SCREENING OF FERTILITY RESTORERS FOR CYTOPLASMIC GENIC MALE STERILE (CGMS) LINES IN RICE (*Oryza sativa* L.)

By

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2011

DECLARATION

I, hereby declare that this thesis entitled **"Screening of fertility restorers for cytoplasmic genic male sterile (CGMS) lines in rice (*Oryza sativa* L.)"** is a bonafide record of research work done by me during the course of research and that it has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Introduction

1. INTRODUCTION

Rice (*Oryza sativa.* L) is the world's most important food after wheat. It is a warm season crop grown extensively in the humid tropical and subtropical regions of the world. It is grown over 110 countries in the world. Production is geographically concentrated in Western and Eastern Asia. Asia is the biggest rice producer, accounting for 92 per cent of the world's production and consumption of rice. China and India, which account for more than one-third of global population, supply over half of the world's rice. Brazil is the most important non-Asian producer, followed by the United States. Italy ranks first in Europe.

The world's major rice-producing countries - including the two most populous nations, China and India - have emphasized the importance of continuing to develop new rice varieties to guarantee Asia's food security and support the region's economic development. In China, hybrid rice accounted for roughly 18.5 million hectares or 63 per cent of the acreage in 2008 and the yield advantage over inbred rice cultivars ranged from 17.0 per cent to 53.2 per cent from 1976 to 2008, which equates to a 30.8 per cent higher average yield. (Durand-Morat *et al.*, 2011).

Hybrid rice in India

Research to develop hybrid rice had started in India way back in 1970s but with limited success till 1989. Hybrid rice research programme was accelerated and intensified within a period of 5 years after 1989. In India 45 hybrid varieties have been released for commercial use (Durand-Morat *et al.*, 2011). In India, hybrids have contributed to 1.5 to 2.5 metric million tonnes of additional rice, and experts forecast that hybrid rice might expand up to 5 million hectares by 2015 (Barclay, 2010).

Kerala has a long history of food grains deficit, especially in rice. For instance, deficit in rice has increased steadily from 45 per cent to 85 per cent between 1957 and 2008. However, not enough attention has been paid to mitigate the food insecurity problem in the State in the context where there has been a large scale decline in the area and production of paddy (Manikandan, 2011).

Importance of hybrid rice

Utilization of heterosis in agricultural crops is one of the most attractive achievements in Plant Breeding science in the century. With yield per unit area rise by about 30 per cent than the conventional rice varieties, hybrid rice has helped China to increase food production by over 300 million tonnes, since 1970s when the hybrid rice began to expand in the country. The major effective way to make use of crop heterosis is by developing hybrids utilizing male sterility (Aananthi and Jebaraj, 2006).

Male sterility is controlled by the interaction of a genetic factor S present in the cytoplasm and nuclear gene(s). It is now known that the male sterility factor S is located in the mitochondrial DNA. A line is male sterile when the male sterility- controlling factor S is in the cytoplasm and recessive alleles *(rf)* of fertility-restoring genes are present in the nucleus. The maintainer line (B line) is isogenic to the CMS line since it is similar to it for nuclear genes but differs in cytoplasmic factor (N), which makes it self-fertile. A restorer or R line possesses dominant fertility-restoring genes *(Rf)* when crossed as a pollen parent with a CMS (A) line as a female parent, restores the fertility in the derived F_1 hybrid (Virmani *et al.*, 2003). Since, the nuclear genes are same in A line and B line, in the progeny of A x B where B line is used as the male parent, will have the sterile cytoplasm with no variation in the nuclear genes, thus helping to maintain the A line.

Forty five hybrids have been released in India using cytoplasmic genic male sterility (Durand-Morat *et al.*, 2011). However, these hybrids are not popular in Kerala because of the specific quality preferences of people of Kerala. Most of the hybrids developed have IR 58025A, a sticky aromatic cytoplasmic genic male sterile genotype as female parent.

Hence, the present work was undertaken to find out potential restorers from the popular rice varieties of Kerala for cytoplasmic genic male sterile (CGMS) lines CMS 2A and IR 68897A.

Review of Literature

2. REVIEW OF LITERATURE

Rice (*Oryza sativa* L.) is one of the most important food crops in the world. Rice farming represents the largest single agricultural land use, covering more than 154 million hectares of world's arable land (IRRI, 2004). As the possibilities for area expansion are limited, it is inevitable to enhance the productivity levels. Of the various genetic approaches contemplated to break the existing yield barriers in rice, the exploitation of heterosis has become one of the major strategies. Hybrid rice is considered as promising, sustainable and eco-friendly technology.

Impressive progress and success made by China in hybrid rice has encouraged other rice growing countries to adopt the technology. Rice hybrids are cultivated in more than 50 per cent of rice area in China and considerable area has been brought under hybrid rice in India, Vietnam, Philippines and Bangladesh. In India, hybrid rice occupied 0.75 million hectares during the year 2005 and it is expected that by 2020, the area will expand to 10 million hectares (Viraktamath, 2006).

Despite significant contributions realized by exploiting heterosis to improve crop productivity worldwide, the biological mechanisms of heterosis remain largely uncharacterized (Huang *et al.*, 2006). Understanding the mechanism underlying heterosis will enhance our ability to form the basis for future selection programmes towards a more targeted exploitation of heterosis and may also provide more efficient ways for predicting heterosis in crop breeding programmes (Xiong *et al.*, 1998). The dissection of this phenomenon into individual genetic components should help to plan new approaches for enhancing the efficiency of hybrid technology.

Choice of appropriate parents is an important criterion in any hybridisation programme to generate variability. Line x tester analysis, proposed by

Kempthorne (1957) is an extension of top cross method. Combining ability of several parents can be estimated at a time by this method and it is also helpful to identify appropriate cross combinations.

2.1. COMBINING ABILITY ANALYSIS

The concept of combining ability was put forth by Sprague and Tatum (1942). Griffing (1956) expressed that *gca* included both additive as well as additive x additive interaction effects and *sca* include dominance and epistatic deviation. Information on combining ability facilitates the breeder to plan his breeding work effectively. Studies on the nature of the gene action in hybrid rice reviewed hereunder.

A study was conducted by Yu *et al.* (2004) on nine parents of three-line indica rice, including 5 sterile lines and 4 restoring lines, were chosen to analyze the combining ability of 14 yield characters and related characters. The results showed that both general combining ability (*gca*) and specific combining ability (*sca*) of all the characters tested were highly significant level. Additive variation was principal for the characters of days to initial heading, plant height and spikelets per panicle. Non additive variation was greater for the character of 1000-grain weight. Most characters were more greatly influenced by restorer line than by sterile line. There was a relatively greater effect of sterile line on 1000-grain weight. The yield characters and related characters of *gca* and *sca* were greater for Jin 23A and Zhong 9A in sterile line and R121and R120 in restoring lines. Effects of various characters on the *gca* and *sca* were not significantly related to each other, which suggested that it is essential to pay attention to improvement of the parent characters.

Kshirsagar *et al.* (2005) made crosses by utilizing four cytoplasmic genetic male sterile lines *viz.*, IR-58025A, IR-68886A, IR-68887A and IR-68888A and ten testers in line x tester design. The analysis of variance revealed that the variances due to lines were significant for days to 50 per cent flowering, grain yield per hill, kernel breadth and L:B ratio. Variances due to testers were significant for days to 50 per cent flowering, panicle length, grains per panicle and grain yield per hill. On the other hand, specific combining ability variances for line x tester interaction were highly significant for all the characters. The magnitude of SCA variances was higher than the GCA variances for all the characters.

A study was undertaken by Gunasekaran *et al.* (2006) to know the genetic potentialities of genotypes belonging to three different races of *Oryza sativa* L. Fifteen wide compatible genotypes were crossed in line x tester mating design. The resultant hybrids were evaluated for mean performance and combining ability effects for different yield component traits. Based on mean performance and *gca* effects, four genotypes were found as best. The hybrid ASD 16 x Langi, with high additive effect, was suggested for recombination breeding to obtain better segregants with high grain yield and wide compatabile genes.

Jagadeesan and Ganesan (2006) used six lines and three testers to make crosses as per line x tester analysis. They studied ten characters and traits were tested for *gca* and *sca* in F_1's and their parents. The results revealed the predominance of non additive gene actions for all the traits studied. The variances of GCA and SCA were highly significant.

Six lines and five testers were crossed by Karthikeyan and Anbuselvam (2006) in line x tester fashion and F_1's were evaluated. The ratio between the estimates of additive and dominance variance indicated preponderance of non-additive gene action for plant height, productive tillers, panicle length and grain yield per plant. With regard to specific combining ability effect, all the superior hybrids recorded additive gene action except ADT 45 x Nootripathu for which additive type epistasis observed.

Eleven rice genotypes were selected to produce 33 F_1 partial diallel crosses. They were evaluated for the characters *viz.,* plant height, number of effective tillers, number of grains per panicle, test weight, grain yield per plant and days to maturity. In general, non-additive genetic variance was larger than the additive for most of the characters studied except number of grains per panicle and test weight (Yadav *et al.*, 2006).

Nine rice genotypes were used to study the combining ability and heterosis for grain yield and its component characters by Narasimman *et al.* (2007). The study revealed that ADT 44 was good general combiner for all the six traits studied. The parent CR1009 was also observed to be good combiner for all the traits. The cross ADT 44 x CR 1009 exhibited highly significant positive sea effects coupled with highly significant positive heterobeltiosis and standard heterosis for number of filled grains per panicle, and grain yield per plant.

A set of diallel crosses involving nine genotypes were evaluated for grain yield, morpho–physiological and some of the quality traits by Sanjeev Kumar *et al.* (2008). The result revealed that both additive and non additive gene actions for traits *viz.*, plant height, days to 50 per cent flowering, grain yield, panicle length, 100 grain weight, grain length and grain breadth. Non-additive gene action (dominance and epistasis) were predominant as compared to additive gene action except for L\B ratio, which is easily transferred through hybridization for crop improvement programme.

Thirty hybrids generated from crossing three lines with ten testers were studied along with parents for combining ability and gene action. The *gca* and *sca* effects were significant for all the characters, indicating the importance of both additive and non-additive genetic components (Pradhan and Singh, 2008).

Sharma and Mani, (2008) studied combining ability for grain yield and its component characters in eighteen hybrids generated from crossing six basmati lines with three tester parents. It was found that additive gene action was predominant for panicle length and grain yield per plant while days to flowering and grains per panicle exhibited preponderance of non-additive gene action.

Line x tester studies by Tyagi *et al.* (2008) by using nine indica rice varieties as lines revealed that among the nine lines, Pusa-1463 was a good general combiner for the characters days to 50 per cent flowering, days to maturity, plant height, number of grain per panicle, panicle length, grain yield per plant and test weight.

Dalvi and Patel, (2009) developed sixty rice hybrids from crossing four CMS lines with fifteen restorers. These hybrids were studied along with parents for thirteen yield and yield attributing characters. Among the male parental lines, BR-827-35-3-1, RTN-3 and IR-46 appeared the best general combiner for grain yield and most of the component characters. The female line IR-58025A was found to be good general combiner for all the traits except plant height and L:B ratio of grain. The most promising specific combinations were IR-58025A x BR-827-35-3-1, IR-58025A x RTN-3 and IR-68885A x RTN-711 for grain yield per plant.

A study on combining ability conducted by Sanjeev Kumar *et al.* (2009) in hybrid rice on grain yield, various yield components and selected grain quality traits revealed the predominance of additive gene action for all the traits except plant height. The parent HPR2047, VL93-3613, JD8, VL93-6052 and HPR1164 were good general combiners for grain yield, its components and grain quality characters. On the basis of specific combining ability effects, the cross combinations HPR2047x JD8, China 988 x VL91-1754, HPR1164xVLDhan221 and HPR1164x HPR2047 were having high grain yield per plant and grain quality traits.

Salgotra *et al.* (2009) crossed five genetically diverse varieties in a line x tester design. The preponderance of dominant gene action was observed for plant height, effective tillers per plant, panicle length, number of grain per panicle, spikelet sterility, 1000-grain weight and grain yield per plant. They concluded that Pusa 2517-2-51-1, Sanwaal Basmati, Super Basmati, Ranbir Basmati and Basmati 370 as good general combiners which can be taken up to generate desirable segregates for further selection. High *sca* effects were observed in the crosses, Super Basmati / Ranbir Basmati, Pusa 2517-2-51-1 / Pusa Basmati 1, P1121-92-8-1-1-3-3 / Ranbir Basmati and PAU 29-35-16-3-5-2 / Basmati 370. The crosses Pusa 2517-2-51-1 / Pusa Basmati 1, P1121-91-8-1-1-3-3 / Ranbir Basmati and PAU 2935-16-3-5-2 / Basmati 370 found to be the best for grain yield and its components which can be used for exploitation of heterosis for yield.

Saidaiah *et al.* (2010) carried out an experiment involving one hundred and fifteen crosses from five CMS lines and 23 restorers along with parents evaluated in line x testers design for grain yield and yield components in rice. Predominance of non additive gene action was observed for all the characters, suggesting the development of hybrids in rice. The lines APMS and PUSA 5A, IBL-57, SG 27–77, SG 26–120 and KMR-3 were good general combiners for grain yield and contributing traits. IRRI genotypes IR 43, IR 55 and IR 60 were good general combiners for dwarf plant type. The hybrid combinations IR 79156A x IBL-57, APMS 6A x GQ-25, APMS 6A x 517, IR 58025A x GQ-70, APMS 6A x SG26–120 and PUSA 5A x IR55 showed good specific combining ability for grain yield and components.

2.2. HETEROSIS STUDIES

The genetic basis of heterosis was studied through mid-parent, standard variety and better parent for 11 quantitative traits by Alam *et al.* (2004) in 17 parental lines and their 10 selected hybrids in rice. The characters included plant height, panicle length, days to maturity, number of fertile spikelet per panicle, number of effective tillers per hill, grain yield and 1000-grain weight. In general, the hybrids performed significantly better than the respective parents. Significant heterosis was observed for most of the studied characters. Among the 10 hybrids, four hybrids *viz.*, 17A×45R, 25A×37R, 27A×39R, 31A×47R, and 35A×47R showed highest heterosis in grain yield.

Babu *et al.* (2005) found that hybrid TS 29/BTS 24 had good *per se, sca* and standard heterosis among thirty six hybrids along with their thirteen parents. It recorded high mean values for all the traits taken for study except 100 grain weight. They also observed high standard heterosis percentage for days to 50 per cent flowering, productive tillers per plant, and grain yield along with high *sca* effect for productive tillers per plant and grain yield. Hybrids TS 29/Jaya, TS 6/Pokkali and IR 58025 A/Vytilla 1 were also recorded high mean, *sca* effect and standard heterosis value for grain yield.

Dalvi *et al.* (2005) based on their investigations in hybrid rice involving four females (CMS lines), fifteen restorers and their resultant sixty hybrids, observed significant differences among genotypes, parents and hybrids for all the characters. Comparison of parents and hybrids showed existence of heterosis. A considerable degree of heterosis in desired direction was manifested by many hybrids over two standard checks *viz.*, Jaya and Pro-agro-6201 in respect of grain yield per hill and various component traits. Seven hybrids exhibited significant positive heterosis over standard check hybrid Pro-agro for grain yield per hill.

Thiyagarajan *et al.* (2005) evaluated thirty two private and public bred hybrids along with the hybrid check CORH 2. None of the hybrids exhibited significant standard heterosis for plant height except MRP 5951 and RHP 129. The hybrids DRRH 21, PAC 8008, MRP 5603, UPHR 1554, DRRH 18 and IAHS 21, PAC 8008, MRP 5603, UPHR 1554 and IAHS 200-011 recorded significant positive heterosis for number of productive tillers per plant. The hybrid LA-HS 200-011 recorded high standard heterosis (23.39%) followed by MRP 5603

(20.72%). The hybrid MRP 5303 with maximum spikelet fertility among the hybrids showed superior performance over the check CORH 2. Significant positive heterosis was also observed in all the hybrids except HKRH 1102 and HKRI 146. Among the hybrids the hybrid MRP 5303 recorded the maximum grain yield followed by the hybrids HKRH 668 and EXPH 668. The yield increase in these hybrids was due to more number of productive tillers per plant. This study suggested that the hybrids *viz.*, MRP 5303. HKRH 1102, HKRH 1064, EXPH 668 and HRI 146 can be exploited commercially.

Five cytoplasmic male sterile lines and ten testers of diverse origin were crossed in line x tester fashion to obtain 50 hybrid combinations. The performance of the hybrids was estimated based on relative heterosis, heterobeltiosis and standard heterosis with ASD 16 as check for seed yield and its contributing characters. The hybrids, IR 688886A/ ADT 41, IR 688897A / ADT 41, IR 688886A / ASD 19, IR 68885A / ASD 16 and IR 58025A / ACK 03002 exhibited significantly negative heterobeltiosis as well as standard heterosis for days to flowering and maturity indicating the possibility of exploiting heterosis for earliness. The best hybrid was IR 68885A / White ponni, which showed standard heterosis and heterobeltiosis for panicle length, spikelets per panicle, grains per panicle and grain yield. Based on *per se* performance and standard heterosis the hybrids IR 68885A / White ponni, IR 688886A / White ponni, IR 688886A /ADT 41and IR58025A /CO 43 were identified as the superior hybrids for the characters of panicle length, grains per panicle and grain yield (Malini *et al.*, 2006).

Zhen *et al.* (2007) studied heterosis and correlation for 34 three-line japonica hybrid rice in 8 agronomic characters. The results showed that the heterosis was significant in characters panicles per plant, kernels per panicle and 1000-grain weight. While the heterosis for seed per panicle was weak.

The NCD II cross design of 8×8 (8 CMS lines and 8 restorer lines) was adopted to find out the yield heterosis of 38 hybrid rice combinations. The heterosis was showed in spikelets per panicle, grains per panicle, plant height and yield per plant (Chou-zhi *et al.*, 2008).

Parihar and Pathak, (2008) conducted a study to estimate the extent of heterobeltiosis, standard heterosis and the nature of gene action for various quantitative traits using line x tester analysis in hybrid rice. High magnitude of heterobeltiosis and standard heterosis were observed for grain yield per plant, plant height, effective tillers plant-1, 1000-grain weight and grains per panicle. Cross combinations GR 7 x IR 64, GR 7 x Narmada, Gurjari x Jaya, Gurjari x GR 102, GR 104 x NWGR 97042 and GR 11 x TN 1 exhibited highly significant heterosis over GR 7.

Venkatesan *et al.* (2008) estimated heterosis, heterobeltiosis and standard heterosis for grain yield, its attributes and other physical characters in 32 cross combinations generated through line x tester mating design. In general, the estimates of heterosis values were low for physical characters when compared to yield and yield components. Nine hybrids manifested positive and significant heterosis over mid parent, better parent and standard check for grain yield per plant.

Ten F_1 rice hybrids were developed by Ramakrishnan *et al.* (2009) and studied the extent of heterosis for plant height, panicles per plant, panicle length, grains per panicle, 1000-grain weight, panicle exertion, spikelet fertility, kernel L/B ratio and grain yield per plant. Most of the hybrids expressed hybrid vigour for yield contributing traits. The best performing F_1 hybrid ASD 18 x ADT 36 showed maximum heterosis and heterobeltiosis for yield. The hybrids ASD 16 x ADT 30, ASD 18 x ADT 36 and ADT 39 x ASD 18 showed more than 20% of heterobeltiosis for grain yield.

Roy *et al.* (2009) developed twenty rice hybrids through a Line× Tester crossing programme involving five high yielding lines and four superior grain quality testers. These were evaluated for yield and quality characters. Significant heterosis for grain yield and quality traits was observed in most of the hybrids. Higher magnitude of heterosis against all yield and quality traits were not expressed in a single hybrid combination which varied from cross to cross due to diverse genetic background of their parents. Most of the heterotic crosses for grain yield per plant were accompanied by heterosis for two or more component traits. In general, heterosis was found to be low for quality traits as compared to yield and yield components.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation was conducted in the Department of Plant Breeding and Genetics, College of Horticulture, Vellanikkara, during the period 2009 to 2011. The experiments related to the investigation were laid out in the farms of College of Horticulture, Vellanikkara. Location was situated at an altitude of 40 M above MSL at 10^0 32 N latitude and 76^0 16 E longitude. The experiment was laid out as complete randomized design (CRD) with two replications in pots. The whole investigation was grouped into two experiments.

3.1 MATERIALS

3.1.1 Female lines

Two male sterile lines IR 68897A and CMS 2A were used for the study. The first male sterile female genotype was IR 68897A collected from Directorate of Rice Research (DRR) Hyderabad. The second CGMS female line was CMS 2A, collected from Paddy Breeding Station of Tamil Nadu Agricultural University Coimbatore.

3.1.2 Male lines

Seven popular high yielding varieties belonging to short and medium duration collected from various research stations of Kerala Agricultural University were used as male parents. Details are presented in Table 1.

Table 1. Characteristics of restorers used as male parents

Sl No.	Variety	Station from which evolved	Duration (Days)	Kernel colour	Grain type
1	Aiswarya (T1)	RARS, Pattambi	120-125	Red	Long Bold
2	Jaya (T2)	DRR, Hyderabad	120-125	White	Long Bold
3	Jyothi (T3)	RARS, Pattambi	110-125	Red	Long Bold
4	Kanchana (T4)	RARS, Pattambi	105-110	Red	Long Bold
5	Matta Triveni (T5)	RARS, Pattambi	100-105	Red	Medium Bold
6	Onam (T6)	RRS, Kayamkulam	95-105	Red	Long Bold
7	Uma (T7)	RRS, Mankombu	115-120	Red	Medium Bold

(Leenakumari and Nayar, 1996)

3.2. METHODS

Experiment-1

3.2.1 Morphological Evaluation of Parents

3.2.1.1 Preparation of pots

Square pots of 30x30cm inch dimensions without drainage holes were used for sowing. Potting mixture comprising of soil, vermi compost and sand in the ratio of 2:1:1, respectively, was prepared and filled in the pots.

3.2.1.2 Raising of parents

Seeds of both male and female parents were sown in pots. Twenty seeds were sown in each pot with three pots/ variety on 11th June, 2010. The pots were irrigated regularly. The fertilizer application was done as per package of practices recommendations (KAU, 2007). Need based pest and disease control was taken up. The field study is showed as Plate 1.

Observations of parents were recorded as described by Shobha Rani *et al.* (2004).

Plant characters

Days to 50 per cent flowering

Actual number of days from sowing to fifty per cent of the plants with panicles computed as days to 50 per cent flowering.

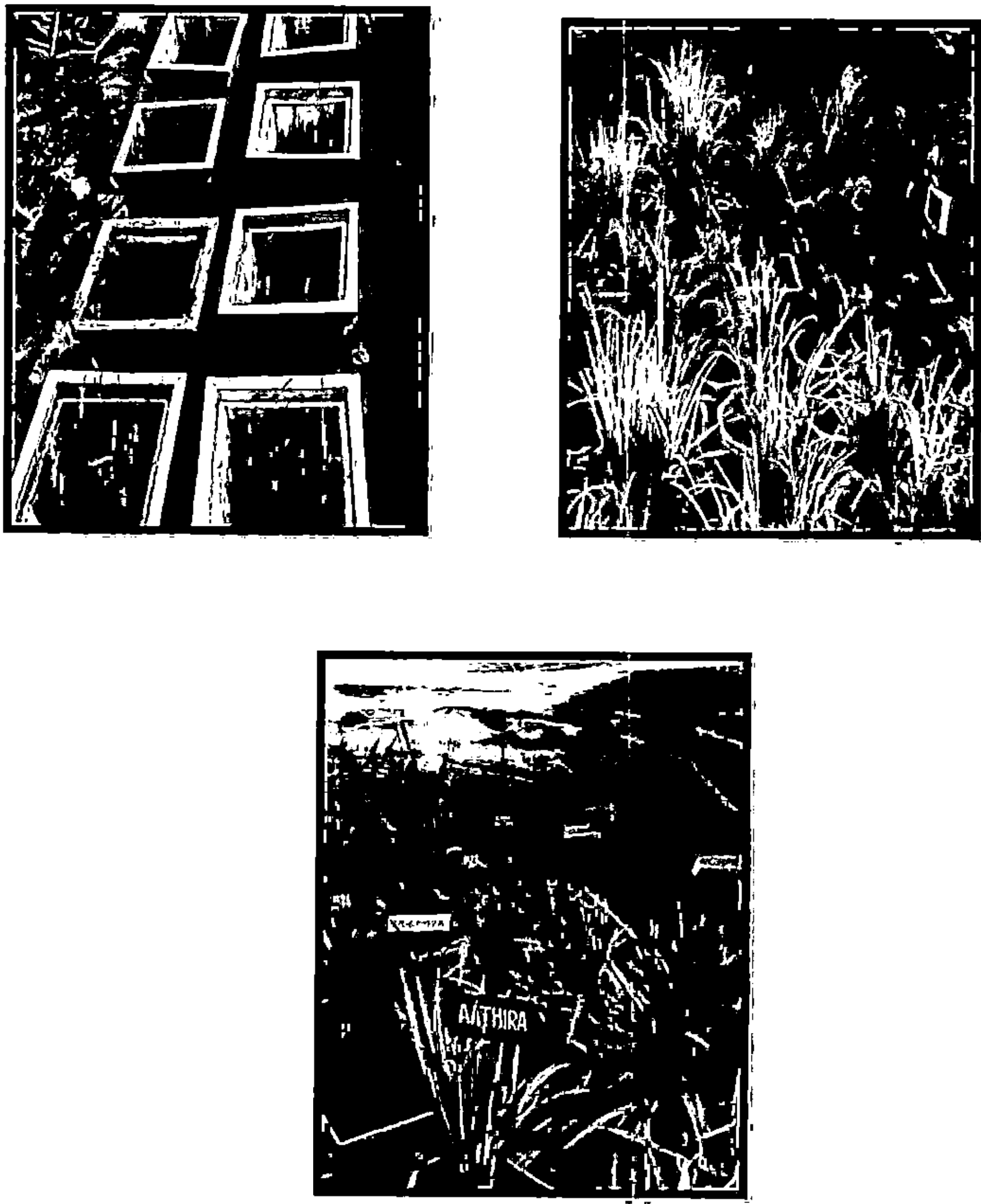


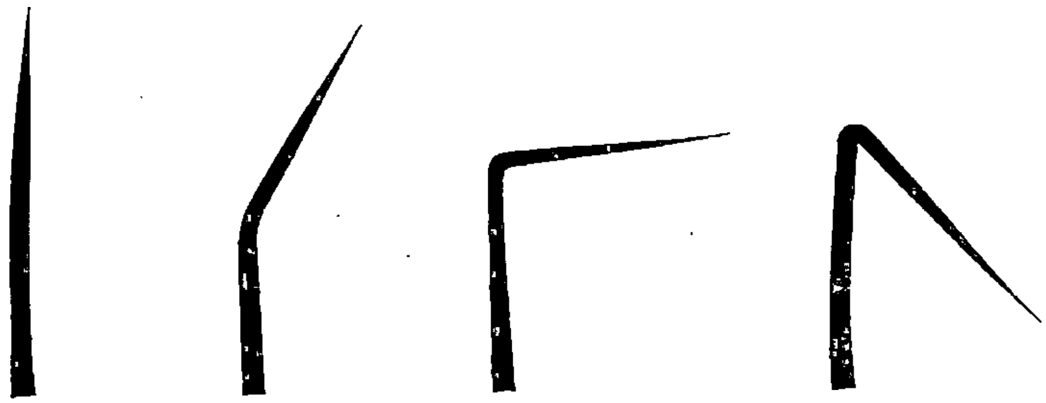
Plate1. Evaluation of parents

Days to maturity

Days to maturity was recorded as actual number of days from sowing to physiological maturity of the grains.

Flag leaf orientation

Flag leaf of ten randomly selected plants from each pot was observed for its orientation. The orientation of leaf was rated as erect, semi-erect, horizontal, and deflexed as given in the following diagram.



Erect Semi-erect Horizontal Deflexed

Spikelet sterility per cent

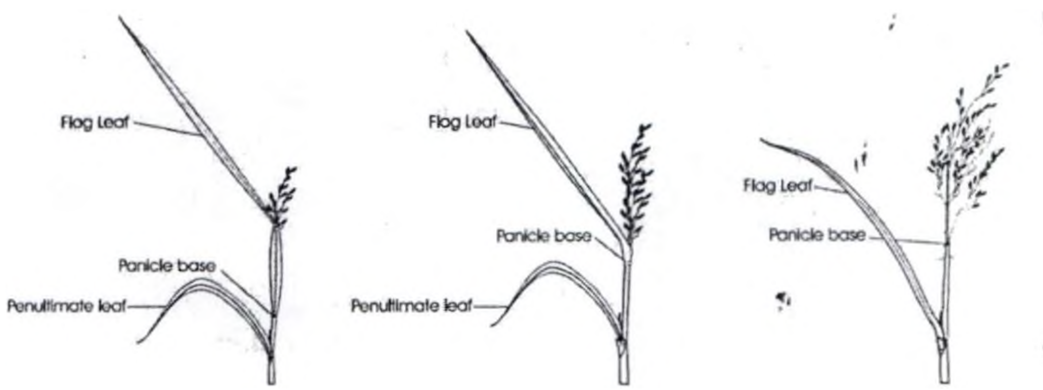
Spikelet sterility was examined by counting filled and unfilled grains in ten panicles randomly chosen in each replication and expressed in per cent. It was calculated by using the formula;

$$\textbf{Spikelet sterility per cent} = \frac{\text{Number of sterile spikelets}}{\text{Total number of spikelets}} \times 100$$

Panicle Characters

Panicle exsertion

The extent of panicle exsertion was recorded from ten randomly selected plants in each replication of each genotype. Panicle was observed from the flag leaf junction to panicle base for its exsertion. The panicle exsertion was grouped into partially exserted, if the panicle base is covered by flag leaf, mostly exserted, if the panicle base is present exactly at flag leaf junction and well exserted, if the panicle base is above the flag leaf junction as shown in the diagram.



Partly exserted   Mostly exserted   Well exserted

Stigma exsertion

Stigma exsertion was recorded by observing florets which have completed anthesis on a given day. Anthesis in rice is showed in Plate 2. It was recorded from ten florets of randomly selected five panicles in each pot. Stigma exsertion was grouped as very high exsertion (>80%), high exsertion (60-79%), medium exsertion (40-59%), low exsertion (20-40%) and very poor exsertion (<20%).

Plate 2. Anthesis in Rice

Angle of floret opening

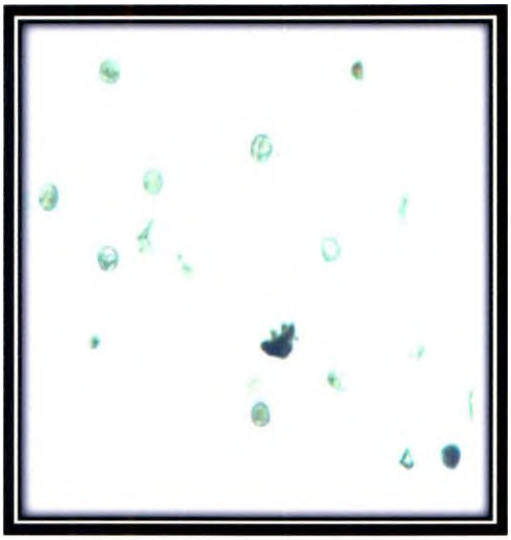
Angle of floret opening was observed and recorded at the time of anthesis from ten florets of randomly selected five panicles in each pot. It was grouped into three ratings as $<30^0$ as narrow, $31\text{-}44^0$ medium and $>45^0$ as wide.

Narrow Medium Wide

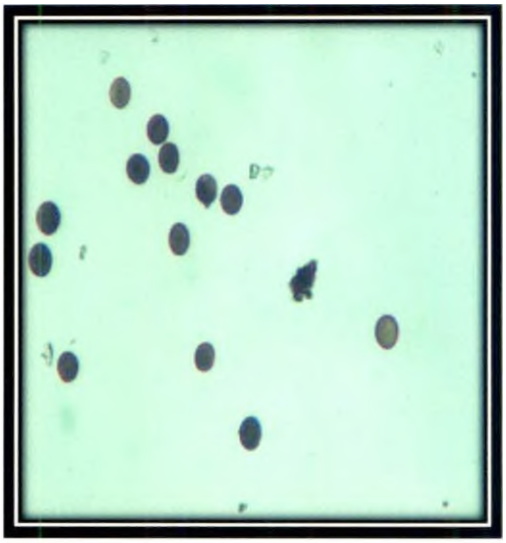
Pollen fertility per cent

Pollen fertility percentage was recorded through examination of pollen grains under microscope. The mature anthers were collected from five randomly selected florets of each panicle. Pollen grains were squeezed out from well-matured anthers and stained with one per cent potassium iodide stain and examined under microscope at two magnifications *viz.,* 10 X and 40 X. Microscopic counts of five fields were taken. Round, well filled and deeply stained pollen grains were considered as fertile and unstained or poorly stained or shriveled pollen grains were counted as sterile. Microscopic evaluation of pollen grain is given in Plate 3. Pollen fertility was calculated as;

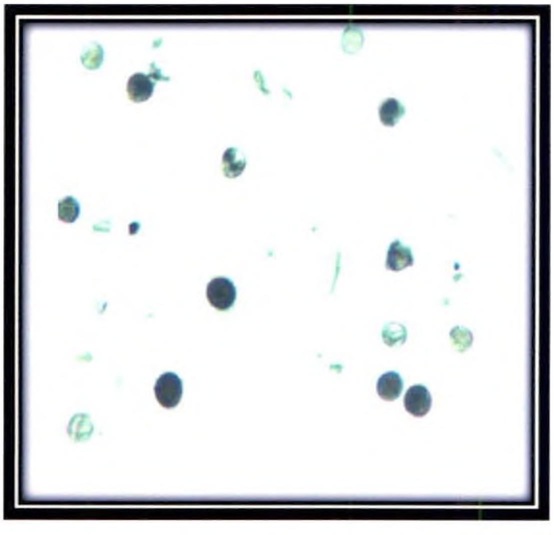
$$\text{Pollen fertility per cent} = \frac{\text{Number of fertile pollen grains}}{\text{Total number of pollen grains}} \times 100$$



Sterile pollens



Fertile pollens



Partially fertile pollens

Plate 3. Pollen studies

Duration of flower opening

Duration of flower opening was recorded as the time between initiation of anthesis to complete closing of flower. Flower opening duration was recorded for ten spikelets on selected panicles of all varieties in each replication. The duration was grouped into <30 min, 30-60 min, 60-90 min and >90 min.

Colour of stigma

Colour of stigma was observed using hand lens of 4X zoom. Stigma was observed during its exsertion and the colour was recorded. It was rated as white, light green, yellow, light purple and purple.

Experiment-2

3.2.2. Development and Evaluation of F_1 Hybrids

3.2.2.1 Raising the parental lines for crossing

The development of hybrids (F_1s) involved controlled crossing between male and female parents. The CGMS (A-line) and varieties were raised in pots. Ten seeds of IR68897A were sown in ten pots with two replications. Ten seeds of each variety were also sown to each pot containing seeds of IR68897A male sterile line. Staggered sowing of male and female lines was taken up to ensure pollen availability at time of stigma receptivity of female lines. Sowing was done at weekly interval starting from 11th June 2010. Similar sowing procedure was also followed in case of CMS 2A.

3.2.2.2 Hybridization programme

Crossing was done in line x tester model using two male sterile varieties as lines and seven male fertile varieties as testers. Crossing was done from 10.00 a.m. up to 01.00 p.m. depending on the anthesis time of the variety. Field level hybridization work is given in Plate 4. The panicle of CGMS (A-line) with open flowers and panicle of variety (R-line) with open flowers were brought closer and rubbed each other followed by covering both the panicles with a long polythene cover. The crossing was continued till all the florets were crossed. The time taken to cross a panicle completely varied from three days to a week, depending upon the weather conditions.

3.2.2.3 Collection of hybrid seeds

Seeds from fourteen cross-combinations formed the basic materials for experiment 2.

3.2.2.4 Evaluation of hybrids and parents

Hybrids obtained by crossing CGMS lines (A-lines) and varieties from the experiment 1 were sown in pots for their evaluation. A total of fourteen hybrids are obtained out of two lines and seven varieties and observations were recorded. Filed evaluation of hybrids in line x tester design is showed in Plate 5.

3.2.2.5 Preparation of pots and sowing

Nine parents and fourteen hybrids to be evaluated were raised in two pots each as two replications. The number of seeds sown in each pot was four. The fertilizer application was done as per package of practices recommendations (KAU, 2007). Need based pest and disease control was taken up.

Plate.4. Crossing

Plate.5. Evaluation of Hybrids

3.2.2.6 Hybrids/crosses

Parents and the hybrids detailed below obtained from crossing in line x tester model alone formed the materials for the study.

Line x tester design

Lines/Testers	Aiswarya (T1)	Jaya (T2)	Jyothi (T3)	Kanchana (T4)	Matta Triveni (T5)	Onam (T6)	Uma (T7)
CMS 2A (L1)	L1 X T1	L1 X T2	L1 X T3	L1 X T4	L1 X T5	L1 X T6	L1 X T7
IR 68897A (L2)	L2 X T1	L2 X T2	L2 X T3	L2 X T4	L2 X T5	L2 X T6	L2 X T7

3.2.2.7 Observations Recorded

All observations for the quantitative traits were recorded from randomly selected plants in each pot as suggested by Shobha Rani *et al.*, 2004.

Plant characters

Plant height (cm)

Plant height was taken from the base of plant at soil level to tip of plant using a scale.

Total number of tillers

The total numbers of tillers per plant were counted in each plant.

Productive tillers

Productive tillers per plant were taken in each plant by counting number of tillers which are productive as they produced panicle.

Number of leaves per tiller

Number of leaves per tiller was counted from five randomly selected tillers in each plant.

Yield per plant (g)

Yield per plant was taken and expressed in grams per plant.

Panicle characters

Panicle length (cm)

Panicle length was taken from the panicle base to tip in centimetres. It was grouped as very short (<15 cm), short (16-20 cm), medium (21-25 cm), long (26-30 cm) and very long (>30 cm).

Number of primary branches

The number of primary branches in main axis of panicle were counted from five randomly selected panicles in each plant

Number of secondary branches

The number of secondary branches were counted from five randomly selected panicles in each plant.

Number of spikelets / panicle

Number of spikelets per panicle was counted in number and recorded from each plant.

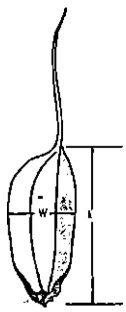
Number of grains per panicle

Number of grains per panicle was counted in number and recorded from each plant.

Grain Characters

Grain length (mm)

Longitudinal dimension measured as the distance from the base of the lower most sterile lemma to the tip (apiculus) of the lemma or palea whichever is longer. In the case of awned varieties, length is measured to a point comparable to the tip of the apiculus. It was taken from five randomly selected grains of each panicle and measured in millimetre.



Length and width measures of the grain

Grain width (mm)

Dorsiventral diameter measured as the distance across the lemma and the palea at the widest point. It was taken from five randomly selected grains of each panicle and measured in millimetre.

100 grain weight (g)

Weight of 100 seeds from each plant was taken and expressed in grams.
In addition to above, following observations recorded under morphological evaluation of parents were also taken.

Plant characters

Days to 50 per cent flowering

Days to maturity

Panicle characters

Pollen fertility per cent

Spikelet sterility per cent

3.2.3. Statistical Analysis

3.2.3.1. Analysis of Variance

The data collected for all the biometrical traits were subjected to an analysis of variance suggested by Panse and Sukatme (1954).

Source	d.f.	Expected mean squares
Replication (r)	(r-1)	$\sigma_e^2 + g \, . \, \sigma_r^2$
Genotype (g)	(g-1)	$\sigma_e^2 + r \, . \, \sigma_g^2$
Error	(r-1) (g-1)	σ_e^2
Total	(rg-1)	

3.2.3.2. Combining Ability Analysis

The data for all the biometrical traits were subjected to analysis of variance appropriate for line x tester design as suggested by Kempthrone (1957). The mean squares due to different sources of variation were obtained and the genetic expectations were worked out using the following analysis of variance (Nadarajan and Gunasekaran, 2008).

Analysis of variance for combining ability

Source	d.f.	Mean squares	Expected mean squares
Replications	(r-1)		
Hybrids	(lt-1)		

Lines	(l-1)	MS_1	σ^2_e + r (COV. FS – 2 COV. HS) + rt (COV. HS)
Testers	(t-1)	MS_2	σ^2_e + r (COV. FS – 2 COV. HS) + rl (COV. HS)
Line x testers	(l-1) (t-1)	MS_3	σ^2_e + r (COV. FS – 2 COV. HS)
Error	(r-1) (lt-1)	MS_4	σ^2_e
Total	(rlt-1)		

Where,

r – Number of replications

l – Number of lines

t – Number of testers

Estimation of gca and sca effects

The *gca* and *sca* effects for each cross were estimated. The analysis was done in the following model (Nadarajan and Gunasekaran, 2008).

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

Where,

X_{ijk} = Value of the ijkth observation

μ = Population mean

g_i = *gca* effect of the ith line

g_j = *gca* effect of jth tester

s_{ij} = *sca* effect of the ijth hybrid

e_{ijk} = Error effect associated with ijkth observation

l = Number of lines

j = Number of testers

k = Number of replications

The individual effects of *gca* and *sca* were obtained from the two way table of lines versus testers in which each figure was a total over replications as follows:

$\mu = x/rlt$

$\hat{g}_i = x_i/rt - x_{..}/rlt$

$\hat{g}_j = x_j/rl - x_{..}/rlt$

$\hat{S}_{ij} = x_{ij}/r - x_i/rt - x_i/rl + x_{..}/rlt$

The standard errors pertaining to *gca* and *sca* effects were calculated from the square root of the variance effects as indicated below.

a) Standard error effects for lines SE $(g_i) = (\sigma_e^2/rt)^{1/2}$
b) Standard error effects for testers SE $(g_j) = (\sigma_e^2/rl)^{1/2}$
c) Standard error effects for hybrids SE $(s_{ij}) = (\sigma_e^2/r)^{1/2}$

3.2.3.3. Estimation of Heterosis

Magnitude of heterosis was estimated over mid-parent, better parent as well as standard parent (Nadarajan and Gunasekaran, 2008). Jyothi was used as the standard parent.

i). Relative heterosis (di)

The superiority or inferiority of F_1 over the mid parental value was estimated as:

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

Where,

$\overline{F}$ – Mean value of hybrid

$\overline{MP}$ – Mid parental value

ii). Heterobeltiosis (dii)

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

Where,

$\overline{BP}$ – Mean value of better parent

iii). Standard heterosis

Superiority or inferiority of F_1 over standard was calculated as

$$diii = \frac{\overline{F} - \overline{SV}}{\overline{SV}} \times 100$$

Where,

$\overline{SV}$ – Mean value of the standard variety. For each character best performing tester was used as standard.

Test of significance

Significance of estimates of heterosis was tested at error degrees of freedom as suggested by Turner (1953).

$$\text{'t' for relative heterosis} = \frac{\overline{F} - \overline{MP}}{\sqrt{M_e / r \times 3/2}} \times 100$$

$$\text{'t' for heterobeltiosis} = \frac{\overline{F} - \overline{BP}}{\sqrt{M_e / r \times 2}} \times 100$$

$$\text{'t' for standard heterosis} = \frac{\overline{F} - \overline{SV}}{\sqrt{M_e / r \times 2}} \times 100$$

Where, 'M_e' was error variance and 'r' was the number of replication.

Results

4. RESULTS

Two cytoplasmic male sterile lines of rice *viz.* CMS 2A (L1) and IR-68897A (L2) were crossed to seven popular high yielding varieties as testers namely, Aiswarya (T1), Jaya (T2), Jyothi (T3), Kanchana (T4), Matta Triveni (T5), Onam (T6) and Uma (T7). The resultant 14 hybrids were evaluated to identify potential restorers and maintainers based on the *per se* performance.

The experimental results on mean performance of parents and the hybrids, combining ability, gene action and heterosis, were obtained. The results obtained are presented below.

Experiment-1

4.1 MORPHOLOGICAL EVALUATION OF PARENTS

The qualitative characters which are important in improving the cross pollination in rice have been observed in parents and are presented in Table 2.

4.1.1 Panicle exsertion

Both the lines CMS 2A and IR 68897A exhibited mostly exserted panicle. Among the testers Jyothi, Matta Triveni, Onam and Uma exhibited well exserted panicle. The remaining testers exhibited mostly exserted panicle.

4.1.2 Flag leaf orientation

Semi-erect type of flag leaf orientation was seen in both the lines as well as in all the seven testers.

Table 2. Morphological characters of parents

Characters	PE	FLO	SE	AFO	DFO (min)	CS
Female lines						
CMS 2A	Mostly exserted	Semi-erect	Well exserted	29^0	126.3	White
IR 68897A	Mostly exserted	Semi-erect	Well exserted	29.52^0	123.1	White
Male lines						
Aiswarya	Mostly exserted	Semi-erect	Moderately exserted	29.1^0	123.5	Light green
Jaya	Mostly exserted	Semi-erect	Well exserted	31.32^0	129.7	Light green
Jyothi	Well exserted	Semi-erect	Moderately exserted	24.2^0	126.7	Light green
Kanchana	Mostly exserted	Semi-erect	Well exserted	29.7^0	130.2	Light green
Matta Triveni	Well exserted	Semi-erect	Moderately exserted	23.5^0	120.5	Light green
Onam	Well exserted	Semi-erect	Well exserted	31.17^0	127.8	Light green
Uma	Well exserted	Semi-erect	Well exserted	27.53^0	131.3	Light green

PE- Panicle exsertion; FLO- Flag leaf orientation: SE-Stigma exsertion; AFO-Angle of floret opening; DFO- Duration of flower opening; CS- Colour of stigma

4.1.3 Stigma exsertion

Well exserted stigma was observed in both the lines *viz.,* CMS 2A and IR 68897A.Whereas well exserted stigma was observed in Jaya, Kanchana, Onam and Uma. The other three testers *viz.*, Aiswarya, Jyothi and Matta Triveni exhibited moderately exserted stigma.

4.1.4 Angle of floret opening

The narrow angle of floret opening observed in both the lines *viz.*, CMS 2A- 29^0 and IR 68897A- 29.52^0. Among testers Aiswarya (29.1^0), Jyothi (24.2^0), Kanchana (29.7^0), Matta Triveni (23.5^0), and Uma (27.53^0) had narrow angle of floret opening. Whereas the testers Jaya- 31.32^0 and Onam- 31.17^0 had medium angle of floret opening.

4.1.5 Duration of flower opening (minutes)

Duration of flower opening observed in parents as follows; CMS 2A- 126.3min, IR 68897A- 123.1min, Aiswarya- 123.5min, Jaya- 129.7min, Jyothi- 126.7min, Kanchana- 130.2min, Matta Triveni- 120.5min, Onam- 127.8min and Uma- 131.3min.

4.1.6 Colour of stigma

The white colour stigma was observed in both the male sterile lines. Whereas light green colour stigma was observed in all the male parents.

Experiment-2: Hybridization

4.2. ANALYSIS OF VARIANCE

Estimates of variances for seventeen characters of parents and F_1 hybrids are presented in Table 3. The analysis of variance showed significant differences among genotypes for number of leaves per tiller, panicle length (cm), pollen fertility per cent, number of primary branches, number of secondary branches, spikelet sterility per cent, 100 grain weight (g), grain length (mm), grain width (mm) and yield per plant (g).

4.3. STUDIES ON COMBINING ABILITY

Combining ability analysis was done for the 14 hybrids made in Line x Tester design and the results are presented in Table 4.
Estimates of variance due to general and specific combining ability in a Line x Tester analysis for observed quantitative characters are given in Table 4.
Combining ability analysis showed significant variations in lines for plant height and spikelets per panicle. In case of testers, significant differences were seen with respect to days to 50 per cent flowering, days to maturity, number of leaves per tiller and 100 grain weight. Line x Tester interaction showed significance differences for all characters except days to 50 per cent flowering and days to maturity. The variances due to GCA were predominant for days to 50 per cent flowering, days to maturity, plant height, number of total tillers, number of productive tillers, number of leaves per tiller, panicle length, number of secondary branches, number of grains per panicle, spikelet sterility per cent, 100 grain weight, grain length, grain width and yield per plant. The variances due to SCA were predominant for number of primary branches, pollen fertility per cent and spikelet sterility. The ratios of variances due to GCA and SCA ranged from 0.26 of pollen fertility per cent to 116.08 for grain width.

Table 3. Analysis of variance for parents and hybrids

	MSS			
Character/Source of variation	Replication (df=1)	Genotype (df=22)	Error (df=22)	SE
Days to 50 per cent flowering	5.28	14.92	3.93	1.98
Days to maturity	20.10	14.92	3.93	1.98
Plant height (cm)	14.34	226.89	64.03	8.00
Total tillers	375.72	2090.43	251.76	15.87
Productive tillers	225.62	1184.02	129.09	11.36
Number of leaves per tiller	0.01	1.48**	0.09	0.31
Panicle length (cm)	0.20	12.26**	0.95	0.97
Primary branches	0.00	4.19**	0.48	0.69
Secondary branches	2.81	104.19**	8.53	2.92
Pollen fertility (%)	12.37	1574.54**	13.85	3.72
Spikelets per panicle	499.69	1467.14	445.25	21.10
Grains per panicle	184.17	2491.24	113.76	10.67
Spikelets sterility (%)	20.20	2543.22**	57.55	7.59
100 grain weight (g)	0.04	1.90**	0.02	0.16
Grain length (mm)	0.01	16.16**	0.10	0.31
Grain width (mm)	0.03	0.14**	0.02	0.13
Yield per plant (g)	34.01	420.49**	9.20	3.03

* significance at 5 per cent level

** significance at 1 per cent level

df = degrees of freedom

MSS = mean sum of square

Table 4. Analysis of variance for combining ability

Character/ source of variation	Mean squares of genotypes				GCA variance	SCA variance	GCA/ SCA
	Lines (df=1)	Testers (df=6)	Line x Tester (df=6)	Error (df=22)			
Days to 50 per cent flowering	2.59	12.65**	5.39	3.93	11.46	0.73	15.72
Days to maturity	2.59	12.65**	5.39	3.93	11.46	0.73	15.72
Plant height (cm)	341.51**	236.42	116.71	64.03	8.71	0.54	16.13
Total tillers	3125.56	3727.69	4198.12**	251.76	18.5	4.12	4.49
Productive tillers	317.81	1726.77	1461.14**	129.09	521.55	130.05	4.01
Number of leaves per tiller	1.39	2.67*	1.17**	0.09	-7308.11	2090.62	-3.5
Panicle length (cm)	15.31	14.55	9.18**	0.95	6.91	2.61	2.64
Primary branches	7.36	3.95	5.70**	0.48	26.12	51.66	0.51
Secondary branches	83.75	159.08	111.85**	8.53	4335.19	240.56	18.02
Pollen fertility (%)	141.06	933.99	4195.08**	13.85	608.18	2316.38	0.26
Spikelets per panicle	4597.55**	1583.39	926.38*	445.25	-1535.98	1973.18	-0.78
Grains per panicle	9571.63	522.58	4746.51**	113.76	-870.7	666.02	-1.31
Spikelets sterility (%)	5390.72	330.08	5604.34**	57.55	-5480.89	2773.4	-1.98
100 grain weight (g)	0.77	3.09*	1.39**	0.02	8.07	0.68	11.81
Grain length (mm)	0.01	17.25	28.40**	0.1	-32.54	14.15	-2.3
Grain width (mm)	0.05	0.22	0.14**	0.02	6.99	0.06	116.08
Yield per plant (g)	354.2	150.52	1011.96**	9.2	-1512.21	501.38	-3.02

* significance at 5 per cent level
** significance at 1 per cent level
df= degrees of freedom

4.4. PROPORTIONAL CONTRIBUTION OF LINES, TESTERS AND LINE X TESTER INTERACTION

The proportional contributions of lines were higher for characters like plant height and number of spikelets per panicle. The proportional contributions of testers were higher for days to 50 per cent flowering, days to maturity and 100 grain weight. Line x Tester interaction was significant for most of the characters except days to 50 per cent flowering, days to maturity and plant height (Table 4).

4.5. COMBINING ABILITY EFFECTS

Combining ability effects and values were calculated based on Line x Tester analysis using CMS 2A (L1), IR-68897A (L2), Aiswarya (T1), Jaya (T2), Jyothi (T3), Kanchana (T4), Matta Triveni (T5), Onam (T6) and Uma (T7) as parents. The results are presented in Table 5, 6, 7 and 8.

4.5.1. Days to 50 per cent flowering

The *gca* of lines were found to be non significant (Table 5) for the character days to 50 per cent flowering. Among hybrids positive significant sca values were exhibited by hybrids L1 x T6 and L2 x T5 and the values were 4.22 and 3.50, respectively (Table 6).

4.5.2. Days to maturity

None of the parents were having significant *gca* effects for days to maturity. Similar to days to 50 per cent flowering hybrids L1 x T6 and L2 x T5 recorded positive significant values of 4.22 and 3.50 respectively for *sca* effects.

Table 5. General combining ability effects of parents for plant characters

Parents	days to 50 per cent flowering	days to maturity	plant height	total tillers	productive tillers	leaves per tiller	yield per plant
L1	0.82	0.82	-4.91	-2.8	-2.37	-0.08	-0.9
L2	-0.82	-0.82	4.91	2.8	2.37	0.08	0.9
SE	3.71	3.71	14.97	11.10	10.25	0.57	5.68
T1	1.81	1.81	4.43	-6.83	-7.13	-0.35	1.68
T2	1.54	1.54	5.75	25.51	30.62*	1.27**	-1.21
T3	-1.46	-1.46	-6.1	-5.72	-8.9	-0.58	1.38
T4	-0.48	-0.48	-5.81	-11.51	-13	-0.27	0.53
T5	1.94	1.94	-10.9	-6.49	-8.88	-1.13	-1.83
T6	-0.55	-0.55	15.79	6.76	7.62	1	-1.79
T7	-2.8	-2.8	-3.14	-1.7	-0.33	0.06	1.25
SE	1.98	1.98	8.00	5.93	5.48	0.31	3.03

Table t value for 22 edf. @ 5% SL= 2.074*

@ 1% SL= 2.819**

Table 6. Specific combining ability effects of hybrids for plant characters

Hybrids	days to 50 per cent flowering	days to maturity	plant height	total tillers	productive tillers	leaves per tiller	yield per plant
L1 X T1	-0.87	-0.87	1.02	3.96	4.12	-0.19	-1.78
L1 XT2	1.69	1.69	2.01	-13.7	-14.13	0.48*	-
L1 X T3	0.47	0.47	-3.69	-8.1	-4.98	-0.11	0.01
L1X T4	-0.69	-0.69	5.56	11.15	7.5	0.63**	1.73
L1 X T5	-3.5	-3.5	-8.84	-16.7	-9.63	-1.12	-
L1 X T6	4.22**	4.22**	-0.78	2.05	-1.63	-0.24	0.89
L1 X T7	-1.32	-1.32	4.71	21.34	18.74*	0.56*	-1.97
L2 X T1	0.87	0.87	-1.02	-3.96	-4.12	0.19	1.78
L2 X T2	-1.69	-1.69	-2.01	13.7	14.13	-0.48	-0.25
L2 X T3	-0.47	-0.47	3.69	8.1	4.98	0.11	-0.01
L2 X T4	0.69	0.69	-5.56	-11.15	-7.5	-0.63	-1.73
L2 X T5	3.50*	3.50*	8.84	16.7	9.63	1.12**	-0.87
L2 X T6	-4.22	-4.22	0.78	-2.05	1.63	0.24	-0.89
L2X T7	1.32	1.32	-4.71	-21.34	-18.74	-0.56	1.97
SE	1.40	1.40	5.66	4.20	3.88	0.22	2.15

Table t value for 22 edf. @ 5% SL= 2.074*
@ 1% SL= 2.819**

Table 7. General combining ability effects of parents for panicle and grain characters

Parents	panicle length	primary branches	secondary branches	pollen fertility	spikelets per panicle	grains per panicle	spikelet sterility	grain length	grain width	100 grain weight
L1	-0.78	-0.12	-0.71	1.06	-4.17	-2.29	-1.39	-1	-0.07	-0.11
L2	0.78	0.12	0.71	-1.06	4.17	2.29	1.39	1	0.07	0.11
SE	1.82	1.29	5.46	6.96	39.48	19.95	14.19	0.58	0.24	0.29
T1	1.61	-0.64	-2.31	8.69*	0.98	8.89	-9.36	0.99	0	0.94**
T2	2.59*	1.75*	13.11**	-11.66	6.21	1.55	13.42	-2.97	-0.15	-0.83
T3	-2.19	-0.63	-5.03	7.71*	-19.61	4.37	-6.54	1.31	-0.11	0.86**
T4	-1.63	0.09	-0.04	-2.78	7.69	3.97	11.2	0.87	0.09	0.55**
T5	-3.67	-2.38	-11.39	-0.21	-42.39	-12.2	-0.45	-2.45	-0.1	-0.83
T6	3.17**	1.71*	6.53*	-1.75	44.16*	-10.53	-14.41	0.76	0.06	-0.83
T7	0.14	0.1	-0.87	-0.02	2.97	3.96	6.15	1.49	0.21	0.14
SE	0.97	0.69	2.92	3.72	21.10	10.67	7.59	0.31	0.13	0.16

Table t value for 22 edf. @ 5% SL= 2.074*

@ 1% SL= 2.819**

Table 8. Specific combining ability effects of hybrids for panicle and grain characters

Hybrids	panicle length	primary branches	secondary branches	pollen fertility	spikelets per panicle	grains per panicle	spikelet sterility	grain length	grain width	100 grain weight
L1 X T1	0.23	0.29	-2.31	-6.67	-7.86	0.05	-2.05	1.01**	-0.13	0.14
L1 XT2	-0.17	0.62	3.51	-7.05	-14.13	-	-	-	-	-
L1 X T3	-0.01	-0.16	-1.72	-2.3	-3.49	8.81	-5.12	1.07**	0	0.13
L1X T4	2.38**	1.23*	6.39**	16.18**	32.75*	8.54	-6.38	0.45	0.43**	0.24*
L1 X T5	-3.41	-1.26	-6.39	-3.55	-19.93	-	-	-	-	-
L1 X T6	-0.2	-1.1	-3.22	14.42**	-8.48	3.21	6.92	2.14**	0.18	0.11
L1 X T7	1.17	0.39	3.74	-11.03	21.14	-9.95	5.75	0.59*	-0.07	-0.85
L2 X T1	-0.23	-0.29	2.31	6.67*	7.86	-0.05	2.05	-1.01	0.13	-0.14
L2 X T2	0.17	-0.62	-3.51	7.05*	14.13	12.21	-4.63	2.37**	0.18	-0.11
L2 X T3	0.01	0.16	1.72	2.3	3.49	-8.81	5.12	-1.07	0	-0.13
L2 X T4	-2.38	-1.23	-6.39	-16.18	-32.75	-8.54	6.38	-0.45	-0.43	-0.24
L2 X T5	3.41**	1.26*	6.39**	3.55	19.93	-1.54	3.75	2.88**	0.23*	-0.11
L2 X T6	0.2	1.10*	3.22	-14.42	8.48	-3.21	-6.92	-2.14	-0.18	-0.11
L2X T7	-1.17	-0.39	-3.74	11.03**	-21.14	9.95	-5.75	-0.59	0.07	0.85**
SE	0.69	0.49	2.07	2.63	14.92	7.54	5.36	0.22	0.09	0.11

Table t value for 22 edf. @ 5% SL= 2.074*
@ 1% SL= 2.819**

4.5.3. Plant height (cm)

The *gca* effects of parents were non significant for plant height (Table 5). None of the hybrids also showed significant *sca* effect (Table 6).

4.5.4. Number of total tillers

The *gca* of lines ranged from -2.37 (L1) to 2.37 (L2) and for testers it was -13.00 (T4) to 30.62 (T2) for the character total tillers. One tester T2 had significant of *gca* value of 30.62. among the hybrids L1 x T7 (18.74) had positive *sca* value.

4.5.5. Number of leaves per tiller

For the character number of leaves per tiller positive significant values showed by two testers (T2 & T6). Among the hybrids four hybrids (L1 x T2), (L1 x T4), (L1 x T7) and (L2 x T5) were showed positive significant values for *sca* effect. Values being 0.48, 0.63, 0.56 and 1.12, respectively.

4.5.6. Panicle length (cm)

The character panicle length had *gca* of lines ranged from -0.78 (L1) to 0.78 (L2), for testers it was -3.67 (T5) and 3.17 (T6). Two testers T2 and T6 had significant values of *gca* effects (Table 7). The hybrids L1 x T4 and L2 x T5 showed positive significant values for *sca*. The values were 2.38 and 3.41, respectively (Table 8).

4.5.7. Number of primary branches

The *gca* value of primary branches was ranged from -0.12 (L1) to 0.12 (L2) for lines and for testers it was -2.38 (T5) to 1.75 (T2). Two testers showed significant positive values for *gca*. The values were 13.11 and 6.53, respectively (Table 7). Among the hybrids three hybrids (L1 x T4), (L2 x T5) and (L2 x T6) were showed positive significant values *viz.*, 1.23, 1.26 and 1.10 respectively for *sca* effects (Table 8).

4.5.8. Number of secondary branches

The values ranged -0.71 (L1) to 0.71 (L2) as *gca* for lines testers values ranged between 11.39 (T5) to 13.11 (T2) for the character secondary branches. Two testers T2 (13.11) and T6 (6.53) recorded significant values. Among the hybrids two hybrids L1 x T4 (6.39) and L2 x T5 (6.39) were showed positive significant values for *sca* effects.

4.5.9. Pollen fertility per cent

Among the parents two parents T1 and T3 had significant values 8.69 and 7.71 respectively for *gca* effects (Table 7). Five hybrids L1 x T4 (16.18), L1 x T6 (14.42), L2 x T1 (6.67), L2 x T2 (7.05) and L2 x T7 (11.03) were showed positive significant values for *sca* effects (Table 8).

4.5.10. Number of spikelets per panicle

The *gca* effect of the parents for number of spikelets per panicle was significant only in one tester T6 having value of 44.16 (Table 7). For hybrids *sca* values ranged from -32.75 (L2 x T4) to 32.75 (L1 x T4). One hybrid L1 x T4 (32.75) was showed positive significant values.

4.5.11. Grain length (mm)

The *gca* effects of parents were non significant (Table 7). The hybrids had *sca* values ranging from -2.14 (L2 x T6) to 2.88 (L2 x T5). Six hybrids L1 x T1

(1.01), L1 x T3 (1.07), L1 x T6 (2.14), L1 x T7 (0.59), L2 x T2 (2.37) and L2 x T5 (2.88) showed positive significant values for *sca* effects (Table 8).

4.5.12. 100 grain weight (g)

The 100 grain weight *gca* of lines ranged from -0.01 (L2) to 0.01 (L1) and testers it was -0.71 [(T2), (T5), (T6)] to 1.06 (T1). Testers T1 (0.94), T3 (0.86) and T4 (0.55) showed significant values. For hybrids *sca* values ranged from -0.97 (L1 x T7) to 0.97 (L2 x T7). Two hybrids L1 x T4 (0.24) and L2 x T7 (0.85) were showed positive significant values for *sca* effects.

4.5.13. Grain width (mm)

The value of *gca* effects for grain width was non significant among parents. Among the hybrids only two hybrids L1 x T4 (0.43) and L2 x T5 (0.23) showed positive significant value for *sca* effects (Table 8).

4.6. STUDIES ON HETEROSIS

The result on mean performance of parents and hybrids, are presented in Table 9 & 10. The values of relative heterosis (di), heterobeltiosis (dii) and standard heterosis (diii) calculated form values of parents and hybrids are presented in Table 11-15. The data on mean performance and heterotic effect with respect to individual traits are given below.

Observations on days to 50 per cent flowering, days to maturity, number of leaves per tiller, panicle length , plant height, pollen fertility per cent, number of primary branches, number of secondary branches, number of spikelets per panicle, number of grains per panicle, number of total tillers, number of productive tillers, spikelet sterility per cent, 100 grain weight, grain length, grain

Table 9. Mean performance of parents and hybrids for plant characters

Genotypes/ Character	DF (50%)	DM	PH (cm)	TT	PT	LT	YP (g/plant)
L1	77.54*	106.54*	74.00*	25.4	22.7	7.10*	-
L2	79.50*	108.50*	69.03*	19.67	15.33	5.77*	-
T1	78.27*	107.27*	76.18*	16.5	11.75	7.00*	22.25*
T2	82.00*	111.00*	87.15*	20	17	7.00*	35.87*
T3	81.80*	110.80*	81.63*	21.5	17.25	6.90*	25.68*
T4	78.73*	107.73*	84.40*	24.83	20.83	6.63*	39.23*
T5	81.66*	110.66*	80.65*	9.25	4	5.93*	7.27*
T6	75.65*	104.65*	80.94*	31.67	24	7.10*	32.20*
T7	81.03*	110.03*	82.75*	45.88*	35.38*	6.25*	41.86*
L1 X T1	80.56*	109.56*	69.69*	27.33	20.5	5.71*	0.86
L1 X T2	82.85*	111.85*	72.00*	42.00*	40.00*	8.00*	-
L1 X T3	78.64*	107.64*	54.45	16.38	9.63	5.55*	2.35
L1 X T4	78.45**	107.45*	63.98*	29.83	18	6.60*	3.23
L1 X T5	78.06*	107.06*	44.5	7	5	4	-
L1 X T6	83.30*	112.30*	79.25*	39	29.5	7.00*	0.07
L1 X T7	75.5	104.5	65.81*	49.83*	41.92*	6.86*	0.24
L2 X T1	80.67*	109.67*	77.47*	25	17	6.25*	6.21
L2 X T2	77.83*	106.83*	77.80*	37.5	36.50*	7.20*	1.3
L2 X T3	76.05*	105.05*	71.64*	38.17	24.33	5.93*	4.14
L2 X T4	78.20*	107.20*	62.69*	13.13	7.75	5.50*	1.56
L2 X T5	83.43*	112.43*	72.00*	46.00*	29	6.40*	0.06
L2 X T6	73.22	102.22	90.63*	40.50*	37.50*	7.65*	0.08
L2 X T7	76.5	105.5	66.21*	12.75	9.19	5.90*	5.98
CD	4.11	4.11	16.6	32.91	23.56	0.64	6.29

*** Significance @ p (0.05)**

DF- Days to 50 per cent flowering; **DM-** Days to maturity; **PH-** Plant height (cm); **LT-** Number of leaves per tiller **TT-** Total number of tillers; **PT-** Number of productive tillers; **YP-** Yield per plant (g)

Table 10. Heterosis for days to 50 per cent flowering, days to maturity and yield per plant

	Days to 50 per cent flowering			Days to maturity			Yield per plant		
	di	dii	diii	di	dii	diii	di	dii	diii
L1 X T1	3.41	2.93	-1.52	2.48	2.13	-1.12	-92.25	-96.12	-96.64
L1 XT2	3.86	1.04	1.28	2.83	0.77	0.95	-	-	-
L1 X T3	-1.3	-3.87	-3.87	-0.95	-2.86	-2.86	-81.7	-90.85	-90.85
L1X T4	0.41	-0.36	-4.1	0.3	-0.26	-3.02	-83.53	-91.76	-87.42
L1 X T5	-1.93	-4.41	-4.57	-1.42	-3.25	-3.38	-	-	-
L1 X T6	8.76**	7.44**	1.83	6.35**	5.41**	1.35	-99.57	-99.78	-99.73
L1 X T7	-4.77	-6.82	-7.7	-3.49	-5.03	-5.69	-98.87	-99.43	-99.08
L2 X T1	-48.87	1.47	-1.39	-49.17	1.07	-1.02	-72.06	-72.06	-75.8
L2 X T2	-3.62	-5.09	-4.85	-2.66	-3.76	-3.58	-92.76	-96.38	-94.94
L2 X T3	-5.7	-7.03	-7.03	-4.2	-5.19	-5.19	-67.79	-83.9	-83.9
L2 X T4	-1.16	-1.64	-4.4	-0.85	-1.2	-3.25	-92.02	-96.01	-93.91
L2 X T5	3.53	2.16	1.99	2.6	1.59	1.47	-98.31	-99.15	-99.76
L2 X T6	-5.62	-7.91	-10.5	-4.09	-5.79	-7.75	-99.5	-99.75	-99.69
L2X T7	-4.69	-5.59	-6.48	-3.45	-4.12	-4.78	-71.43	-85.71	-76.71

di- Relative Heterosis dii- Heterobeltiosis diii- Standard Heterosis

Table t-value for 22 edf. @ 5% SL = 2.074*
@ 1% SL = 2.819**

width and yield per plant were taken from two lines, seven testers and fourteen hybrids developed by hybridization in Line x Tester fashion were taken.

Difference between mean values of hybrids and mid parental value, better parental value and standard check was calculated as percentage. The standard variety used was Jyothi.

4.6.1. Days to 50 per cent flowering

The days to 50 per cent flowering ranged from 77.53 (L1) to 79.5 (L2) for lines and from 75.65 (T6) to 82.00 (T2) for testers. Among the hybrids the values varied between 73.22 (L2 x T6) and 83.43 (L2 x T5) (Table 9).

Relative Heterosis over mid parental value for days to 50 per cent flowering ranged between -48.87 per cent (L2 x T1) and 8.76 per cent (L1 x T6). The cross (L2 x T6) had the lowest value for heterobeltiosis -7.91 per cent. The highest value for heterobeltiosis was 7.44 per cent (L1 x T6). One hybrid L1 x T6 exhibited positive value for relative heterosis (8.76%) as well as heterobeltiosis (7.44%) (Table 10).

4.6.2. Days to maturity

The days to maturity showed mean values from 106.54 (L1) to 108.50 (L2) for lines and from 104.65 (T6) to 111.00 (T2) for testers. The values varied between 102.22 (L2 x T6) and 112.43 (L2 x T5) in hybrids.

Days to maturity character had relative heterosis over mid parental value for ranged between -49.17 per cent (L2 x T1) and 6.35 per cent (L1 x T6). The cross (L2 x T6) had the lowest value for heterobeltiosis -5.79 per cent. The highest value for heterobeltiosis was 5.41 per cent (L1 x T6). One hybrid L1 x T6 exhibited positive value for relative heterosis (6.35%) as well as heterobeltiosis (5.41%) (Table 10).

4.6.3. Plant height (cm)

The plant height ranged from 69.03 (L2) to 74.00 (L1) for lines and from 80.65 (T5) to 87.15 (T2) for testers. Among the hybrids the values varied between 44.50 (L1 x T5) and 90.63 (L2 x T6).

The cross (L2 x T6) alone exhibited positive value for all heterosis. The values were 20.85, 11.96 and 11.03 per cent, respectively, for relative heterosis, heterobeltiosis and standard heterosis. Relative Heterosis over mid parental value for plant height ranged between -42.45 per cent (L1 x T5) and 20.85 per cent (L2 x T6). The cross (L1 x T5) had the lowest value for heterobeltiosis -44.82 per cent and for standard heterosis -45.48 per cent (L1 x T5). The highest value for heterobeltiosis was 11.96 per cent (L2 x T6), where as that of standard heterosis was 11.03 per cent (L2 x T6).

4.6.4. Total tillers

Number of total tillers ranged from 19.67 (L2) to 25.40 (L1) for lines and from 9.25 (T5) to 45.88 (T7) for testers. Among the hybrids the values varied between 7.00 (L1 x T5) and 49.83 (L1 x T7) (Table 9).

Relative Heterosis over mid parental value for total tillers ranged between -89.72 per cent (L1 x T5) and 278.15 per cent (L2 x T2). One hybrid (L2 x T2) exhibited positive value of 278.15 per cent for relative heterosis and 248.84 per cent for standard heterosis. The hybrid (L2 x T5) had relative heterosis of 218.16% for total tillers (Table 11).

Table 11. Heterosis for plant height, total tillers, productive tillers and number of leaves per tiller

	Plant height			Total tillers			Productive tillers			Leaves per tiller		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
L1 X T1	-7.19	-8.51	-14.62	-61.9	-78.48	27.13	-67.27	-81.94	18.84	-19.03	-19.6	-17.27
L1 XT2	-10.64	-17.38	-11.79	-42.86	-66.93	95.35	-38.7	-64.76	131.88	13.48**	12.68**	15.94**
L1 X T3	-30.02	-33.29	-33.29	-77.95	-87.11	-23.84	-85.28	-91.52	-44.2	-20.71	-21.83	-19.57
L1X T4	-19.21	-24.19	-21.61	-60.7	-76.51	38.76	-73.2	-84.14	4.35	-3.88	-7.04	-4.35
L1 X T5	-42.45	-44.82	-45.48	-89.72	-94.49	-67.44	-91.49	-95.59	-71.01	-38.58	-43.66	-42.03
L1 X T6	2.3	-2.09	-2.91	-50.84	-69.29	81.4	-57.09	-74.01	71.01	-1.41	-1.41	1.45
L1 X T7	-16.03	-20.47	-19.38	-42.35	-60.76	131.78	-43.69	-63.07	143.00*	2.75	-3.4	-0.6
L2 X T1	-0.8	1.69	-5.1	-30.88	27.12	16.28	-37.23	10.87	-1.45	-51.04	-10.71	-9.42
L2 X T2	-0.37	-10.73	-4.69	278.15**	-13.94	248.84**	351.55**	329.41**	323.19**	12.79**	2.86	4.35
L2 X T3	-4.89	-12.23	-12.23	85.43	90.83	77.52	49.36	41.06	41.06	-6.32	-14.01	-14.01
L2 X T4	-18.28	-25.72	-23.19	-41.01	-38.95	-38.95	-57.14	-62.8	-55.07	-11.26	-17.05	-20.26
L2 X T5	-3.8	-10.73	-11.79	218.16*	85.23	113.95	200	89.13	68.12	9.48*	8.02	-7.25
L2 X T6	20.85**	11.96**	11.03**	57.79	27.89	88.37	90.68	56.25	117.39	18.91**	7.75	10.87*
L2X T7	-12.76	-19.99	-18.89	-61.09	-84.59	-40.7	-63.76	-74.03	-46.74	-1.73	-5.53	-14.43

di- Relative Heterosis **dii-** Heterobeltiosis **diii-** Standard Heterosis

Table t-value for 22 edf. @ 5% SL = 2.074*
@ 1% SL = 2.819**

4.6.5. Productive tillers

Number of productive tiller ranged from 15.33 (L2) to 22.70 (L1) in lines. In testers number of productive tillers varied between 4.00 (T5) to 35.38 (T7). Values for number of productive tillers of the hybrids were varied between 9.19 (L2 x T7) and 41.92 (L1 x T7) (Table 9). Higher number of productive tillers were seen in parent T7 hybrids L1 x T2, L1 x T7 and L2 x T6. All three types of heterosis for productive tillers was significant only in hybrid L2 x T2 (Table 11). The values were relative heterosis 351.55%, heterobeltiosis 329.41% and standard heterosis 323.19%. The hybrid L1 x T7 showed standard heterosis for productive tiller.

4.6.6. Number of leaves per tiller

The character number of leaves per tiller ranged from 5.77 (L2) to 7.10 (L1) for lines and testers had range between 5.93 (T5) and 7.10 (T6). Among the hybrids the values varied between 4.00 (L1 x T5) and 8.00 (L1 x T2). All the parents and hybrids except L1 x T5 had high values for this character (Table 9).
Four hybrids *viz.*, L1 x T2, L2 x T2, L2 x T5 & L2 x T6 exhibited positive significant values for relative heterosis. The hybrid L1 x T2 had significant positive value for all three types of heterosis, and the values were 13.48, 12.68 and 15.94 per cent, respectively, for relative heterosis, heterobeltiosis and standard heterosis (Table 11).

4.6.7. Yield per plant (g)

Yield per plant ranged from 7.27g/plant (T5) to 39.23g/plant (T4) among testers. Among the hybrids the values varied between 0.06 (L2 x T5) and 5.98 (L2 x T7). None of the hybrids had high yield compared to parents (Table 9).

The negative and non significant value was recorded in all hybrids for all three types of heterosis with respect to yield per plant (Table 10).

4.6.8. Panicle length (cm)

Among the lines, mean value for panicle length ranged from 20.49 (L2) to 23.43 (L1). For testers it varied between 19.98 (T5) and 21.75 (T3). The values varied between 13.14 (L1 x T5) and 25.15 (L2 x T6) among hybrids (Table 12). Relative Heterosis over mid parental value for panicle length ranged between -39.46 per cent (L1 x T5) and 21.38 per cent (L2 x T6). Two hybrids *viz.*, L2 x T2 (17.91, 16.08 & 12.83%) and L2 x T6 (21.38, 20.03 & 15.63%) exhibited positive value for all three types of heterosis. One hybrid L2 x T1 exhibited positive value for relative heterosis as well as heterobeltiosis (11.88 & 10.73%).

4.6.9. Number of primary branches

The value for number of primary branch ranged from 7.38 (L2) to 8.00 (L1) for lines and from 7.06 (T3) to 9.69 (T1) for testers. In hybrids the values varied between 3.75 (L1 x T5) and 10.44 (L2 x T6). Parents and hybrids except L1 x T5 showed high values for number of primary branches per panicle (Table 12).

Relative Heterosis over mid parental value for the character primary branches ranged between -57.24 per cent (L1 x T5) and 33.60 per cent (L2 x T6). One hybrid L2 x T6 exhibited positive value for relative heterosis, heterobeltiosis and standard heterosis and the values were 33.60, 26.52 and 47.79 per cent respectively. Three hybrids L1 x T2, L1 x T4 and L2 x T2 exhibited positive value of 38.05, 23.30 and 23.89 per cent, respectively, for standard heterosis (Table 13).

Table 12. Mean performance of parents and hybrids for panicle and grain characters

Genotypes/ Character	PL (cm)	PB	SB	PF (%)	SP	GP	SS (%)	GL (mm)	GW (mm)	GWT (g)
L1	23.43*	8.00*	24.10*	0.00	112.20*	NA	100.00*	-	-	-
L2	20.49*	7.38*	18.48*	0.00	68.09	NA	100.00*	-	-	-
T1	20.92*	9.69*	30.60*	97.70*	110.05*	89.73*	18.47*	5.88*	0.33	1.85*
T2	21.14*	9.25*	26.30*	97.67*	112.00*	109.42*	2.31	6.73*	0.48*	1.76
T3	21.75*	7.06*	24.30*	99.23*	78.2	70.55*	9.78	7.68*	0.54*	2.46*
T4	20.80*	8.17*	22.93*	92.28*	96.1	89.26*	7.12	6.94*	0.76*	2.33*
T5	19.98*	9.54*	20.23*	88.05*	88.25	86.15*	2.37	6.94*	0.46*	1.78
T6	20.95*	8.25*	25.12*	97.15*	82.95	63.59*	23.34*	6.81*	0.55*	1.73
T7	20.36*	7.81*	19.90*	98.69*	67.7	56.07*	17.17	5.35	0.13	2.21*
L1 X T1	22.06*	7.04*	16.16*	64.46*	72.05	19.59	72.81*	7.33*	0.2	1.79
L1 X T2	22.64*	9.75*	37.40*	43.73*	71	-	100.00*	-	-	-
L1 X T3	18.02*	6.59*	14.03*	67.84*	55.83	23.84*	57.30*	7.71*	0.22	1.7
L1 X T4	20.97*	8.71*	27.13*	75.84*	119.37*	23.17*	80.59*	6.65*	0.85*	1.51
L1 X T5	13.14	3.75	3	58.67*	16.6	-	100.00*	-	-	-
L1 X T6	23.19*	8.00*	24.10*	75.11*	114.60*	3.33	97.09*	8.24*	0.58*	-
L1 X T7	21.53*	7.88*	23.65*	51.38*	103.03	4.67	95.47*	7.42*	0.47*	-
L2 X T1	23.16*	6.69*	22.20*	75.67*	96.1	24.08*	74.94*	7.31*	0.60*	1.75
L2 X T2	24.54*	8.75*	31.80*	55.71*	107.60*	29.00*	73.05*	6.73*	0.50*	-
L2 X T3	19.61*	7.15*	18.89*	70.33*	71.13	10.8	84.82*	7.57*	0.35	1.67
L2 X T4	17.77*	6.48*	15.77*	41.36*	62.2	10.67	82.84*	7.76*	0.14	1.25
L2 X T5	21.52*	6.50*	17.20*	63.65*	64.8	1.5	97.69*	7.76*	0.60*	-
L2 X T6	25.15*	10.44*	31.95*	44.14*	139.90*	1.5	98.93*	5.95*	0.35	-
L2 X T7	20.76*	7.33*	17.59*	71.33*	69.08	29.15*	57.80*	8.23*	0.75*	1.94*
CD	2.02	1.43	6.06	7.72	43.76	22.12	15.73	0.64	0.26	0.32

*** Significance @ p (0.05)**

PL- Panicle length (cm); **PF**- Pollen fertility (%); **PB- Number of** primary branches; **SB**- Number of secondary branches; **GP**- Number of grains per panicle; **SP**- Number of spikelets per panicle; **SS**- Spikelet sterility (%); **GWT**- 100 grain weight (g); **GL**- Grain length (mm); **GW**- Grain width (mm)

Table 13. Heterosis for panicle length primary branches, secondary branches and spikelets per panicle

	Panicle length			Primary branches			Secondary branches			Spikelets per panicle		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
L1 X T1	-0.5	-5.84	1.44	-20.38	-27.31	-0.29	-40.92	-47.19	-33.5	-35.16	-34.53	-7.86
L1 XT2	1.59	-3.37	4.09	13.04	5.41	38.05**	48.41**	42.21**	53.91**	-36.66	-36.72	-9.21
L1 X T3	-20.22	-23.08	-17.14	-12.45	-17.58	-6.64	-42.05	-42.28	-42.28	-41.36	-50.25	-28.61
L1X T4	-5.16	-10.49	-3.57	7.73	6.63	23.30*	15.38	12.59	11.66	14.61	6.39	52.64
L1 X T5	-39.46	-43.92	-39.59	-57.24	-60.7	-46.9	-86.46	-87.55	-87.65	-83.44	-85.2	-78.77
L1 X T6	4.5	-1.02	6.62	-1.54	-3.03	13.27	-2.07	-4.05	-0.82	17.45	2.14	46.55
L1 X T7	-1.64	-8.1	-1	-0.4	-1.56	11.5	7.5	-1.87	-2.67	14.55	-8.17	31.76
L2 X T1	11.88**	10.73*	6.48	-21.61	-30.97	-5.31	-9.54	-27.45	-8.64	7.89	-12.68	22.89
L2 X T2	17.91**	16.08**	12.83**	5.26	-5.41	23.89*	42.02**	20.91	30.86*	19.49	-3.93	37.6
L2 X T3	-7.16	-9.85	-9.85	-0.91	-3.01	1.28	-11.7	-22.27	-22.27	-2.75	-9.04	-9.04
L2 X T4	-13.92	-14.57	-18.3	-16.62	-20.66	-8.26	-23.85	-81.32	-35.1	-24.24	-35.28	-20.46
L2 X T5	6.36	5.04	-1.06	-23.15	-31.88	-7.96	-11.14	-14.97	-29.22	-17.1	-26.57	-17.14
L2 X T6	21.38**	20.03**	15.63**	33.60**	26.52**	47.79**	46.56**	27.21*	31.48*	85.25**	68.66**	78.90**
L2X T7	1.64	1.32	-4.57	-3.43	-6.13	3.83	-8.34	-11.6	-27.61	1.75	1.46	-11.66

di- Relative Heterosis dii- Heterobeltiosis diii- Standard Heterosis

Table t-value for 22 edf. @ 5% SL = 2.074*
@ 1% SL = 2.819**

4.6.10. Number of secondary branches

Secondary branches per panicle was high in all parents and hybrids evaluated except L1 x T5. The values ranged between 18.48 (L2) to 24.10 (L1) for lines and 19.90 (T7) to 30.60 (T1) for testers. Among the hybrids the values varied between 3.00 (L1 x T5) and 37.40 (L1 x T2).

Two crosses L1 x T2 (48.41, 42.21 & 53.91 per cent) & L2 x T6 (46.56, 27.21 & 31.48 per cent) had positive significant values for relative heterosis, heterobeltiosis and standard heterosis, respectively. The cross (L2 x T2) had positive significant value (42.02 & 30.86 per cent) for relative heterosis as well as standard heterosis, respectively.

4.6.11. Number of spikelets per panicle

The spikelet per panicle was significant in L1, T1, T2 in parents and L1 x T4, L1 x T6, L2 x T2 and L2 x T6 in hybrids (Table 12). Only one hybrid, L2 x T6 exhibited positive value of 85.25, 68.66 and 78.90 per cent for all three types of heterosis.

4.6.12. Number of grains per panicle

No grain set was obtained in both lines, L1 and L2 and the parents were 100 per cent male sterile for number grains per panicle. It varied between 56.07 (T7) to 109.42 (T2) for testers. In all the testers it was significant. Grains per panicle was significant in L1 x T3, L1 x T4, L2 x T1, L2 x T2 and L2 x T7. All three types of heterosis was non significant in hybrids (Table 14).

Table 14. Heterosis for grains per panicle, spikelet sterility per cent and pollen fertility per cent

	Grains per panicle			Spikelet sterility (%)			Pollen fertility (%)		
	di	dii	diii	di	dii	diii	di	dii	diii
L1 X T1	-56.33	-78.17	-72.23	3.44	-27.19	644.27**	31.94	-34.03	-35.04
L1 XT2	-	-	-	95.48**	0	922.50**	-10.47	-55.23	-55.94
L1 X T3	-32.42	-66.21	-66.21	-21.03	-42.7	485.74**	36.73**	-31.63	-31.63
L1X T4	-48.09	-74.05	-67.16	10.07	-19.41	723.84**	64.36**	-17.82	-23.58
L1 X T5	-	-	-	95.37**	0	922.50**	33.25**	-33.37	-40.88
L1 X T6	-89.52	-94.76	-95.28	40.38**	-2.91	892.50**	54.62**	-22.69	-24.31
L1 X T7	-83.36	-91.68	-93.39	35.02**	-4.53	875.94**	4.12	-47.94	-48.22
L2 X T1	-46.32	-73.16	-65.86	6.47	-25.06	666.06**	54.90**	-22.55	-23.74
L2 X T2	-46.99	-73.5	-58.89	-1.85	-26.95	646.73**	14.07*	-42.97	-43.86
L2 X T3	-69.38	-84.69	-84.69	16.9	-15.18	767.03**	41.75**	-29.12	-29.12
L2 X T4	-76.08	-88.04	-84.87	13.14	-17.16	746.81**	-10.37	-55.19	-58.32
L2 X T5	-96.52	-98.26	-97.87	31.29**	-2.31	898.57**	44.58**	-27.71	-35.86
L2 X T6	-95.28	-97.64	-97.87	43.03**	-1.07	911.28**	-9.12	-54.56	-55.51
L2X T7	3.97	-48.02	-58.68	-18.25	-42.2	490.90**	44.55**	-27.72	-28.12

di- Relative Heterosis dii- Heterobeltiosis diii- Standard Heterosis

Table t-value for 22 edf. @ 5% SL = 2.074*
@ 1% SL = 2.819**

4.6.13. Spikelet sterility per cent

Hundred per cent spikelet sterility was recorded in both lines. Among the testers, spikelet sterility per cent values ranged from 2.37 per cent (T5) to 23.34 per cent (T6). Among the hybrids the values varied between 57.30 (L1 x T3) and 100.00 per cent [(L1 x T2) & (L1 x T5)]. Since there was 100 per cent sterility no grains were obtained from male sterile female lines and hence no observations on grain characters were recorded in L1, L2, (L1 x T2) and (L1 x T5). Significant spikelet sterility was observed in testers T1 and T6.

Four hybrids had significant values for relative heterosis as well as standard heterosis *viz.*, L1 x T6, L1 x T7, L2 x T5 and L2 x T6 as 40.38, 35.02, 31.29 and 43.03 per cent for relative heterosis and 892.50, 875.94, 898.57 & 911.28 per cent for standard heterosis. The other eight hybrids had significant values for standard heterosis alone namely; L1 x T1 (644.27%), L1 x T3 (485.74%), L1 x T4 (723.84%), L2 x T1 (666.06%), L2 x T2 (646.73%), L2 x T3 (767.03%) L2 x T4 (746.81%) & L2 x T7 (490.90%).

4.6.14. Pollen fertility per cent

Pollen fertility per cent was zero for the both CGMS lines. Pollen fertility per cent ranged from 88.05 per cent (T5) to 99.23 per cent (T3) in testers. Among the hybrids the values varied between 41.36 per cent (L2 x T4) and 75.84 per cent (L1 x T4).

The value of relative heterosis over mid parental value ranged between -10.47 per cent (L1 x T2) and 64.36 per cent (L1 x T4). Nine hybrids L1 x T3 (36.73%), L1 x T4 (64.36%), L1 x T5 (33.25%), L1 x T6 (54.62%), L2 x T1 (54.90%), L2 x T2 (14.07%), L2 x T3 (41.75%), L2 x T5 (44.58%) and L2 x T7 (44.55%) exhibited positive value for relative heterosis for the character pollen fertility per cent.

4.6.15. Grain length (mm)

Grain length varied between 5.35 (T7) to 7.68 (T3) among testers and between 5.95 (L2 x T6) and 8.24 (L1 x T6) among hybrids (Table 12).

Relative Heterosis over mid parental value for grain length ranged between 24.43 per cent (L2 x T1) and 207.66 per cent (L2 x T7) and was significant in all the crosses except L1 x T2 and L2 x T5. Seven hybrids L1 x T1, L1 x T6, L1 x T7, L2 x T1, L2 x T4, L2 x T5 and L2 x T7 had significant values for relative heterosis and heterobeltiosis (Table 15).

4.6.16. Grain width (mm)

The grain width ranged from 0.13 (T7) to 0.76 (T4) for testers. Among the hybrids it varied between 0.14 (L2 x T4) and 0.85 (L1 x T4) (Table 12).

The crosses L1 x T6, L2 x T2 and L2 x T5 had significant relative heterosis. The crosses L1 x T7 (652.00%; 276.00%), L2 x T1 (84.62%; 84.62%) and L2 x T7 (1100.00%; 500.00%) had significant relative heterosis and heterobeltiosis, respectively. Where the cross L1 x T4 had significant relative heterosis as well as standard heterosis (Table 15).

4.6.17. 100 grain weight (g)

The 100 grain weight ranged from 1.73 (T6) to 2.46 (T3) and 1.25 (L2 x T4) to 1.94 (L2 x T7) in testers and hybrids respectively.

Relative Heterosis over mid parental value was ranged between -5.41 per cent (L2 x T1) and 93.89 per cent (L1 x T1) for 100 grain weight. Five hybrids alone exhibited positive values *viz.*, L1 x T1 (93.89%), L1 x T3 (38.41%), L1 x T4 (30.19%) L2 x T3 (35.77%) and L2 x T7 (75.11%) for relative heterosis (Table 15).

Table 15. Heterosis for grain length, grain width and 100 grain weight

	Grain length			Grain width			100 grain weight		
	di	dii	diii	di	dii	diii	di	dii	diii
L1 X T1	149.36**	24.68**	-4.62	23.08	-38.46	-62.62	93.89**	-3.05	-27.09
L1 XT2	-	-	-	-	-	-	-	-	-
L1 X T3	100.65**	0.33	0.33	-17.76	-58.88	-58.88	38.41**	-30.79	-30.79
L1X T4	91.64**	-4.18	-13.41	125.17**	12.58	58.88*	30.19*	-34.9	-38.48
L1 X T5	-	-	-	-	-	-	-	-	-
L1 X T6	142.03**	21.01**	7.23	111.01*	5.5	7.48	-	-	-
L1 X T7	177.20**	38.60**	-3.45	652.00**	276.00*	-12.15	-	-	-
L2 X T1	24.43**	24.43**	-4.82	84.62*	84.62*	12.15	-5.41	-5.41	-28.86
L2 X T2	100.00**	0	-12.43	110.53*	5.26	-6.54	-	-	-
L2 X T3	97.14**	-1.43	-1.43	30.84	-34.58	-34.58	35.77**	-32.11	-32.11
L2 X T4	123.49**	11.74*	0.98	-64.24	-82.12	-74.77	7.74	-46.13	-49.09
L2 X T5	123.65**	11.82*	0.98	158.70**	29.35	11.21	-	-	-
L2 X T6	74.87**	-12.56	-22.53	26.61	-36.7	-35.51	-	-	-
L2X T7	207.66**	53.83**	7.16	1100.00**	500.00**	40.19	75.11**	-12.44	-21.34

di- Relative Heterosis　　**dii-** Heterobeltiosis　　**diii-** Standard Heterosis

Table t-value for 22 edf. @ 5% SL = 2.074*
@ 1% SL = 2.819**

Discussion

5. DISCUSSION

Hybrid rice research in India was slow until a national research network involving 12 research centres was established in 1991. Accelerated research under the network has enabled the development and multilocation evaluation of more than 200 experimental hybrids. Promising hybrids yielding over 1 t/ha more than the highest yielding check varieties have been identified for extensive testing and on-farm verification. Yield performance of hybrids and seed production packages is highly location- and season-specific. Impressive progress has been made on various aspects of basic research, notably on diversification of CMS, gametocide-based two-line breeding, and conservation of F_1 yield through dihaploid breeding (GOI, 2010).

In China, more than 50 per cent of the rice area is under hybrid rice cultivation. India, Philippines, Vietnam, Indonesia, and Bangladesh have also released rice hybrids for commercial cultivation. These hybrids show 15–20 per cent standard heterosis and are based on indica germplasm. Although japonica hybrids are also cultivated commercially in China, the area under such hybrids is limited, primarily because of lower standard heterosis (less than 10 per cent). The current level of standard yield heterosis is economically viable, but, to make hybrid rice technology more attractive, rice hybrids with a higher level of heterosis should be produced (Virmani *et al.*, 2003). Cytoplasmic genic male sterility (CGMS), a condition under which a plant is unable to produce functional pollen, is widespread among higher plants. CGMS systems represent a valuable tool in the production of hybrid seed in self-pollinating crop species, including maize, rice, cotton, and a number of vegetable crops. Hybrids often exhibit heterosis, more commonly known as hybrid vigor, where hybrid progeny exhibit superior growth characteristics relative to either of the parental lines. CGMS systems can be of considerable value in facilitating efficient hybrid seed production (Virmani *et al.*, 2003).

In India, around fifty hybrid rice varieties have been released by public research and private seed companies. However, none of these can be popularized in Kerala because of our specific quality requirements. Most of the hybrids released in India are having IR 58025A as a female line which is aromatic and sticky on cooking. Hence, this present investigation was an attempt to use alternative CGMS source and to find out restorers and maintainers for these CGMS lines. The results of the investigation are discussed below.

5.1 MORPHOLOGICAL EVALUATION OF PARENTS

Rice is a predominantly self pollinated crop. In order to exploit heterosis efforts should be made to enhance cross pollination to get maximum seed set by out crossing either by artificial means like assisted pollination, application of growth regulators or by exploiting natural mechanisms exist in the plant system. The natural mechanisms present in the rice plant for out crossing include panicle and stigma exsertion, angle of floret opening and duration of flower opening. Virmani *et al.*, (2003) emphasized the importance of qualitative characters in commercial hybrid seed production in rice.

The parents Jyothi, Matta Triveni, Onam and Uma exhibited well exserted panicle. Well exserted panicle facilitate higher rate of cross pollination by exposure of spikelets above the canopy level facilitating cross pollination. Virmani (1994) also reported that good panicle exsertion rate in CGMS lines was essential to attain high out crossing rate. However, in the present study CGMS lines were having mostly exserted panicles which can be improved by gibberellic acid application (Suralta *et al.,* 2004).

All the parents exhibited semi-erect flag leaf orientation. This character also got importance in commercial hybrid seed production in rice. The horizontal flag leaf orientation enhances the rate of cross pollination by facilitating the movement of pollen grains by wind without hindrance of flag leaf.

Well exserted stigma was observed in both CGMS lines, CMS 2A and IR 68897A. The well exserted stigma in male sterile lines is desirable character while choosing parents for commercial hybridization programme since, it provides more surface area to adhere pollen grains on it which enhances the success of cross pollination. This leads to restoration of the fertility of male sterile lines in rice hybrids (Singh *et al.*, 2003).

The highest angle of floret opening was observed in IR 68897A among female parents. Whereas, Jaya exhibited highest angle of floret opening among testers. The high angle of floret opening causes more stigma exposure which is helpful in out crossing in female lines. In the case of male lines more angle of floret opening can result in more exposure of anther and easy dispersal of pollen grains. Yadav *et al.*, (2005) used different homeopathic medicines to improve the morphological features in hybrid rice seed production plots to enhance out crossing. They found Pulsatilla 200 as most effective in improving duration of floret opening, blooming duration of panicle, angle of floret opening and stigma exsertion. Improvements of these characters lead to increased yield in hybrid rice.

Based on morphological features both the female lines can be considered as suitable parents with mostly exserted panicle, semi erect flag leaf and well exserted stigma with good duration of flower opening. However, the angle of floret opening was narrow in both the lines.

Among testers, Onam had well exserted panicle, with semi erect flag leaf, well exserted stigma and medium angle of floret opening which facilitate out crossing. Among the parents Uma had maximum duration of flower opening .Based

on duration of flower opening CMS 2A was found to be better. The duration of flower opening is an important qualitative character provides more time for pollination in female lines and pollen dispersal in male lines which enhance the per cent fertility restoration of male sterile lines in F_1 generation (Yadav *et al.*, 2005).
The white colour stigma was observed for the both male sterile lines. Whereas light green stigma was observed in all the male parents.

5.2. STUDIES ON COMBINING ABILITY

Combining ability is an essential criterion to consider a systematic set of crosses between a number of parents and to enquire to what extent of variation among the crosses can be interpreted as due to statistically additive features of the parents and what must be attributed to residual interactions. As it provides an empirical summary of complex observations and a reasonable basis for forecasting the performance of yet untested crosses draws attention of breeders for any varietal improvement programme. Being based on first degree statistics, they are statistically robust and being genetically so to speak neutral, they are equally applicable to in-breeders and out-breeders (Simmonds, 1979).

Combining ability analysis is a powerful tool to discriminate the good as well as poor combiners and for choosing appropriate parental material in the breeding programme in crop plants. The per se performance of parent may not necessarily reveal it to be a good or poor combiner. Therefore, gathering information on nature of gene effects and their expression in terms of combining ability is necessary. At the same time, it also elucidates the nature of gene action involved in the inheritance of characters. General combining ability is attributed to additive gene effects and additive x additive epistasis and is theoretically fixable. On the other hand, specific combining ability attributed to nonadditive gene action may be due to dominance or epistasis or both and is nonfixable. The presence of non-additive genetic variance is the primary justification for initiating the hybrid programme (Kshirsagar *et al*., 2005).

As per the results of present study, the analysis of variance revealed the presence of significant variance exhibited by hybrids, lines, testers and line x tester interaction indicating the prevalence of high variance for most of the characters studied. Significance of line x tester interaction suggested that the lines performed differently in the crosses depending on the type of testers used. The magnitude of variance due to GCA was found high for most of the characters than SCA variance indicating the influence of additive gene action in controlling the characters.

The present study revealed that variance due to GCA was high for the characters days to 50 per cent flowering, days to maturity, plant height, total tillers, productive tillers, number of leaves per tiller, panicle length, secondary branches, grains per panicle, spikelet sterility per cent, grain width, grain length, grain weight and yield per plant indicating the predominance of additive gene action in the population for these characters. It was suggested that simple selection or hybridization and selection with pedigree breeding can be applicable to improve these characters in the population.

The characters, number of primary branches, pollen fertility per cent and number of spikelets per panicle recorded high SCA variance indicating the predominance of non-additive/dominance gene action in the population. Since, non-additive/dominance is non-fixable by selection; heterosis breeding and recombination breeding with postponement of selection at later generations can be employed to improve these characters in the population.

Study by Sanjeev Kumar *et al.* (2009) revealed predominance of additive gene action for yield and yield components in hybrid rice. However, studies by Salgotra *et* *al.* (2009) suggested dominant gene action for most of the characters they studied. So, depending on the population of parents selected for hybridization the gene action was found to be varying. Hence, breeding programme has to be designed to fix the traits by analyzing the parental population for their gene action.

5.3. COMBINING ABILITY EFFECTS

Any breeding programme aimed to develop high yielding varieties and hybrids through hybridization is based on the choice of parents. For choosing the parents, the phenotypic mean performance is taken as sole criterion from the inception of the breeding programmes. Hence, the results obtained for mean performance of the parents and hybrids and their relationship with combining abilities are discussed.

The study of combining ability effect revealed that no significance *gca* effect existed for the characters days to 50 per cent flowering, days to maturity, plant height, total tillers, yield per plant, grains per panicle, spikelet sterility, grain length and grain width.

The characters productive tillers, leaves per tiller, panicle length, number of primary branches, number of secondary branches, pollen fertility, number of spikelets per panicle and grains weight had positive significant *gca* effect in the population.
The combining ability effect revealed that parent Jaya possessed desirable *gca* effect for number of productive tillers and leaves per tiller. This parent can be utilized as a parent in a series of combinations to obtain increased productive tillers and number of leaves which may contribute to the final yield. Productive tillers were having positive correlation with yield in rice as suggested by Bai *et al.* (1992). The trait number of leaves per tiller has direct influence on yield as reported by Neelima *et al.* (2007).

Among nine parents tested Jaya and Onam were found good general combiner for the characters, panicle length, number of primary branches and secondary branches per panicle. Hence, these two parents can be utilized to obtain hybrids with increased panicle length and number of primary and secondary branches per panicle in a series of combinations involving either of these parents. The increased panicle length is a desirable trait with respect to yield in rice hybrids (Immanuel Selvaraj *et al.*, 2011).

Aiswarya and Jyothi were identified as good general combiners for pollen fertility per cent. These two parents can be utilized to obtain a series of crosses with high pollen fertility per cent which has direct influence on the yield of plant (Cecilia Diana *et al.*, 2009).

Onam was best general combiner for number of spikelets per panicle among nine parents tested. Hybrids involving Onam as one of the parent can yield increased spikelets per panicle. Number of spikelets per panicle has direct influence on yield of plant as reported by Nayak *et al.* (2001).

Among nine parents Aiswarya, Jyothi and Kanchana were good general combiners for grain weight. A multiple crossing programme involved any one of these as parent in a combination can be expected to produce hybrids with more grain weight. Since, grain weight had direct influence on yield of plant these parents can be utilized to improve the yield in rice hybrids as reported by Chakraborty *et al.* (2010).

By considering overall *gca* effects, the tester Jaya was found to be best general combiner for five characters *viz.,* number of productive tillers, number of leaves per tiller, panicle length, number of primary and secondary branches followed by Onam for the characters panicle length, primary and secondary branches and number of spikelets per panicle followed by Jyothi for pollen fertility and grain weight.

The study of combining ability effect revealed that no significance *sca* effect existed for the characters plant height, total tillers, yield per plant, number of grains per panicle and spikelet sterility in the tested hybrids.

Among fourteen hybrids IR 68897A x Onam had negative value for *sca* effect for days to 50 per cent flowering and days to maturity. These cross combination can be utilized to induce earliness.

The best cross combination for number of productive tillers was CMS 2A x Uma suggesting this hybrid combination can be utilized further to obtain increased productive tillers in the population which has direct influence on yield (Karthikeyan and Anbuselvam, 2006).

For number of leaves per tiller four hybrids namely; CMS 2A x Jaya, CMS 2A x Kanchana, CMS 2A x Uma and IR 68897A x Matta Triveni had positive *sca* effect. By crossing these specific parents, hybrids can be expected to produce plants with more number of leaves which can finally lead to higher yield in the population. Mahitkar *et al.* (2001) reported that the number of leaves per tiller had direct association with yield.

The two rice hybrids CMS 2A x Kanchana and IR 68897A x Matta Triveni showed positive *sca* value for the character panicle length. By developing specific hybrids with these parents may result in hybrids with longer panicles and increased yield (Karthikeyan and Anbuselvam, 2006).

The hybrids CMS 2A x Kanchana, IR 68897A x Matta Triveni and, IR 68897A x Onam recorded significant *sca* values for number of primary branches per panicle. These specific combinations can be utilized for the improvement of increased primary branches per panicle in the population. Primary branches per panicle is an important trait in rice contributing to higher yield (Zheng-jin *et al.*, 2006).

The hybrids, CMS 2A x Kanchana, IR 68897A x Matta Triveni and IR 68897A x Onam were found to be best specific combiners for the character number of secondary branches. These crosses may be used for commercial exploitation of hybrid rice breeding to obtain increased secondary branch number.

The crosses CMS 2A x Kanchana, CMS 2A x Onam, IR 68897A x Aiswarya, IR 68897A x Jaya and IR 68897A x Uma were the best specific combinations for pollen fertility per cent. The sca effects of hybrids are showed in Figure 1. In hybrid rice developed by exploiting male sterility, pollen fertility is an important character determining the yield of hybrid rice. Improved pollen fertility in F_1 will increase seed set and improve yield (Cecilia *et al.*, 2009).

Hybrid CMS 2A x Kanchana recorded high *sca* effect for the trait number of spikelets per panicle. This hybrid can be utilized to exploit heterosis for the character number of spikelets per panicle.

Six hybrids exhibited high *sca* effect for the character grain length. The hybrid IR 68897A x Matta Triveni was found best combination with highest value among six hybrids. All the significant cross combinations can be utilized in exploiting heterosis to improve the grain length in the population.

Two hybrids CMS 2A x Kanchana and IR 68897A x Matta Triveni were found to be best specific combiners for the character grain width. These hybrid combinations can be utilized in exploiting heterosis for the improvement of grain width.

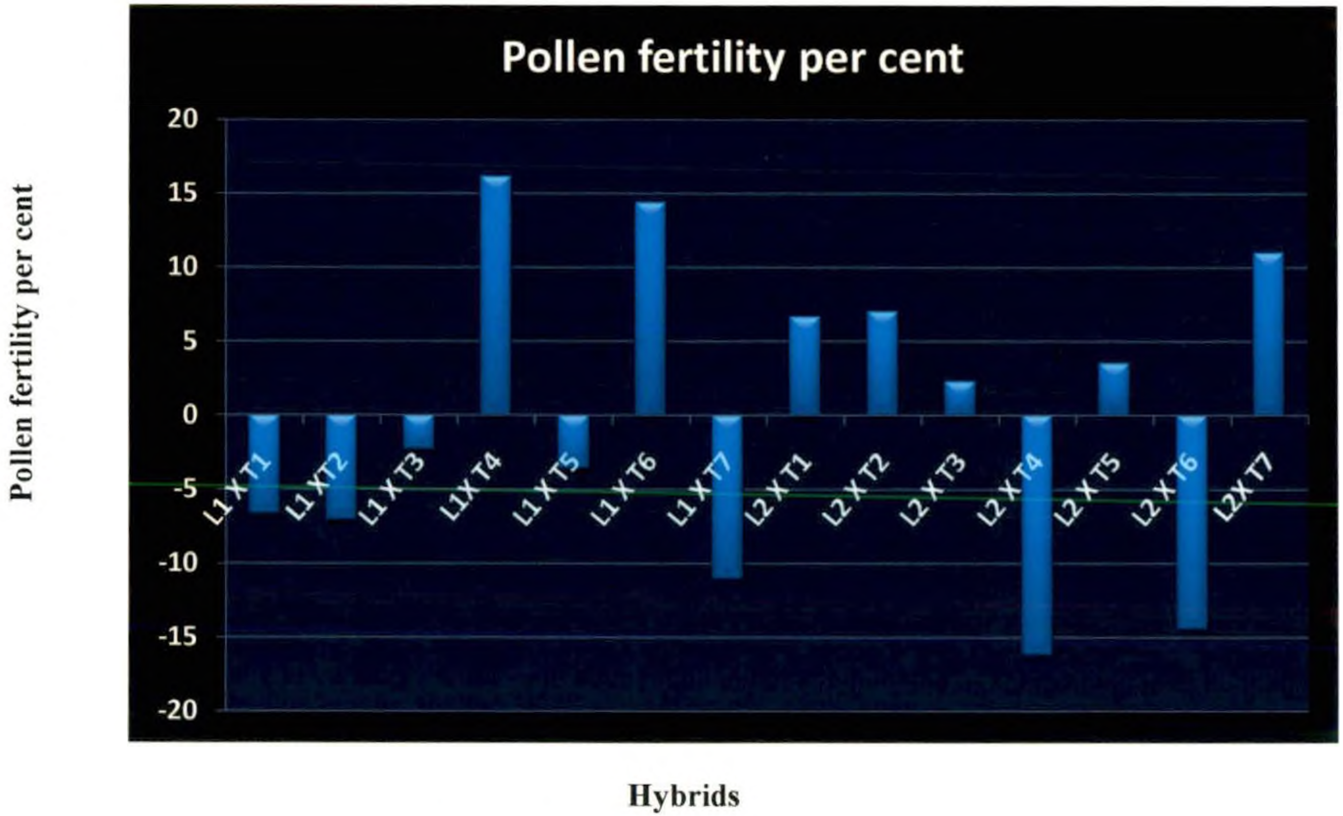


Fig. 1. Specific combining ability effect of hybrids for pollen fertility per cent

The hybrids CMS 2A x Kanchana and IR 68897A x Uma recorded significant *sca* effect for the character grain weight. These specific combinations can be utilized in hybridization programme to obtain increased grain weight which has direct effect on yield of plant.

By considering overall specific combining ability the hybrid, CMS 2A x Kanchana was found to be best combination with eight scorers out of seventeen characters studied followed by IR 68897A x Matta Triveni with eight scores which were found yield attributing characters. By developing specific hybrid combinations with high *sca* effect on yield contributing characters improved yield can be expected in that cross combinations.

5.4. STUDIES ON HETEROSIS IN RICE

Heterosis is the general phenomenon conventionally referred to denote the expression of increased or decreased vigour of the hybrid over mid parent, better parent or standard variety. Hathcock and Mc Daniel (1973) suggested that the expression of heterosis even to a small magnitude for individual component character was a desirable character.

Heterosis manifestation for yield is expressed in the form of increased yield which in turn dependent on the contribution of its components (Grafius, 1959). Therefore, all the component traits of yield need to be studied together with heterosis in order to assess the worth of cross.

Exploitation of heterosis in crops has made crop improvement faster in cross pollinated crops when heterosis was observed in maize. Later heterosis was reported in self pollinated crops also. Expression of heterosis even to a small magnitude for individual character can be desirable factor as the cumulative effect can result in drastic improvement in yield. Line x tester crossing programme with two CGMS lines and seven testers resulted in fourteen hybrids in the present study. Mean performance of hybrids and their heterosis based on mid parental, better parental and standard check variety Jyothi are discussed hereunder.

The analysis of variance revealed significant differences among the parents indicating the presence of adequate genetic variability inherent in the genotypes justifying the selection of the parents for the study. This has further resulted in substantial variability among the crosses as evident from significance of mean squares due to crosses.

Maturity of a crop is determined by days to 50 per cent flowering or days to maturity. Synchrony in flowering is an important trait while considering the parents for hybridization. Mean values days to maturity among the parents showed that all the parents were having maturity duration between 104 days and 111 days indicating a good synchrony in flowering which will be useful in hybridization programme. Figure 2 shows the days to 50 per cent flowering of the parents and hybrids. Even though, mean values of this character varied between genotypes the heterosis was significant only in hybrid CMS 2A x Onam. However, increasing in duration in hybrids cannot be considered as a good character. None of the hybrids showed earliness compared to parents or check variety.

According to Chakraborty *et al.* (2010) plant height was found to be a character contributing to yield in rice. Analysis of data on hybrid rice showed that only in hybrid IR 68897A x Onam there was increase in plant height. Total and productive tillers were high in the crosses CMS 2A x Jaya and CMS 2A x Uma. Figure 3 shows the mean values of productive tillers in parents and hybrids in rice Heterosis showed that the cross IR 68897A x Jaya had heterosis for total and productive tillers. Babu *et al.* (2005) reported heterosis in rice for productive tillers.

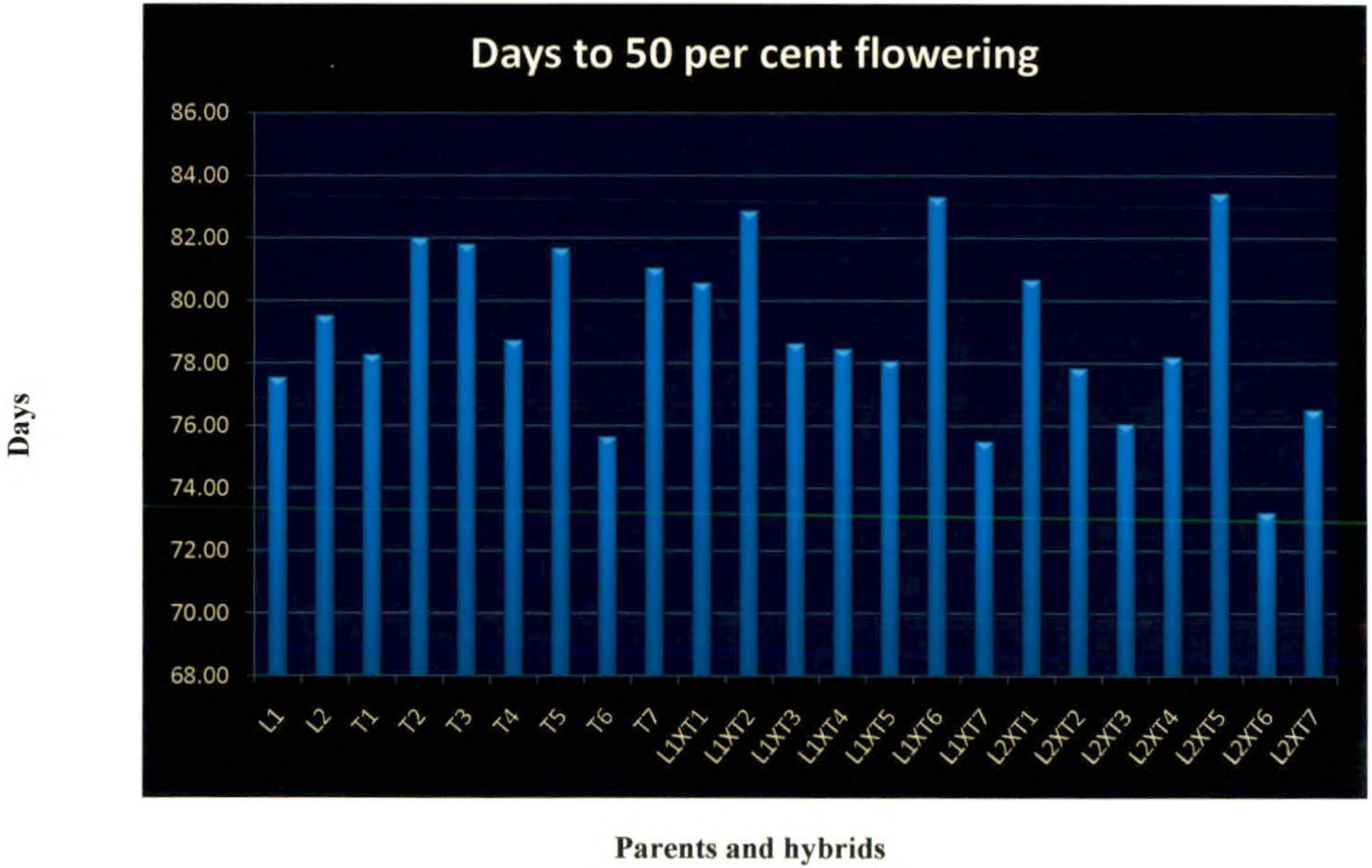


Fig. 2. Mean performance of parents and hybrids for days to 50 per cent flowering

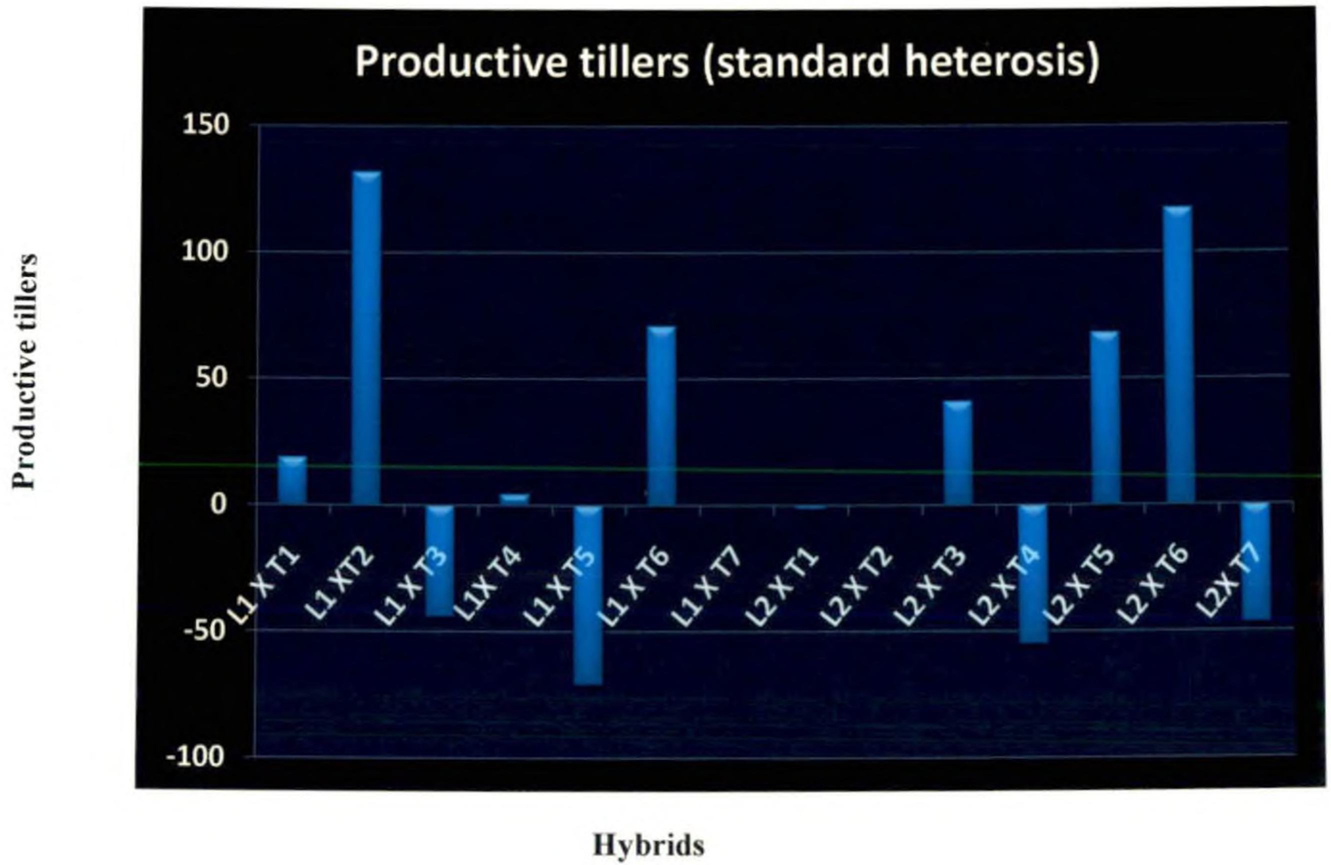


Fig. 3. Heterosis for productive tillers

This trait was found to be contributing to yield of rice plant as reported by Nayak *et al.* (2001).

All the parents and hybrids had significant mean values for number of leaves per tiller indicating presence of variation between genotypes. Neelima *et al.* (2007) reported number of leaves per tiller has positive correlation with yield of rice plant. In the present study hybrid CMS 2A x Jaya recorded high mean value as well as significant heterosis for number of leaves per tiller. This hybrid can be considered best for obtaining hybrids with increased number of leaves per tiller which can enhance the yield.

None of the hybrids was found to be superior over their parents with respect to yield, because of non significant mean and heterotic value for this character as showed in Figure 4.

All the parents and hybrids had significant mean values except CMS 2A x Matta Triveni for panicle length, number of primary and secondary branches. The study of heterosis revealed that hybrids IR 68897A x Jaya and IR 68897A x Onam had significant heterosis for panicle length, number of primary and secondary branches. Earlier studies conducted by Chakraborty *et al.* (2010) reported the presence of significant heterosis in hybrid rice for panicle length. Zheng-Jin *et al.* (2006) observed heterosis for number of primary and secondary branches per panicle.

All the parents and hybrids recorded positive significant mean value for pollen fertility except male sterile lines as showed in Figure 5. Nine hybrids showed positive relative heterosis for pollen fertility as one of the parent was male sterile. None of the hybrids exhibited heterobeltiosis and standard heterosis for pollen fertility.

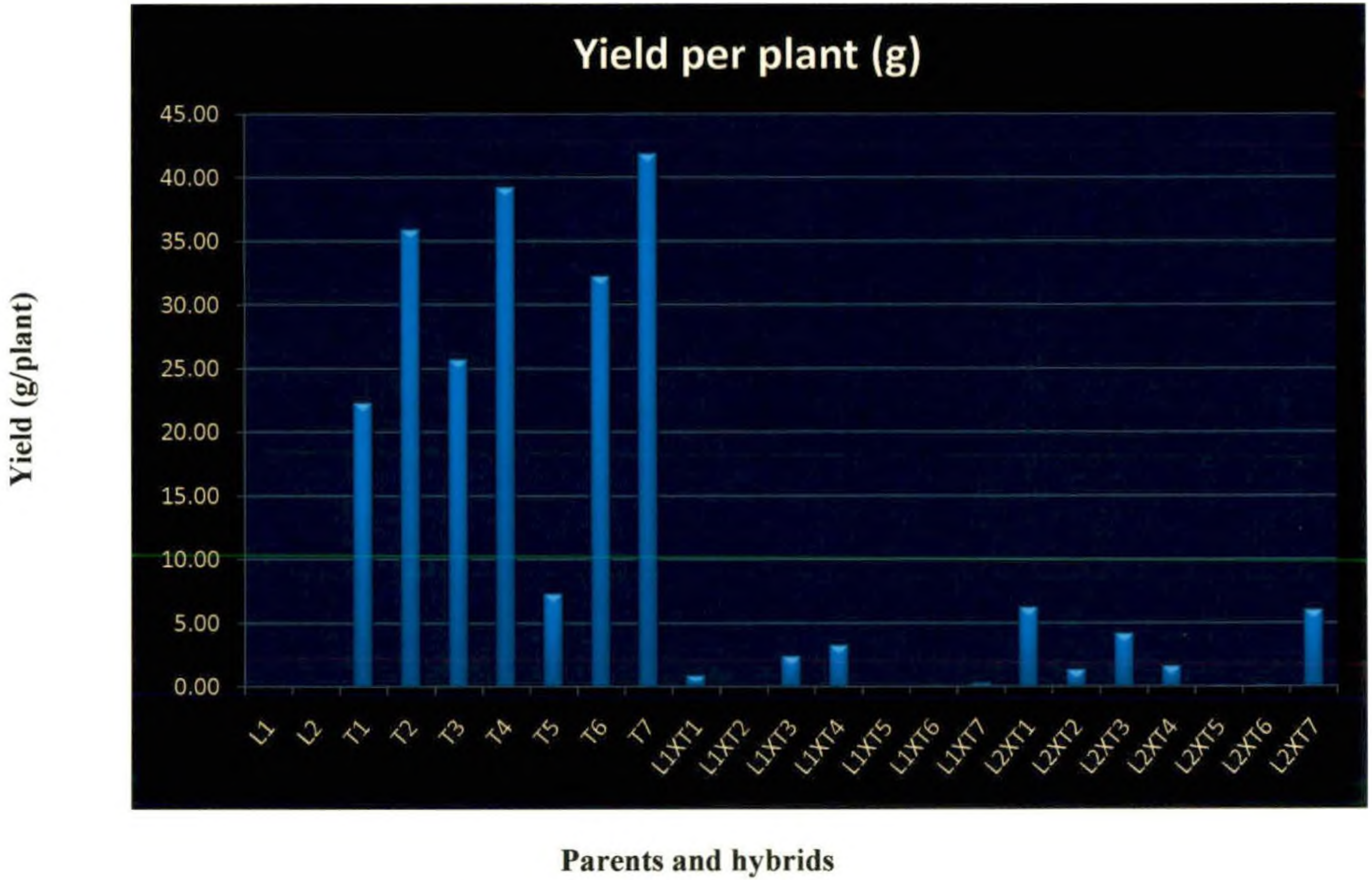


Fig. 4. Mean performance of parents and hybrids for yield per plant

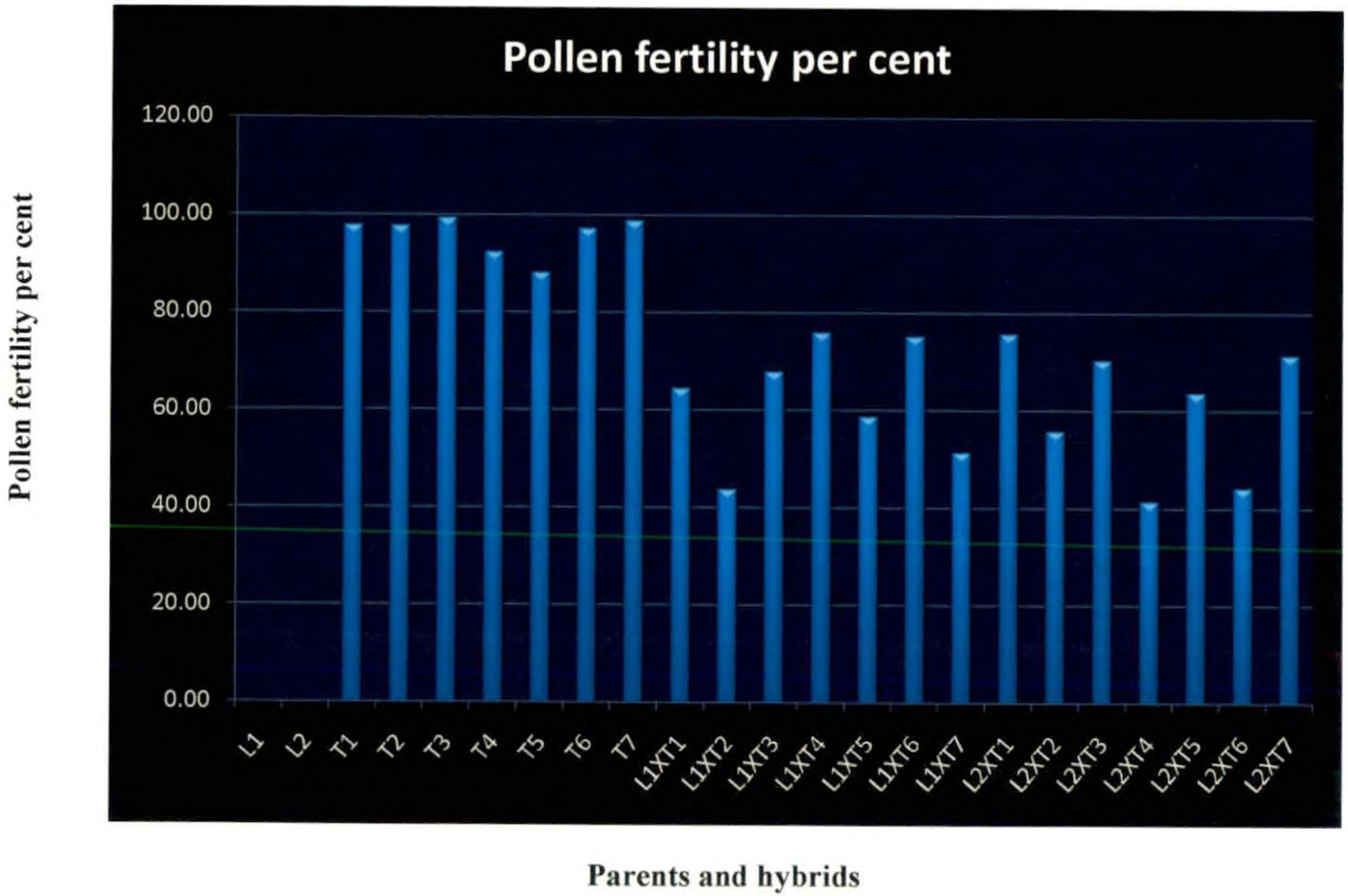


Fig. 5. Mean performance of parents and hybrids for pollen fertility per cent

Among fourteen hybrids tested in the present study, two hybrids CMS 2A x Kanchana and IR 68897A x Jaya exhibited high number of spikelets and grains per panicle. The heterosis for spikelets per panicle was significant in the hybrid IR 68897A x Onam. The spikelets per panicle were very important in determining the yield of plant in hybrid rice as reported by Kole *et al.* (2008). Hairmansis *et al.* (2010) reported that grains per panicle is important in determining yield in rice. However, none of the hybrids showed heterosis for grains per panicle.

Spikelet sterility per cent varied significantly in all the fourteen hybrids. The study of heterosis revealed that highly significant heterosis was recorded in all the hybrids for spikelet sterility per cent. Increased spikelet sterility is an undesirable character in commercial hybrid rice production as it is negatively correlated with yield of plant as reported by Sarawgi *et al.* (1997). In the present study, increased spikelet sterility lead to decrease in yield of the hybrids. However, spikelet sterility per cent plays a major role in classifying the fertility restorers and maintainers for CGMS lines in rice as described by Shobha Rani *et al.* (2004).

Grain length varied in all hybrids except CMS 2A x Jaya and CMS 2A x Matta Triveni where there was no seed set. The mean values for grain width varied between hybrids. The hybrid CMS 2A x Kanchana had highest mean value followed by IR 68897A x Uma. The study of heterosis confirmed presence of significant heterosis in seven hybrids for grain width. The hybrid IR 68897A x Uma was suggested to exploit hybrid vigour for the improvement of grain width in rice hybrids. Grain width is an important yield attributing character, since; it has direct influence on yield of the plant as reported by Selvaraj *et al.* (2011) and Neelima *et al.* (2007). In the present study only one hybrid IR 68897A x Uma had significant mean and relative heterosis for grain weight. The study of heterosis on fourteen hybrids reported existence of significant relative heterosis in five hybrids for this character. By considering mean performance and per cent of heterosis the hybrid IR 68897A x

Uma found best to exploit hybrid vigour for the improvement of grain weight which enhances improved yield per plant in hybrid rice.

Identification of restorers and maintainers

In CGMS system of hybrid seed production male fertility has to be restored in F_1 by crossing female line with a genotype which can restore the male fertility to get good seed set In F_1. In the present study seven varieties were crossed with the two CGMS lines and the pollen fertility was calculated. It was observed that pollen fertility of CGMS lines were zero. Pollen fertility of testers ranged from 88.05 per cent of Matta Triveni to 98.69 per cent of Uma. In the hybrids pollen fertility ranged from 41.36 per cent of IR 68897A x Kanchana to 75.67 per cent in IR 68897A x Aiswarya. According to Virmani *et al.* (1997), genotypes were classified as maintainers if the pollen fertility of F_1 ranged from 0-1 per cent. When values of pollen fertility ranged from 1.5-50 per cent it can be called as partial maintainer. Male line can be called as partial restorer, when the pollen fertility of hybrid varied between 50.1-80 per cent. F_1 hybrid with more than 80 per cent pollen fertility the male line can be considered as a restorer.

As per the classification none of the male lines can be considered as a restorer. The varieties Aiswarya, Jyothi, Kanchana, Matta Triveni, Onam and Uma can be considered as a partial restorer for CGMS line CMS 2A. For the CGMS line IR 68897A, the male lines, Aiswarya, Jaya, Jyothi, Matta Triveni and Uma can be considered as partial restorer considering the pollen fertility percentage.

For CMS 2A, Jaya with 43.73 per cent pollen fertility can be considered as partial maintainer to maintain male sterility of female lines to multiply the male sterile female line. Considering the CGMS line IR 68897A, Kanchana and Onam can be identified as a partial maintainer to maintain male sterility.

Shobha Rani *et al.* (2004) classified genotypes for fertility restoration in hybrids based on pollen fertility as very good (>95%), good (80-94%), medium (70-79%), poor (60-69%) and very poor (<60%). As per this classification the testers Kanchana and Onam can be grouped as medium restorer for fertility for CGMs line CMS 2A. For CGMS line IR 68897A, Aiswarya, Jyothi and Uma can be considered as medium restorer. The testers Jaya, Matta Triveni and Uma can be grouped as very poor restorers for CMS 2A. And for CGMS line IR 68897A, Jaya, Kanchana and Onam can be considered as very poor restorer which is given in the following table.

Classification of restorers and maintainers

CMS 2A		
Restorer	Medium	Kanchana and Onam
	Poor	Aiswarya and Jyothi
	Very poor	Jaya, Matta Triveni and Uma
Maintainer	Maintainer	Jaya and Matta Triveni
	Partial maintainer	Aiswarya, Jyothi, Kanchana, Onam and Uma
IR 68897A		
Restorer	Medium	Aiswarya, Jyothi and Uma
	Poor	Matta Triveni
	Very poor	Jaya, Kanchana and Onam
Maintainer	Maintainer	-
	Partial maintainer	Aiswarya, Jaya, Jyothi, Kanchana, Matta Triveni, Onam and Uma

Based on spikelet fertility Virmani *et al.* (1997) classified genotypes as maintainers if F_1 is having zero fertility, partial maintainer (0.1-50%), partial restorer (50.1-75%), restorers (>75%). As per the present study Jaya and Matta Triveni can be grouped as maintainer for CMS 2A as they were having zero per cent spikelet fertility. Considering the spikelet fertility five testers for CMS 2A and all seven testers for IR 68897A can be grouped as partial maintainers. None of the testers can be considered as restorer based on spikelet fertility per cent.

Shobha Rani *et al.* (2004) classified restorers in hybrids based on spikelet fertility as very good (>90%), good (85-90%), medium (75-85%), poor (60-75%) and very poor (<60%). As per the classification all the testers were found to be very poor with respect to male fertility restoring ability of F_1 hybrid. In few hybrid combinations even though there was pollen fertility, self fertilization and enough seed set was not obtained. Further studies have to be undertaken to explain this phenomenon. Joshi *et al.* (2003) also reported 1 to 82 per cent pollen fertility and 0 to 87 per cent spikelet fertility in IR68888A x Bindeswari, rice hybrids.

Summary

6. SUMMARY

Rice, (*Oryza sativa* L.) is an important cereal grown in almost all parts of India, since, it is staple food. Due to its self pollinated nature, natural variability in a rice population of rice is limited. Exploitation of hybrid vigour in rice is essential to overcome the food deficit as well as to get preferred quality of hybrids. The present study was taken up with the following objectives.

- To identify potential restorers and maintainers for cytoplasmic genic male sterile (CGMS) lines involved in the present study

The important findings are summarized below;

1. Well exserted stigma was observed in both CGMS lines CMS 2A and IR 68897A.

2. All the parents exhibited semi-erected flag leaf orientation. The horizontal flag leaf orientation enhances the rate of cross pollination by facilitating the pollen grains adhere directly into the stigma without leaf barrier.

3. The panicle exsertion varied from mostly to well exsertion. The parents Jyothi, Matta Triveni, Onam and Uma exhibited well exserted panicle. Both CGMS lines possessed mostly exserted panicle. Well exserted panicle facilitate higher rate of cross pollination since panicle exsertion rate is appeared to have an influence on out crossing rate.

4. Angle of floret opening ranged from 23.5^0 to 31.32^0 in Matta Triveni and Jaya, respectively. Both CMS 2A and IR 68897A had narrow angle of floret opening (<30^0).

5. Duration of flower opening ranged between 120.5 and 131.3 minutes in Matta Triveni and Uma, respectively. The CMS 2A had 126.3 minutes and IR 68897A had 123.1 minutes duration of flower opening.

6. As per the results of present study, the analysis of variance revealed the presence of significant variance exhibited by hybrids, lines, testers and line x tester interaction indicating the prevalence of high variance for most of the characters studied.

7. The magnitude of variance due to GCA was found high for most of the characters than SCA variance indicating the influence of additive gene action in controlling the characters.

8. The analysis of variance revealed significant differences among the parents indicating the presence of adequate genetic variability inherent in the genotypes justifying the selection of the parents for the study.

9. All the characters showed positive heterosis except total tillers, yield per plant and grains per panicle.

10. The hybrid IR 68897A x Jaya had high *per se* performance than the standard variety, Jyothi for total and productive tillers.

11. As per the classification based on pollen fertility none of the male lines can be considered as a restorer. The varieties Aiswarya, Jyothi,

Kanchana, Matta Triveni, Onam and Uma can be considered as partial restorer, for CGMS line CMS 2A.

12. For the CGMS line IR 68897A, the male lines, Aiswarya, Jaya, Jyothi, Matta Triveni and Uma can be considered as partial restorers considering the pollen fertility percentage.

13. For CMS 2A, Jaya with 43.73 per cent pollen fertility can be considered as partial maintainer to maintain male sterility of female lines to multiply the male sterile female line.

14. Considering the pollen fertility CGMS line IR 68897A, Kanchana and Onam can be identified as a partial maintainer to maintain male sterility.

15. Based on spikelet fertility Jaya and Matta Triveni (both 100 per cent spikelet sterility) can be grouped as maintainer for CMS 2A and all seven testers for IR 68897A can be grouped as partial maintainers.

16. In few plants of hybrids CMS 2A x Uma and IR 68897A x Onam we could get 91 and 89 percent pollen sterility.

17. High pollen sterility in these plants can be exploited further to develop CGMS lines with the genetic background of Onam / Uma by back crossing.

Future line of studies suggested

Efforts should be directed for the following future studies.

1. Hybrids with increased number of productive tillers, high pollen fertility and grain weight and high spikelet sterility but poor seed set were observed. Being a preliminary study, further confirmation of this result is required.

2. Study involving large number of potential restorers for the CGMS lines CMS 2A and IR 68897A used in the study may yield promising result.

3. In few plants of the hybrids CMS 2A x Uma and IR 68897A x Onam high pollen sterility was observed. These plants can serve as parents for developing maintainers in background of Uma / Onam to develop hybrid rice with desired quality attributes of these popular high yielding varieties by backcross breeding.

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Abstract

SCREENING OF FERTILITY RESTORERS FOR CYTOPLASMIC GENIC MALE STERILE (CGMS) LINES IN RICE (*Oryza sativa* L.)

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ABSTRACT OF THE THESIS

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ABSTRACT

The study entitled "Screening of fertility restorers for Cytoplasmic Genic Male Sterile (CGMS) lines in Rice (*Oryza sativa* L.)" was conducted in the Department of Plant Breeding and Genetics, College of Horticulture during the period 2009-11. The study envisaged evaluation of different CGMS sources and identification of potential restorers and maintainers among high yielding varieties of Kerala. Separate experiments *viz.,* 1. Morphological evaluation of parents and 2. Development and evaluation of F_1 hybrids, conducted to realize the objectives.

Materials for the present study comprised of two CGMS lines *viz.,* CMS 2A from Tamil Nadu Agricultural University, Coimbatore and IR 68897A, from Directorate of Rice Research, Hyderabad. Seven popular high yielding varieties of Kerala were used as male parents. Parental lines were raised and observations on qualitative and quantitative traits were recorded. Hybridization was done between CGMS lines and restorers in Line x Tester design. The F_1 and the parents were raised and observations were recorded.

The results on qualitative traits showed that the male parents Onam and Uma had well exserted panicle, semi-erect flag leaf orientation and well exserted stigma which are helpful in out crossing. None of the hybrids were found to be superior to parents with respect to yield due to increased spikelet sterility. Even though, hybrids CMS 2A x Kanchana, CMS 2A x Onam, IR 68897A x Aiswarya and IR 68897A x Uma recorded high pollen fertility none of the male lines can be considered as restorer. The varieties Aiswarya, Jyothi, Kanchana, Matta Triveni, Onam and Uma can be considered as a partial restorer for CGMS line CMS 2A. For the CGMS line IR 68897A, the male lines, Aiswarya, Jaya, Jyothi, Matta Triveni and Uma can be considered as partial restorer.

Considering the pollen fertility of CGMS line CMS 2A, Jaya with 43.73 per cent pollen fertility can be considered as partial maintainer and for IR 68897A, Kanchana and Onam can be identified as a partial maintainer. However, in the hybrids CMS 2A x Uma and IR 68897A x Onam, few plants exhibited high pollen sterility per cent. These can be utilized to develop CGMS lines in the genetic background of Uma/Onam in future, through backcross breeding programme.