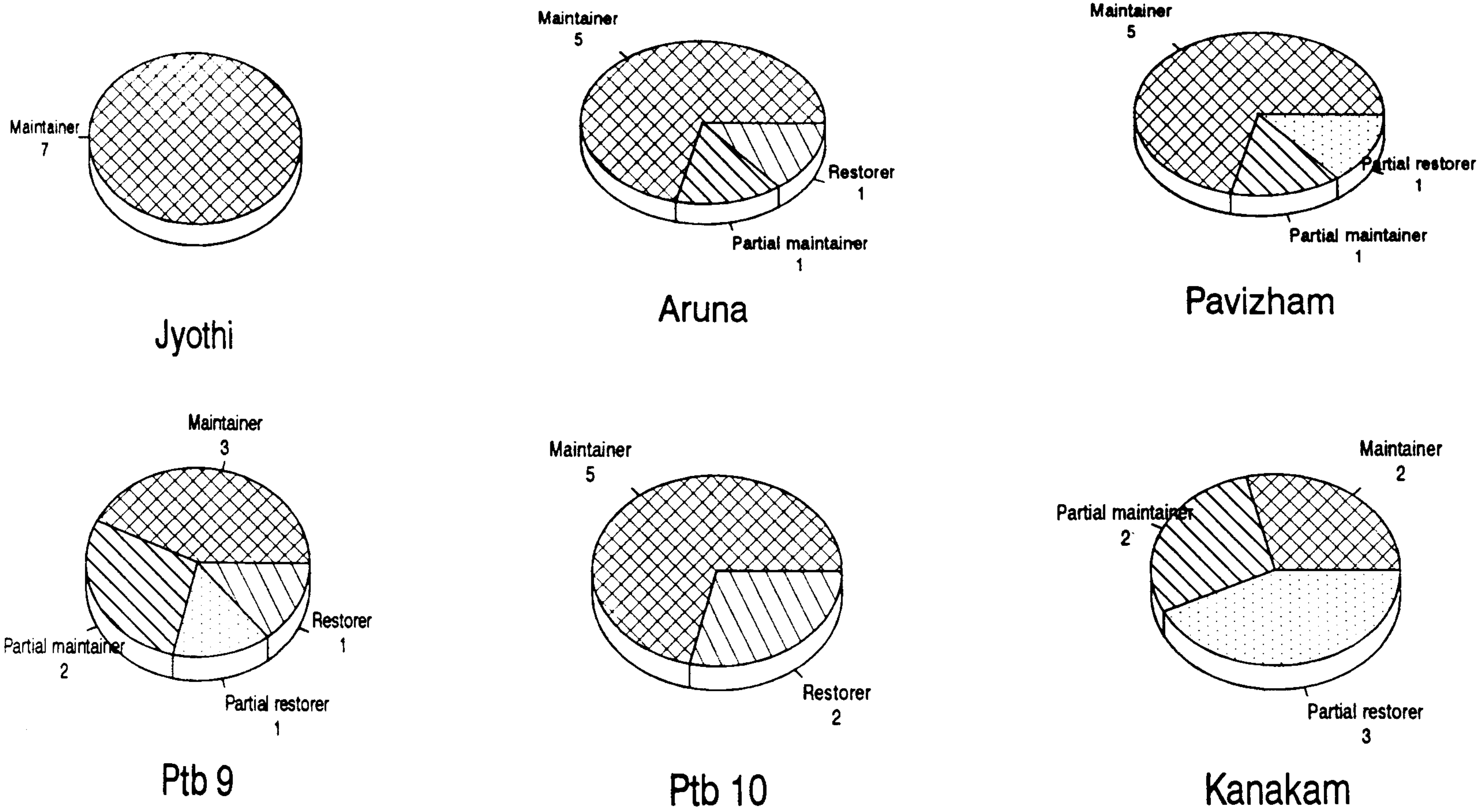


Fig.7b Restoration/Maintenance behaviour of selected rice genotypes

Plate 10 Pavizham - a promising maintainer

Plate 11 Jyothi - a promising maintainer


Pavizham


Jyothi

variations in sterility gene number and/or effectiveness among CMS lines or of the presence of fertility genes that act in a complementary or additive fashion with restorer genes. Excess sterility genes could act as inhibitors of pollen fertility restoration in the F1 generation. Bobby and Nadarajan (1994) reported variation in the restoration ability of R lines for the same CMS source and suggested that cytoplasms of different male sterile lines interact differently with individual pollinator varieties. They also identified that restorer lines are often a mixture of genotypes with regard to the gene(s) for fertility restoration. Therefore purification of restorer lines is essential in developing and breeding F1 rice hybrids.

Ratho and Pande (1985) reported that cytoplasm of the male sterile lines interact differently with different pollinator varieties. Siddiq *et al.* (1994) identified differences in fertility restoration in CMS lines with identical WA cytosterile system and they interpreted that this could be because the CMS lines had varied nuclear backgrounds. According to Virmani (1994) CMS lines which have the same cytoplasm but different nuclear genotypes showed differences in maintainer frequency indicating that the genetic back ground of CMS lines influenced their maintaining ability.

These interpretations may hold good for the differential behaviour of CMS lines to fertility restoration in the present study.

Until recently more than 95 per cent of the CMS lines used in the commercial indica rice hybrids were of CMS WA type. The unitary cytosterility situation has a latent crisis in the long run, which may lead the hybrid rice to a destructive pest. However, recently new CMS sources have been developed to offset potential risks. *Oryza perennis* is such a new source of cytoplasmic male sterility and effective restorers have not yet been identified for this source.

In the present investigation, none of the 31 genotypes tested with IR 66707A (the CMS line with *O. perennis* cytoplasmic source) could restore fertility. All of them expressed 99 to 100 per cent sterility and were effective maintainers. Further screening of genotypes in the germplasm is needed for identification of restorers for this CMS source. Dalmiaco *et al.* (1993) could not identify any restorers for CMS line IR 66707A and he reported high frequency of maintainers in *O. perennis* system with low frequency of restorers. Recently Pradhan and Jachuck (1995) were able to identify few genotypes which could restore partially the fertility of *O. perennis* cytoplasmic source.

5.3 Inheritance of fertility restoration in WA CMS lines of rice

Information on the genetics of fertility restoration in a CMS system facilitates breeding and selection of restorer lines used in the hybrid breeding programme. High yield of F1 hybrids depends on high spikelet fertility which in turn is determined by number of restorer genes and mode of gene action prevalent in the restorer lines.

Several workers have studied the inheritance of genes controlling restoration of pollen fertility in CMS lines of rice (Kitamura, 1962; Govindaraj and Siddiq, 1984; Huang *et al.*, 1986; Virmani *et al.*, 1986; Govindaraj and Virmani, 1988;

Anandakumar and Subramanian, 1992; Ramalingam *et al.*, 1995 and Virmani, 1994). Their reports differed in respect of the number of genes involved in restoration of CMS system, mode of action and relative effectiveness.

In the present study, investigations were undertaken to understand the inheritance of fertility restoration in four promising varieties of rice viz., Matta Triveni, Kanchana, IR 36 and Aiswarya using two CMS lines IR 62829A and IR 68890A. Fertility/sterility behaviour of individual plants in F2 and F3 populations of these crosses were analysed. All the eight cross combinations gave high pollen and spikelet fertility (around 80%) in the F1. The segregation pattern of individual plants in the F2 and F3 generations were studied to find out the number of restorer genes involved and their nature of action.

Monogenic (Govindaraj and Siddiq, 1984), digenic (Li and Yuan, 1986; Virmani *et al.*, 1986; Govindaraj and Virmani, 1988; Bharaj and Sidhu, 1991; Pande *et al.*, 1990; Ramalingam *et al.*, 1992; Virmani, 1994), trigenic (Govindaraj and Siddiq, 1984; Math *et al.*, 1990) mode of inheritance were reported earlier. Polygenic inheritance was reported by early Chinese Workers (Kitamura (1962). Huang *et al.* (1986) reported three or four Rf genes with complementary and additive effect to restore fertility.

In the present study on inheritance of fertility restoration, plants were present in each fertility class, but the frequency curve does not follow a normal distribution. Distribution of plants in each of the classes indicated polygenic inheritance of the character. Deviation from a perfect normal distribution along with more number of plants in certain classes suggest involvement of two or three genes along with modifiers. A continuous variation of fertility ranging from zero to 100 per cent was observed in the F2 population. This continuous distribution of fertility as well as the high influence of environment on this character indicated that fertility has the characteristics of a quantitative character. Continuous variation with regard to pollen and spikelet fertility was reported by Leenakumari (1994). Results of the studies in F3 was clearly indicative of a polygenic mode of inheritance. Partially fertile and fully fertile plants from F2 population exhibited normal distribution for fertility behaviour in the F3 population. Presence of different pairs of R genes along with modifiers and environmental influence made the inheritance of fertility restoration similar to polygenic inheritance.

Recent studies on male sterility in many plants including rice have revealed the role of environmental factors as well as plant growth substances in regulating male sterility/fertility. Nakagima *et al.* (1990) reported that male sterility in rice is correlated with the endogenous levels of giberellins and the levels of giberellic acids in the anthers of male sterile lines were less than 20 per cent of those in normal cultivars. Hormonal control of male sterility and fertility restoration has been reported in crops like wheat (Saini and Aspinall, 1982) and tomatoes (Sawhney *et al.*, 1983).

Interpretation about the number and relative importance of genes controlling fertility restoration is affected by a number of factors. Estimates of gene number could be biased by the criteria used to classify plants in the fertile group. Genotype environment interaction affect the fertility level of segregants and environmental factors like temperature greatly influence fertility restoration. More reliable estimates of number of genes involved and mode of inheritance could be obtained from studies under controlled conditions as well as from monosomic analysis in restorer lines.

5.4 Genetic distance between maintainers and restorers

Rao (1952) suggested the application of D^2 statistics for the assessment of genetic divergence in plant breeding. Genetic diversity plays an important role in crop improvement, since hybrids between lines of diverse origin, generally display a greater heterosis than those between closely related parents. Studies conducted by Xiu (1981) on genetic distance between maintainers and restorers and their relationship to heterosis in hybrid rice breeding programme in China revealed that strong heterosis was associated with maintainers and restorers having greater genetic distance.

In the present study 44 genotypes including selected genotypes from the germplasm and maintainers of ten CMS lines were grouped into nine clusters on the basis of 21 characters under study. Out of the five restorers identified, two were in Cluster III and another two in Cluster VI. Maintainers were more concentrated in Clusters II, V and VI. From the present study no direct relation could be envisaged between genetic divergence of the parents and heterosis of F1 hybrids over mid parent value for grain yield. Genotypes from clusters with medium level of divergence as well as genotypes from the same cluster produced better hybrids.

Singh and Ramanujam (1981) found no correspondence between divergence of the parents as measured by genetic distance and extent of superiority of F1 over mid parent in tomato. Similarly Peter and Pai (1978) failed to find a clearcut correspondence between extent of genetic divergence and heterosis for yield in tomato. Peng *et al.* (1991) did not get a relationship between heterosis and genetic divergence which could be used as a guideline for predicting heterosis in hybrid rice breeding programme. Similar results were reported by Sarathe and Perraju (1990); Patnaik *et al.* (1991); Sarawgi and Shrivastava (1991) ; Pradhan *et al.* (1995) and Singh *et al.* (1996).

Maximum genetic distance was exhibited between clusters VII and VIII, both represented by single genotypes - Ponmani and Hraswa, respectively. Clusters with medium genetic distance were found to produce hybrids with medium to high level of heterosis (Table 57). Highest level of heterosis (125.82%) was expressed by a hybrid combination of parents from cluster V and cluster III, genetic distance between clusters being 1070.29. Second highest heterosis (106.08%) was for the hybrid from a cross between two genotypes of cluster VI which consisted of both maintainers and restorers. Other hybrids produced by genotypes within the same cluster (cluster 6 and cluster 2) also produced medium to high level of heterosis. It was seen that the intracluster genetic distance was moderate for these clusters.

Arunachalam (1981) observed that probability of realising fruitful crosses can be increased by selecting parents with medium to high divergence range which holds true in the interpretation of the present results also. Crosses between extremely

Table 57 Comparison of heterosis for grain yield and distance between clusters in different cross combinations of rice

Sl. No.	Cross combination	Clusters to which parents belong	Distance between clusters	Heterosis over mid parent value (%)
1	IR 62829A/ Annapoorna	6	482.52	15.58
2	IR 62829A/ Matta Triveni	6	482.52	64.34
3	IR 62829A/ Kanchana	6 and 3	1426.35	75.77
4	IR 62829A/IR 36	6 and 2	1106.76	2.66
5	IR 62829A/Aiswarya	6 and 3	1426.35	34.21
6	IR 68890A/ Annapoorna	5 and 6	834.91	73.62
7	IR 68890A/ Matta Triveni	5 and 6	834.91	12.22
8	IR 68890A/ Kanchana	5 and 3	1070.29	79.89
9	IR 68890A/IR 36	5 and 2	1249.79	40.81
10	IR 68890A/ Aiswarya	5 and 3	1070.29	125.82
11	IR 68891A/ Annapoorna	6	482.52	106.08
12	IR 68891A/ Matta Triveni	6	482.52	48.21
13	IR 68891A/ Kanchana	6 and 3	1426.35	45.51
14	IR 68891A/IR 36	6 and 2	1106.76	114.21
15	IR 68891A/ Aiswarya	6 and 3	1426.35	40.56
16	PMS 10A/ Annapoorna	2 and 6	1106.76	23.45
17	PMS 10A/ Matta Triveni	2 and 6	1106.76	31.84
18	PMS 10A/ Kanchana	2 and 3	2272.58	24.60

Contd....

Table 57 contd...

19	PMS 10A/IR 36	2	491.52	54.75
20	PMS 10A/ Aiswarya	2 and 3	2272.58	58.42
21	IR 58025A/IR 8	2 and 1	2323.75	61.78
22	IR 58025A/Jaya	2 and 1	2323.75	-9.40
23	IR 58025A/ Aiswarya	2 and 3	2272.58	-5.60
24	IR 62829A/ Kairali	6 and 3	1426.35	34.80
25	IR 62829A/ Aathira	6 and 3	1426.35	79.60
26	IR 67684A/ Kanchana	2 and 3	2272.58	10.28
27	IR 68890A/ Ptb 10	5	475.87	74.25
28	IR 68891A/IR 8	6 and 1	2336.96	40.70
29	IR 68891A/Jaya	6 and 1	2336.96	45.00
30	PMS 3A/Jaya	2 and 1	2323.75	17.80
31	PMS 3A/ Aiswarya	2 and 3	2272.58	26.50
32	PMS 10A/Aruna	2 and 1	2323.75	62.20
33	PMS 10A/Ptb 9	2 and 4	4249.23	72.70
34	PMS 10A/Ptb 10	2 and 5	1249.79	72.50

divergent parents create a situation where the harmonious functioning of alleles to produce desirable enzyme system is disturbed. Consequently physiological functions may not be as efficient as in a situation where the alleles have a similar pressure. Hence while selecting parents for an appropriate heterotic combination, stress should be given on parents with intermediate genetic distance rather than with high genetic distance.

5.5 Genetic analysis of the hybrids

A critical pre-requisite for the successful production of hybrid varieties is that sufficient hybrid vigour be available in the parental combinations. This will ensure that yield of hybrids would significantly exceed those obtained from best conventionally bred varieties available. For selecting parental combinations that can produce better heterotic expression, varieties with high gca and sca are to be identified through combining ability analysis.

Heterosis

In the present study heterosis of 34 fertile hybrids and their 24 reciprocals were evaluated for different characters and the results are discussed here. There was difference in mean performance of hybrids for different characters and magnitude of heterosis expressed by hybrids also varied between crosses. Both positive as well as negative heterosis was observed for most of the characters. Similar results were reported by many workers for different characters (Karunakaran, 1968; Singh *et al.*, 1980; Balan, 1987; Manuel, 1992 and Uma, 1994).

Seventeen hybrids expressed positive heterosis for plant height. Positive heterosis for plant height is not generally favoured since the tall hybrids will have a chance to lodge under high fertiliser management (Kim and Rutger, 1988). In the present study tall hybrids produced using tall pollen parents such as Ptb9 and Ptb10 expressed lodging character, whereas semitall hybrids from Aathira, Aiswarya and IR 68890A did not express lodging behaviour. Manuel (1992) and Uma (1994) reported positive as well as negative heterosis for plant height.

All the hybrids expressed high positive values of relative heterosis, heterobeltiosis and standard heterosis for panicles per plant. Among reciprocal hybrids also heterosis was positive in most cases though it was low compared to direct hybrids, indicating a higher tiller production in direct hybrids than their reciprocals.

With regard to days to flowering, most of the direct and reciprocal hybrids expressed highly significant negative heterosis. Significant heterosis for earliness has been reported by Govindaraj and Siddiq (1986); Vidya Chandra (1991); Manuel and Palaniswamy (1989); Sahai and Chaudhary (1991;) while both negative and positive standard heterosis have been reported by a few other workers (Panwar *et al.*, 1983b; Sharma and Mani, 1990; Yogeesha, 1991 and Patil 1993). PMS 10A/IR 36 expressed highest negative heterosis over mid parent value and this is of significance, since early varieties with maximum heterosis has to be identified for achieving higher production per day.

Eventhough hybrids from tall parents such as Ptb9 and Ptb10 had high heterosis for plant height, heterosis for straw yield could not be achieved due to poor tillering, whereas parents with semitall stature produced F1s with medium height and high tillering which led to high heterosis for straw yield. Both positive as well as negative heterosis was exhibited by different hybrids for harvest index. Most of the hybrids had a higher production of dry matter due to higher vegetative growth. This can be the reason for negative heterosis exhibited by most of the hybrids eventhough they had higher grain production. Peng and Virmani (1991) also reported positive as well as negative heterosis for harvest index.

Significant positive heterosis for filled grains per panicle was exhibited only by three hybrids viz., IR 68891A/IR 36, PMS 10A/Ptb 9 and PMS 10A/Ptb 10. Eventhough total number of spikelets were high the increased sterility percentage expressed by A/R hybrids may be the reason for this phenomenon. This is more evident from the positive heterosis expressed for this character by the reciprocal hybrids. All the hybrids recorded positive standard heterosis for spikelet sterility. Negative heterosis for spikelet sterility is desirable for high yield and none of the hybrids expressed negative standard heterosis. Only few of them recorded negative heterosis over mid parent and better parent. IR 62829A/Aathira, IR 68890A/Ptb10 and PMS 10A/Ptb10 recorded non-significant standard heterosis and negative heterobeltiosis which indicate that these hybrids have high fertility restoration. The spikelet sterility of the hybrids may be due to incomplete fertility restoration resulting from the use of partial restorers as male parents or due to high genotype x environment interaction resulting in improper expression of the trait. High negative heterosis for the character expressed by reciprocal hybrids also favours this argument. Rangaswamy and Natarajamoorty (1988) reported very low (-46.9%) to as high as 238.5 per cent heterosis for spikelet sterility in various hybrids. Manuel and Palaniswamy (1989) and Patnaik *et al.* (1991) also reported similar results.

Most of the hybrids exhibited significant and negative values for all the three estimates of heterosis for panicle exsertion. This was reported to be due to the influence of sterile cytoplasm which is inherited from female parent and is evident from the positive significant heterosis exhibited by reciprocal hybrids. Hybrids IR 68890 A/Ptb10, PMS 3A/Jaya, PMS 3A/Aiswarya, PMS 10A/ Aruna and PMS 10 A/ Ptb9 had significant positive heterosis for this character which indicate that genotypes such as PMS 3A, PMS 10A, Ptb9, Ptb10, etc. which have high panicle length and with better exsertion can express this character even in the presence of sterile cytoplasm. Identification of parents which can produce hybrids with good panicle exsertion had much relevance since this has a direct relation with spikelet sterility as well as filled grains per panicle. Manuel (1992) and Uma (1994) reported positive as well as negative heterosis for panicle exsertion.

Significant negative heterosis was expressed by most of the hybrids for hundred seed weight. This can be attributed to the very low 100 seed weight of the fine grained CMS lines compared to the coarse grained varieties of Kerala. Among the CMS lines only IR 68890 A had high test weight and grain shape similar to those of Kerala varieties and two hybrids viz., IR 68890 A/Annapoorna and IR 68890A/ Aiswarya recorded positive heterosis for 100 seed weight. Positive as well as negative heterosis for this trait was reported by Karunakaran (1968); Panwar *et al.* (1983);

Amrithadevarathinam (1984); Bijral *et al.* (1989); Patnaik *et al.* (1991); Ramalingam *et al.* (1995) and Yolanda and Vijendradas (1996).Similar to 100 seed weight almost all hybrids recorded negative values of heterosis for grain density. Eventhough few of them had significant positive values over mid parent, they expressed negative values over better parent and standard check variety. Only two hybrids viz., PMS 10A / Ptb 9 and PMS 10A / Ptb 10 expressed significant positive heterosis for this character. Low values for grain density as well as negative heterosis for this character may be attributed to the peculiar grain shape of the hybrids and poor grain filling due to various degrees of sterility expressed by them.

Most of the hybrids expressed significant and positive values of heterosis for leaf area index. Increase in leaf area of the plant can be attributed to the high tillering habit of hybrids, which in turn led to high dry matter production. In reciprocal hybrids, significant heterosis for leaf area index was exhibited by only very few hybrids. Lang and Bui (1993) reported high and positive heterosis for leaf area index in hybrids.

In the present study eventhough 23 hybrids recorded significant positive relative heterosis for grain yield and 12 hybrids expressed significant positive heterobeltiosis, only five hybrids had significant positive standard heterosis over check variety, Kanchana. Since relative heterosis and heterobeltiosis are more of academic importance and standard heterosis is of practical importance, more emphasis is given for standard heterosis in hybrid breeding programmes of rice. Hybrids IR 62829A/Kanchana, IR 68890A/Kanchana, IR 68890A/Aiswarya, IR 68891A/IR 36 and IR 62829A/Aathira recorded significant positive standard heterosis and can be used for the production of hybrids in rice (Plates 12 to 17). Heterosis for grain yield is due to simultaneous heterosis in more than one components of yield. In this study it can be seen that heterosis for vegetative characters viz., tiller number, flag leaf area, leaf area index etc. were high, whereas heterosis for grains per panicle, grain density, hundred seed weight etc. were lower or negative in most of the cases which in turn can limit heterosis for grain yield. Positive as well as negative standard heterosis for grain yield have been reported by many rice workers in different hybrids (Pillai, 1961; Karunakaran, 1968; Saini *et al.*, 1974; Singh *et al.*, 1980; Ravikumar, 1983; Rangaswamy *et al.*, 1988; Manuel, 1992; Leenakumary *et al.*, 1993).

Combining ability

Combining ability effects of parents have been used for evaluating the ability of parents to transmit desirable traits to their offspring. In the present study combining ability of nine parents and 20 hybrid combinations were analysed through line x tester analysis. The analysis of variance for combining ability revealed that variance due to lines, testers and line x tester interaction were significant for most of the characters studied, indicating the presence of adequate variability in the experimental material. Magnitude of sca variance was more than gca variance for plant height, tillers per plant, panicles per plant, total dry matter, panicle length, filled grains per panicle, spikelet sterility, panicle exsertion, panicle weight, flag leaf area, leaf area index, grain yield and straw yield suggesting predominance of non additive

Plate 12 IR 62829A/Aathira - a better performing hybrid combination

Plate 13 IR 62829A/Kanchana - a better performing hybrid combination


29A/Aathira

Plate 14 IR 68890A/Aiswarya - a better performing hybrid combination

Plate 15 IR 68891A/IR 36 - a better performing hybrid combination


xIR36

Plate 16 Earheads from promising rice hybrids

Plate 17 IR 36/PMS 10B - a reciprocal hybrid


10A/Aruna
10A/Ptb 9
10A/Ptb 10
90A/Kanchana
91A/Annapoorna
29A/Aiswarya
91A/IR 36


IR36/PMS10B

genetic variance for these traits which could be exploited through heterosis breeding. Similar results were reported by Srivasthava and Seshu, 1982; Panwar and Paroda, 1983; Nilakanta Pillai, 1987; Manuel and Palanisamy, 1989.

In the present study IR 68890 A, Kanchana and Aiswarya had high positive gca effects for most of the characters studied. Among the female parents IR 68890 A recorded high positive gca for characters viz., panicles per plant, days to flowering, grain yield per plant, straw yield per plant, total dry matter accumulation, hundred seed weight, grain breadth, grain thickness, panicle weight, grain density and leaf area index. These results indicate that this particular CMS line can be effectively utilised in the hybrid breeding programme aimed at production of superior hybrids. Among the testers high gca for different characters were expressed by different genotypes. Kanchana exhibited high gca values for panicles per plant, grain yield and grain density, whereas Aiswarya recorded high gca values for plant height, duration, grain yield, straw yield, total dry matter, hundred seed weight and leaf area index. Matta Triveni recorded high gca for harvest index and IR 36 recorded high gca for filled grains per panicle as well as panicle exsertion. Singh (1977); Virmani *et al.* (1981), and Peng and Virmani (1991) also reported different varieties to have high gca effect for different characters.

Specific combining ability effect is the index to determine the usefulness of a particular cross combination in the exploitation of heterosis. IR68890 A / Aiswarya recorded highest sca for grain yield and both the parents of this particular cross combination had highest positive gca. Second highest sca for grain yield was recorded by the cross IR 68891A / IR36 in which both the parents had non-significant gca effect. IR 62829A / Matta Triveni recorded high positive sca eventhough both the parents had significant negative gca. All these reveal that the sca effect of a particular cross combination may not depend much on gca of parents and that almost all kinds of sca effects can be obtained from any type of parental combination. Similar findings were reported by Ranganathan *et al.* (1973) and Singh (1977).

Positive and significant sca effect for straw yield was recorded by IR 62829A/Aiswarya. For plant height, PMS 10A/Aiswarya recorded significant positive sca effect and IR 62829A/Aiswarya showed significant negative sca effect. IR 68890A/Aiswarya, which recorded highest positive sca effect for grain yield also recorded high positive sca effect for total dry matter production and harvest index. This particular hybrid also had high sca for panicle exsertion and 100 seed weight which are highly desirable in hybrid breeding programmes in rice.

The number of cross combinations generated from parents having different types of gca effect (viz., positive significant, negative significant or non-significant) and their corresponding sca effects are listed in Table 58. Almost all types of sca effects were obtained from any type of parental combinations. Parents with high, medium and low general combining ability produced hybrids with high sca. In the case of plant height, negative sca is preferred and hybrid combinations from one parent having positive gca and the other having negative gca produced more number of hybrids with negative sca. For this particular character it was also found that when both the parents have negative gca, most of the hybrid combinations had

Table 58 Number of cross combinations generated from parents with different types of gca effects and their corresponding sca effects for different characters

GCA effects of parents	SCA effects of hybrid combinations	Plant height	Tiller per plant	Panicles per plant	Flowering duration	Grain yield per plant	Straw yield per plant	Chaff per cent	Harvest index	Panicle exsertion	Filled grains per panicle	Hundred seed weight	Grain density	Leaf area index
+/+	+	1	1	-	1	1	-	-	-	1	-	2	1	-
	0	1	1	1	2	1	1	1	-	-	-	1	1	1
	-	-	-	-	1	-	-	-	-	1	-	1	-	1
Total	-	2	2	1	4	2	1	1	-	2	-	4	2	2
+/- or -/+	+	1	1	-	2	1	-	-	-	1	-	1	-	3
	0	1	1	1	2	2	1	1	1	1	-	1	5	1
	-	5	3	2	2	1	-	1	-	2	1	4	1	3
Total	-	7	5	3	6	4	1	2	1	4	1	6	6	7
+/0 or 0/+	+	1	1	2	1	-	2	2	-	3	1	1	1	1
	0	1	1	1	2	2	1	3	3	1	2	3	2	1
	-	-	3	1	1	3	3	-	-	1	-	-	1	9
Total	-	2	5	4	4	5	6	5	3	5	3	4	4	2
-/0 or 0/-	+	-	-	-	-	1	1	-	3	3	1	1	-	2
	0	1	4	4	3	3	1	5	4	-	7	2	4	2
	-	2	-	2	-	1	1	-	1	2	-	1	-	2
Total	-	3	4	6	3	5	3	5	8	5	8	4	4	6
0/0	+	4	1	1	-	1	1	1	-	-	1	-	-	-
	0	-	1	2	-	1	6	3	4	1	4	-	-	-
	-	-	-	1	1	-	2	2	2	1	1	-	-	-
Total		-	2	4	1	2	9	6	6	2	6	-	-	-
-/-	+	4	1	1	1	1	-	-	-	1	-	2	1	2
	0	1	1	1	1	1	-	1	1	-	2	-	2	1
	-	1	-	-	-	-	-	-	1	1	-	-	1	-
Total		6	2	2	2	2	-	1	2	2	2	2	4	3

+ Positive significant; 0 non-significant and - negative significant gca or sca effect positive sca effects. Hence for producing dwarf hybrids, it is better to select one parent with positive gca and the other with negative gca. Hybrids with positive and significant sca for grain yield was produced by almost all types of parental combinations. The high yield potential in the cross combinations (high x low) can be attributed to interaction between positive alleles from good combiner and negative alleles from poor combiner while heterosis involved in high x high combiners involve interaction between positive x positive alleles. In the present study low x low combinations also produced hybrids with high sca and this can be attributed to overdominance or epistasis (Khaleque *et al.*, 1977; Amrithadevarathinam, 1984). All these results revealed that there is no direct relation between gca effects of parents and sca effects of hybrid combinations. This can be also explained from the point of gene action, since gca is more due to additive gene action whereas, sca is due to dominance and epistasis. Peng and Virmani (1991) reported that eventhough there is no direct relation between hybrid performance and gca of parents, it is better to select one parent with high gca.

5.6 Association of characters in hybrids

Knowledge of the association between grain yield and yield contributing characters will help to select characters of importance in hybrid breeding programmes. In the present study total dry matter production of the plant followed by harvest index recorded highest positive correlation with grain yield. Number of filled grains per panicle, grain breadth, panicle weight, grain density, flag leaf area and leaf area index at 60 days after sowing exhibited significant positive correlation with yield (Fig.8).

X_1	Total dry matter per plant
X_2	Harvest index
X_3	Number of grains per panicle
X_4	Grain length
X_5	Grain breadth
X_6	Panicle weight
X_7	Flag leaf area
X_8	Grain density
X_9	Leaf area index
X_{10}	l/b ratio
X_{11}	Straw yield per plant
Y	Grain yield per plant

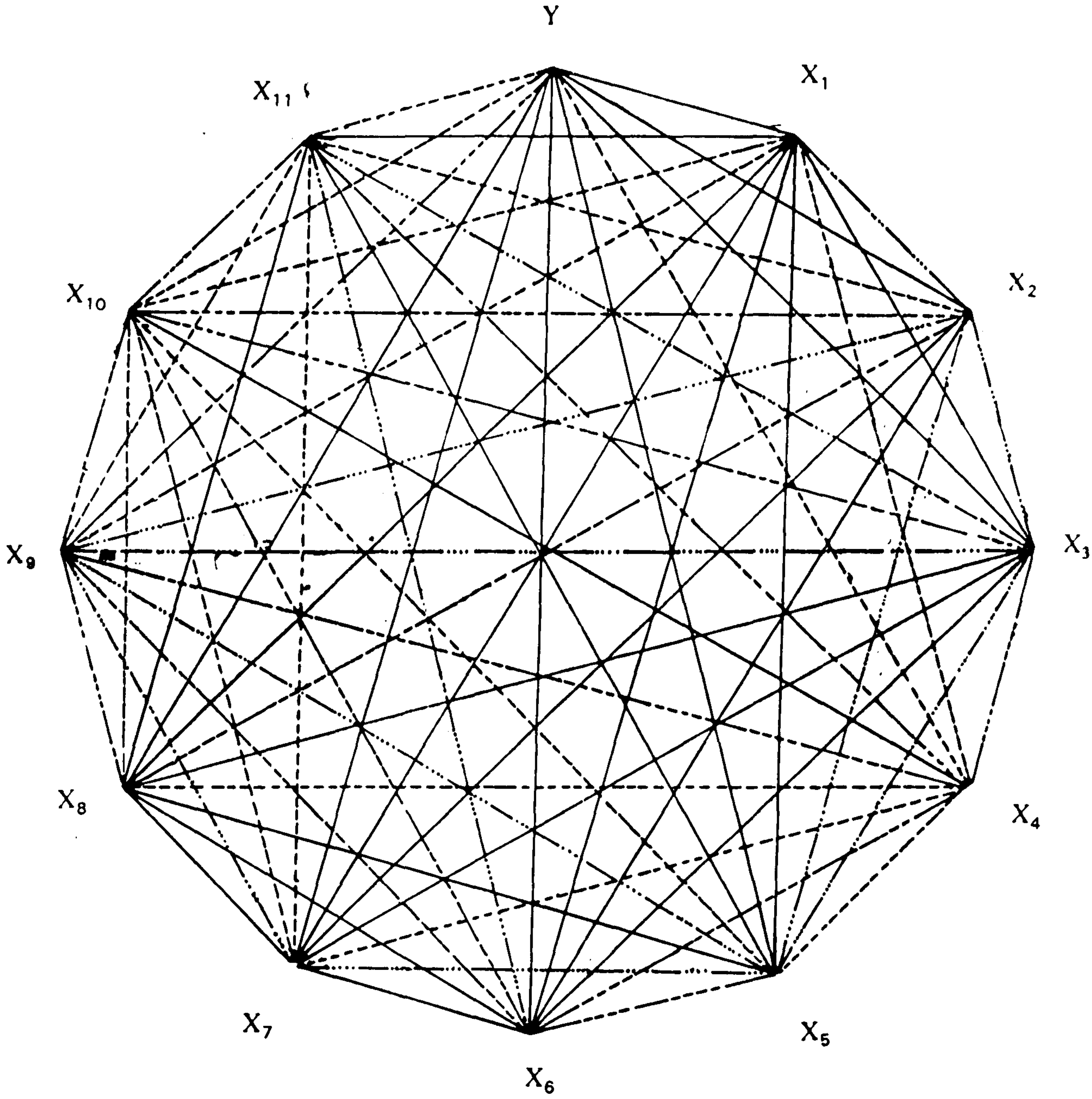


Fig.8 Genotypic correlations among different characters in rice hybrids

———— Significant positive genotypic correlation

- - - - - - - Significant negative genotypic correlation

—·····—·····— Nonsignificant positive genotypic correlation

——— - - - - Nonsignificant negative genotypic correlation

These results indicate that grain yield of the hybrids does not depend much on the plant characters during vegetative phase like tiller number, duration or panicles per plant. This can be due to the peculiar behaviour of the hybrids to produce more number of tillers which in turn can hinter translocation efficiency. since it is difficult to identify superior hybrids based on total drymatter and harvest index, which can be calculated only after harvest, characters like number of filled grains per panicle, flag leaf area, grain breadth etc. which have high correlation with dry matter accumulation and harvest index can be given more emphasis. These results are in conformity with the findings of Manuel and Rangaswamy (1993b), Geetha *et al.* (1994); Yuan *et al.* (1995) and Dash *et al.* (1996).

Jun (1985) reported high correlation between grain length and yield. In the present study grain length had negative correlation with all the characters except L/B ratio. This difference in the results can be because of the difference in grain shape of the genotypes under study. Genotypes included in the present study were having coarse grains in which grain breadth and thickness contribute to grain yield unlike the slender types in which grain length is of importance.

5.7 Cytoplasmic influence on agronomic attributes

In a hybrid breeding programme based on cytoplasmic male sterility, the effects of sterility inducing cytoplasm on agronomic traits is of much importance. In maize, reciprocal differences for yield, maturity and other agronomic traits have been related to the cytoplasmic differences (Kalsy and Sharma, 1972). Bhat and Dhawan (1969) and Kalsy and Sharma (1972) reported a high level of cytoplasm x environment interactions. In rice, the effects of sterile cytoplasm have been studied in China and the results indicated that sterile cytoplasms reduced the productive capacity of hybrids compared with normal cytoplasms of maintainers (Lin and Yuan, 1980; Yang *et al.*, 1980).

In the present study cytoplasmic influence on agronomic attributes were studied by evaluating the direct and reciprocal hybrids produced using WA cytoplasmic male sterile lines and restorer lines. Results of the `t' test indicated significant difference between direct hybrids (A/R-CMS lines as female parents and restorer lines as male parents) and reciprocal hybrids (R/B- restorer lines as the female parents and maintainer line as male parent). The reciprocal cross effects were highly significant for plant height, tiller production, grain yield, straw yield, harvest index, grains per panicle, spikelet sterility, panicle exsertion, panicle weight, grain density and leaf area index. Reciprocal difference was not found in characters like duration, total dry matter production, panicle length and 100 seed weight. Eventhough there was difference for grain and straw yield, total dry matter did not differ significantly, which indicate that though the hybrids produced using CMS lines are capable of producing high dry matter, partitioning into economic yield is being suppressed. This may be due to increased vegetative growth and poor translocation in these hybrids. This is more evident from the low harvest index of these hybrids compared to the hybrids in which restorers with normal cytoplasm are the female parents. AxR hybrids had less number of fertile grains per panicle and high spikelet sterility. These factors along with poor panicle exsertion made these hybrids less productive than the reciprocal hybrids. These differences in performance can be attributed to cytoplasmic difference.

Eventhough these are the average performance of the two groups of hybrids, when different cross combinations are considered it can be seen that these are cross specific and each cross differs in their performance. Since there are differences in performance between crosses, it can be interpreted that the cytoplasmic influence differ with nuclear back ground and it is actually the result of interaction between cytoplasmic and nuclear genes and hence the undesirable effects of cytoplasm can be eliminated by selecting suitable parents in hybrid breeding programmes.

Differences in performance between reciprocal hybrids have been reported by Virmani and Tan (1983) and Hassan and Siddiq (1984). Virmani and Edwards (1983) indicated that sterile cytoplasm had negative effects on number of spikelets per panicle, number of filled grains per panicle, 1000 grain weight and yield per plant, although it had positive effect on number of tillers per hill. These results hold good in the present study also. Similar results were reported by Lin and Wu (1990), Young and Virmani (1990a), Cai (1995), Skikh (1995).

There was difference in magnitude as well as direction of heterosis in the direct and reciprocal hybrids for different characters. Almost all reciprocal hybrids expressed positive and significant heterosis for grain yield and the magnitude of heterosis was also much higher than that of direct hybrids. Only very few hybrids (AxR) expressed significant standard heterosis over Kanchana, whereas out of the

24 reciprocal hybrids, 12 expressed significant and positive standard heterosis for grain yield. This indicates that eventhough there is high vegetative growth for AxR hybrids, there are some factors which hinter grain production in these hybrids. Since these two sets of hybrids differ only in their cytoplasm, it can be considered as the negative influence of sterile cytoplasm on grain yield. In the case of straw yield, all the reciprocal hybrids expressed lower heterosis than the AxR hybrids indicating a favourable source sink relationship in reciprocal hybrids. This is more evident from the positive and higher heterosis for filled grains per panicle in reciprocal hybrids compared to negative heterosis in AxR hybrids. Behaviour of hybrids were just reverse for spikelet sterility, where AxR hybrids expressed high positive heterosis for spikelet sterility. These factors explain the lower level of heterosis expressed by AxR hybrids for grain yield than their corresponding reciprocal hybrids. This is of considerable importance in heterosis breeding programmes in rice; since hybrid seed production can be made economic only by the use of CMS lines and if these lines are having negative influence on economic traits it can hinter the pace of development of hybrid rice programmes. Young and Virmani (1990a) also reported negative influence of cytoplasm on agronomic attributes and they have opined that different genotypes interact differently with the same cytoplasm showing different cytoplasmic effects and proper selection of CMS lines as well as restorers can lead to better heterotic combinations. These findings are in conformity with the results of the present study.

Summary

SUMMARY

An investigation was carried out in rice, at College of Horticulture, Vellanikkara and Agricultural Research Station, Mannuthy, to evaluate cytoplasmic - genic male sterile lines for stability of male sterility and floral traits influencing outcrossing, to identify maintainers and restorers for WA and *O. perennis* cytoplasmic sources, to find out the inheritance of fertility restoration in the available restorers identified, to estimate genetic distance between maintainers and restorers, to identify superior hybrids after studying heterosis and combining ability, to study association of characters in rice hybrids and to find out the influence of sterile cytoplasm on agronomic attributes.

1. Evaluation of CMS lines for stability in pollen and spikelet sterility behaviour revealed that IR 66707A, with *O. perennis* cytoplasmic source recorded 100 per cent pollen and spikelet sterility during all the four seasons and was stable.

2. Among the CMS lines with WA cytoplasm IR 58025A, IR 62829A, IR 68890A, IR 68891A and PMS 10A were identified as stable with more than 99.5 per cent pollen and spikelet sterility.

3. Evaluation of floral traits influencing out crossing revealed that eventhough male sterile lines have higher percentage of flowers with exserted stigma and higher blooming duration, they had poor panicle exsertion and lesser number of opened florets compared to their maintainer lines.

4. There was significant genotype-environment interaction for all the floral traits which indicated difference in performance of genotypes in different environments.

5. Comparison of *kharif* and *rabi* seasons for floral traits showed that almost all floral traits influencing outcrossing are well expressed during *rabi* season than during *kharif* season.

6. Out of 200 F_1 hybrids from seven CMS lines of WA cytoplasmic source and selected genotypes, 36 were completely fertile. More number of fertile hybrid combinations were produced by Annapoorna, Matta Triveni, Kanchana, IR 36 and Aiswarya.

7. Jyothi, Aruna, Pavizham and Ptb 10 produced more number of sterile hybrids and can be utilised in back cross breeding programmes for evolving locally adapted male sterile lines.

8. All the hybrids produced using *O. perennis* cytoplasm were sterile and can be used as maintainers. Restorers were not identified for this new source of cytoplasmic male sterility.

9. Inheritance studies on fertility restoration indicated polygenic mode of inheritance for this particular character.

10. Forty four rice genotypes included in the source germplasm for hybrid rice breeding were grouped into nine clusters, each having different number of

genotypes. Maintainers and restorers were distributed in different clusters and no direct relation could be established between heterosis and genetic distance of the parents.

11. Cluster No.VII, which is represented by a single genotype viz., Ponmani recorded highest mean value for 14 out of 23 characters studied. It recorded highest mean value for most of the agronomic attributes.

12. Genetic analysis of the hybrids for assessing their superiority resulted in the identification of five hybrids having significant positive heterosis over standard check variety, Kanchana for grain yield. IR 62829A / Kanchana, IR 68890A/ Kanchana, IR 68890A/Aiswarya, IR 68891A/IR 36 and IR 62829A/Aathira were identified as the promising hybrids.

13. High positive heterosis for spikelet sterility along with negative significant heterosis for hundred seed weight and number of filled grains per panicle expressed by most of the hybrids can be due to incomplete fertility restoration or due to high genotype x environment interaction resulting in improper expression of the trait.

14. Magnitude of the gca variance was more than the variance due to sca for days to flowering, total duration, harvest index, 100 seed weight, grain length, grain breadth, grain thickness, grain density and l/b ratio indicating predominance of additive variance for these characters.

15. Variance due to sca was more for plant height, tillers per plant, total drymatter production, grain yield per plant, straw yield per plant, panicle length, filled grains per panicle, spikelet sterility, panicle exsertion, panicle weight, flag leaf area and leaf area index indicating predominance of variance due to dominance and epistasis.

16. Among the male sterile lines IR 68890A was identified as the best combiner for most of the agronomic traits and among restorers Kanchana, Aiswarya, IR 36 and Matta Triveni were identified as good combiners for different yield contributing characters.

17. Hybrid combination IR 68890A / Aiswarya was the best specific combiner for grain yield, total drymatter production, harvest index, hundred seed weight and panicle exsertion.

18. Studies on association of characters in hybrids revealed that total drymatter accumulation, harvest index, number of filled grains per panicle, grain breadth, panicle weight, grain density, flag leaf area and leaf area index at 60 days after sowing are positively correlated with grain yield produced by the hybrids.

19. Genotypic and phenotypic correlation of the selected characters between themselves and with yield revealed that harvest index, number of grains per panicle, grain breadth, panicle weight, flag leaf area and grain density had significant positive genotypic correlation with yield, whereas, grain

length, l/b ratio and straw yield per plant had significant negative genotypic correlation with yield. Total dry matter produced by the plant had higher phenotypic correlation with grain yield than genotypic correlation.

20. Investigations on the influence of sterile cytoplasm on various agronomic attributes by studying direct and reciprocal hybrids revealed the negative influence of sterile cytoplasm on yield and other agronomic attributes like plant height, tiller production, number of grains per panicle, harvest index, spikelet sterility, panicle exsertion, panicle weight, grain density and leaf area index.

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Appendices

APPENDIX I

Meteorological data during the cropping period (1995 to 1997)

Year/ Month	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Sunshine (hrs)
	Maximum	Minimum		1	2	
1995						
April	36.6	24.9	118.7	87	55	9.1
May	33.5	23.9	370.5	91	65	6.5
June	31.6	23.1	500.4	94	77	3.7
July	29.9	23.2	854.7	96	81	2.1
August	30.6	23.7	448.7	94	78	3.7
September	30.1	23.5	282.5	94	70	6.1
October	33.2	23.2	110.4	91	65	8.3
November	31.3	22.5	88.4	91	69	6.5
December	32.5	21.3	0.0	71	43	10.3
1996						
January	33.1	22.4	0.0	71	35	9.4
February	34.7	23.4	0.0	72	34	9.9
March	36.4	24.3	0.0	82	37	9.3
April	34.6	25.0	152.0	87	59	8.3
May	32.8	25.2	95.4	91	63	7.7
June	30.5	23.8	400.3	94	75	4.7
July	28.8	23.1	588.7	96	83	2.7
August	29.1	23.6	310.0	95	78	3.7
September	29.2	23.7	391.6	94	74	4.3
October	30.1	22.9	219.3	93	70	6.0
November	31.5	23.6	22.1	84	59	7.1
December	30.5	21.8	60.4	80	55	6.8

Contd....

Appendix I contd...

1997						
January	32.0	22.9	0.0	78	45	9.6
February	33.9	21.8	0.0	82	39	9.3
March	35.7	24.0	0.0	82	37	9.6
April	35.2	24.5	8.2	83	50	9.6
May	34.4	24.5	63.0	87	57	6.7
June	31.2	23.0	720.5	93	71	5.9
July	28.6	21.8	979.2	95	84	1.9
August	29.0	22.8	636.8	95	78	3.4
September	30.6	23.4	164.0	93	71	6.8
October	32.2	23.6	194.7	88	65	7.3

Appendix II

General combining ability effects of parents for different characters

Genotypes	gca effects								
	Plant height	Panicles per plant	Days to flowering	Grain yield per plant	Total dry matter	Filled grains per panicle	Spikelet sterility	Panicle exsertion	100 seed weight
Female parents									
IR 62829A	-2.26**	0.39	-3.55**	-1.19**	-2.36**	-0.75	-2.25**	-4.84**	0.09**
IR 68890A	3.89**	0.66*	1.90**	2.32**	3.67**	-5.25*	0.34	-0.37	0.20**
IR 68891A	-1.21*	0.24	1.75**	0.45	-0.17	1.65	2.59**	2.22	-0.15**
PMS 10A	-0.41	-1.26**	-0.10	-0.86	-1.14	4.35	-0.67	2.99*	-0.14**
Male parents									
Annapoorna	-5.54**	-1.77**	-2.16**	-1.84*	-3.62**	-9.21**	0.43	4.87**	-0.03
Matta Triveni	-1.16*	0.41	-2.60**	-2.23**	-2.56*	-9.71**	1.44*	-0.46	-0.01
Kanchana	2.15**	2.48**	-0.16	1.98*	1.03	2.91	0.28	-2.46*	0.06**
IR 36	-1.41*	-1.59**	0.65**	-0.25	-0.08	12.66**	-2.66**	5.04**	-0.29**
Aiswarya	5.96**	0.48	4.28**	2.34**	5.23**	3.35	0.52	-6.99**	0.27**

* Significant at 5% level ** Significant at 1% level

Appendix III

Specific combining ability effects of hybrid combinations for different characters

Genotypes	sca effects								
	Plant height	Panicles per plant	Days to flowering	Grain yield per plant	Total dry matter	Filled grains per panicle	Spikelet sterility	Panicle exsertion	100 seed weight
IR 62829A / Annapoorna	-3.11**	-0.08	-1.64**	-2.48	-4.61*	-0.19	0.76	-4.98*	-0.02
IR 62829A / Matta Triveni	5.01**	-2.76**	1.80**	4.82**	8.12**	-9.19	-0.73	9.92**	-0.02
IR 62829A / Kanchana	0.95	1.67*	0.11	4.30**	1.04	3.94	0.16	10.27**	0.11*
IR 62829A / IR 36	3.01**	-0.51	1.55**	-4.32**	-7.33**	-7.06	1.99	-7.93**	-0.06*
IR 62829A / Aiswarya	-5.86**	1.67*	-1.83**	-2.31	2.78	12.50*	-2.18	-7.27**	-0.02
IR 68890A / Annapoorna	4.24**	0.67	1.66**	0.57	-0.67	-2.69	-2.43	5.87*	0.17**
IR 68890A / Matta Triveni	-4.64**	2.24**	-1.90**	-5.12**	-8.86**	5.06	4.34**	-3.68	-0.01
IR 68890A / Kanchana	3.30**	0.42	0.66	1.49	2.38	17.69**	-4.18**	4.44*	-0.18**
IR 68890A / IR 36	-2.64*	-1.76*	1.35**	-3.20*	-0.26	-16.31**	0.46	-17.38**	-0.20**

Contd....

Appendix III contd....

IR 68890A / Aiswarya	-0.26	-1.58*	-1.78**	6.26**	7.41**	-3.75	1.81	10.75**	0.23**
IR 68891A / Annapoorna	3.09**	-1.43*	0.31	3.57**	6.32**	-7.09	0.79	15.85**	-0.12**
IR 68891A / Matta Triveni	3.71**	0.89	0.00	-0.64	-0.37	1.91	-1.62	-4.62*	-0.03
IR 68891 A / Kanchana	-3.85**	-0.68	0.31	-3.23*	-1.93	-15.21**	0.82	-11.90**	0.10**
IR 68891A / IR 36	-0.04	-0.11	-1.00*	5.27**	4.41*	28.79**	-3.17*	10.30**	0.15**
IR 68891 A / Aiswarya	-2.91**	1.32	0.38	-4.96**	-8.43**	-8.40	3.18*	-9.64**	-0.11**
PMS 10A / Annapoorna	-4.21**	0.82	-0.34	-1.65	-1.04	9.96	0.88	-16.74**	-0.03
PMS 10A / Matta Triveni	-4.09**	-0.36	0.10	0.94	1.10	2.21	-2.00	-1.62	0.06*
PMS 10A / Kanchana	-0.40	-1.43*	-1.09**	-2.55	-1.49	-6.41	3.21	-2.82	-0.04
PMS 10A / IR 36	-0.34	2.39**	-1.90**	2.25	3.18	-5.4	0.72	15.01**	0.11
PMS 10A / Aiswarya	9.04**	-1.43*	3.22**	1.02	-1.76	-0.35	-2.81*	6.16**	-0.10**

* Significant at 5% level ** Significant at 1% level

IDENTIFICATION OF STABLE MALE STERILE LINES AND BETTER COMBINERS FOR EXPLOITATION OF HYBRID VIGOUR IN RICE (*Oryza sativa* L.)

By

C. A. ROSAMMA

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Doctor of Philosophy in Agriculture

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF PLANT BREEDING AND GENETICS
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 654

1998

ABSTRACT

Investigations to identify stable male sterile lines and better combiners for the exploitation of hybrid vigour in rice were conducted at College of Horticulture, Vellanikkara and at Agricultural Research Station, Mannuthy during 1994-98. The study included evaluation of cytoplasmic - genic male sterile (CMS) lines to identify stable lines, identification of maintainers and restorers for different CMS lines, inheritance of fertility restoration, studies on the genetic distance between maintainers and restorers and genetic analysis of the hybrids.

Out of the ten CMS lines evaluated, seven were identified as stable for pollen and spikelet sterility behaviour. Studies on the floral traits which influence outcrossing expressed variation between CMS lines and between seasons.

Jyothi, Aruna, Pavizham and Ptb 10 produced more number of sterile hybrids when crossed with CMS lines having WA cytoplasm and hence these varieties can be used as maintainers. More number of fertile hybrid combinations were produced by Annapoorna, Matta Triveni, Kanchana, IR 36 and Aiswarya indicating the use of these varieties as restorers for WA cytoplasmic source.

All the genotypes under study produced sterile hybrids when crossed with CMS lines having *O. perennis* cytoplasm and no restorers could be identified for this new source of cytoplasmic male sterility.

Inheritance studies on fertility restoration indicated polygenic mode of inheritance for this particular character.

Forty four rice genotypes included in the hybrid rice breeding programme were grouped into nine clusters, each having different number of genotypes. Maintainers and restorers were distributed in different clusters and no direct relation could be established between heterosis and genetic distance of the parents.

Genetic analysis of the 34 fertile hybrids resulted in the identification of five hybrids having significant positive standard heterosis. Among the male sterile lines IR 68890A was identified as the best combiner for most of the agronomic traits and IR 68890A/Aiswarya was the best specific hybrid combination.

Magnitude of the gca variance was more than the variance due to sca for days to flowering, total duration, harvest index, 100 seed weight and other grain characters indicating predominance of additive variance for these characters. Variance due to sca was more for plant height, tillers per plant, total dry matter production, grain yield per plant, straw yield per plant, panicle length and filled grains per panicle indicating predominance of variance due to dominance and epistasis.

Studies on association of characters in hybrids revealed that total drymatter accumulation, harvest index, number of filled grains per panicle, grain breadth, panicle weight, grain density, flag leaf area and leaf area index at 60 days after sowing were positively correlated with grain yield produced by the hybrids.

Negative influence of sterile cytoplasm was identified for most of the agronomic attributes.