ALTERNATIVE SOURCES OF CYTOPLASMIC MALE STERILITY AND GENETIC ANALYSIS OF FERTILITY RESTORATION IN RICE (*Oryza sativa* L.)

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled "**Alternative sources of cytoplasmic male sterility and genetic analysis of fertility restoration in rice (*Oryza sativa* L.)**" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis, entitled "**Alternative sources of cytoplasmic male sterility and genetic analysis of fertility restoration in rice (*Oryza sativa* L.)**" is a record of research work done independently by **Mr. BIJU, S.**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to him.

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Dedicated to

My Father

Late Prof. K. Sidhartha

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INTRODUCTION

INTRODUCTION

Rice (*Oryza sativa.* L) is the world's most important food crop after wheat. It is a warm season crop grown extensively in the humid tropical and subtropical regions of the world. It is grown in over 110 countries of the world totaling 146 million hectares. Among the major rice producing countries, India leads in hectarage (29% of the world's total) while China follows in planted area (23%) but leads in production (36%). Although world's rice production increased by about 40 per cent during the 1960's and by about 30% during the 1970's largely because of increase in per hectare grain yield, the per capita food production in the developing countries has not shown any substantial increase from 1965 to 1980 as the human population increases more rapidly than food production during that period. Contributing consistently around 45 per cent of India's cereal production, rice continues to hold the key to sustained food security of the country. With rice area getting stabilized, if not registering negative growth, the future rice production targets has to be met exclusively through progressive yield growth. The demand for rice is projected to be 100 million tonnes in 2006–2007 and to achieve this the country has to aim an average productivity target of 2454 kg/ha from the present level of 1985 kg/ha, which is quite a difficult task.

With the release of fourteen hybrids developed by public and private sector institutions and with 1.2 lakh hectares under them, now India has earned the unique distinction of being the second country after China to make hybrid rice a commercial reality. Now even at the one tonne yield advantage, adoption of hybrid rice technology is expected to add 1-1.5 million tonnes of milled rice annually by 2001 and the additional volume is bound to steadily rise to over 5-6 million tonnes by 2006.

The People's Republic of China announced the successful development and use of F_1 rice hybrids in the late 1970's. Since then commercial exploitation of hybrid rice attracted the attention of researchers around the world. It is accepted that about twenty per cent yield advantage of hybrid rice would help to meet the extra cost of seed production and future demands of a growing world population.

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

Hybrid rice seed production involves multiplication of CMS lines and production of F_1 hybrid seeds. Outside China hybrid rice research is exploratory. In India vigorous attempts are in progress to make head way in hybrids on several crops including rice under a special project launched by ICAR, on hybrid seeds. Cytoplasmic male sterility is the most effective genetic tool for developing F_1 rice hybrids. Practically all hybrid rice area in China is planted to hybrids derived from cytoplasmic male sterility system. About 95 per cent of the area under CMS derived hybrids is occupied by hybrids from wild abortive (WA) cytosterility system. For the success of hybrid rice it is essential that their yield must be superior to the commercial variety at least by a margin of 25 per cent. When the magnitude of increment is decreased we may go for breeding high yielding, better quality, disease and insect resistant varieties etc.

Traits under the control of cytoplasmic elements have not received their share of attention and critical analysis in rice research. Other than a small number of maternally affected traits under grain weight, plant height in interspecific crosses and protein content (Chang and Lin, 1974), the only notable activities were focused on the CMS sources and fertility – restoring genes. In addition to the Chin Surah Boro II and WA sterile cytoplasms, other sources have been identified including Gambiaca, Taichung Native 1, Leed, *O. rufipogon*, *O. sativa*, f. *spontanea* and ARC 13829-26 (Virmani *et al.*, 1986).

In order to isolate purely cytoplasmic effect a long series of backcrosses to both parents should be made to develop substitution (of chromosomes.) lines in an alien cytoplasm, as was done in wheat. However, the diploid nature of *Oryza sativa* does not tolerate such a drastic manipulation.

Recent attempts in determining gene sequences have led to a better understanding of chloroplast genes and mitochondrial genes. The structure of chloroplast DNA and its physical map have been made. The chloroplast DNA contains the genetic code for photosynthesis. But the cytoplasmic component remains to be explored. Plasmids like mitochondrial (mt) DNA associated with CMS have been reported by Kadowaki *et al.*, (1988). The DNA fraction differs between sativa and glaberrima cytoplasm (Sakamoto *et al.*, 1990)

Rice varieties evolved in India and elsewhere are now facing a stalemate in increasing yield potentiality. Main bottleneck in the development of hybrid rice suitable to differed ecogeographical conditions is the non- availability of alternative sources of cytoplasmic male sterility (CMS). So far in most of the countries wild abortive (WA) cytoplasm evolved in China is utilized for the evolution of hybrid rice. Performance of WA cytoplasm in tropical climate especially in warm humid conditions is unstable in sterility manifestation. This is a felt need as far as the rice breeder is concerned to find out alternative sources of CMS other than WA. Isolated attempts were succeeded at IRRI in screening of CMS. It has been found that certain local saline resistant varieties exhibit sterility when crossed with IRRI high yielding varieties. The sterility exhibited by the local cultivars can be overcome by crossing with some of the high yielding varieties. Saline resistant varieties exhibiting CMS phenomena can be successfully maintained by repeated backcrosses with identified IRRI varieties. Over the years large number of CMS lines with various cytosterility sources have been developed.

But only a few are now used in India. Usefulness of male sterility sources is dependent on the availability of restorer line. Effective restorer line for GA, GAM boro and ARC cytosterility system have been identified among cultivated rice varieties and elite breeding lines. Fertility restoration in WA lines is sporophytic and is governed by two pairs of major genes and modifier genes.

In view of the above, the present study was undertaken to evolve,

- Alternative sources of cytoplasmic male sterility.
- Screening of elite varieties for identification of restorer and potential CMS lines.
- Genetic analysis of fertility restoration

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 Alternative sources of CMS in rice

Cytoplasmic male sterility is the most effective genetic tool for developing F_1 rice hybrids.

Wu *et al.* (1994) studied the abortive processes of pollen in five genetically male sterile (GMS) rice lines (bred artificially since 1986) and one cytoplasmically – genetically-male sterile (CGMS) line with cytoplasm from wild rice. The CGMS line Zhenshan 97 A had typical nuclear degenerative pollen abortion. Degeneration began at the late mononuclear stage. The GMS lines were all typical nuclear proliferative types. The membrane between two daughter nuclei at telophase in the first meiotic division failed to form; this type of male sterility was very stable, producing flowers with dehiscent anthers.

Jayamani *et al.* (1995) used pollen and spikelet fertility to identify restorers and maintainers of CMS in 101 hybrids, their pollen parents and five isogenic maintainers grown during rabi 1993. Potential (<5% pollen fertility) and partial (6-20% pollen fertility) maintainers, and partial (20-95% pollen fertility) and potential (96-100% pollen fertility) restorers were identified.

Zhang and Zhu (1995) derived the hybrid by crossing mimghui 63 and the cytoplasmically male sterile (CMS) line maxie A, which was bred from a CMS plant found in the land race Maweinian at Wuhan University, China, by crossing the CMS plant with xieqingzao and back crossing for 18 generations to obtain the CMS line. This line is of a new stable CMS type with 99.99 per cent pollen sterility. Maxie 63 has a growth period of about 138 days and reaches a height of 115 cm. Its mean yield is 9.3 t/ha and its 1000 grain weight 30 g. It is resistant to magnaparthe grisea and xanthomonas oryzae.

Dalmacio *et al.* (1996) crossed 48 accessions of 3 wild *Oryza* species (AA genome with IR 64, one of the restorers of wild abortive (WA) cytoplasm. Hybrids with $\geq$ 70 per cent pollen sterility was subsequently backcrossed with the recurrent parent. Of all the backcrossed derivatives, on line, designated IR 69700A with maepatula cytoplasm was stable for complete pollen sterility. Crosses of IR 69700A with nine restorers of WA cytoplasm showed almost complete (88-100%) pollen sterility, indicating that male sterility in IR 69700A is different from WA cytoplasmic sterility. The new CMS line resembles maintainer IR 69700B in morphological characters, except that it flowers five to seven days later. It has complete sterility and does not set seed on selfing.

Motomura (1996) identified male sterile cytoplasm and restorer gene of three restorer lines, RT 61C, RT 98C and RT 102C and studied allelic relationships between the restorer genes. Each line was an isogenic line of Taichung 65, developed by the backcrossing method, with a male cytoplasm and a dominant fertility restorer gene derived from the original line of the wild species *O. rufipogon*. Male sterile lines RT 61A, RT 98A and RT 1022A, which were used as testers, were derived from the restorer lines through two back crossings with

Taichung 65, to replete dominant restorer gene of the restorer lines with the recessive non-restorer allele of Taichung 65. The results suggested that the genes of the three restorer lines were located at the same locus.

Pradhan and Jachuck (1996) converted thirteen popular low land rice cultivars to cytoplasmic male sterile (CMS) lines through repeated backcrossing with three male sterility sources wild abortive, Kaling-1 and *Oryza perennis*. All 13 CMS lines developed were completely pollen sterile with white anthers and did not set seed. The CMS lines are semi-dwarf to semi-tall in stature, with stiff straw. All of the CMS lines were shorter than their respective isonuclear maintainers. Their heights and durations are considered ideal for use in developing hybrids for shallow rain fed low land areas in India.

Liu *et al.* (1996), by a simple sequence repeat marker, CMS lines and their maintainers were identified in hybrid rice of the 109 varieties screened, two possessed different CMS resources. It is concluded that the SSR method should prove useful in screening for CMS resources to develop hybrid rice.

Prasad and Rao (1996) carried out cytological, cytohistological and morphological causes for pollen break down in two cytoplasmic genetic male sterile lines, MS 577A and IR 58025A, in comparison with their corresponding maintainer lines (MS 577B and IR 58025B) and a restorer line (Vajram). The anther sex layers i.e., the inner tapetum, middle endothecium and outer epidermis showed slight variation in their thickness at all stages among the lines but showed normal behaviour in development in all studied genotypes. In IR 58025A, the critical stage of break down was at the binucleate stage, whereas in MS 577A pollen grains were morphologically similar to its maintainer line but failed to fertilize on selfing. The reason for pollen break down may be the incompatibility between nuclear and cytoplasm genes.

Ganesan and Rangaswamy (1996) evaluated ten crosses involving three wild abortive (WA) cytoplasmically male sterile lines and eight tester lines of rice, for inbreeding depression in F_2 on the basis of data on plant height, number of tillers per plant, productive tillers per plant, spikelets per panicle and yield per plant. Inbreeding depression was significant in five of ten crosses and was the highest in the cross IR 62829A/White Ponni and the lowest in IR 58025A/C20.

Kumar *et al.* (1996) screened several hundred elite rice genotypes in Maruteru, India, for their maintaining ability. Two effective maintainers for the wild abortive (WA) type cytoplasm and one for the ARC type were identified and successfully converted into local cytoplasmic male sterility (CMS) lines through backcrossing. Three lines with complete pollen sterility identified from the BC_6 generation (APMS1A, APMS2A and APMS5A) were evaluated for their agronomic and floral traits, and the results of the trials are tabulated and discussed. It is concluded that the three CMS lines are potential female parents for developing heterotic rice hybrids adapted to different ecological conditions, including coastal regions of Andhra Pradesh.

Hoan *et al.* (1997) searched for male sterility inducing cytoplasm in wild species of the genus *Oryza*, with a view to diversify the base of the cytoplasmic genetic male sterility system currently used in the development of commercial rice hybrids. Wild accessions possessing sterility inducing cytoplasms were identified following reciprocal and sterile F_2 backcross methods. Sterile segregants were pursued through substitution backcrosses to develop cytoplasmically male sterile lines. CMS lines were developed with the cytoplasm of either *O. rufipogon* or *O. nivara.* Based on shape, staining and abortive pattern of pollen, and also on type of interaction with a set of restorers and maintainers for known CMS lines from a WA source (V20A), the newly developed CMS lines were grouped into four classes. Of these, RPMS1 and RPMS2 showed gametophytic and male sterility with a restorer reaction different from WA CMS stocks.

Zhang *et al.* (1997) found that abortive pollen of *Oryza sativa* variety maxie A was circular in shape and pollen abortion occurred later than in Zhengshan 97A segregation in crosses with Mimghui 63, Xieqinzaxuan and Zhengshan 97 indicated that fertility restoration in both CMS lines was controlled by two dominant genes.

Gautam *et al.* (1997) evaluated twenty rice lines from IRRI, all except one carrying wild abortive male sterile cytoplasm (CMS – WA) and 13 local CMS – WA lines at Kapurthala during kharif 1996 for degree of male sterility, days to 50 per cent flowering, plant height, anther colour and grain type. Nine local and 11

IRRI lines were classed as completely male sterile. Days to 50 per cent flowering ranged from 73 to 114. Seven lines were dwarf (< 80 cm tall); CMS WA reduced height by 5.9-33.0 per cent compared to the respective maintainers. Lines with desirable white anthers (allowing visual discrimination of CMS lines) were identified. All lines except Pb CMS 7A, V 20A and IR 68888A had long slander grains.

Ganesan and Rangaswamy (1997) observed morphological variations viz., purple base in the stem, internodal purple, purple panicle, purple gloom tip and purple stigma in rice hybrids containing the WA source of CMS. These colorations were not recorded in hybrids containing the *Oryza perennis* (IR 66707A) CMS source, except for puple glume tips and stigmas.

Ahmed *et al.* (1998) evaluated some 64 CMS rice lines from India, China, Malaysia and IRRI along with IR 58025A, IR 62829A and standard controls in the wet seasons of 1995 and 1996 and dry seasons of 1994 and 1995 to assess their suitability for commercial use. Data were recorded on pollen sterility, panicle and stigma exsertion, out crossing rate, duration and angle of glume opening, growth duration, number of effective tillers, spikelets per panicle, grain type, adaptability and pigmentation. Only 11 of the tested CMS lines were better for all the characters studied i.e., IR 58025A and IR 62829A. Some 31 CMS lines possessed one or two good characters and can be used for specific purposes.

Vanaja and Radhakrishnan (1998) for studying gene action in high yielding rice varieties of diverse origin, 13 genetically distinct parents were selected from nine clusters, comprising 56 genotypes of different ecogeographic origin following a Mahalanobis D^2 analysis. Full diallel crosses were performed and, among the 156 F_1 progenies obtained, two highly sterile lines from Vytila-3/IR 36 and Vytila-3/Hraswa were identified. Progenies of their reverse crosses were fully fertile suggesting that Vytila-3 possesses sterility inducing cytoplasm.

Quan *et al.* (1998) derived information on nucleocytoplasmic interaction from data on seven yield traits in 4x6 incomplete diallel cross of rice involving CMS lines, restorers and a wide compatibility variety.

Subudhi *et al.* (1998) found that the cytoplasmically genetic male sterile (CMS) lines developed at the International Rice Research Institute are valuable in producing tropical rice hybrids. Efficient use of CMS lines in hybrid rice production will depend on their level of genetic diversity. Aside from morphological characterization, molecular analysis based on DNA markers can provide information on the genetic diversity of the germplasm. The amplified fragment length polymorphism (AFLP) technique was used to fingerprint 71 CMS lines and four rice cultivars (IR 64, Azucena, IR 74 and FR 13A). Eleven primer pair combinations specific to the enzymes P st 1 and Mse 1 were used to generate 530 AFLP markers, 176 of which are polymorphic. Each CMS line revealed a distinct fingerprint. The AFLP marker – based dendrogram depicted genetic variation among the CMS lines. The CMS lines developed in japonica background grouped with Azucena, a japonica cultivar. None of the CMS lines clustered with FR 13A, a flooding tolerant traditional indica variety. IR 64 was distinct from the other indica CMS lines and clustered with lines developed in its background. The grouping of CMS lines into a few groups is useful for breeders in selecting genetically diverse CMS lines for hybrid rice production and in avoiding test crossing every CMS line empirically.

Casal and Virmani (1998) outlined the development of rice hybrids suitable for use in the tropics. By 1989, IRRI had developed two commercially usable CMS lines that, when combined with easily available restorers among elite tropical indica rice cultivars, produced hundreds of experimental of rice hybrids. Some of these yielded about 1 t/ha more than inbred controls in national trials under irrigated conditions, and by 1994, India, Vietnam and the Philippines had released some promising rice hybrids for commercial cultivation. New improved CMS lines are now available in the genetic backgrounds of irrigated rain fed, boro and aromatic rice cultivars, and the cytoplasmic base has been diversified. Breeding indica/tropical japonica hybrids has begun with the development of CMS lines in the background of tropical japonica.

Hoan *et al.* (1998) to identify new sources of CMS within the A genome of genus *Oryza*, 132 interspecific crosses were made involving four wild (*O. rufipogon, O. nivara, O. barthii* and *O. longistaminata*) and two cultivated species (*O. sativa* and *O. glaberrima).* Accessions possessing sterility inducing cytoplasm were identified following reciprocal and F_2 backcross methods, and advanced through substitution backcrossing to develop CMS lines. The newly developed CMS lines were grouped into four types based on pollen morphology and staining pattern, and type of interaction with a set of maintainers and restorers of wild abortive cytosterile stock. All of the new CMS lines possessed complete panicle exsertion essential for enhancing out crossed seed yield. For the two stable CMS lines, MS 577A and IR 66707A, no restorers are available in the cultivated rice germplasm, and therefore a search for restorer sources was made among wild accessions of A genome species. Studies on the genetics of fertility restoration in these cross combinations indicated that two dominant genes act in an additive manner to restore fertility.

Jayamani *et al.* (1998) made Dular, a rice cultivar with a wide compatibility gene crossed with different cytoplasmic male sterility (CMS) lines during the 1990 dry season. F_1 hybrids of V 20A x Dular showed 100 per cent pollen sterility and substitution backcrosses were then made. In each backcross generation, 36 plants were raised along with parental lines. Completely male sterile plants were identified and used for subsequent backcrossing up to the BC_6 generation, until the genome of Dular had been transferred into a V 20A cytoplasmic background. In the BC_7 generation, a completely male sterile population was built up. The resulting new male sterile lines Coms 8A, has the wide compatibility allele and a high rate of panicle exsertion.

Rangaswamy and Jayamani (1998) made direct and reciprocal crosses between AA genome species *Oryza nivara*, *O. spontanea*, *O. rufipogon*, *O. barthii*, *O. glaberrima* and *O. sativa* cultivars in order to diversify cytoplasmic male sterility sources for hybrid rice breeding. F_1 progenies with over 99 per cent pollen or spikelet sterility were *O. nivara* x Co 45, *O. barthii* x ASD 16, *O. barthii* x IR 50 and *O. nivara* x IR 64. These sterile hybrids were backcrossed with their respective recurrent parents. Determination of pollen sterility on the BC_1-BC_4 generations showed these lines to be stable for complete male sterility.

Rao and Yuan (1998) studied morphological and physiological characters of eight male sterile rice lines belonging to diverse cytoplasm during the winter 1993-94, lines tested were wild abortive types, IDR or Indonesian paddy rice type (VIA), dwarf abortive type and BT or Japonica type. Lines Jin 23 A, V 20A and Zhengshan 97A showed 100 per cent unstained and irregular – shaped pollen, where as Zhi A, BDA and UIA showed 99.0-99.5 per cent sterile, irregular pollen.

Natarajan *et al.* (1998) observed male sterile segregants in the F_2 generation of the cross Pusa 743 x Pusa 3, whereas in the reciprocal Pusa 33 x Pusa 743, all F_2 plants were fertile. This indicated that Pusa 743 has sterility inducing cytoplasm of several breeding lines tested for fertility restoration. In this cytoplasm, 30 per cent were restorers; initially 21 per cent of the lines were identified as maintainers. But only 10 per cent showed a stable reaction for sterility maintenance in later backcross generations. This indicated that fertility restoration is governed by a single dominant gene. Japonica rices are likely to maintain sterility in this cytoplasm. Of three cytoplasmic male sterile lines with stable sterility reaction that were developed, Pusa 1127A was agronomically promising.

Pradhan and Jachuck (1998) developed four CMS lines of Krishna with sterile cytoplasm from four sources i.e., wild abortive (WA), *Oryza perennis*, Kalinga 1 and Lalruma. All of the lines are dwarf in stature, of medium duration and have reduced white anthers and exhibit unstained with red pollen grain. Crosses of these cytosterility sources with four maintainers and five elite inbred lines showed that their sterility was maintained by the four maintainer lines. Krishna A (WA) restorer SPR 7210-1-3 was a maintainer of the other 3 CMS lines, where as restorer IR 48725-B-B-120-1 of Krishna A (WA) behaved as partial restorer of Krishna A (Kalinga l) and Krishna A (Lalruma), and a maintainer of Krishna A (Kalinga 1) and Krishna A (*O. perennis*).

Wang *et al.* (1998) investigated the effects of the male sterile cytoplasm on twelve yield and agronomic characters in F_1 japonica hybrid rice (*Oryza sativa).* Cytoplasmic effects significantly varied with the different male sterile cytoplasms used which may be due to the different restoring abilities of the R lines for the four male sterile cytoplasms. BT and D type cytoplasms with appropriate R lines showed positive effects on grain yield, and their hybrids showed midparent heterosis and heterobeltiosis with an average value higher than 20 per cent. In addition, cytoplasmic effects were also dependent on the nuclear genetic back ground of the B and R lines and their interactions. The results suggested that it could be possible to minimize negative cytoplasmic effects in order to obtain a hybrid with marked heterosis for grain yield by appropriate selection of the male sterile cytoplasm and B and R lines.

Kumar *et al.* (1998) in an effort to develop long duration (145-150 days) and stable local CMS rice lines, several testcrosses were made using local long duration elite lines and IRRI CMS lines to screen the elite varieties for their maintaining or restoring ability. A few long duration maintainer lines were identified and MTU 4870 was selected and successfully converted into a local cytosterile line in a wild abortive cytoplasm background through backcrossing. This line was designated APMS 5A. It is 100 per cent sterile and has desirable agronomic and floral traits. APMS 5A will facilitate the development of long duration rice hybrids suitable for cultivation in coastal areas.

Bijoya *et al.* (1999) using protoplast fusion between cytoplasmic male sterile and fertile maintainer lines, transfer of wild abortive cytoplasmic male sterility to the nuclear background of RCPL 1-2C is reported, an advance breeding line which also served as maintainer of this cytoplasm. In total, 27 putative hybrids between V 20A and RCRL 1-2C and 23 lines between V 20A and V 20B were recovered and all of them were sterile. DNA blots from Hind III digested mitochondrial DNA of these BC_1 plants when probed with Orf 155 again exhibited localization of 1555 in wild abortive cytoplasm specific 1.3 Kb Hind III digested mitochondrial DNA fragments. This demonstrated that the cytoplasmic male sterility transferred through protoplast fusion retained intact female fertility and was inherited and expressed in BC_1 plants.

Sariat and Singh (1999) studied on cytoplasmic male sterility (CMS) break down and relative stability of CMS lines for their sterility, twelve CMS lines were evaluated over two seasons at Delhi. The CMS lines PMS 2A, PMS 3A and PMS 10A were completely pollen sterile, had zero spikelet fertility and were highly stable while PMS 5A and IR S8025A were had comparatively longer stigma, style and anther length favorable for out crossing during seed production of A x B and A x R combination. In general all CMS lines were semi-dwarf in height had medium to high tillering and were of medium duration except IR 62829A.

About 65 rice hybrids were developed by Viswakarma *et al.* (1999) by crossing two cytoplasmically male sterile lines, IR 58025A and PMS 10A with 45 diverse male parents. Evaluation was performed during kharif 1996 using the standard check Sarjoo 52 and heterosis was estimated using data from nine yield components. The estimates of mean squares were highly significant for all the nine characters indicating the presence of wide variation in the material. The cross IR 58025 x NDRK 5042 showed the highest heterosis for grain yield per plant.

Xue-Shiyu *et al.* (2000) bred a series of new restorer lines of rice such as Lishui SIS 216, by convergent back crossing, their main recurrent parents being IR 26 restorer lines. Blast resistance and combining ability were noticeably improved in the lines. Some new hybrid rice combinations, such as II YOU 621 which were selected in crosses involving the new restorer lines, showed high yields resistance to blast and good grain quality in different regional trials.

Srivastava (2000) recent advances in molecular biology of plant mitochondria have yielded some new insights. A common basic set of genes is encoded in all mitochondrial genomes. Although their sizes differ greatly, with plant mitochondrial DNA's being the most complex. Mitochondrial genome mutation encodes cytoplasmic male sterility (CMS), which in turn leads to stamen sterility or pollen abortion in several higher plants. CMS is the result of an incompatability between the nucleus and mitochondrial genomes, so that male pollen is aborted or not properly formed. The CMS system in agriculturally important crops has been used to produce high yielding and heterotic hybrid seeds because it eliminates the need for labour intensive and expensive hand emasculation. Hybrid seeds (or varieties) hold great potential for improving crop economic yields, even when the average yields are much higher in a many of the traditional food and field crops. An important feature of mutations responsible for CMS is the discovery of Chimaeric genes and different open reading frames joined together or placed in proximal locations for cotranscriptions with other standard mitochondrial genes. Twenty nine mitochondrial CMS related genes in over 12 higher plant species have been characterised so far together with a specific DNA coding sequences. The recent development of *in vitro* system for transcription initiation and RNA processing has yielded intriguing details of transcription and post transcriptional regulation of plant mitochondrial CMS genes. The latest findings on the subject support the notion that intergenomic interaction i.e., specific nuclear mitochondrial gene or transcription is operational on the plausible molecular mechanism for the manifestation of maternally and cytoplasmically inherited CMS lines.

2.2 Screening of elite varieties for identification of restorer and potential CMS lines

2.2.1 Partial diallel analysis

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

The predominant role of additive gene effect was established for all yield components except panicle number (Chang *et al.*, 1973).

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

Combining ability analysis was made in rice through line x tester by Amrithadevarathinam (1983) for major yield and yield components. Considerable degree of genetic variability was observed in the parents. The combining ability variances were significant and indicated the importance of both additive and non-additive gene action in the expression of yield characters. But general combiners and best cross combinations with respect to different characters were identified. The cross Chithariyan/Kannagi and Chithariyan/IR 5 showed very high heterosis for three important yield components namely productive tillers, grains per panicle and plant yield. Both Chithariyan and Kannagi possessed high gca coupled with superior sca effects and in view of this, the above two crosses would be preferred for further breeding.

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

In order to diversify sources of CMS rice, research is in progress in China, at IRRI, and elsewhere to identify additional CMS sources. At IRRI a highly sterile BC_4F_1 progeny from the cross AR C13829-26/IR 10179-2-3-1 was obtained suggesting that AR C3829-26 does processes sterility inducing cytoplasm (Virmani *et al.*, 1985).

Anandakumar and Rangaswamy (1986) in a line x tester analysis of data from eight dwarf cultivars used as females and two tall cultivars testers revealed significant general and specific combining ability effects for the four traits measured. Non-additive gene action (dominance epistasis) conditioned plant height, panicle length and yield per plant. Three crosses were superior on the basis of *per se* performance and sca effects.

In a 9 x 9 diallel cross, Kuo and Liu (1986) observed that additive effects were more important than dominance effects for grain length, width, L/B ratio and 1000 grain weight. General and specific combining ability effects were significant for all four characters, all the former were more important than the latter. Narrow sense heritability estimates were high in all cases. Maternal effects were detected for all four characters. Dominance was partial or incomplete.

Mohapatra and Mohanty (1986) crossed 12 early varieties in a diallel fashion without reciprocals and scored for 30 characters. The gca and sca effects were highly significant for almost all characters. Additive effect appeared to predominate for 21 traits including days to flowering and number of spikelets and grain per panicle. Spikelet fertility and harvest index showed predominantly sca effects. The four parents with high gca also showed high variety heterosis.

Genetic analysis of grain yield and yield attributes in rice by Kalaimani and Sundaram (1987) with 7 x 7 diallel revealed that although both additive and dominance components are significant for all the characters studied, additive genetic component was predominant for plant height and grain yield and non-additive genetic components for days to flowering, productive tillers per plant and number of grains per panicle. Over dominance was observed for days to flowering, productive tillers per plant and number of grains per panicle, dominance for grain yield and partial dominance for plant height and 100 grain weight.

Koh (1987) analyzed combining ability and heterosis of F_1 hybrids using cytoplasmic genic male sterile lines of rice and reported highly significant gca and sca effects for yield and yield related characters.

Sardana and Borthakur (1987) in a 5 x 5 diallel cross excluding reciprocals reported that genetic variability, general combining ability (gca) and specific combining ability (sca) were significant for grain yield per plant, days to flowering, plant height, effective tillers per plant, panicle length, flag leaf length, flag leaf width, filled grain per panicle and 100 grain weight. Both additive and non-additive gene effects were important for all the traits. Best general combiner and best cross combination for different characters were identified.

Gene action and combining ability for yield and its component characters in rice in seven parents F_1 diallel excluding reciprocals was studied by Kaushik and Sharma (1988). Gene action as estimated as Hayman and Griffing approaches revealed the predominance of additive gene action for plant height, panicle length and spikelets per panicle, predominance of non-additive generation for 1000 grain weight and presence of non-additive gene action for sterility and yield per plant. Griffing approach revealed the presence of both additive and non-additive components for days to flowering and number of tillers. Hayman approach revealed the presence of only non-additive gene action for number of tillers. The results revealed the presence of epistatic interaction for days to flower, number of tillers, sterility and yield per plant and the interaction was of probably complementary nature for all but yield per plant.

Manuel and Palanisamy (1989) conducted line x tester analysis of combining ability in rice. The ratio of gca and sca variances revealed the importance of additive action for days to flowering, plant height and panicles per plant.

Using line x tester analysis involving seven maintainers and 11 restorer lines, Peng and Virmani (1990a) studied combining ability for grain yield, dry matter, harvest index, plant height and days to flower. It was found that general combining ability and specific combining ability variances were significant for yield, dry matter, days to flowering and plant height.

Banumathy and Prasad (1991) studied combining ability for the development of new hybrids in rice. The sca variances were higher than the gca variances for plant height, number of filled grain, percentage of spikelet sterility and grain yield per plant indicating the prevalence of non-additive gene action in the expression of these traits. Additive gene action was found to be important for number of productive tillers and length of panicle. Among parents' good combiners for grain yield, plant height and number of filled grains were identified.

Importance of both additive and non-additive gene action for the characters plant height, panicle length, productive tillers per plant, number of spikelets per panicle and grain yield were revealed by Lokaprakash *et al.* (1991), with the preponderance of non-additive gene action for all the characters except for plant height.

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

In a diallel cross involving seven varieties of different duration groups, the additive nature of gene was predominant for heading duration, numbers of primary branches per panicle, number of secondary branches per panicle, 100 grain weight, grain length and grain breadth. The high heritability in narrow sense was also established for all the characters (Mohanty *et al.*, 1995).

Verma *et al.* (1995) in the study of 9 x 9 diallel analysis in F_2 generation excluding reciprocals in rice for various yield components revealed significant differences for general and specific combining ability for all the characters. The magnitude of gca variance was relatively higher than sca variance and thus predominance of additive gene action was observed for all the characters except for biological yield per plant and number of effective tillers per plant. Based on sca effects, the cross PP 72 x Mahsuri, Jaya x Sita and PP 72 x Sita are suggested for isolation of high yielding lines through pedigree method while crosses Jaya x Govind, Jaya x T_3, Sita x Prasad, Jaya x Prasad and Sita x Govind can be exploited for hybrid breeding.

Combining ability studies in F_1 and F_2 populations of a 9 x 9 diallel set in rice by Katre and Jambhale (1996) indicated Mahsuri and Kasturi as good general combiners for yield and other important traits under both transplanted and direct seeded conditions. Ramalingam *et al.* (1997) also observed similar results in a line x tester analysis promising combinations were identified based on *per se* performance and sca effects for yield and yield components.

Combining ability and heterosis were estimated for 10 characters in a line x tester analysis with three lines, five testers and their 15 hybrids by Padmavathy *et al.* (1997). Gca and sca variances were significant for days to 50 per cent flowering, number of tillers per plant, number of panicles per plant and 1000 grain weight. Parents showing more than one desirable traits indicating their utility in heterosis breeding programmes were identified. Similarly crosses with high sca effects for each character and those recorded significant heterosis for yield and its contributing characters were identified. It was observed that crosses involving one high and the other low, medium or high general combining parents would produce heterotic hybrids.

Lee Kyu Seong *et al.* (1997) crossed nine varieties differeing in salinity tolerance in a partial diallel. Twelve day old hybrid seedlings were grown in saline solutions, initially at an EC of 6 ds/m for four days followed by an EC of 12 ds/m for 20 days. Agronomic characters such as plant height, dry shoot weight and dry root weight were measured in seedlings after 20 days. General combining ability and specific combining ability effects were highly significant for all tested parameters. However, mean squares of gca were about five time larger than those for sca suggesting the preponderance of additive gene action. Among tolerant varieties, Gaori and Namyang 7 were good combiners for improving salinity tolerance at the seedling stage

2.2.2 Heterosis

The estimation of heterosis provides information about the type of gene action involved in the expression of various quantitative traits. To use the heterosis manifested in the hybrids had been a common notion pursued by a number of rice breeders for decades.

Zhuang and Wa (1982) examined ten economic characters in the their abortion type male sterile lines and their maintainers, six restorer lines and 28 F_1 hybrids between them. The majority of F_1 population showed negative heterosis for the majority of characters. Only number of effective ears per plant and grain weight per plant showed high positive heterosis in most hybrid combinations.

Zeng (1983) in a correlation study and path analysis of 34 F_1 hybrids and their parents in 1978, heterosis for grain weight per plant was closely and positively correlated with heterosis for other characters. Number of panicles per plant and number of filled grains per plant had the greatest direct effect on heterosis for grain weight per plant and number of tillers per plant and number of spikelets per panicle had an indirect effect through the first two characters, respectively.

Evaluation of the effect of GAM male sterile and cytoplasm was carried out by Yang *et al.* (1984) comparison of 10 yield components between the F_1's of the GAM male sterile line Zhaoyang IA and three fertility restorers (a F_1) and the corresponding F_1's of the maintainer x restorer lines d F_1 showed that grain weight was lower in former than in the latter. Heterosis was significant or highly significant in b F_1 hybrids involving the restorers IR 30 and Shuiliangu but there was no significant heterosis in the a F_1 hybrids. It is suggested that GAM male sterile cytoplasm derived from the indica variety Gambiaka Kokum has negative effect on the yield in crosses where restoring ability of restorer is weak.

Heterobeltiosis was observed in hulled rice by Jun (1985) in eleven crosses for grain thickness and its seven crosses for width and weight in brown rice, it was seen in nine crosses for grain width and thickness in five crosses for weight in four crosses for length/width ratio and in their crosses for length.

Anandakumar and Rangaswamy (1986) by using the performance of 13 parents and 17 hybrids studied heterobeltiosis and standard heterosis over the superior parent for yield per plant and six related characters. Heterobeltiosis and standard heterosis for grain yield ranged from –76.1 to 97.6 per cent and from –51.2 to 42.4 per cent respectively.

Anandakumar and Rangaswamy (1986) evaluated 21 crosses involving 14 parents of rice for heterosis and heterobeltiosis in F_1 and for inbreeding depression in F_2. The better expression of component character like plant height, tiller number and panicle length resulted in heterosis vigour for grain yield in 12 crosses. The hybrid vigour in F_1 and in breeding depression in F_2 was noticed in all cross combinations for atleast one of the characters.

Three hybrid combinations showing high yield and three hybrids showing low yield were evaluated by Paramasivan and Rangaswamy (1987) for plant height, number of productive tillers, panicle length, number of grains per panicle, 100 grain weight and grain yield per plant in F_1 and F_2 generations. Heterosis was manifested for plant height, tiller number, panicle length, number of grains per panicle, grain weight and grain yield per plant in two high yielding crosses. The mean expression and the extent of transgression noticed in different F_2's are attributed to the gene action of modifier present in parents.

Heterosis for yield per plant was due to heterosis for other yield component characters as reported by Paramasivam and Rangaswamy (1988) and Lokaprakash *et al.* (1992). They also observed that there was a close relationship between the frequencies of crosses showing significant sca effect and those showing heterosis over better parent for all traits studied.

High mean heterosis for yield per plant, biological yield and tiller numbers in plants grown under irrigated conditions and for flag leaf area, biological yield and tiller number per plant in those grown under rain fed condition was recorded by Sarawgi and Shrivastava (1988). Heterosis was only moderate for tiller number in plants grown under rain fed conditions. The remaining character had either very low negative hybrid vigour.

Hybrids from crosses involving a male sterile line used as common female parent and for rice cultivars as males were screened for nine quality characters by Mandal and Saren (1989), in respect of heterobeltiosis and standard heterosis. Kernel length values over the better parent and standard check were positive in all the hybrids except Mr 365 A x IR 36 where heterobeltiosis was negative. Kernel breadth was found to be negative in all the hybrids except Mr 365 A x IR 36 which showed a positive heterobeltiosis. The L/B ratio showed a positive heterobeltiosis in all the hybrids except in the above mentioned cross. Water uptake, kernel elongation and volume expansion on values were negative in almost all the hybrids, the only exception was heterobeltiosis for water uptake in one cross (3.57%).

In a field experiment conducted by Peng and Virmani (1990b) seventy five hybrids and 18 parental lines were evaluated for heterosis for yield, dry matter, harvest index, days to flowering and plant height. Mean performance of hybrids was superior to that of the inbred for all the traits. Thirty one hybrids significantly out yielded their better parent. High dry matter production and for high harvest index may be the reason for heterosis for yield in these hybrids.

Genetic diversity and heterosis were studied in 65 rice varieties grouped into 18 clusters by Sarathe and Perraju (1990), on the basis of diversity estimate.

High positive heterosis for grain yield was obtained for some crosses suggesting that parents having fairly high to medium diversity estimate may be utilised in hybridization programme in order to increase the chance of getting high heterotic manifestation.

Patnaik *et al.* (1991) studied the magnitude of heterosis in relation to genetic divergence in the line x tester crosses, which involved four cytoplasmic genetic male sterile (CMS) and 34 restorers. The genotypes were grouped into clusters using Mahalonobis D^2 statistics. The results revealed that the frequency of heterotic crosses and specific combining effects were found to be higher in crosses between the parents in intermediate genetic divergence classes than the extreme ones.

Sarawgi and Shrivastava (1991) observed that parents of F_1 showing high yield were in the same cluster. This indicated that genetic diversity might not be related to high heterosis.

Superior combinations of kernel length and breadth exhibiting significant heterosis in desired direction were identified by Singh *et al.* (1993). The heterosis of length to breadth ratio was not found to be accompanied by simultaneous heterosis for kernel length and kernel breadth though quite wide range of heterosis for this character was recorded. Based upon the heterotic effect in conjunction with specific combining ability estimate, good combinations were identified and offered great promises for their utilisation in hybrid breeding programmes.

Heterosis and inbreeding depression for grain size, shape and weight were studied in five intervarietal crosses by Chauhan and Chauhan during 1995. The lack of heterobeltiosis for grain size in this study indicated that there was no dominance/over dominance in the expression of this character. Low level of heterosis and inbreeding depression in general was recorded for grain size and shape. Substantial positive heterosis and heterobeltiosis for grain weight in some of the crosses appeared to be due to non-additive gene interaction as indicated by high magnitude of inbreeding depression.

In a heterosis study for kernel character, Vivekandan and Giridharan (1995) reported that heterosis for kernel length was low and that for L/B ratio was significant and negative indicating that none of the hybrids were superior for grain fineness.

In rice, heterosis over mid parent, mid and better parent in 42 crosses was worked out for 12 physiological characters including grain yield by Murthy and Kulkarni (1996) and reported that magnitude of heterosis was more for leaf area at early stage, total biological yield and grain yield, while it was comparatively low for harvest index. Top three heterotic crosses over their respective better parent for each trait were identified.

Ganesan *et al.* (1997) in a heterosis study on seven crosses among 28 rice hybrids derived from four early maturing varieties as lines and seven extra early varieties as testers revealed that heterosis over the mid and better parent was negative for days to panicle emergence and positive for panicles per plant, grain yield per plant and harvest index. The inbreeding depression was negative for days to panicle emergence and plant height whereas residual heterosis was positive for these traits. In contrast, inbreeding depression was positive and residual heterosis was negative for grain yield per plant and harvest index.

Mishra and Pande (1998) reported that the higher yielding hybrids did not show significant heterosis for the character number of panicles per plant and observed that heterosis for yield was largely attributed to heterosis in number of spikelets per panicle, panicle length, harvest index and thousand grain weight. He also reported negative standard heterosis, negative heterobeltiosis for the character harvest index.

Information on heterosis is derived by Mishra and Pandey (1998) on 10 yield related traits in 30 F_1 hybrids derived from crosses between two wild abortive cytoplasmically male sterile lines (V 20A) and (IR 62829A) and 18 elite genotypes suited to irrigated situation. About 17-20 per cent of all the hybrids manifested significant and positive heterobeltiosis and standard heterosis for seed yield in the range 44.7 to 230.9 and 42.4 to 81.4 percentage respectively. Heterosis for seed yield was due to positive and significant heterosis for components like panicle length and 100 grain weight. Most of the higher yielding hybrids manifested positive heterosis for harvest index and number spikelets per panicle.

A study was conducted by Sathya *et al.* (1999) to assess the nature and extent of heterosis, heterobeltiosis and standard heterosis for yield and its components in line x tester design. The hybrids such as IR 62829A x IR 50, IR 62829A x AS 90043 and IR 58025 x AS 89090 were adjudged best for exploitation of heterosis based on standard heterosis pertaining to grain yield per plant. The two former cross combinations showed significant standard heterosis for productive tillers per plant in addition to heterosis for grain yield

Xing *et al.* (1999) aneuploid progeny were observed from the cross of homologous triploid rice plants with diploid plants self progenies of normally developed diploid F_1s were agronomically stable. The triploid line could be crossed with both indica and japonica restorer lines to obtain stable F_2 population with desirable heterotic traits.

Information on heterosis was derived by Singh and Haque (1999) from data on six yield components in 10 cultivars and their F_1 hybrids. The cross Birsadhan 105 x IR 36 had the highest positive heterosis over better parent for grain yield per plant (99.6%) and ear bearing tillers per plant (83.8%). The cultivars Birsadhan 105, IR 36, Birsadhan 202, Rajendradhan 202 and Rasi were promising, giving high heterosis estimate for most of the yield component studied.

Chen Liang *et al.* (2000) analysed heterosis and yield for its components in the F_1s from crosses of photoperiod (thermo) sensitive genetic male sterile lines N 4225 and PEIAI 64s with IRRI's new plant type lines, newly improved japonica varieties of the north and north east China types, South Asian aus varieties and early and mid season indica varieties from south China. The results showed that PEIAI 64s and the new plant type lines had strong heterosis for filled grains per plant, number of spikes per plant and grain weight per plant, but heterosis for spike fertility was low. The new plant type line could be used in breeding two line inter sub specific hybrids if the problem of low seed setting percentage was solved.

Eight parent and their 16 hybrids were evaluated by Thirumeni and Subramanian(2000) under coastal salinity at Karaikal in 1996 for heterosis in nine characters. The hybrid SSRC 92076/TRY 1 was found to be superior for productive tiller per plant, spikelet sterility, Na^+:K^+ ratio and grain yield per plant and hence recommended for commercial exploitation.

2.3 Genetic analysis of fertility restoration

Over the years a large number of CMS lines with various cytosterility sources have been developed, but only a few are now used in India. Usefulness of male sterile cytoplasmic sources is dependent on the availability of restorer lines. Cytoplasmic genic male sterility system can be used to exploit heterosis in grain crops only when effective restorer lines are available.

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

An attempt to isolate a number of effective maintainers for three CMS lines viz, V20A, WU 10A and Pankhari 203A was carried out by Ratho and Pande (1985). No effective restorer was identified for WU 10A and Pankhari 203A whereas effective restorers were found for V 20A. The results also indicated that cytoplasm of the male sterile lines interact differently with the pollinator varieties used. Effective restorers for WA cytoplasm were also reported by Sahai *et al.* (1986); Singh and Sinha (1987); Saran and Mandel (1988) and Bijral *et al.* (1989).

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

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

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

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

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

2.3.1 Genetics of fertility restoration

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

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

Inheritance of fertility restoration in WA cytoplasm was studied by Virmani *et al.* (1986) in three different crosses involving restorers like IR 54, IR 9761-19-1 and IR 42. F_2 and back cross segregation data indicate that pollen fertility restoration ability of these restorers was governed by two independent and dominant genes but the mode of action of the two genes varied in three crosses.

Govindaraj and Virmani (1988) studied inheritance of fertility restoration in WA type CMS system utilizing two CMS lines and five restorers. Results indicated that fertility restoration in all the restorers studied was governed by two independent and dominant genes, and one of the genes appeared to be stronger in action than the other. Allelism test involving six R lines revealed that IR 26, IR 36, IR 54 and IR 9761-19-1 possessed identical restorer genes. Test cross observations involving parental lines in the pedigree of IR 36 and IR 42 revealed that Cina, Latisail, Tadukan, TN 1, TKM 6, Ptb 18 and SL0 17 are the probable original sources of R genes in the two restorer lines.

Math *et al.* (1990) studied the inheritance of fertility restoration in 10 segregating F_2 families involving CMS lines Zhenshan 97A and V 20A, and eight complete restorers and two partial restorers. Depending on the type of restorers used, the mode of inheritance was digenic or trigenic and the genes involved were found to inherit in duplicate as well as inhibitory fashion in different restorers.

Inheritance studies conducted by Pande *et al.* (1990) indicated that different CMS lines behaved differently with pollen parents. Anandakumar and Subramanian (1992) made cross combinations involving 14 male sterile lines and different maintainers and found that fertility was restored in certain combinations.

Fertility restoration in F_2 segregating population was found to be governed by 3:1, 9:3:3:1 and 12:3:1 ratios due to allelic differences.

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

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

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

Shanxin and Cai-Sx (1997) obtained nine combinations by crossing nine male sterile lines, having three types of male sterile cytoplasms, Y, CW, WA with their restorer T 54, respectively. The different effects of the male sterile cytoplasms on panicle number, panicle length and grain yield were compared in a homogeneous background. The cytoplasms of Y and CW types were superior to the WA type but nucleocytoplasmic interaction was important.

Yao *et al.* (1997) found that genomic locations of the 2 fertility restorers (Rf) were determined by their linkage to molecular markers. Rf containing regions were identified by surveying two bulk population composed of 30 fertile and 46 sterile plants from a large F_2 population (derived from the cross Zhenshan 97 A x Mimghui 63), with RFLP markers covering the entire genome. The survey identified two likely Rf containing regions, located on chromosomes 1 and 10, respectively. This was confirmed by analyzing a large random sample from the same F_2 population and also with a genome wide quantitative trait loci of a test cross population.

Kumari *et al.* (1998) fertility restoration studies involving four wild abortive (WA) CMS lines resulted in the identification of 20 restorer lines. Segregation for fertility was studied in the F_2 and backcross progenies of these CMS lines with four restorer lines (ARC 11353, IR 30864, IR 13419-113-3 and IR 9761-19-1). Results indicated that fertility restoration in WA CMS lines was controlled by two additive major genes whose effects were sporophytic and thus displayed differential gene interactions depending on the parents involved in the cross. Differential segregations was observed in F_2 and backcross progenies in crosses involving IR 9761-19-1, depending on the female parent. This suggested that the expressivity of the R (Restorer) genes varied according to the nuclear background of the female parent.

Tan *et al.* (1998) studied the inheritance of fertility restoration of rice cytoplasmic male sterility of the wild abortive (WA) type was studied by means of

QTL mapping. The two segregating populations examined showed high frequencies of highly sterile and highly fertile progenies, but a low frequency of partially sterile and partially fertile progenies. The distributions suggested that fertility restoration was mainly controlled by major genes.

2.3.2 Generation mean analysis

In self-pollinated crops, generation mean analysis is a useful technique to understand the gene effects for a polygenic character (Hayman, 1958). Various gene effects such as additive x additive (i), additive x dominance (j), dominance x dominance (l) can be estimated using this technique. Genetic improvement can be carried out by knowing the nature and magnitude of gene action of grain yield and its component characters.

A study was conducted by Khaleque *et al.* (1978) to evaluate the genetic architecture of yield and yield components in rice using nine single crosses made with IRRI varieties and between IRRI and local varieties. Non-additive gene effects were found to be predominant in the inheritance of these characters. High heritability accompanied by high genetic advance was observed for all the characters except for primary branch number in some of the crosses. Transgressive segregation detected in either direction indicated that selection breeding for high yielding may be started in early generation of the cross 1, 5, 9 and 7. Non-allelic interaction was mostly of the additive x additive (i) and dominance x dominance (l) type heterosis in most cases was due to over dominance and/or non-allelic interaction still in some cases no heterosis was caused by mutual cancellation of d, b, i and l components.

Srivastava (1981) in a programme for evolving rice varieties for low land conditions, IR 127 and Pankaj were used as donors for intermediate plant height. Derivatives with intermediate plant height, evolved from Pankaj x ARC 12773 and Taichung Native 1 x IR 27 were examined for variation and interrelationships of agronomic characters. Several derivatives from both crosses showed intermediate plant height and non-lodging characteristics. Despite low to moderate tillering, many derivatives yielded better than their intermediate statured parents. Evidence suggested that IR 127, like Pankaj, could be a suitable donor for intermediate stature in varietal improvement.

Three types of genetic system to be involved with intermediate stature in the study when Pankaj, Asgro and IR127 indicated polygenic and S_3 showed digenic behaviour with normal (tall) parent. The polygenic genes for plant height in IR 127 and digenic genes of S_3 showed non-allelic interaction with Deo-Geo-Woo-Gen semi dwarfing gene showing over dominance of tallness in F_1 generation and higher percentage of taller segregants in F_2 generation (Srivastava and Roy, 1985).

Genetic architecture of yield, harvest index and component characters in rice was studied by Sharma *et al.* (1986) using generation mean approach for seven cross combinations. The epistatic effect (i, j and l) varied in different characters and crosses and was much less than the mean effect (m). For yield, the major component of genetic variation was due to dominance and additive x additive gene effects, whereas for harvest index the major combination was from additive x dominance and dominance x dominance effect.

Dhanraj *et al.* (1987) studied the F_2 generation of 10 F_1s previously categorized for sca effects indicated that mean grain yield was not significantly different between sca categories. RNR 29692 x Rajendra (high sca in the F_1) gave the highest yield per plant (21.4 gm) followed by Prabhat x Rajendra (negative sca in the F_1, 23.3 gm).

While studying the F_2 population of some crosses Chauhan *et al.* (1990) reported that polygenes govern the expression of plant height, tillers per plant and panicles per plant. However, the F_2 distribution was bimodal with transgressive segregants only towards the tall parent in one cross studied indicating the presence of major gene(s) and modifiers for tallness.

Kim and Vergara (1991) studied the combination of the main stem and different tillers and concluded that inbreeding for grain yield low tillering cultivar with up to five tillers would be ideal as the first five tillers to develop are the most productive.

In a cross of Begunbuchi and Irat 102 varieties of rice having extreme variations for number of grains and thousand-grain weight. Chauhan *et al.* (1993) found that additive and additive x additive interaction effects were found important in the inheritance of grains per panicle and 1000 grain weight. However, grain yield was predominantly governed by dominance effects and additive x dominance and dominance x dominance interaction effects. Complementary type epistasis was observed for grains per panicle and 1000 grain weight, while duplicate type epistasis was prominent for grain yield. The mid parent heterosis was maximum (29.3%) for grain yield per plant. It is therefore suggested that for simultaneous improvement of yield and its two important components, grain number per panicle and 1000 grain weight, a single breeding system capable of exploiting additive and non-additive gene effect should be used. In order to achieve this, the use of recurrent selection is advocated.

The components of gene effect for yield and five-yield traits were studied by Ram (1994) in four crosses using popular indigenous cultivars as one parent. The character mean, over six generation were subjected to scaling test. In the presence of epistasis six parents model was used to detect all types of gene effects. The analysis revealed the importance of dominance and epistatic components for yield, tillers per plant, grains per panicle and 100 grain weight in all the crosses. Additive and dominance effects were important for plant height and panicle length. Among the digeneic interactions additive x additive and dominance x dominance effects contributed more in most of the characters. Additive x dominance gene effect was important for 100 grain weight in some crosses. In general, most crosses revealed duplicate non-allelic interaction for majority of characters. All the crosses exhibited heterosis in F_1 and inbreeding depression in F_2 generation.

To know the genetics of grain yield and its components in rice, a study was undertaken by Nandarajan and Kumaravelu (1994). Information was generated on genetic architecture for six quantitative traits by using six generations in each of five cross combinations, to build up five drought resistant genotypes. The analysis of generation mean showed that in general the traits productive tillers per ear, grain weight, grain yield were governed by additives, dominance and epistatic gene interaction.

Chakraborthy and Hazarika (1996) performed analysis of gene effects using means of six generations viz. P_1, P_2, F_1, F_2, BC_1 and BC_2 of a cross Mahsuri x Manoharsati to determine the nature and magnitude of gene action governing yield and yield components like plant height, plant length, spikelets per panicle, panicle number and 100 grain weight. It was found that both additive and non-additive gene action were important in controlling all the characters studied. Breeding methods such as reciprocal recurrent selection could be useful in the genetic improvement of the character studied.

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 1998 to 2001. Field experiments relating to the investigation were laid out at Agricultural Research Station (ARS), Mannuthy, which is located at an altitude of 15 m above sea level and is situated at 10° 32' N latitude and 76° 10' E longitude. The soil type is laterite loam with pH around 5.6. (The weather parameters during the course of study is given in Appendix 1)

The whole investigation was grouped into three experiments.

3.1 Experiment Number 1

Evolution of alternative sources of cytoplasmic male sterility

In a Ph.D. research programme of the department, which involved large number of crosses, F_1s of certain crosses were partially male sterile whereas normal fertility was exhibited by the reciprocal F_1s. It indicated premise for the male sterility inducing cytoplasm in certain varieties.

3.1.1 Materials

Three crosses that produced partially male sterile F_1s were the following.

1. Vytila-3 x IR 36
2. Bhadra x Hraswa
3. Bhadra x IR 60133

Back cross of these F_1's with male parent (BC_1) was studied. F_2 seeds of the following four crosses were also studied.

1. Vytila-3 x Hraswa
2. Vytila-3 x IR 36
3. Bhadra x Hraswa and
4. Bhadra x IR 60133

Thus, BC_1 and F_2 and their parents formed the starting material for the study (Table 1). The seeds of three BC_1s and four F_2 cross combinations were sown during February 1998. BC_1's were raised in the net house at Agricultural Research Station, Mannuthy. F_2 generation of the cross combinations were raised in the field. Pollen analysis was carried out. Based on the above analysis backcrossing was carried out selecting plants showing higher pollen sterility percentage with respective male parents. This cycle is repeated to next generations namely BC_2/F_2BC_1, BC_3/F_2BC_2 and BC_4/F_2BC_3. All cultural operations were carried out as per the package of practices, recommendations of the Kerala Agricultural University.

3.1.1.1 Observations Recorded

Pollen Sterility percentage

Pollen sterility counts were taken from three randomly selected spikelets of two panicles. The pollen grains were squeezed out from well-matured anthers and stained with two per cent iodine potassium iodide stain and examined under microscope. Round, well filled and deeply stained pollen grains were considered as

Table 1. Genotype, parentage and origin of breeding lines included in the study

Number	Genotype	Parentage	Origin	Desirable characters
1	IR 60133-184-3-2-2	IR 42000-211-1-2-2-3/IR 42015-83-3-2-2-2/IR 42068-22-3-3-1-3	IRRI	High number of panicles/m², high amylose and white kernel
2	IR 36	IR 1561-228//4* IR 24/0 NIVA RA///CR 94-13	IRRI	Large number of panicles/m², high amylose and white kernel
3	Bhadra	IR 8/Ptb-20	Kerala (India)	High number of panicles/m², intermediate amylose and red kernel
4	Hraswa	IR 8/T 140	,,	Short duration, short stature, high amylose and red kernel
5	Karthika	TRIVENI/IR 1539	,,	High harvest index high amylose and red kernel
6	Mattatriveni	Annapoorna/Ptb-15	,,	High harvest index, high amylose and red kernel
7	Vytila-3	Vytila-IT (N) 1	,,	Large panicle length, heavy grains, high amylose and red kernel
8	Kanjana	IR 36/Pavizham	,,	Large panicle length and high harvest index
9	Jyothi	PTB 10/IR 8	,,	High number of panicles/m² and high amylose

fertile and unstained or poorly stained or shriveled pollen grains were counted for each spikelet and pollen sterility was expressed in percentage of total number of pollen grains present.

3.1.1.2 Statistical analysis

Measures like mean, variance, standard deviation, standard error and coefficient of variation were calculated as per Snedecor-1946

3.2 Experiment Number 2

Screening elite varieties for the identification of restorer and potential CMS lines.

3.2.1 Materials

BC_4 (Backcross generation four)/F_2BC_3 (F_2 back cross generation three) were grown along with elite varieties and crosses made between developed cytosterile lines and elite varieties on a line x tester design to produce hybrid seeds. The main elite varieties used for the identification of restorers include (1) Karthika, (2) Bhadra, (3) Vytila-3, (4) Kanjana, (5) Jyothi, (6) Mattatriveni, (7) Hraswa, (8) IR 36 and (9) IR 60133.

3.2.1.1 Observations recorded

1. Tillers at harvest (per plant)

Total number of tillers (at harvest) in five plants were counted and average was taken.

2. Panicle length

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

3. Degree of panicle exsertion

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

4. Angle of panicle exsertion

The angle between the main panicle and the flag leaf was measured using a protractor.

5. Spikelets per panicle

Total number of spikelets was counted in five panicles selected at random from five plants and averaged.

6. Grain density

A known weight of seed was kept under water and the quantity of water displaced was measured using a measuring cylinder. From these values grain density was calculated as

$$\text{Grain density} = \frac{\text{Weight of seeds taken}}{\text{Volume of water displaced}}$$

7. 100 grain weight

Weight of 100 well filled grains was recorded from three random samples in each replication and expressed in grams.

8. Grain L/B ratio (Length /breadth ratio)

The ratio of length to the breadth of the grains was recorded from three random samples using vernier calipers.

9. Grain yield per plant

Weight of grains in grams obtained from three plants was taken after drying.

10. Spikelet sterility percentage

The fertile spikelets were identified by pressing the spikelets with the fingers at maturity and those spikelets without grains were considered as sterile ones.

$$\text{Sterility percentage} = \frac{\text{Number of sterile spikelets}}{\text{Total number of spikelets}} \times 100$$

11. Percentage pollen sterility

Pollen sterility counts were taken from randomly selected spikelets of each panicle. Percentage of pollen sterility was calculated using the formula.

$$\text{Sterility percentage} = \frac{\text{Number of sterile pollen grains}}{\text{Total number of pollen grains}} \times 100$$

3.2.3 Statistical analysis

3.2.3.1 Partial diallel analysis

Various components and combining ability were estimated as suggested by Kempthorne and Curnov (1961). Partial diallel may be defined as the number of sampled crosses per parent or per array in all possible combinations of a given set of parents. This analysis provides information on GCA, SCA variance and **gca** effects. Here more parents are evaluated and is most commonly used for evaluation of parents in terms of combining ability.

The total number of sampled crosses is equal to ns/2, where n is the number of parents and s is the number of sampled crosses per parent or array. When parents are inbreds (F=1) and there is no epistasis ,the genetic components of variance would be as follows

Cov HS = 1/2 VA = Variance GCA

Cov FS = VA+VD

Variance SCA = Cov FS-2Cov HS=VD

=VA+VD-2 (1/2VA)=VD

where VA is the additive variance and VD is the dominance variance.

3.2.3.2 Heterosis

Heterosis is esmimated in **3** different ways i.e., (1) over mid parent value (2) over better parent value and (3) over commercial variety.

1. Relative heterosis

Here heterosis is estimated over the mid parent i.e., mean value or average of the two parents.

Relative heterosis,

$$di = \left[\frac{F_1 - mp}{mp} \times 100 \right]$$

where F_1 is the mean value of F_1s and mp is the mean value of two parents involved in the cross.

2. Heterobeltiosis

Here heterosis is estimated over superior or better parent.

Heterobeltiosis

$$dii = \left[\frac{F_1 - bp}{bp} \times 100 \right]$$

where bp is mean value of the better parent of the particular cross.

3. Standard heterosis

Here heterosis is worked out over the standard variety. This is of direct practical importance in plant breeding. It is estimated as follows.

Standard heterosis

$$diii = \left[\frac{F_1 - sv}{sv} \times 100 \right]$$

where sv is the average performance of standard variety (The standard variety used was Bhadra)

Different types of heterosis were estimated for eleven characters in the F_1 generation and were evaluated.

3.3 Experiment Number 3

Genetic analysis of fertility restoration.

3.3.1 Materials

The materials included were (1) parents of cytosterile lines that is, Vytila-3, Hraswa, IR 36, Bhadra and IR 60133. (2) F_1 and F_2 of various crosses. (3) $BC_{1.1}$ and $BC_{1.2}$ of the above mentioned crosses i.e., Vytila-3 x Hraswa, Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133.

3.3.2 Observations recorded

Observations on the following eleven characters were recorded as in 3.2.1

1. Tillers at harvest (per plant)
2. Panicle length
3. Degree of panicle exsertion
4. Angle of panicle exsertion
5. Spikelets per panicle
6. Grain density
7. 100 grain weight
8. Grain L/B ratio (Length/breadth ratio)
9. Grain yield per plant

10. Spikelet sterility percentage
11. Percentage pollen sterility

3.3.3 Statistical analysis

3.3.3.1 Generation mean analysis

Six-parameter model was first suggested by Hayman (1958) for estimation of various genetic components from the generation mean. This method is used when non-allelic interactions are present. Various genetic parameters include allelic interactions like mean effect (m), additive gene effect (d), dominance gene effect (h), additive x additive type of gene interaction (i), additive x dominance type of gene interaction (j) and dominance x dominance type of gene interaction (l). In order to estimate the presence or absence of allelic and non-allelic interactions and types, scaling test viz., A, B, C, D as suggested by Mather (1949) were used.

RESULTS

4. RESULTS

4.1 Experiment Number 1

4.1.1 Development of alternative sources of cytoplasmic male sterility

Wild abortive (WA) is the only source of male sterile cytoplasm that has widely been used in rice hybrid development. This has led to genetic vulnerability of the crop to pest and diseases. Negative effect on yield heterosis by WA cytoplasm is higher compared to that by Indica cytoplasm. Besides, break down of male sterility due to WA may occur in tropical climate. In view of the above drawbacks, it is desirable to diversify the source of cytosterility suited to specific regions.

The crosses that produced partially male sterile F_1s were the following.

Vytila-3 x IR 36

Bhadra x Hraswa

Bhadra x IR 60133

A limited number of F_2 and BC_1 (back cross with male parent) seeds available under the above crosses were used as the starting material for the first experiment of this research programme.

Male sterility phenomena expressed by a genotype can be assessed by estimating the pollen sterility percentage. The percentage of pollen sterility is estimated by pollen analysis. The result of this pollen analysis can be used to identify the genotypes showing higher cytoplasmic male sterility. These plants can again be used for successive back cross programme to evolve cytoplasmic male sterile lines.

4.1.1.1 First back cross generation (BC_1)

4.1.1.1.1 [(Vytila-3 x IR 36) x IR 36]

In the case of back cross generation (BC_1) of the cross [Vytila-3 x IR 36) x IR 36], the minimum and maximum values for percentage of pollen sterility were 68 per cent and 71 per cent respectively. Their mean value was 69.5 per cent and variance 4.5. The standard deviation (S.D) was 2.12 and the coefficient of variation (C.V) was 3.05 per cent (Table 2).

4.1.1.1.2 [(Bhadra x Hraswa) x Hraswa]

In the back cross generation of the cross [(Bhadra x Hraswa) x Hraswa], the pollen sterility showed a minimum and maximum value of 18 and 51 per cent respectively. Mean value observed was 38.6 per cent. Variance, Standard deviation and Coefficient of variation were 184, 13.6 and 35.23 per cent respectively (Table 2).

4.1.1.1.3 [(Bhadra x IR 60133) x IR 60133]

In this back cross, the range of pollen sterility was from 36 to 43 per cent. The cross showed a mean value of 39.5 per cent and a variance of 9.66. Standard deviation and Coefficient of variation were observed to be 3.109 and 7.87 per cent, respectively (Table 2).

Table 2. Pollen sterility percentage (of various cross combinations) in backcross-1 generation

Back cross-1	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
1. (Vytila-3 x IR 36) x IR 36	68	71	69.50	4.50	2.12	1.50	3.05
2. (Bhadra x Hraswa) x Hraswa	18	51	38.60	18.40	13.60	6.08	35.23
3. (Bhadra x IR 60133) x IR 60133	36	43	39.50	9.66	3.109	1.56	7.87

4.1.1.2 Second back cross generation (BC_2)

4.1.1.2.1 [(Vytila-3 x IR 36 x IR 36) x IR 36]

In the cross [(Vytila-3 x IR 36 x IR 36) x IR 36], the pollen sterility showed a range of 64 to 88 per cent. Mean value obtained (72.73%) was the highest among the three crosses. It showed a variance of 65.02, S.D of 8.06 and C.V of 11.14 per cent, respectively (Table 3).

4.1.1.2.2 [(Bhadra x Hraswa x Hraswa) x Hraswa]

This back cross showed a minimum 31 per cent and maximum of 59 per cent with respect to pollen sterility. Mean and variance obtained were 46.13 per cent and 152.13 S.D and C.V values obtained were 12.33 and 26.72 per cent, respectively (Table 3).

4.1.1.2.3 [(Bhadra x IR 60133 x IR 60133) x IR 60133]

In this back cross generation the range of pollen sterility was between 29 per cent and 63 per cent with a mean value of 43.66 per cent and variance of 151.14. Standard deviation value was 12.29 and Coefficient of variation 28.14 per cent (Table 3).

4.1.1.3 Third Back cross generation (BC_3)

4.1.1.3.1 [(Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36]

In this backcross, the range of pollen sterility obtained was from 34 per cent to 92 per cent. The mean value obtained for the above cross was 75.11 per

Table 3. Pollen sterility percentage (of various cross combinations) in backcross-2 generation

Back cross-2	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
1. (Vytila-3 x IR 36 x IR 36) x IR 36	64	88	72.73	65.02	8.06	2.43	11.14
2. (Bhadra x Hraswa x Hraswa) x Hraswa	31	59	46.13	152.13	12.13	4.36	26.72
3. (Bhadra x IR 60133 x IR 60133) x IR 60133	29	63	43.66	151.14	12.29	4.64	28.14

cent with a variance of 267.11. The S.D and C.V were 16.34 and 21.75 per cent, respectively (Table 4).

4.1.1.3.2 [(Bhadra x Hraswa x Hraswa x Hraswa) x Hraswa]

The above cross showed a minimum sterility percentage of 22 and a maximum of 67. The mean value was 49 per cent with a variance of 166. S.D and C.V values were 12.89 and 26.30 per cent, respectively (Table 4).

4.1.1.3.3 [(Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133]

The range of pollen sterility was between 24 per cent and 68 per cent. Mean value observed was 49.24 per cent with a variance of 199.44. It had a Standard deviation of 14.12 and Coefficient of variation of 28.67 per cent (Table 4).

4.1.1.4 Fourth back cross generation (BC_4)

4.1.1.4.1 [(Vytila-3 x IR 36 x IR 36 x IR 36 x IR 36) x IR 36]

This cross showed a range of pollen sterility from 37 per cent to 96 per cent. The mean obtained was 76.50 per cent and was the highest among the three crosses. Variance of 250.57, S.D of 15.83 and C.V of 20.69 per cent were also observed (Table 5).

4.1.1.4.2 [(Bhadra x Hraswa x Hraswa x Hraswa x Hraswa) x Hraswa]

The range of percentage of pollen sterility observed was 32 to 68 with the mean value estimated to be 52.70 per cent. Variance and S.D obtained were

Table 4. Pollen sterility percentage (of various cross combinations) in backcross-3 generation

Back cross-3	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
1. (Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36	34	92	75.11	167.11	16.34	3.96	21.75
2. (Bhadra x Hraswa x Hraswa x Hraswa)x Hraswa	22	67	49.00	166.00	12.89	3.32	26.30
3. (Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133	24	68	49.24	199.44	14.12	2.82	28.67

119.12 and 10.91 respectively with a coefficient of variation 20.70 per cent (Table 5).

4.1.1.4.3 [(Bhadra x IR 60133 x IR 60133 x IR 60133 x IR 60133) x IR 60133]

The range of pollen sterility was 21 per cent to 67 per cent with a mean value of 51.64 percent. The variance and S.D were evaluated to be 198.86 and 14.10 respectively. The C.V was 27.30 percent (Table 5).

The F_2 segregants of the following crosses, Vytila 3 x Hraswa, Vytila 3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133 were also used to screen cytoplasmic male sterile lines.

Among the segregants, plants showing higher male sterility were used for further backcrossing.

4.1.1.5 F_2 back cross generation

4.1.1.5.1 F_2BC_1 of [(Vytila-3 x Hraswa) x Hraswa]

In the case of F_2 backcross generation of the cross [(Vytila-3 x Hraswa) x Hraswa], the pollen sterility was evaluated to a minimum and maximum values of 9 per cent and 68 per cent respectively. Their mean value was found to be 42.78 per cent. The value of variance was 515.94. The S.D value and the C.V value were estimated to be 22.71 and 53.08 per cent respectively (Table 6).

4.1.1.5.2 F_2BC_1 of [(Vytila-3 x IR 36) x IR 36]

The cross F_2 [(Vytila-3 x IR 36) x IR 36] showed the percentage of pollen sterility in the range of 32 to 84. Its mean value of 61.55 per cent was the

Table 5. Pollen sterility percentage (of various cross combinations) in backcross-4 generation

Back cross-4	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
1. (Vytila-3 x IR 36 x IR 36 x IR 36 x IR 36) x IR 36	37	96	76.50	250.57	15.83	4.23	20.69
2. (Bhadra x Hraswa x Hraswa x Hraswa x Hraswa) x Hraswa	32	68	52.70	119.12	10.91	3.45	20.70
3. (Bhadra x IR 60133 x IR 60133 x IR 60133 x IR 60133) x IR 60133	21	67	51.64	198.86	14.10	3.76	27.30

highest among the four crosses. Variance, S.D and C.V values were evaluated to be 245.27, 15.66 and 25.44 per cent respectively (Table 6).

4.1.1.5.3 F_2BC_1 of [(Bhadra x Hraswa) x Hraswa]

From the analysis of F_2 of [(Bhadra x Hraswa) x Hraswa] it was found that, the cross exhibited a range of pollen sterility between 20 per cent and 58 per cent with a mean value of 36.83 per cent. The values that corresponds to variance, S.D and C.V were estimated to be 179.77, 13.41 and 36.41 per cent respectively (Table 6).

4.1.1.5.4 F_2BC_1 of [(Bhadra x IR 60133) x IR 60133]

Finally, in the case of F_2 back cross generation of the cross F_2 [(Bhadra x IR 60133) x IR 60133] the minimum and maximum values for percentage of pollen sterility were 11 and 67 respectively. Their mean value was 44.25 per cent. Variance, S.D and C.V values were 371, 19.25 and 43.50 per cent respectively (Table 6).

4.1.1.6 F_2 Backcross generation (F_2BC_2)

4.1.1.6.1 F_2BC_2 [(Vytila-3 x Hraswa x Hraswa) x Hraswa]

In the case of F_2BC_2 generation of [(Vytila-3 x Hraswa x Hraswa) x Hraswa], the pollen sterility percentage showed a minimum and maximum values of 6 and 73 respectively. Their mean value was evaluated to be 47.47 per cent. The values of variance, S.D and C.V were 593.01, 24.35, and 51.29 per cent respectively (Table 7).

Table 6. Pollen sterility percentage (of various cross combinations) in F_2 backcross-1

Back cross-1	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
(F_2 Vytila-3 x Hraswa) x Hraswa	9	68	42.78	515.94	22.71	7.57	53.08
(F_2 Vytila-3 x IR 36) x IR 36	32	84	61.55	245.27	15.66	4.72	25.44
(F_2 Bhadra x Hraswa) x Hraswa	20	58	36.83	179.77	13.41	5.47	36.41
(F_2 Bhadra x IR 60133) x IR 60133	11	67	44.25	371.00	19.25	6.81	43.50

4.1.1.6.2 F_2 BC_2 of [(Vytila-3 x IR 36 x IR 36) x IR 36]

In F_2 back cross generation of the cross [(Vytila-3 x IR 36 x IR 36) x IR 36], the minimum and maximum values of percentage of pollen sterility were 43 and 92 respectively. Their mean value was 60.63 per cent, which was the highest among the four crosses. Variance, S.D and C.V values were 211.80, 14.55 and 23.99 per cent respectively (Table 7).

4.1.1.6.3 F_2 BC_2 of [(Bhadra x Hraswa x Hraswa) x Hraswa]

In the cross F_2 [(Bhadra x Hraswa x Hraswa) x Hraswa], percentage of pollen sterility exhibited minimum and maximum values of 18 and 68 respectively. Their mean value was 42.23 per cent. Variance, S.D, C.V values were 333.03, 18.25 and 43.21 per cent respectively (Table 7).

4.1.1.6.4 F_2 BC_2 of [(Bhadra x IR 60133 x IR 60133) x IR 60133]

Finally in the F_2 back cross generation of the cross F_2 [(Bhadra x IR 60133 x IR 60133) x IR 60133] the percentage of pollen sterility exhibited a minimum and maximum values of 15 and 74 respectively. Their mean value was 43.22 per cent and variance was 315.12. Standard deviation and coefficient of variation were 17.75 and 41.06 per cent respectively (Table 7).

4.1.1.7 F_2 Back cross generation of (F_2BC_3)

4.1.1.7.1 [(Vytila-3 x Hraswa x Hraswa x Hraswa) x Hraswa]

In the case of F_2BC_3 generation of [(Vytila-3 x Hraswa x Hraswa x Hraswa) x Hraswa], the minimum and maximum values for percentage of pollen

Table 7. Pollen sterility percentage (of various cross combinations) in F_2 backcross-2

Back cross-2	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
(F_2 Vytila-3 x Hraswa x Hraswa) x Hraswa	6	73	47.47	593.01	24.35	5.90	51.29
(F_2 Vytila-3 x IR 36 x IR 36) x IR 36	43	92	60.63	211.80	14.55	3.33	23.99
(F_2 Bhadra x Hraswa x Hraswa)x Hraswa	18	68	42.23	333.03	18.25	5.06	43.21
(F_2 Bhadra x IR 60133 x IR 60133) x IR 60133	15	74	43.22	315.12	17.75	4.18	41.06

sterility were 8 and 73 respectively. Their mean value was 54 per cent and variance 281.9. The S.D value of 16.79 and C.V value of 31.09 per cent were also estimated. (Table 8).

4.1.1.7.2 F_2BC_3 [(Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36]

In the cross F_2 [(Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36], the percentage of pollen sterility exhibited a minimum and maximum values of 44 and 100 respectively. This cross showed the highest mean value of 71.04 per cent. Variance, S.D and C.V values were 273.54, 16.53 and 23.26 per cent respectively (Table 8).

4.1.1.7.3 F_2BC_3 [(Bhadra x Hraswa x Hraswa x Hraswa) x Hraswa]

In the case of the cross [(Bhadra x Hraswa x Hraswa x Hraswa) x Hraswa], the minimum and maximum values for percentage of pollen sterility were 23 and 72 respectively. Their mean value was 49.07 per cent. Variance, S.D and C.V values were 283.91, 16.85 and 34.33 percent, respectively (Table 8).

4.1.1.7.4 F_2 BC_3 [(Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133]

In the F_2 back cross generation of the cross [(Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133], the minimum and maximum values for percentage of pollen sterility were 17 and 82 respectively. Their mean value was 50.96 per cent. Variance, S.D and C.V values were 316.43, 17.78 and 34.89 per cent respectively (Table 8).

Table 8. Pollen sterility percentage (of various cross combinations) in F_2 backcross-3

Back cross-3	Minimum	Maximum	Mean	Variance	Standard deviation	Standard error	Coefficient of variation (%)
(F_2 Vytila-3 x Hraswa x Hraswa x Hraswa) x Hraswa	8	73	54.00	281.91	16.79	3.43	31.09
(F_2 Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36	44	100	71.04	273.54	16.53	3.30	23.26
(F_2 Bhadra x Hraswa x Hraswa x Hraswa) x Hraswa	23	72	49.07	283.91	16.85	4.67	34.33
(F_2 Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133	17	82	50.96	316.43	17.78	3.48	34.89

4.2 Experiment Number 2

4.2.1 Screening of elite varieties for identification of restorers and potential CMS lines

4.2.1.1 Partial diallel analysis

Partial diallel analysis proposed by Kempthorne and Curnove (1961) provides information on (1) nature and amount of genetic parameters and (2) general and specific combining ability of parents and their crosses respectively. The parental lines involved are Mattatriveni, Karthika, Vytila-3 and Bhadra. Analysis of variance for combining ability (Table 9) showed that mean squares due to general combining ability was significant for all the characters. GCA/SCA ratio ranged from 0.036 in the case of angle of panicle exsertion to 7.33 in the case of percentage pollen sterility (Table 10). The results obtained for the eleven characters studied are given below.

1. Tillers at harvest

The parent Vytila-3, showed the highest positive gca effect (14.375) and the remaining three parents showed negative gca effects. Maximum negative GCA effect was shown by Karthika (-7.625) followed by Mattatriveni (-5.625). GCA/SCA ratio was found to be 0.1849 for the character tillers at harvest.

2. Panicle length

The highest positive gca effect was exhibited by the parent Karthika (1.700) followed by Vytila-3 (0.300). Mattatriveni showed the highest negative

Table 9. General combining ability of parents for various characters

Parents	Tillers at harvest	Panicle length	Degree of panicle exsertion	Angle of panicle exsertion	Spikelets per panicle	Grain density	100 grain weight	Grain L/B ratio	Grain yield per plant	% spikelet sterility	% pollen sterility
Mattatriveni	-5.625	-1.400	-6.000	5.375	-10.250	-0.209	-0.048	-0.498	5.996	-0.593	-6.288
Karthika	-7.625	1.700	6.000	9.375	30.750	0.121	0.087	-0.457	0.319	-11.920	1.912
Vytila-3	14.375	0.300	-4.250	-13.875	-52.750	0.216	0.167	0.520	-14.751	4.722	3.787
Bhadra	-1.125	-0.600	4.250	-0.875	32.250	-0.129	-0.207	0.435	8.436	7.790	0.587

gca effect (-1.400), followed by Bhadra (-0.600). With respect to GCA/SCA ratio, the value obtained was 0.1695 for this particular character.

3. Degree of panicle exsertion

Maximum positive gca effect was exhibited by the parent Karthika (6.00) followed by Bhadra (4.25). Negative gca effect was maximum in Mattatriveni (-6.00) followed by Vytila-3 (-4.25). GCA/SCA ratio for this character was found to be 1.852.

4. Angle of panicle exsertion

Positive gca effects were observed in Karthika (9.375) and Mattatriveni (5.375). Negative gca effect for this character was maximum in Vytila-3 (-13.875). Bhadra exhibited negative gca effect (-0.875). GCA/SCA ratio observed for this character was 0.036.

5. Spikelets per panicle

Positive gca effects were observed in Bhadra (16.125) and Karthika (15.375). Negative gca effects for this character were observed in Vytila-3 (-26.375) and Mattatriveni (-5.125). GCA/SCA ratio for spikelets per panicle was 0.573.

6. Grain density

Positive gca effects were observed in the case of Vytila-3 (0.216) and Karthika (0.121). Negative gca effect was observed in Mattatriveni (-0.209) and Bhadra (-0.129). GCA/SCA ratio obtained for grain density was 0.667.

7. 100 grain weight

Maximum positive gca effect was shown by Vytila-3 (0.167) followed by Karthika (0.087). Negative gca effects were exhibited by Mattatriveni (-0.048) and Bhadra (-0.207). GCA/SCA ratio for this character was found to be 0.289.

8. Grain L/B ratio

gca effect was positive for Vytila-3 (0.520) followed by Bhadra (0.435). Negative gca effect was observed in Mattatriveni (-0.498) and Karthika (-0.457). GCA/SCA ratio for this character was estimated to be 1.325.

9. Grain yield per plant

The highest positive gca effect was observed in Bhadra (8.436) followed by Mattatriveni (5.996) and Karthika (0.319). Negative gca effect was observed in Vytila-3 (-14.751). GCA/SCA ratio for grain yield per plant was 0.353.

10. Percentage spikelet sterility

Both Mattatriveni (0.593) and Karthika (-11.92) exhibited negative gca effects. Vytila-3 (4.722) and Bhadra (7.79) exhibited positive gca effects. GCA/SCA ratio for percentage spikelet sterility was found to be 0.314.

11. Percentage pollen sterility

Mattatriveni exhibited negative gca effect (-6.288). Karthika (1.912), Vytila-3 (3.787) and Bhadra (0.587) showed positive gca effects. GCA/SCA ratio for this character was estimated to be 7.330.

Table 10. Ratio of GCA/SCA for various characters

Parents	Tillers at harvest	Panicle length	Degree of panicle exsertion	Angle of panicle exsertion	Spikelets per panicle	Grain density	100 grain weight	Grain L/B ratio	Grain yield per plant	% spikelet sterility	% pollen sterility
Gca	26.645	0.294	27.645	7.916	214.958	2.293	2.015	0.220	258.929	28.816	17.95
Sca	144.091	1.736	14.925	221.100	375.250	3.438	6.977	0.166	733.099	91.882	2.449
Gca/Sca	0.1849	0.1695	1.852	0.036	0.573	0.667	0.289	1.325	0.353	0.314	7.330

4.2.1.2 Estimation of Heterosis

Heterosis was worked out by utilizing the overall mean of each hybrid for each trait (Table 11). Relative heterosis was estimated as per cent deviation of the F_1 from its midparent value. Heterobeltiosis was estimated as per cent increase or decrease of F_1 value over better parent value. Similarly, standard heterosis for each character was expressed as per cent increase or decrease of F_1 value over the standard variety.

1. Number of tillers

Results indicated significant positive relative heterosis for IR 36/Mattatriveni, IR 36/Karthika, Hraswa/Karthika, Hraswa/Vytila-3, IR 60133/Bhadra and Hraswa/Bhadra with a range from 19.63 (IR 36/Mattatriveni) to 193.83 (Hraswa/Vytila-3) per cent. The hybrid Hraswa/Bhadra showed negative relative heterosis (-22.86). The range of heterobeltiosis was from 0 (IR 36/Mattatriveni) to 95.08 (Hraswa/Vytila-3). Negative heterobeltiosis was observed in the hybrid Hraswa x Bhadra (-31.65). In the case of standard heterosis, two hybrids showed negative standard heterosis i.e., IR 36 x Mattatriveni (-18.99) and Hraswa x Bhadra (-31.65). The highest standard heterosis for number of tillers was obtained in the hybrid Hraswa/Vytila-3 i.e., 50.63 followed by hybrid IR 60133 x Bhadra (48.10) (Table 12).

2. Panicle length

The magnitude of positive relative heterosis for panicle length varied from 3.93 for Hraswa/Karthika to 21.21 for Hraswa/Vytila-3. Negative relative

Table 11. Mean values of 11 characters of the rice hybrids

Hybrids	Tillers at harvest	Panicle length	Degree of panicle exsertion	Angle of panicle exsertion	Spikelets per panicle	Grain density	100 grain weight	Grain L/B ratio	Grain yield/plant	% spikelet sterility	% pollen sterility
F_2BC_3 (Vytila-3xIR 36) x Mattatriveni	32.00	21.60	103.5	66.00	112.50	1.07	2.42	2.45	38.61	14.92	3.90
BC_4 (Vytila-3xIR 36) x Karthika	44.50	19.55	87.5	22.50	82.00	1.28	2.88	2.90	28.31	18.01	7.95
BC_4 (Bhadra x Hraswa) x Karthika	46.00	21.00	99.5	40.50	97.00	1.09	2.30	2.86	82.05	26.85	4.35
F_2BC_3 (Vytila-3 x Hraswa) x Vytila.-3	59.50	25.00	103.0	31.50	75.00	1.76	2.81	2.98	53.18	12.45	15.75
BC_4 (Bhadra x Hraswa) x Bhadra	27.00	21.75	108.0	39.50	145.00	1.27	2.64	2.86	45.83	9.74	12.95
BC_4 (Bhadra x IR60133) x Bhadra	58.50	21.00	103.5	36.50	92.00	1.25	2.34	4.36	25.99	39.95	12.65

Table 12. Heterosis in hybrids for number of tillers at harvest

	Plant cross	No. of tillers		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	19.63	0	-18.99
H_2	(IR 36 x Karthika)	43.55	39.06	12.66
H_3	(Hraswa x Karthika)	52.07	50.82	16.46
H_4	(Hraswa x Vytila-3)	193.83	95.08	50.63
H_5	(IR 60133 x Bhadra)	81.40	48.10	48.10
H_6	(Hraswa x Bhadra)	-22.86	-31.65	-31.65

Table 13. Heterosis in hybrids for panicle length

	Plant cross	Panicle length		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	-1.68	-11.62	0.465
H_2	(IR 36 x Karthika)	-7.80	-14.67	-9.07
H_3	(Hraswa x Karthika)	3.93	-8.34	-2.33
H_4	(Hraswa x Vytila-3)	21.21	5.26	16.28
H_5	(IR 60133 x Bhadra)	-6.67	-10.64	-2.33
H_6	(Hraswa x Bhadra)	11.54	1.16	1.16

heterosis was shown by IR 36/Mattatriveni, IR 36/Karthika and IR 60133/Bhadra. In the case of heterobeltiosis range was from –14.67 in IR 36/Karthika to 5.26 in Hraswa/Vytila-3. Highest standard heterosis was obtained in the case of Hraswa/Vytila-3 (16.28). Positive standard heterosis was obtained in IR 36/Mattatriveni and Hraswa/Bhadra. Negative standard heterosis was observed in IR 36/Karthika (-9.07). Negative standard heterosis was also observed in Hraswa/Karthika and IR 60133/Bhadra (Table 13).

3. Degree of panicle exsertion

Percentage of relative heterosis for degree of panicle exsertion of hybrids ranged from –4.81 in Hraswa/Karthika to 4.35 in Hraswa/Bhadra. Heterobeltiosis range was from –16.71 in IR 36/Karthika to 3.85 in Hraswa/Bhadra. Negative heterobeltiosis was observed in IR 36/Mattatriveni, IR 36/Karthika, Hraswa/Karthika, Hraswa/Vytila-3 and IR 60133/Bhadra. The hybrid Hraswa/Bhadra showed a standard heterosis of 4.85. Hraswa/Vytila-3 showed standard heterosis value of zero. The highest negative standard heterosis was observed in IR 36/Karthika (-15.05) (Table 14).

4. Angle of panicle exsertion

The highest relative heterosis for angle of panicle exsertion was observed in Hraswa/Karthika (88.37) followed by IR 36/Mattatriveni 84.62. Positive heterosis was observed in Hraswa/Vytila-3, IR 60133/Bhadra and Hraswa/Bhadra. Significant negative relative heterosis was observed in the case of IR 36/Karthika (-35.25). In the case of heterobeltiosis, maximum positive value

Table 14. Heterosis in hybrids for degree of panicle exsertion

	Plant cross	Degree of panicle exsertion		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	-0.433	-4.08	0.49
H_2	(IR 36 x Karthika)	-0.15	-16.71	-15.05
H_3	(Hraswa x Karthika)	-4.81	-5.28	-3.39
H_4	(Hraswa x Vytila-3)	3.54	-0.96	0
H_5	(IR 60133 x Bhadra)	-2.13	-4.61	-0.49
H_6	(Hraswa x Bhadra)	4.35	3.85	4.85

Table 15. Heterosis in hybrids for angle of panicle exsertion

	Plant cross	Angle of panicle exsertion		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	84.62	34.69	123.73
H_2	(IR 36 x Karthika)	-35.25	-54.08	-23.73
H_3	(Hraswa x Karthika)	88.37	80.00	37.29
H_4	(Hraswa x Vytila-3)	17.76	1.61	6.78
H_5	(IR 60133 x Bhadra)	17.74	12.31	23.73
H_6	(Hraswa x Bhadra)	51.92	33.89	33.89

was obtained in Hraswa/Karthika. Positive heterobeltiosis was observed in IR 36/Mattatriveni, Hraswa/Vytila-3, IR 60133/Bhadra and Hraswa/Bhadra. Significant negative heterobeltiosis was observed in IR 36/Karthika (-54.08). In the case of standard heterosis range was from 123.73 (IR 36/Mattatriveni) to –23.73 (IR 36/Karthika). Positive standard heterosis was observed in Hraswa/Karthika (37.29), Hraswa/Bhadra (33.89), IR 60133/Bhadra (23.73) and Hraswa/Vytila-3 (6.78) (Table 15).

5. Spikelets per panicle

The range of relative heterosis was from –28.06 (Hraswa/Vytila-3) to 54.67 (Hraswa/Bhadra). Positive relative heterosis was observed in the case of IR 36/Mattatriveni (1.81). Negative relative heterosis was observed in IR 36/Karthika, Hraswa/Karthika and IR 60133/Bhadra. The range of heterobeltiosis was from – 41.18 (Hraswa/Vytila-3) to 36.15 (Hraswa/Bhadra). Negative heterobeltiosis was observed in all other hybrids. The range of standard heterosis was from –29.58 in Hraswa/Vytila-3 to 36.15 in Hraswa/Bhadra. A positive standard heterosis was observed in IR 36/Mattatriveni. Negative standard heterosis was observed in IR 36/Karthika, Hraswa/Karthika and IR 60133/Bhadra (Table 16).

6. Grain density

The highest percentage of relative heterosis was observed in Hraswa/Vytila-3 (57.85). Lowest positive value was observed in IR 36/Mattatriveni i.e., 0.47. The hybrids IR 36/Karthika, Hraswa/Karthika, IR 60133/Bhadra and Hraswa/Bhadra showed positive relative heterosis. In the

Table 16. Heterosis in hybrids for spikelets per panicle

	Plant cross	Spikelets per panicle		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	1.81	-30.77	5.63
H_2	(IR 36 x Karthika)	-12.99	-36.92	-0.23
H_3	(Hraswa x Karthika)	-8.06	-25.38	-8.92
H_4	(Hraswa x Vytila-3)	-28.06	-41.18	-29.58
H_5	(IR 60133 x Bhadra)	-16.17	-18.58	-13.62
H_6	(Hraswa x Bhadra)	54.67	36.15	36.15

Table 17. Heterosis in hybrids for grain density

	Plant cross	Grain density		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	0.47	-0.93	-6.96
H_2	(IR 36 x Karthika)	16.36	14.29	14.29
H_3	(Hraswa x Karthika)	1.40	-2.68	-5.22
H_4	(Hraswa x Vytila-3)	57.85	46.67	53.04
H_5	(IR 60133 x Bhadra)	11.71	7.83	7.83
H_6	(Hraswa x Bhadra)	16.51	10.43	10.43

case of heterobeltiosis the highest value was exhibited by Hraswa/Vytila-3 (46.67). Negative heterobeltiosis was observed in IR 36/Mattatriveni and Hraswa/Karthika. IR 60133/Bhadra and Hraswa/Bhadra exhibited positive heterobeltiosis. The highest standard heterosis for grain density was observed in Hraswa/Vytila-3 (53.04). IR 36/Karthika, IR 60133/Bhadra and Hraswa/Bhadra showed positive standard heterosis. Negative standard heterosis was shown by IR 36/Mattatriveni and Hraswa/Karthika (Table 17).

7. 100 grain weight

The highest relative heterosis was observed in the hybrid Hraswa/Vytila-3 (18.57). Positive relative heterosis was observed in IR 36/Mattatriveni, IR 36/Karthika, Hraswa/Vytila-3 and Hraswa/Bhadra. Heterosis over mid parent was negative for Hraswa/Karthika and IR 60133/Bhadra. In the case of heterobeltiosis, three hybrids showed positive heterobeltiosis and the highest value was obtained in Hraswa/Vytila-3 (17.08). Negative heterobeltiosis was exhibited by Hraswa/Karthika, IR 60133/Bhadra and Hraswa/Bhadra. In the case of standard heterosis range was from –13.86 to 9. Positive standard heterosis was exhibited by IR 36/Karthika (7.57), Hraswa/Vytila-3 (5.24). The hybrids namely Hraswa/Karthika, IR 60133/Bhadra and Hraswa/Bhadra showed negative value for standard heterosis (Table 18).

8. Grain L/B ratio

Heterosis over mid parent was positive and significant for two hybrids, while it was negative for four hybrids with a range from –14.93

Table 18. Heterosis in hybrids for 100 grain weight

	Plant cross	100 grain weight		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	5.00	24.00	9.00
H_2	(IR 36 x Karthika)	22.00	2.13.00	7.87
H_3	(Hraswa x Karthika)	-10.85	-18.44	-13.86
H_4	(Hraswa x Vytila-3)	18.57	17.08	5.24
H_5	(IR 60133 x Bhadra)	-3.31	-12.36	-12.36
H_6	(Hraswa x Bhadra)	5.60	-1.12	-1.12

Table 19. Heterosis in hybrids for grain L/B ratio

	Plant cross	Grain L/B ratio		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	-14.93	-23.68	-17.51
H_2	(IR 36 x Karthika)	-0.34	-9.66	-2.36
H_3	(Hraswa x Karthika)	4.00	-1.04	-3.70
H_4	(Hraswa x Vytila-3)	-6.58	-14.37	0.34
H_5	(IR 60133 x Bhadra)	22.82	5.57	46.80
H_6	(Hraswa x Bhadra)	-2.39	-3.70	-3.70

(IR 36/Mattatriveni) to 22.82 (IR 60133/Bhadra). All hybrids except one exhibited negative heterosis over better parent. Positive heterobeltiosis was recorded in IR 60133/Bhadra (5.57). Standard heterosis ranged from –17.51 in IR 36/Mattatriveni to 46.8 in IR 60133/Bhadra. Positive standard heterosis was observed in Hraswa/Vytila-3 (0.34) (Table 19).

9. Grain yield per plant

Heterosis over mid parent was positive in all the six hybrids. The highest positive relative heterosis was exhibited by Hraswa/Karthika (413.78). Relative heterosis for IR 36/Mattatriveni was 79.08. For Hraswa/Vytila-3, it was 107.98. Heterosis over better parent was positive in four hybrids and negative in two. The highest heterobeltiosis was exhibited by Hraswa/Karthika (249.15). Negative heterobeltiosis was shown by IR 60133/Bhadra (-14.68) and Hraswa/Bhadra (-50.48). In the case of standard heterosis over Bhadra, it was positive in three hybrids IR 36/Mattatriveni, Hraswa/Karthika and Hraswa/ Vytila-3. The highest standard heterosis over Bhadra was observed in Hraswa/Karthika (169.46) followed by Hraswa/Vytila-3 (74.65) (Table 20).

10. Percentage spikelet sterility

Heterosis over mid parent was negative and significant for five hybrids, while it was significant and positive in the case of Hraswa/Karthika (42.67). Maximum negative relative heterosis was observed in Hraswa/Bhadra (-77.69). Heterosis over better parent was negative and significant for all the six hybrids. Negative value was observed in Hraswa/Bhadra and in Hraswa/Karthika (-9.75). In

Table 20. Heterosis in hybrids for grain yield per plant

	Plant cross	Grain yield per plant		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	79.08	43.27	26.79
H_2	(IR 36 x Karthika)	42.69	20.47	-7.03
H_3	(Hraswa x Karthika)	413.78	249.15	169.46
H_4	(Hraswa x Vytila-3)	107.98	24.50	74.65
H_5	(IR 60133 x Bhadra)	2.08	-14.68	-14.68
H_6	(Hraswa x Bhadra)	135.58	-50.48	-50.48

Table 21. Heterosis in hybrids for percentage spikelet sterility

	Plant cross	% spikelet sterility		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	-26.14	-55.28	-74.08
H_2	(IR 36 x Karthika)	-12.66	-46.01	-68.72
H_3	(Hraswa x Karthika)	42.67	-9.75	-53.36
H_4	(Hraswa x Vytila-3)	-52.43	-58.15	-78.37
H_5	(IR 60133 x Bhadra)	-14.53	-30.61	-30.61
H_6	(Hraswa x Bhadra)	-77.69	-83.08	-83.08

Table 22. Heterosis in hybrids for percentage pollen sterility

	Plant cross	% pollen sterility		
		Relative heterosis (di)	Heterobeltiosis (dii)	Standard heterosis (diii)
H_1	(IR 36 x Mattatriveni)	22.64	-8.23	52.94
H_2	(IR 36 x Karthika)	94.85	87.06	211.76
H_3	(Hraswa x Karthika)	-32.77	51.88	70.59
H_4	(Hraswa x Vytila-3)	162.50	74.23	517.69
H_5	(IR 60133 x Bhadra)	493.89	396.08	396.08
H_6	(Hraswa x Bhadra)	123.08	43.25	407.84

the case of heterosis over standard variety all the six hybrids exhibited negative heterosis. Least negative heterosis was shown by IR 60133/Bhadra (-30.61). Maximum negative standard heterosis for spikelet sterility was observed in Hraswa/Bhadra (-83.08) (Table 21).

11. Percentage pollen sterility

Relative heterosis was positive and significant in the five hybrids. Maximum was obtained in the case of IR 60133/Bhadra (493.89). Negative relative heterosis was observed in Hraswa/Karthika (-32.77). Heterosis over better parent was maximum in the case of IR 60133/Bhadra (396.08). Negative heterobeltiosis was shown by IR 36/Mattatriveni (-8.23). IR 36/Karthika, Hraswa/Karthika, Hraswa/Vytila-3 and Hraswa/Bhadra showed positive heterobeltiosis. Maximum heterosis over standard variety was exhibited by Hraswa/Vytila-3 (517.69) followed by Hraswa/Bhadra (407.84) and IR 60133/Bhadra (396.08) (Table 22).

4.3 Experiment Number 3

Genetic analysis of fertility restoration

4.3.1 Generation mean analysis

Eleven characters which were found to have high heritability and significant correlation with yield namely tillers at harvest, panicle length, degree of panicle exsertion, angle of panicle exsertion, spikelets per panicle, grain density, 100 grain weight, grain L/B ratio, grain yield per plant, percentage spikelet sterility and percentage pollen sterility were taken for generation mean analysis. Six generations namely P_1, P_2, F_1, F_2, $BC_{1.1}$, $BC_{1.2}$ of the four crosses namely,

1. Vytila-3 x Hraswa
2. Vytila – 3 x IR 36
3. Bhadra x Hraswa and
4. Bhadra x IR 60133 were included in the analysis.

1. Number of tillers

Significant mean effect was observed in all the four crosses. Additive effect was significant and negative in all the four crosses. Dominance effect was non-significant in the crosses Vytila-3 x Hraswa and Bhadra x Hraswa. Two crosses Vytila-3 x IR 36 and Bhadra x IR 60133 exhibited significant dominance effect. Among the interaction effects additive x additive was non- significant in the crosses Vytila-3 x Hraswa and Bhadra x Hraswa. This effect was significant in Vytila-3 x IR 36 and Bhadra x IR 60133. Dominance x dominance interaction was significant and negative in crosses Vytila-3 x Hraswa, Vytila-3 x IR 36 and Bhadra x IR 60133. This effect was significant in Bhadra x Hraswa. Additive x dominance effect was significant and negative in all crosses (Table 23).

2. Panicle length

Significant mean effect was observed in all the four crosses. Additive effect was significant and negative in the crosses Vytila-3 x Hraswa (-4.80) and Bhadra x IR 60133 (-3.52). It was positive and significant in Vytila-3 x IR 36 (5.66) and Bhadra x Hraswa (5.06). Dominance effect was non-significant in the cross Vytila-3 x Hraswa, Bhadra x Hraswa and Bhadra x IR 60133. It was negative and significant in Vytila-3 x IR 36. Among the interactions, additive x additive effect was non-significant in the crosses Vytila-3 x Hraswa and Bhadra x IR 60133. This interaction was negative in the cross Vytila-3 x IR 36 (-4.89) and positive in the cross Bhadra x Hraswa (3.02). Additive x dominance interaction was significant and negative in Vytila-3 x Hraswa (-5.91) and it was positive and significant in Vytila-3 x IR 36(2.52) and Bhadra x Hraswa (2.51). It was non-significant in Bhadra x IR 60133. Dominance x dominance interaction was significant in all the four crosses (Table 23).

3. Degree of panicle exsertion

Significant mean effect was observed in all the four crosses. Additive effect was significant and negative in the crosses Vytila-3 x Hraswa (-3.11), Vytila-3 x IR 36 (-3.58), Bhadra x Hraswa (-10.29) and Bhadra x IR 60133 (-3.41). Dominance effect was non-significant in the cross Vytila-3 x IR 36. It was negative and significant in the crosses Vytila-3 x IR 36 (-4.16), Bhadra x Hraswa (-3.05) and Bhadra x IR 60133 (-16.24). Among the interactions, additive x additive effect was non-significant in Vytila-3 x Hraswa and Vytila-3 x IR 36. It was significant and negative in Bhadra x Hraswa (-3.49) and Bhadra x IR 60133 (-16.46). Additive x dominance interaction was significant and negative in Vytila-3 x Hraswa (-15.49), Vytila-3 x IR 36 (-2.38) and Bhadra x Hraswa (-6.41). It was non-significant in Bhadra x IR 60133. Dominance x dominance interaction was significant in Vytila-3 x Hraswa (4.36), Bhadra x Hraswa (3.31) and Bhadra x IR 60133 (14.98). It was non-significant in Vytila-3 x IR 36 (Table 23).

4. Angle of panicle exsertion

In all the four crosses mean effect was found to be significant. Additive effect was significant and negative in Vytila-3 x IR 36 (-9.15) and non-significant in Bhadra x Hraswa. This was significant and positive in Vytila-3 x Hraswa (12.73) and Bhadra x IR 60133 (7.07) Dominance effect was significant and negative in Vytila-3 x Hraswa (-8.79). It was non-significant in Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133. Among the interactions, additive x additive interaction was non-significant in Vytila-3 x IR 36. This was negative in Vytila-3 x Hraswa (-10.61), Bhadra x Hraswa (-2.84) and Bhadra x IR 60133 (-9.81). Additive x dominance was non-significant in Vytila-3 x Hraswa, negative in Vytila-3 x IR 36 (-4.48), Bhadra x Hraswa (-4.76) and positively significant in Bhadra x IR 60133 (2.78). For dominance X dominance interaction, positive significance was observed in Vytila-3 x Hraswa (5.02), Vytila-3 x IR 36 (7.51) and Bhadra x IR 60133 (12.51) (Table 23).

5.Spikelets per panicle

Significant mean effect was found in all the four crosses. Additive effect was found to be positively significant in Vytila-3 x Hraswa (3.39), Vytila-3 x IR 36 (15.18) and Bhadra x Hraswa (21.91). It was negatively significant in Bhadra x IR 60133 (-4.59). Dominance effect was negative in all the four crosses i.e., Vytila-3 x Hraswa (-4.11), Vytila-3 x IR 36 (-3.95), Bhadra x Hraswa (-3.79) and Bhadra x IR 60133 (-3.69). Among the interactions, additive x additive interaction was significant and negative in all the four crosses i.e., in Vytila-3 x Hraswa, –3.02, in Vytila-3 x IR 36, –3.95, in Bhadra x Hraswa, –3.95, in Bhadra x Hraswa, –3.22 and in Bhadra x IR 60133, –3.02. In the case of additive x dominance interaction, negative and significant interaction was observed in Vytila-3 x Hraswa (-38.86) and Vytila-3 x IR 36 (-6.67). It was found to be positively significant in Bhadra x Hraswa (6.71). In the case of Bhadra x IR 60133, this was non-significant. In the case of dominance x dominance interaction, it was found to be non-significant in Vytila-3 x Hraswa. This was found to be positive and significant in Vytila-3 x IR 36 (14.52), Bhadra x Hraswa (2.23) and Bhadra x IR 60133 (5.49) (Table 23).

6. Grain density

Positive significant mean effect was observed in all the four crosses. For additive effect, this was positive and significant in Vytila-3 x Hraswa (2.60) and Vytila-3 x IR 36 (14.63). It was negative in the case of Bhadra x Hraswa and non-significant in the case of Bhadra x IR 60133. Dominance effect was non-significant in Vytila-3 x Hraswa and Bhadra x IR 60133. It was found to be positively significant in Vytila-3 x IR 36 (11.78) and Bhadra x Hraswa (3.15). Among the interactions, additive x additive interaction was negatively significant in Vytila-3 x Hraswa (-2.07) and Bhadra x Hraswa (-3.66). This was found to be positively significant in Vytila-3 x IR 36 (10.82) and non-significant in the case of Bhadra x IR 60133. In the case of additive x dominance interaction, it was non-significant in

Table 22. Generation mean analysis of various cross combinations

Characters	Cross combinations	Mean (m)	Additive (d)	Dominance (h)	Additive x additive (i)	Additive x dominance (j)	Dominance x dominance (l)
1	2	3	4	5	6	7	8
Number of tillers at harvest	Vytila-3 x Hraswa	26.33	-16.55	-1.74	-0.16	-9.44	-4.09
	Vytila-3 x IR 36	36.00	-16.25	12.28	14.10	-9.44	-20.13
	Bhadra x Hraswa	24.00	-7.59	-1.58	1.18	-13.05	2.94
	Bhadra x IR 60133	13.00	-14.14	10.60	12.14	-18.73	-9.80
Panicle length	Vytila-3 x Hraswa	43.83	-4.80	-0.41	-1.96	-5.91	2.42
	Vytila-3 x IR 36	49.00	5.66	-2.72	-4.89	2.52	5.89
	Bhadra x Hraswa	21.00	5.06	1.97	3.02	2.51	-4.69
	Bhadra x IR 60133	18.20	-3.52	-1.34	-0.91	-0.03	3.17
Degree of panicle exsertion	Vytila-3 x Hraswa	131.00	-31.11	-4.16	-2.11	-15.49	4.36
	Vytila-3 x IR 36	11.00	-3.58	-0.94	-1.33	-2.38	-0.74
	Bhadra x Hraswa	55.50	-10.29	-3.05	-3.49	-6.41	3.31
	Bhadra x IR 60133	115.00	-3.41	-16.24	-16.46	-0.51	14.98
Angle of panicle exsertion	Vytila-3 x Hraswa	79.00	12.73	-8.79	-10.61	-2.20	5.02
	Vytila-3 x IR 36	81.00	-9.15	0.77	-0.73	-4.48	7.51
	Bhadra x Hraswa	77.00	-0.73	-1.37	-2.86	-4.76	1.69
	Bhadra x IR 60133	85.00	7.07	-2.09	-9.81	2.78	12.51

Contd.

Table 22. Continued

1	2	3	4	5	6	7	8
Spikelets per panicle	Vytila-3 x Hraswa	47.33	3.39	-4.11	-3.02	-38.86	-0.98
	Vytila-3 x IR 36	55.00	15.18	-2.52	-3.95	-6.67	14.52
	Bhadra x Hraswa	15.67	21.91	-3.79	-3.22	6.71	2.23
	Bhadra x IR 60133	11.63	-4.59	-3.69	-3.02	0.25	5.49
Grain density	Vytila-3 x Hraswa	122.00	2.60	-1.88	-2.07	1.22	0.87
	Vytila-3 x IR 36	76.33	14.63	11.78	10.82	12.59	-11.38
	Bhadra x Hraswa	236.34	-7.60	3.15	-3.66	-11.80	5.56
	Bhadra x IR 60133	122.01	0.98	0.20	-0.89	-0.11	-0.21
100 grain weight	Vytila-3 x Hraswa	83.67	22.39	-8.71	-11.19	20.38	0.06
	Vytila-3 x IR 36	101.00	29.53	22.26	21.32	24.44	-20.88
	Bhadra x Hraswa	72.67	10.11	-7.05	7.02	7.02	12.47
	Bhadra x IR 60133	41.67	-2.73	-6.67	-7.50	-7.50	5.60
Grain L/B ratio	Vytila-3 x Hraswa	63.01	4.71	0.83	-1.59	6.61	0.31
	Vytila-3 x IR 36	109.67	-10.32	-9.88	-5.89	-8.05	2.94
	Bhadra x Hraswa	7.52	13.59	-10.04	-10.97	12.56	18.85
	Bhadra x IR 60133	79.44	-6.32	-9.34	-9.59	0.49	12.35

Contd.

Table 22. Continued

1	2	3	4	5	6	7	8
Grain yield per plant	Vytila-3 x Hraswa	56.87	0.34	13.09	16.28	6.94	16.45
	Vytila-3 x IR 36	24.65	10.55	16.84	17.38	2.94	-15.74
	Bhadra x Hraswa	17.27	7.25	-5.21	-5.49	-1.07	5.54
	Bhadra x IR 60133	29.71	-7.73	-2.45	-2.85	-9.82	4.86
Percentage spikelet Sterility	Vytila-3 x Hraswa	54.37	-0.18	3.36	3.05	-1.09	-18.39
	Vytila-3 x IR 36	90.44	-2.73	-11.02	-15.82	33.03	10.96
	Bhadra x Hraswa	94.54	-20.34	-6.66	-5.55	-20.88	-20.14
	Bhadra x IR 60133	54.55	-9.55	-16.38	-20.96	-4.26	19.75
Percentage pollen sterility	Vytila-3 x Hraswa	42.10	-7.55	21.91	16.65	-8.14	-21.16
	Vytila-3 x IR 36	41.77	-12.13	37.54	26.69	-10.83	-46.57
	Bhadra x Hraswa	30.73	-6.54	14.35	8.43	-7.86	-13.04
	Bhadra x IR 60133	21.97	-17.61	23.20	18.42	-16.74	-24.15

Vytila-3 x Hraswa and Bhadra x IR 60133, positive and significant in Vytila-3 x IR 36 (12.59) and negatively significant in Bhadra x Hraswa (-11.8). In the case of dominance x dominance interaction, it was non-significant in the crosses Vytila-3 x Hraswa and Bhadra x IR 60133. Negatively significant effect was found in Vytila-3 x IR 36 (-11.38) and positively significant in the case of Bhadra x Hraswa (5.56) (Table 23).

7. 100 grain weight

Positive significant mean effect was observed in all the four crosses. Additive effect was positive and significant in Vytila-3 x Hraswa (22.39), Vytila-3 x IR 36 (29.53) and Bhadra x Hraswa (10.11). It was negative and significant in Bhadra x IR 60133 (-2.73). Dominance effect was negative and significant in Vytila-3 x Hraswa (-8.71), Bhadra x Hraswa (-7.05) and Bhadra x IR 60133 (-6.67). It was positive and significant in Vytila x IR 36 (22.26). Among the interaction effects, additive x additive interaction was negative and significant in Vytila-3 x Hraswa (-11.19), Bhadra x Hraswa (-7.02), and Bhadra x IR 60133 (-5.45). It was positive and significant in Vytila-3 x IR 36 (21.32). In the case of additive x dominance interaction, positive and significant interaction was observed in Vytila-3 x Hraswa (20.35), Vytila-3 x IR 36 (24.44) and Bhadra x Hraswa (7.02). It was found to be negative in Bhadra x IR 60133 (-7.5). Dominance x dominance interaction was non-significant in the case of Vytila-3 x Hraswa, negatively significant in Vytila-3 x IR 36 (-20.58), positively significant in the crosses Bhadra x Hraswa (12.47) and Bhadra x IR 60133 (5.60) (Table 23).

8.Grain L/B ratio

Mean effect was found to be significant in all the four crosses. Additive effect was positively significant in Vytila-3 x Hraswa (4.71) and Bhadra x Hraswa (13.59). It was found to be negatively significant in Vytila-3 x IR 36 (-10.32) and Bhadra x IR 60133 (-6.32). In the case of dominance effect non-significant effect was observed in Vytila-3 x Hraswa. It was found to be negatively significant in the case of Vytila-3 x IR 36 (-9.88), Bhadra x Hraswa (-10.04) and in Bhadra x IR 60133 (-9.37). In the case of additive x additive interaction, negative significance was observed in all the four crosses except in the case of Vytila-3 x Hraswa for which it was non-significant. In the case of additive x dominance, positive interaction was observed in Vytila-3 x Hraswa (6.61) and Bhadra x Hraswa (12.56). It was negative in Vytila-3 x IR 36 (8.05) and non-significant in Bhadra x IR 60133. Dominance x dominance effect was non-significant in Vytila-3 x Hraswa, significant interaction effect was observed in Vytila-3 x IR 36 (2.94), Bhadra x Hraswa (18.85) and Bhadra x IR 60133 (12.35) (Table 23).

9.Grain yield per plant

Significant mean effect was observed in all the four crosses. Additive effect was non-significant in Vytila-3 x Hraswa, significant and positive in Vytila-3 x IR 36, (10.55), Bhadra x Hraswa (7.25) and negatively significant in Bhadra x IR 60133 (-7.73). Dominance effect was significant in Vytila-3 x Hraswa (13.09) and Vytila-3 x IR 36 (16.84). Dominance effect was negative and significant in Bhadra x Hraswa (-5.21) and Bhadra x IR 60133 (-2.45). Among the interactions, additive x additive interaction was significant in Vytila-3 x Hraswa (16.28) and Vytila-3 x IR 36 (17.38). It was negative in Bhadra x Hraswa (-5.49) and Bhadra x IR 60133 (-2.85). Additive x dominance effect was significant in Vytila-3 x Hraswa (6.94) and Vytila-3 x IR 36 (2.94). It was negatively significant in Bhadra x IR 60133, non-significant in Bhadra x Hraswa. In the case of dominance x dominance interaction, positive significance was observed in Vytila-3 x Hraswa (16.44), Bhadra x Hraswa (5.54) and Bhadra x IR 60133 (4.86). Negative significance was observed in Vytila-3 x IR 36 (-15.74) (Table 23).

10. Percentage spikelet sterility

Mean effect was found to be significant in all the four crosses. Negative significance for additive effect was observed in three crosses - Vytila-3 x IR 36 (-2.73), Bhadra x Hraswa (-20.34) and Bhadra x IR 60133 (-9.55). Non-significant effect was observed in Vytila-3 x Hraswa. Dominance effect was significant in Vytila-3 x Hraswa (3.36). Negative dominance effect was observed in Vytila-3 x IR 36 (-11.02), Bhadra x Hraswa (-6.66) and Vytila-3 x IR 60133 (-16.38). Additive x additive interaction effect was significant in Vytila-3 x Hraswa (3.05). Negative interaction effect was observed in Vytila-3 x IR 36 (-15.82), Bhadra x Hraswa (-5.55) and Bhadra x IR 60133 (-20.96). Non-significant additive x dominance interaction observed in Vytila-3 x Hraswa and significant interaction effect was in Vytila-3 x IR 36 (33.03). Negative significant additive x dominance effect was observed in Bhadra x Hraswa (-20.88) and Bhadra x IR 60133 (-4.26). Dominance effect was negatively significant in Vytila-3 x IR 36 (-18.39) and

Bhadra x Hraswa (-20.14) and was positively significant in Vytila-3 x IR 36 (10.96), and Bhadra x IR 60133 (19.75)(Table 23).

11. Percentage pollen sterility

Mean effect was significant in all the four crosses. Additive effect was negative in all the four crosses i.e. Vytila-3 x Hraswa (-7.554), Vytila-3 x IR 36 (-12.125), Bhadra x Hraswa (-6.538) and Bhadra x IR 60133 (-17.614). Dominance effect was significant in Vytila-3 x Hraswa (21.91), Vytila-3 x IR 36 (37.53), Bhadra x Hraswa (14.34) and Bhadra x IR 60133 (23.20). In additive x additive interaction positive significance was observed for Vytila-3 x Hraswa (16.65), Vytila-3 x IR 36 (26.693), Bhadra x Hraswa (8.426) and Bhadra x IR 60133 (18.42). Negatively significant additive x dominance effect was observed in Vytila-3 x Hraswa (-8.13), Vytila-3 x IR 36 (-10.83) Bhadra x Hraswa (-7.85) and Bhadra x IR 60133 (-16.74). Dominance x dominance interaction was negatively significant for Vytila-3 x Hraswa (-21.157), Vytila-3 x IR 36 (-46.57), Bhadra x Hraswa (-13.04) and Bhadra x IR 60133 (-24.15) (Table 23).

DISCUSSION

5. DISCUSSION

Hybrid rice technology is identified to be the most readily adaptable and viable technique among the various possible genetic approaches. The development of high yielding varieties of rice helped in improving the crop yield to cater the growing needs of rice consumers all over the world. Essential prerequisite for commercial exploitation of heterosis in any self-pollinated crop is the availability of an effective seed production technique that should be economically viable. Male sterility system is widely used for this purpose and in rice; various types of male sterility systems are being utilized. Among these, cytoplasmic genic male sterility system has been recognized as the most effective and practical one for development of hybrids under tropical conditions. In most of the countries wild abortive cytoplasm (WA) evolved in China is utilized for the evolution of hybrid rice. Performance of WA cytoplasm in tropical climate especially in warm humid conditions is unstable in sterility manifestation. This paves out the scope for finding alternative sources of CMS other than WA. Thus the present investigation was undertaken with the objectives mentioned earlier and the results are discussed below.

5.1 Experiment Number 1

5.1.1. Evolution of alternative sources of cytoplasmic male sterility

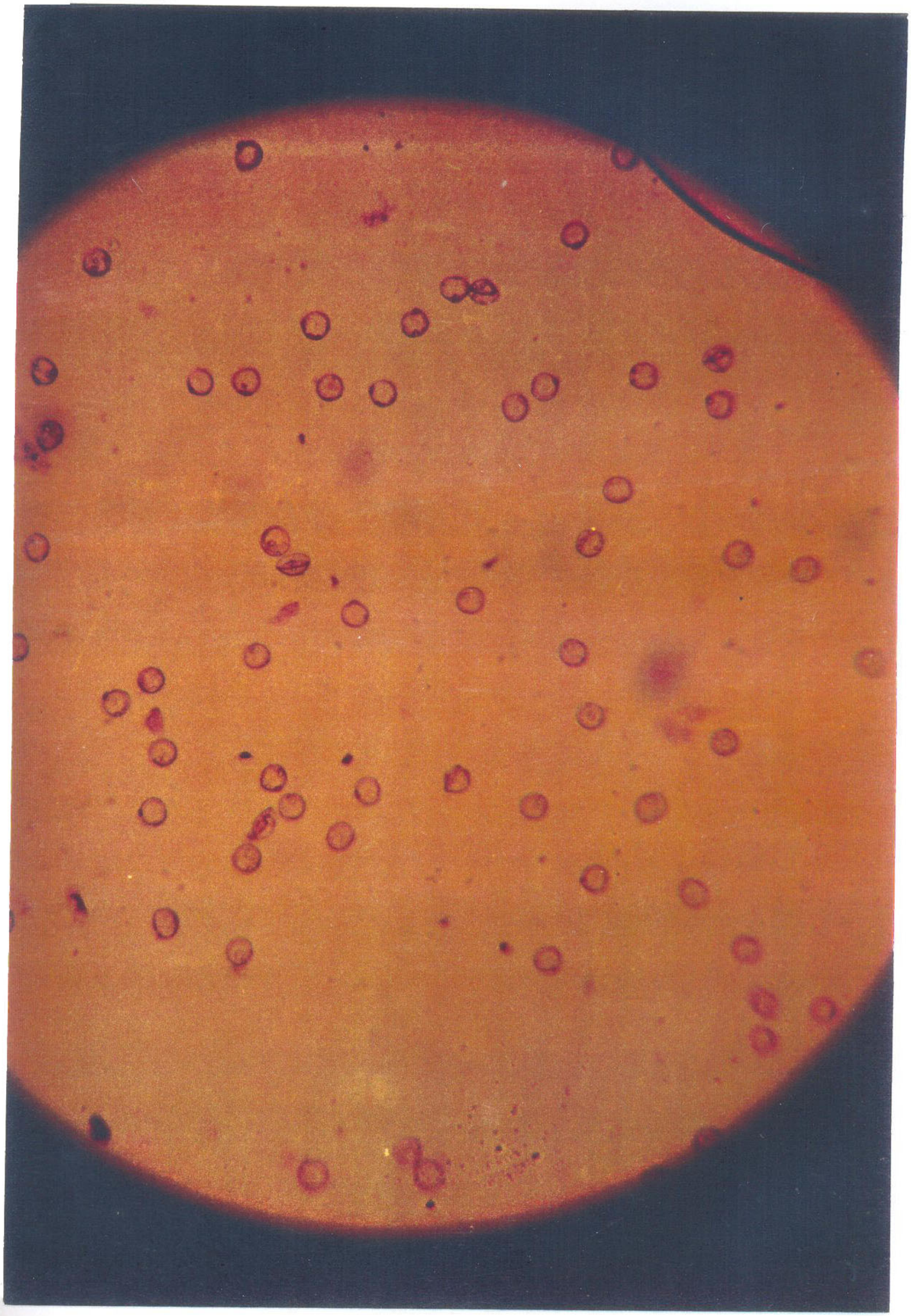
The CMS line needed for commercial rice hybrid production was first developed in China in 1973 from a naturally occurring male sterile plant and was designated as WA (wild abortive) cytosterile lines (Yuan, 1977). Performance of WA cytoplasm in tropical climate especially in warm humid conditions is unstable in sterility manifestation. This points out the need for the diversification of CMS sources. Hoan et al., (1997) searched for male sterility inducing cytoplasm in wild species of the genus Oryza with a view to diversify the base of the cytoplasmic genetic male sterility system. Wild accessions possessing sterility inducing cytoplasms were identified following reciprocal and sterile F_2 backcross methods. Sterile segregants were pursued through substitution backcrosses to develop cytoplasmically male sterile line.

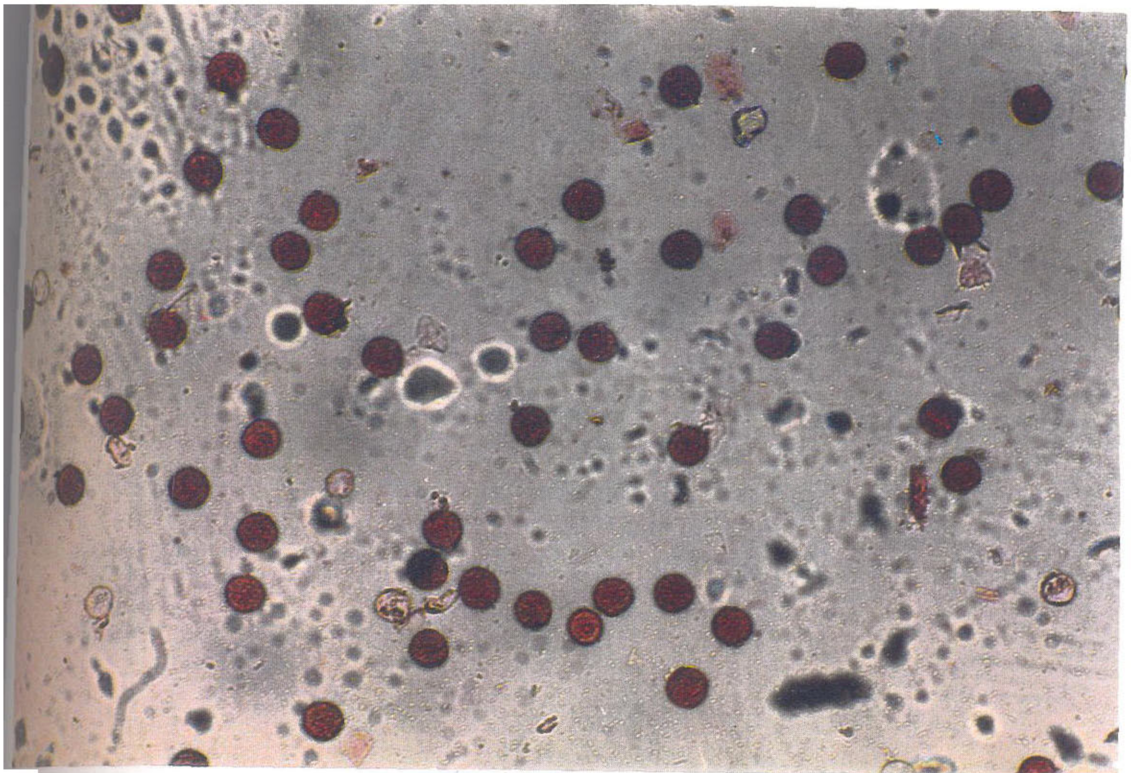
Among the identified sources of male sterility, Vytila-3 x IR 36 cross combination was found to have highest sterility manifestation initially (about 70%) followed by Bhadra x Hraswa (40%) and Bhadra x IR 60133 (39.5%). Developing these combinations into fully sterile lines through back cross programme was the main aim of the first experiment.

In back cross two (BC_2) generation, the male sterility of cross combinations exhibited significant increase, i.e. [(Vytila-3 x IR 36) x IR 36] (72.7%), [(Bhadra x Hraswa) x Hraswa] (46.13%) and [(Bhadra x IR 60133) x IR 60133] (43.66%).

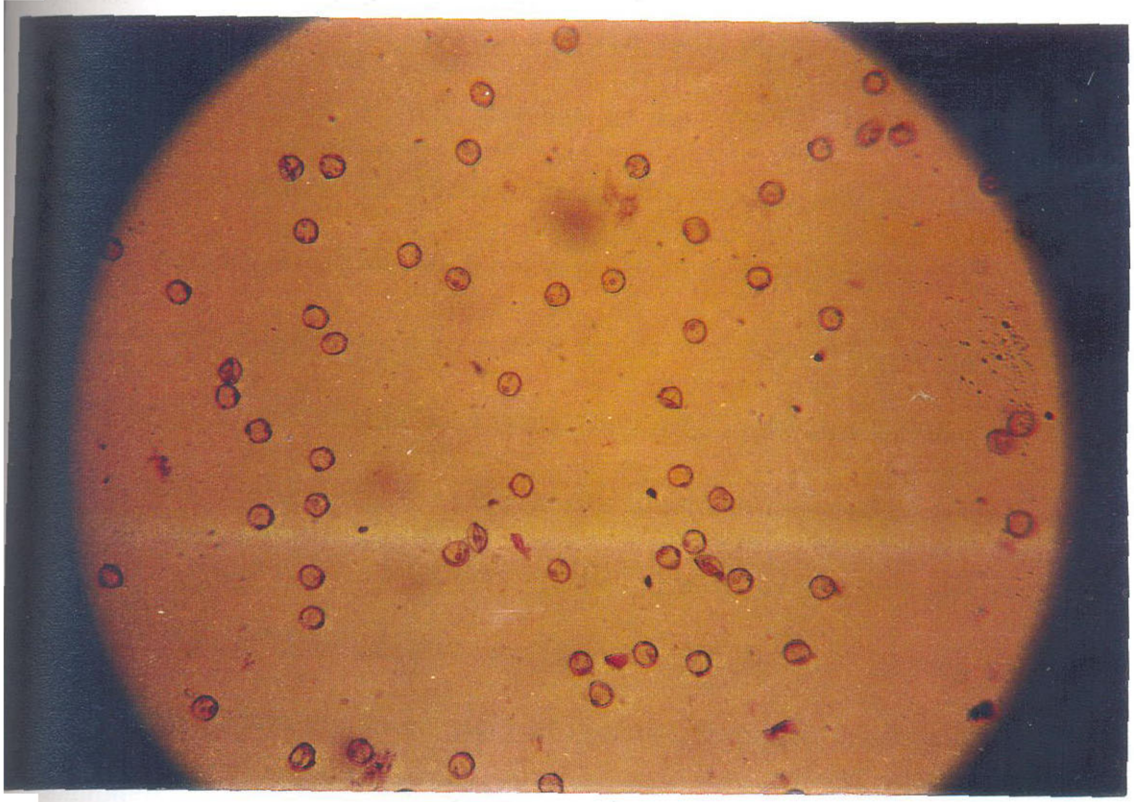
In back cross three (BC_3), [(Vytila-3 x IR 36 x IR 36) x IR 36], mean value of percentage of sterility has been increased to 75.11 per cent. In [(Bhadra x Hraswa x Hraswa) x Hraswa] the mean value of pollen sterility increased to 49 per

Hundred per cent sterile pollen grains of Vytila - 3 x IR 36_2 (F_2BC_3)





Fertile pollen grains of rice



Sterile pollen grains of CMS line

cent. Similarly, in [(Bhadra x IR 60133 x IR 60133) x IR 60133], the percentage of pollen showed significant improvement i.e., 49.24 per cent.

In back cross four (BC_4), [(Vytila-3 x IR 36 x IR 36 x IR 36) x IR 36], mean value of percentage of pollen sterility increased significantly to 75.50 per cent. In [(Bhadra x Hraswa x Hraswa x Hraswa) x Hraswa], the increase in the mean value of percentage of pollen sterility was 52.7 per cent. In [(Bhadra x IR 60133 x IR 60133 x IR 60133) x IR 60133], the mean value of percentage of pollen sterility was 51.64 per cent.

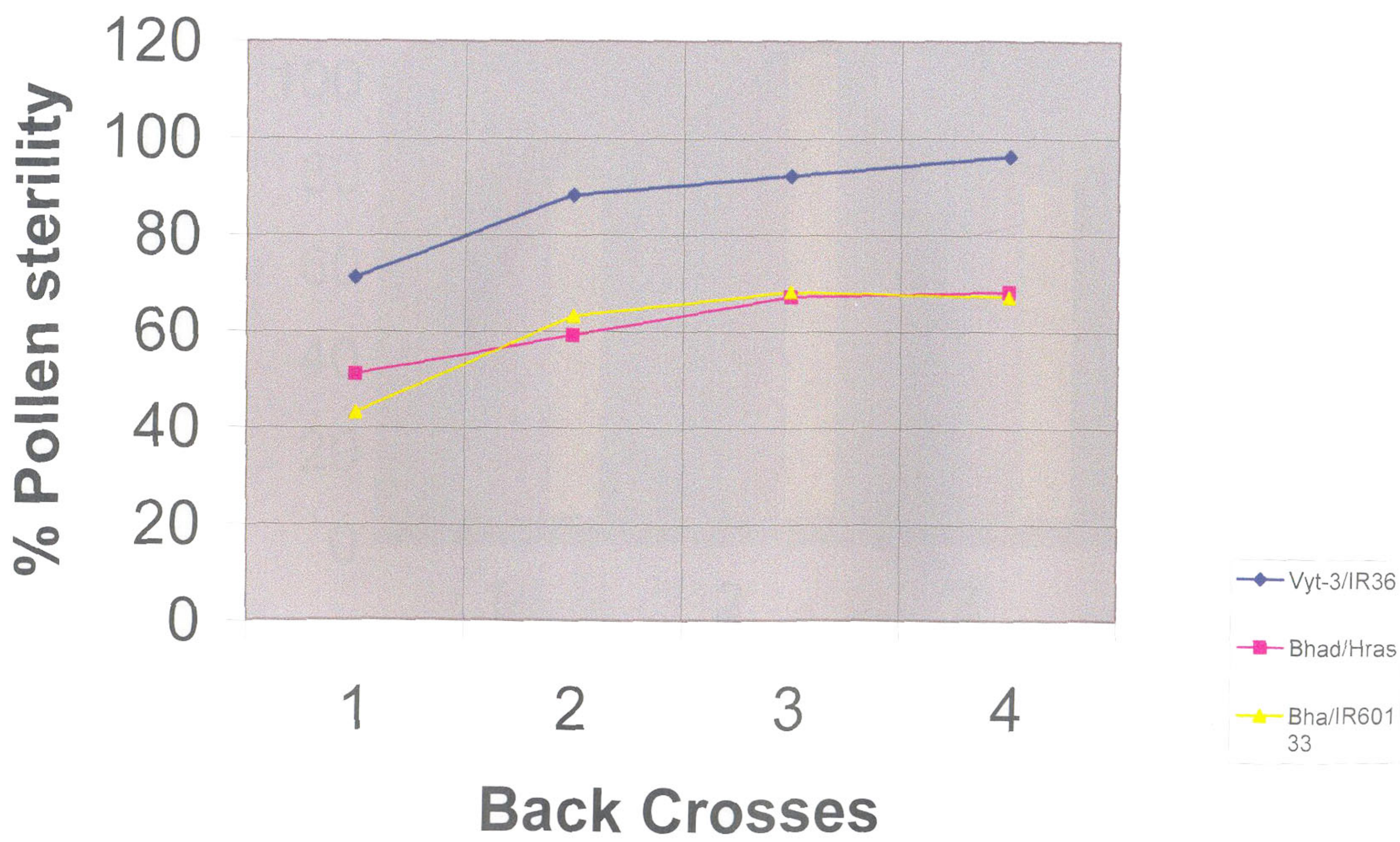
Thus, it was observed that from back cross generation one to back cross generation four, the incorporation of more nuclear genes of IR 36 under Vytila-3 cytoplasm resulted in an increase in mean value of percentage of pollen sterility from 69.50 per cent to 76.50 percent. In the case of Bhadra x Hraswa and its repeated backcrosses with Hraswa the sterility manifestation was significant and it exhibited an increase from 38.6 per cent (BC_1) to 52.7 per cent (BC_4). This is due to the fact that more and more nuclear genes of male parents get incorporated into the progeny at each step of back cross. Similarly, in the case of Bhadra x IR 60133 and its back crosses with the male parent the mean value of percentage of pollen sterility increased from 39.5 per cent (BC_1) to 51.64 per cent (BC_4) due to the incorporation of more and more nuclear genes of IR 60133 in each back cross. It was observed that the same trend of increase in pollen sterility percentage was exhibited in the maximum value of pollen sterility from each Back cross generation. The incorporation of more nuclear genes of IR 36 under Vytila-3 cytoplasm resulted in an increase in maximum value of percentage of pollen sterility from 71 to 96 per cent. With respect to Bhadra x Hraswa and its repeated Back crosses with Hraswa, the maximum sterility manifestation showed an increase from 51 to 68 per cent. Similarly Bhadra x IR 60133 showed a maximum sterility per cent increase from 43 to 67 per cent. This has been presented graphically in Fig. 1. Pradhan and Jachuk (1996) converted thirteen popular low land rice cultivars to cytoplasmic male sterile lines through repeated backcrossing with three male sterility sources.

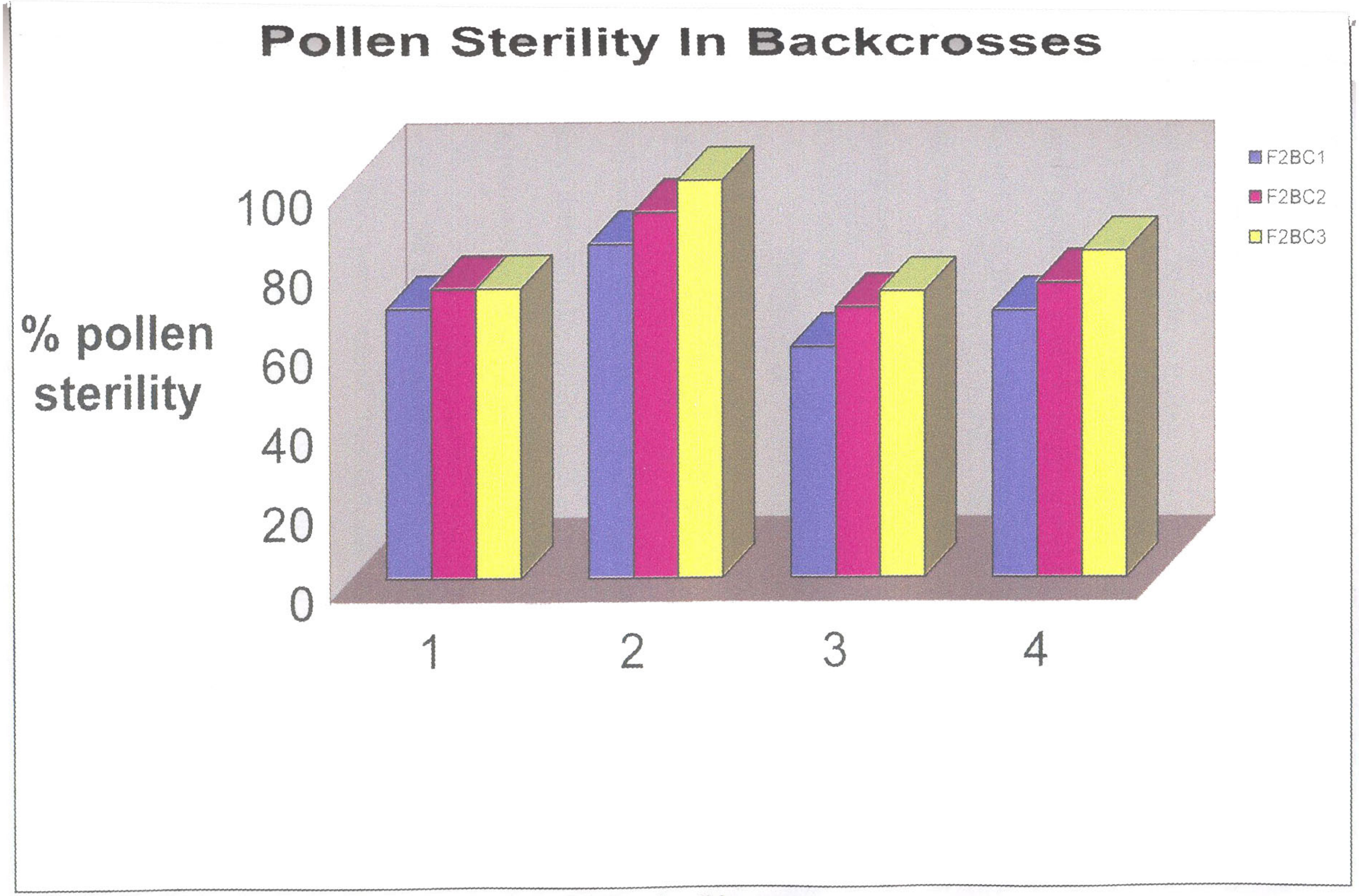
In the case of F_2 backcrosses also, the increase in the mean value of percentage of pollen sterility was significant i.e., in the cross Vytila-3 x Hraswa and its backcrosses with Hraswa, the mean value of percentage of pollen sterility increased from 42.78 per cent (F_2BC_1) to 54.00 per cent (F_2BC_3). This is due to the coming, together of more and more nuclear genes of Hraswa with the cytoplasm of Vytila-3. In the cross, Vytila-3 x IR 36 and its backcrosses, the increase in the mean value of pollen sterility percentage was from 61.55 per cent (F_2BC_1) to 71.04 per cent ((F_2BC_3). As in the previous cross here also there is increase in nuclear gene of male parent i.e., IR 36 under Vytila-3 cytoplasm resulted in increase of male sterility. In Bhadra x Hraswa, in F_2BC_1, the mean value of percentage of pollen sterility was 36.83 per cent, while it was 49.07 per cent in F_2BC_3. In Bhadra x IR 60133, the mean value of percentage of pollen sterility increased from 44.25 per cent (F_2BC_1) to 50.96 per cent (F_2BC_3). Here also coming together of more and more male nuclear genes with female cytoplasm of Bhadra resulted in increased

4. IR 60133 - recurrent parent

5. IR 36 - a promising maintainer line (B line)

1. Increase Of Pollen Sterility In Each Back Cross





1.Vytila-3/Hraswa
2.Vytila-3/IR36
3.Bhadra/Hraswa
4.Bhadra/IR60133

development of male sterility phenomenon. F_2 Back cross maximum values in the case of Vytila-3 x Hraswa showed an increase from 68 per cent in F_2BC_1 to 73 per cent in F_2BC_3. It was interested to note the case of Vytila-3 x IR 36 Back cross where maximum value of sterility percentage increased from 84 in F_2BC_1 to 100 percentage in F_2BC_3 Bhadra x Hraswa showed an increase from 58 per cent to 72 per cent in F_2BC_3. Bhadra x IR 60133 exhibited an increase of maximum value of sterility of 67 per cent in F_2BC_1 to 82 per cent in F_2BC_3. This has been presented graphically in Fig. 2. Dalmacio *et al.,* (1996)) reported that hybrids with $\geq$ 70 per cent pollen sterility were subsequently backcrossed with the recurrent parent, of all the backcross derivatives, one line with maepatula cytoplasm was stable for complete pollen sterility.

Thus, it can be seen from the experiments that increase in pollen sterility is observed in each backcross generation, with respect to the previous generations. The sterility inducing cytoplasm in Vytila-3 and Bhadra (local varieties) and the nuclear genes present in elite varieties such as IR 36 and IR 60133 are responsible for the expression of pollen sterility.

In the last backcross generation F_2BC_3 of Vytila-3 x IR 36, 100 per cent sterile CMS lines were obtained. This indicates that further backcrossing with pollen parent IR 36 (maintainer line) can evolve 100 per cent male sterile CMS lines.

6. Vytila-3 - source of CMS cytoplasm

7. Hraswa - male recurrent parent used in Bhadra x Hraswa

5.2 Experiment Number 2

5.2.1 Screening of elite varieties for identification of restorers and potential CMS lines

5.2.1.1 Partial Diallel Analysis

The concept of partial diallel mating design was developed by Kempthorne and Curnov in 1961. This fractional diallel has to be used in this experiment, since only a part of possible crosses could be used. This is mainly because that only a few pollen parents are capable of restoring fertility. An idea of genetic components of variance, general combining ability and ratio of variance GCA/SCA were obtained in the partial diallel crosses, four pollen parents namely Mattatriveni, Karthika, Vytila-3 and Bhadra and the six hybrids were used in the above analysis. Results are discussed below.

Parent Vytila-3 showed the highest positive gca effect (14.375) and the rest 3 parents showed negative gca effects. Its additive genetic variance is 53.39 and its dominance variance is equal to SCA variance i.e., 144.091. GCA/SCA ratio was estimated to be 0.1849 for this character. Since the SCA variance is three times higher than additive genetic variance, it can be assumed that through hybrids there is scope for hybrid vigour exploitation. It also indicated that there is little scope for parental selection. Vytila-3 is the only one parent, which can contribute an improvement in this character because of its high positive gca effect.

8. Bhadra - a CMS source

. F1 Bhadra x Hraswa

In the case of panicle length, positive gca was exhibited by the parent Karthika followed by Vytila-3. Other two parents showed negative gca effect. Additive genetic variance of this character (0.588), which is twice the value of GCA (0.294) and is lower than its dominance variance, which is equal to SCA variance (1.736). GCA/SCA ratio was estimated to be 0.1694 for this character. Since SCA variance is higher than the additive genetic variance, it can be assumed that through heterosis breeding there is scope for hybrid vigour exploitation. It also establishes the fact that there is little scope for parental selection. Karthika and Vytila-3 can contribute an improvement in this character because of their positive gca effect.

With respect to degree of panicle exsertion positive gca effect was showed by Karthika and Bhadra, while other two parents manifested negative gca effect. The additive genetic variance of this character was 55.29, which is higher than its SCA variance (14.925). GCA/SCA ratio was found to be 1.852 for the degree of panicle exsertion. Since additive genetic variance was higher than SCA variance it can be assumed that through selection and improvement there is scope for crop improvement. It also establishes the fact that there is little scope for hybridization.

For angle of panicle exsertion positive gca effect was manifested by Mattatriveni and Karthika. The additive genetic variance of this character was 215.832 and is lower than its SCA variance (375.25). The GCA/SCA ratio was found to be 0.036. Since SCA variance was higher than the additive genetic

10. F1 Vytila_3 x IR 36

11. F1 Bhadra x IR 60133

variance, it may be assumed that there is scope for exploitation of heterosis and hybridization.

gca effect for the character spikelet per panicle was positive and significant in the case of Karthika and Bhadra. While other two parents showed negative gca effects. Additive genetic variance for this character was 429.91, which is higher than its SCA variance. GCA/SCA ratio was found to be 0.573. Since additive genetic variance was higher than SCA variance, it can be predicted that through selection and improvement there is scope for further enhancement. In this case it may be assumed that there is less scope for hybridization.

For grain density none of the four crosses showed significant gca effect. The additive genetic variance for this character was 4.586 and was higher than its SCA variance 3.438. GCA/SCA ratio was estimated to be 0.667. Since additive genetic variance was higher than SCA variance, it can be assumed that through selection and improvement there is scope for crop improvement. It also confirms the fact that there is little scope for hybridization.

For 100 grain weight, gca effect was positive for Karthika and Vytila-3. None of the four crosses exhibited significant gca effect. Additive genetic variance for this character was 4.030, which is less than its SCA variance. Since additive genetic variance was lower than its SCA variance, it can be assumed that through the hybrids, there is scope for hybrid vigour exploitation. It also indicates that there is little scope for parental selection.

F_2 Bhadra x IR 60133

13. F_2 Vytila-3 x Hraswa

For grain L/B ratio, gca effect was non-significant in all the four crosses. Additive genetic variance of this character was 0.44, which is higher than the SCA variance (0.166). GCA/SCA ratio was found to be 1.325. As the additive genetic variance was two times higher than the SCA variance it can be assumed that through parental selection the character may be enhanced. It also indicates that there is little scope for exploitation of hybrid vigour.

For grain yield per plant, Bhadra showed the highest positive gca effect followed by Mattatriveni. Its SCA variance (733.099) is higher than additive genetic variance (517.86) and it can be assumed that there is scope for hybrid vigour exploitation. It also brings about the fact that there is little scope for parental selection. Both Mattatriveni and Bhadra can contribute an improvement in this character because of its positive gca effect.

For spikelet sterility, significant negative gca effect was observed in Karthika. Vytila-3 and Bhadra exhibited positive gca effect. Its additive genetic variance (57.63) was less than SCA variance (91.88) GCA/SCA ratio was estimated to be 0.314 for this character. Since the SCA variance is of high value it can be assumed that through the exploitation of hybrid vigour this character can be enhanced. It also indicates that there is little scope for parental selection. Karthika is the only parent, which can contribute towards the decrease of spikelet sterility or in other words fertility restoration, because of its high negative gca effect. Hence Karthika can be identified as a good possible fertility restorer.

15. F_2 Bhadra x Hraswa

For pollen sterility, Mattatriveni showed significant negative gca effect. Vytila-3 exhibited significant positive gca effect. Additive genetic variance of this character (35.9) is much higher than SCA variance. GCA/SCA ratio was estimated to be 7.33. Since additive genetic variance is much higher than the dominance variance (2.4), it can be assumed that there is scope for parental selection. Mattatriveni is the only parent, which can contribute towards the decrease of percentage pollen sterility because of its negative gca effect or in other words increase of pollen fertility. Hence Mattatriveni can be considered as a second possible fertility restorer.

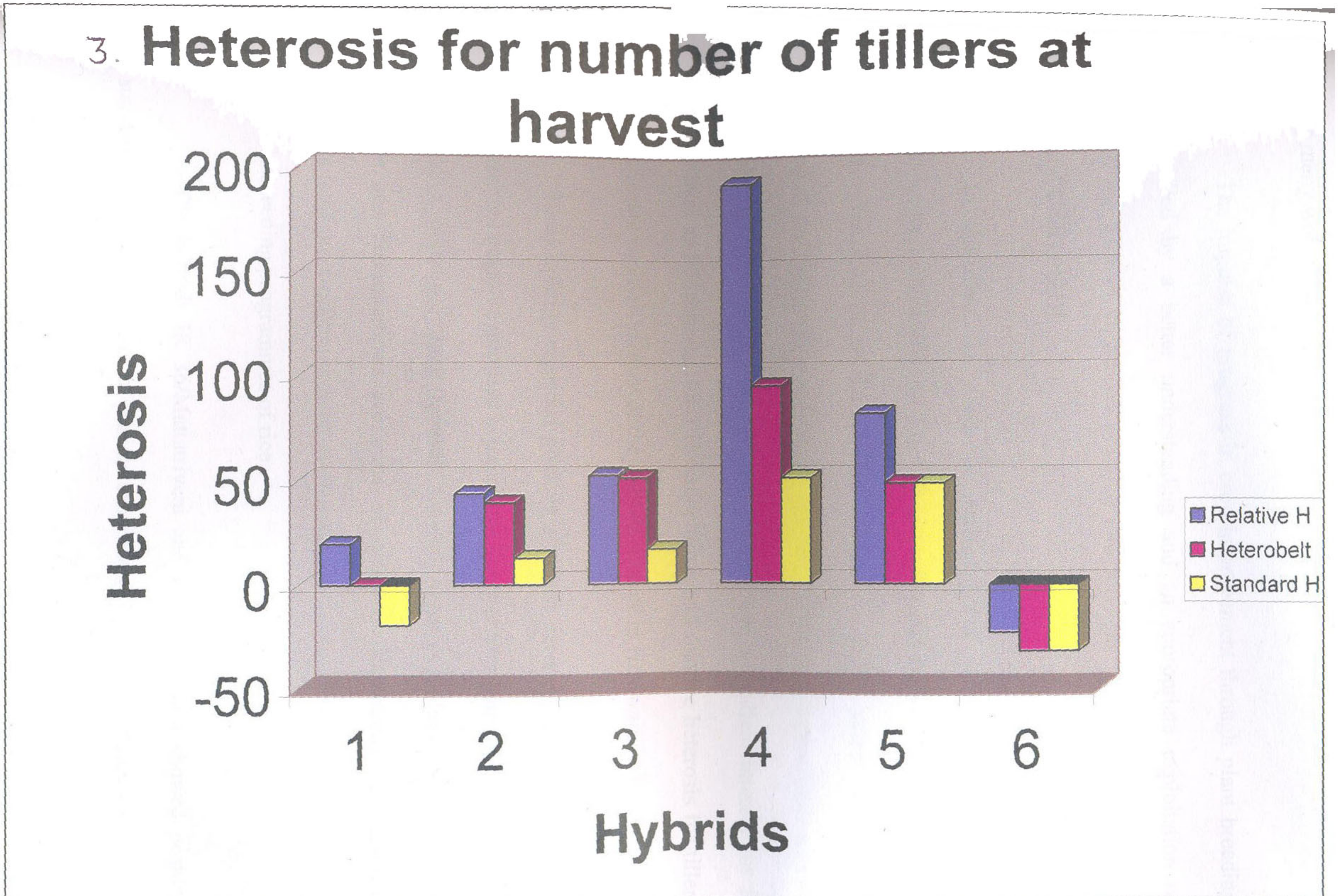
5.2.1.2 Estimation of Heterosis

Heterosis leads to increase in yield, reproductive ability, adaptability, disease and insect resistance, general vigour, quality etc. For most of the characters, the desirable heterosis is positive. But for some characters such as earliness, height, spikelet sterility etc. in cereals, negative heterosis is important.

In the present study heterosis of six fertile hybrids were evaluated for different characters and the results are discussed here. The use of the heterosis manifested in F_1 hybrids had been a popular notion pursued by a number of rice breeders for decades. Practical use of hybrid rice hinges not only on the magnitude of true heterosis expressed but also on the ease and cost of F_1 hybrid seeds. There was difference in mean performance of hybrids for different characters and magnitude of heterosis expressed by hybrids also varied between the crosses. Both

16. $BC_{1.2}$(Vytila-3xIR 36)xIR 36

17. $BC_{1.2}$ (BhadraxIR 60133)xIR 60133


3. Heterosis for number of tillers at harvest
200
150
100
50
0
-50
Heterosis
1
2
3
4
5
6
Hybrids
Relative H
Heterobelt
Standard H

positive as well as negative heterosis was observed for most of the characters. Earlier many workers have reported similar results.

The impulse of progress in crop improvement through plant breeding was propelled by a better understanding and an appropriate exploitation of heterosis, the gain in vigour on crossing two inbreeds [Balan (1987), Manual (1992) and Uma (1994)].

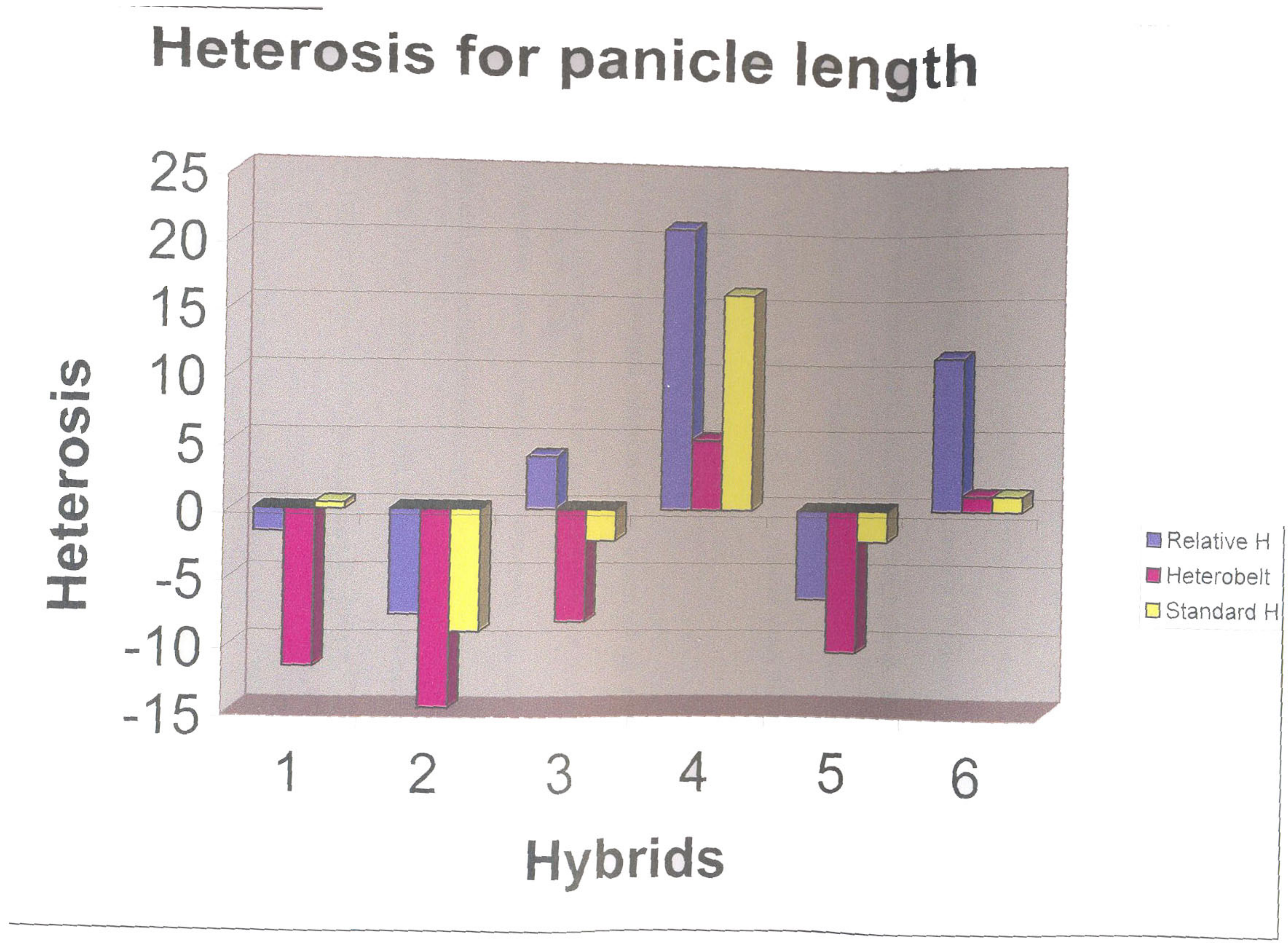
In the case of tillers at harvest, four hybrids IR36/Karthika, Hraswa/Karthika, Hraswa/Vytila-3 and IR 60133/Bhadra showed positive standard heterosis. The highest standard heterosis over the check parent Bhadra was estimated in the hybrid Hraswa/Vytila-3 (50.63). Overdominance effects may be the chief cause for heterobeltiosis based on inter and intraalleic interactions in nature.(Singh and Richharia,1980) Heterobeltiosis and relative heterosis for tillers at harvest were positive in most of the hybrids, except in Hraswa/Bhadra (Fig. 3).

Three hybrids recorded positive standard heterosis and the remaining three, recorded negative standard heterosis for the character panicle length (Fig. 4). For relative heterosis, three hybrids showed negative values. Since relative heterosis and heterobeltiosis are more of academic importance and standard heterosis is of practical importance more emphasis is given for standard heterosis in hybrid breeding programmes of rice.

The hybrids IR 36/Mattatriveni and Hraswa/Bhadra showed positive standard heterosis for degree of panicle exsertion (Fig. 5). Identification of parents

18. BC 1.1 (Vytila 3 x IR-36) x Vytila-3

19. Hraswa x BHADRA - a better performing hybrid



Heterosis for panicle length
Heterosis
25
20
15
10
5
0
-5
-10
-15
1
2
3
4
5
6
Hybrids
Relative H
Heterobelt
Standard H

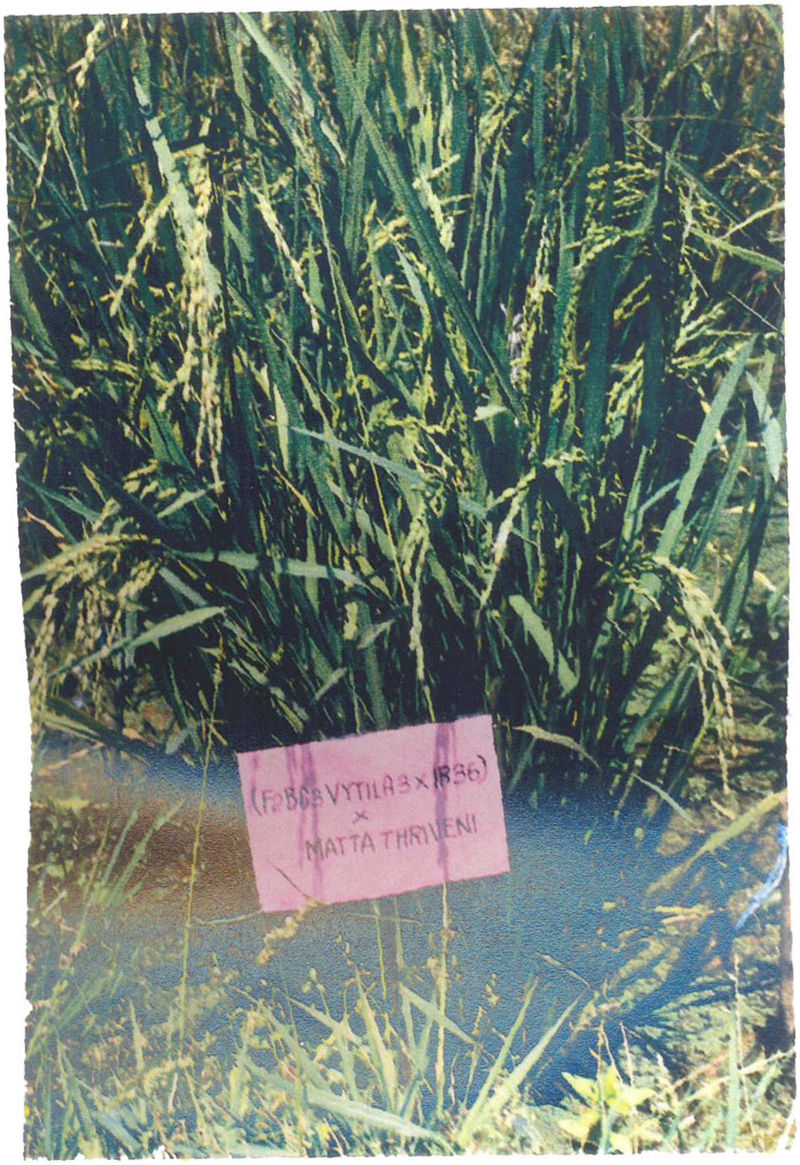
which can produce hybrids with good panicle exsertion has much relevance since this has a direct relation with spikelet sterility as well as filled grains per panicle [Manuel (1992) and Uma, (1994)]. Heterobeltiosis was negative for all the hybrids except Hraswa/Bhadra and Hraswa/Vytila-3 showed positive relative heterosis.

Standard heterosis was maximum for hybrid IR 36/Mattatriveni) for the character angle of panicle exsertion. Negative value was observed in IR 36/Karthika for all the three types of heterosis. Positive relative heterosis and heterobeltiosis were observed in the case of five hybrids. Higher angle of panicle exsertion is favourable for hybrids as far as yield character is concerned (Siddiq *et al.,* 1994). All the hybrids except one in the present study showed positive standard heterosis for this character (Fig. 6).

Positive standard heterosis was observed in two hybrids while the remaining four hybrids showed negative heterosis for the character spikelets per panicle. Negative heterobeltiosis was observed in all the hybrids except Hraswa/Bhadra, IR 36/Mattatriveni and Hraswa/Bhadra showed positive relative heterosis (Fig. 7) [an increase in angle of exsertion will have a correlated response in spikelet fertility in hybrid rice (Siddiique *et al.,* 1994)].

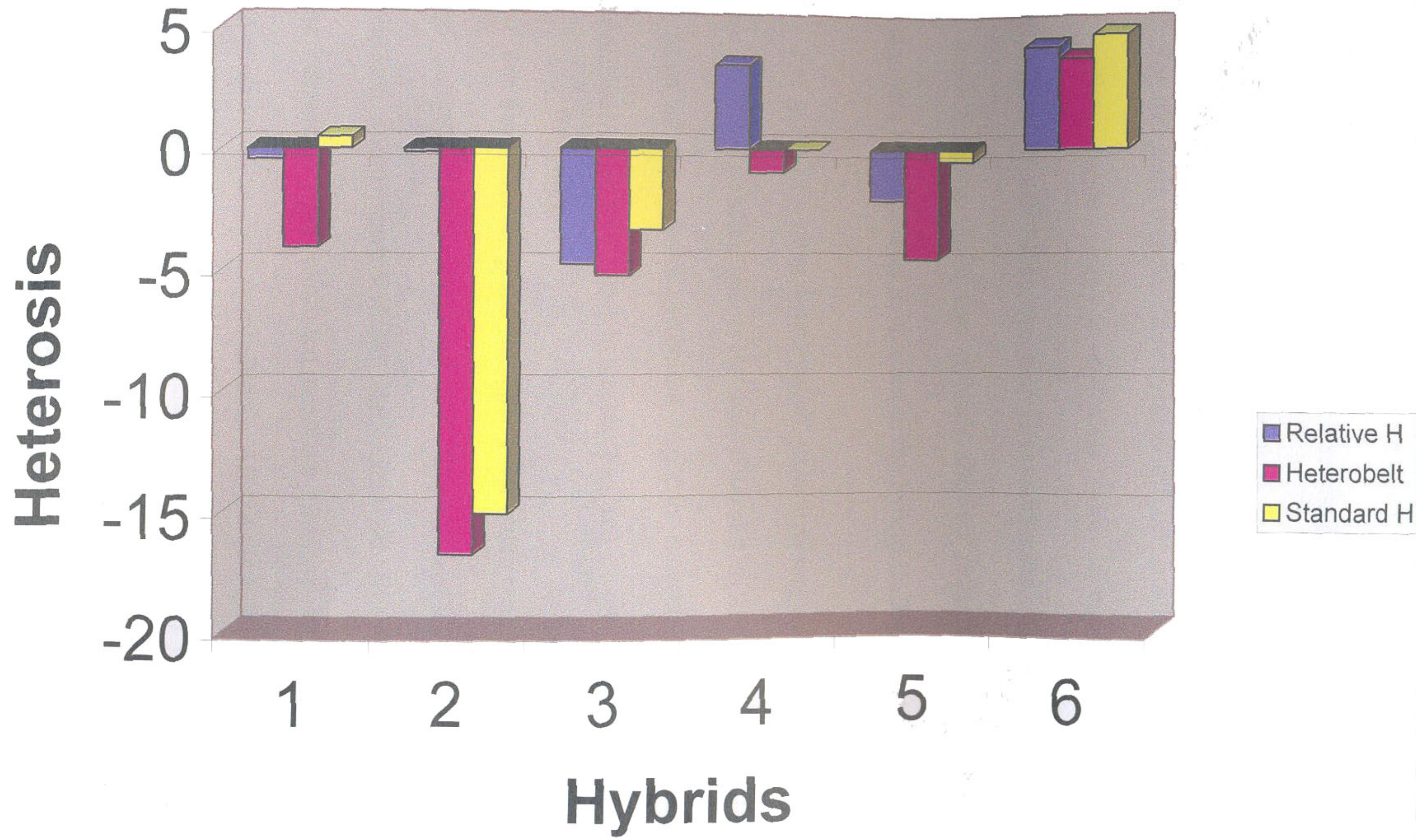
For grain density the hybrid Hraswa/Vytila-3 exhibited maximum value for standard heterosis while two hybrids IR 36/Mattatriveni and Hraswa/Karthika exhibited negative standard heterosis. All the hybrids showed positive relative heterosis for grain density. Negative heterobeltiosis was manifested in hybrid

20. IR-36 x MATTATRIVENI



21. Hraswa x KARTHIKA- a better performing hybrid.

5. Heterosis for degree of panicle exsertion



IR 36/Mattatriveni and Hraswa/Karthika (Fig. 8). Shamsuddin (1982 reported that an increase in grain density is necessary for grain yield in rice hybrids. In the present study four hybrids namely IR 36 x Karthika, Hraswa x Vytila-3, IR 60133 x Bhadra and Hraswa x Bhadra showed increased standard heterosis.

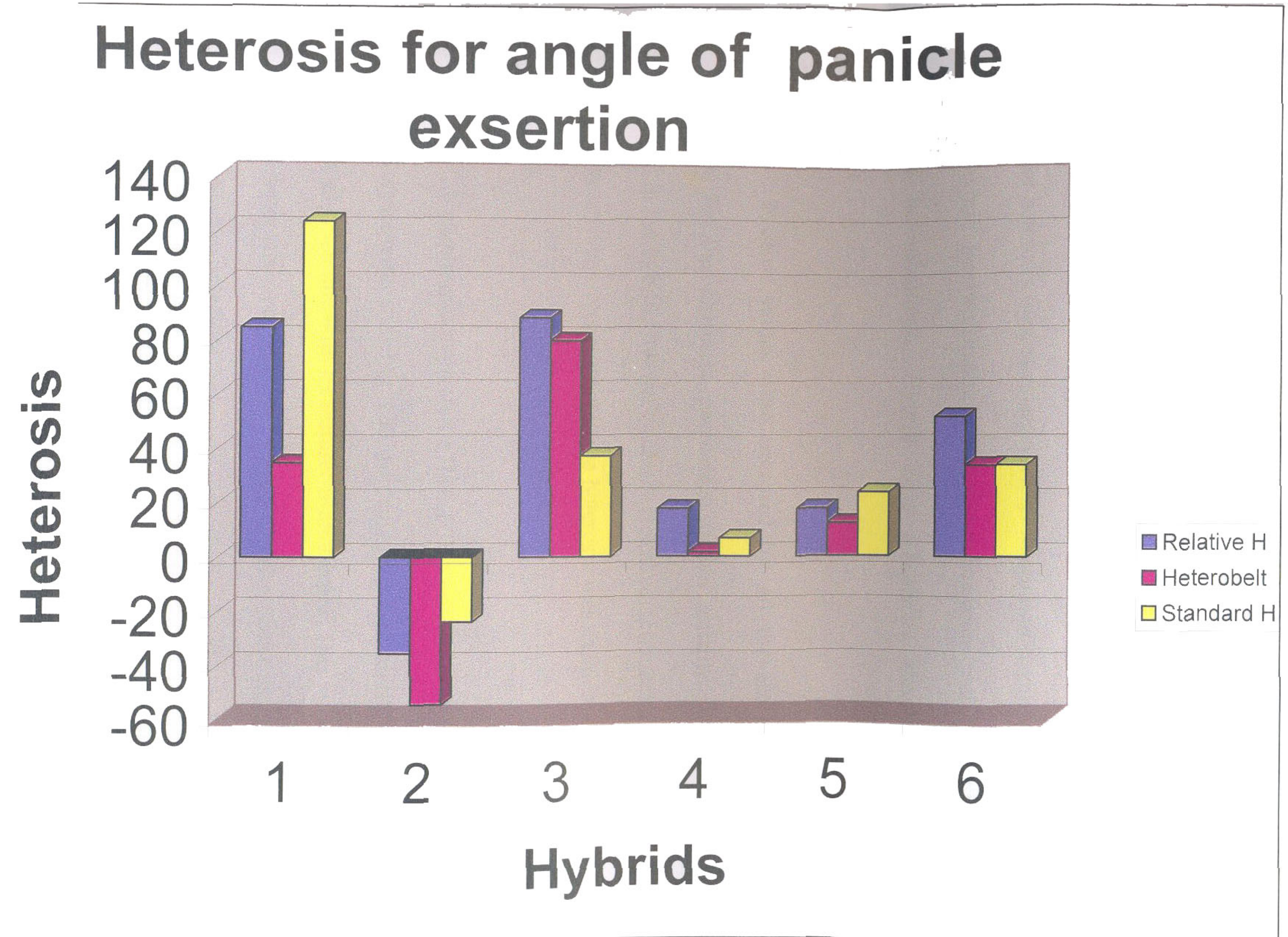
For 100 grain weight, three hybrids exhibited positive heterosis over the standard variety while negative heterosis was observed in the hybrids Hraswa/Karthika, IR 60133/Bhadra and Hraswa/Bhadra. Three hybrids showed negative heterobeltiosis while two hybrids showed negative relative heterosis. Positive standard heterosis was maximum in the hybrid IR 36/Mattatriveni (Fig. 9).

For grain L/B ratio, four hybrids exhibited negative standard heterosis. Maximum positive standard heterosis was observed in the hybrid IR 60133 x Bhadra. Most of the hybrids exhibited negative heterobeltiosis. Two hybrids showed positive values for relative heterosis (Fig. 10).

For the character grain yield per plant maximum value for all the three types of heterosis were exhibited by Hraswa/Karthika. The hybrids IR 36/Mattatriveni and Hraswa/Vytila-3 also exhibited positive standard heterosis while the remaining three exhibited negative standard heterosis. Four hybrids exhibited positive value for heterobeltiosis. All the six hybrids exhibited positive values for relative heterosis. Swaminathan *et al.* (1972) reports that in self pollinated plant, the hybrids to be economically advantageous must give 20-50 per cent higher grain yield than the best available commercial variety and the better

22. IR 60133 x Bhadra - a better performing hybrid

23. IR 36 x Karthika - a better performing hybrid


Heterosis for angle of panicle exsertion
Heterosis
140
120
100
80
60
40
20
0
-20
-40
-60
1
2
3
4
5
6
Hybrids
Relative H
Heterobelt
Standard H

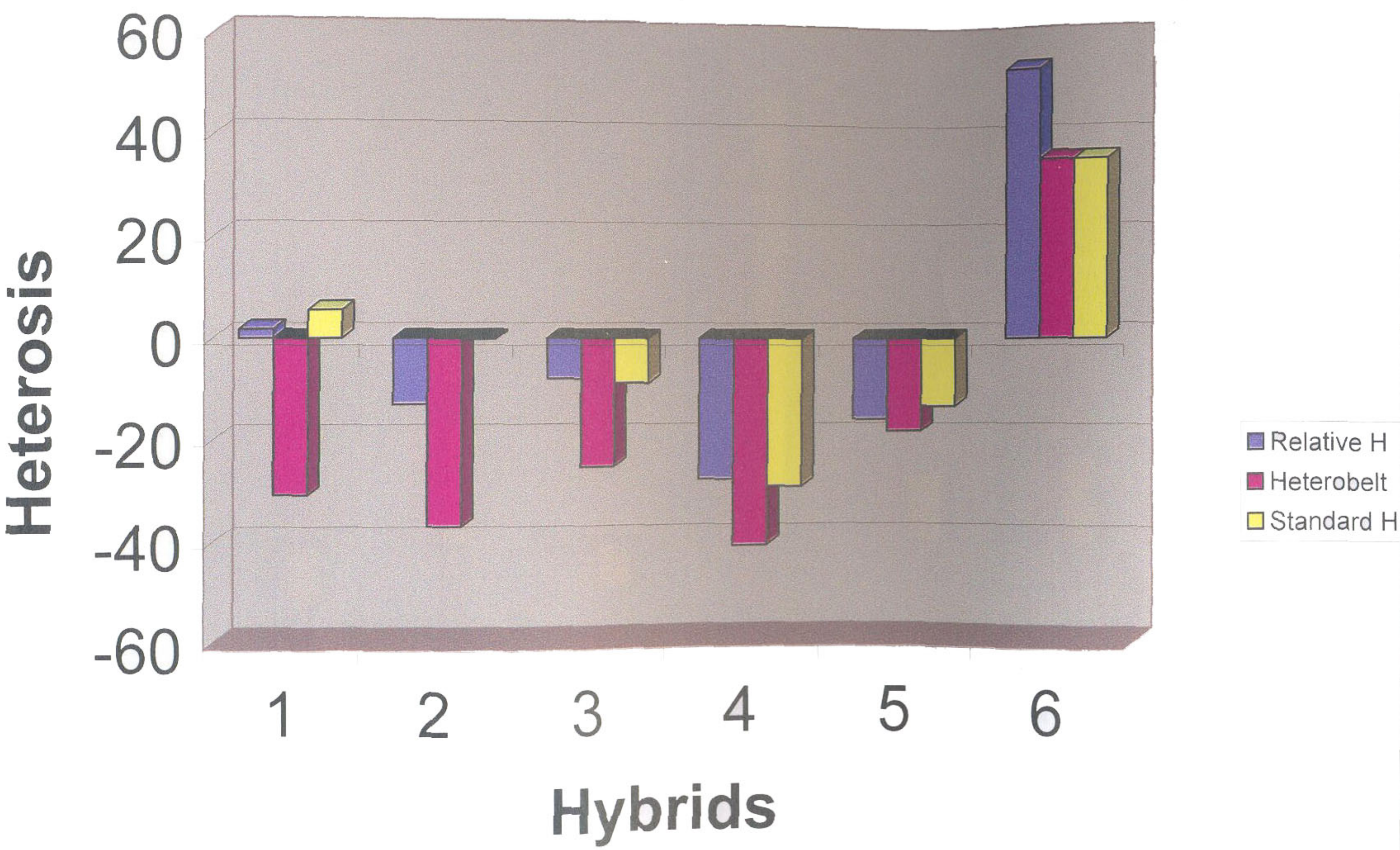
parent. In the present study three hybrids namely IR 36 x Mattatriveni, Hraswa x Karthika and Hraswa x Vytila-3 showed more than 25 per cent standard heterosis (Fig. 11).

For percentage spikelet sterility all the six hybrids showed negative values for heterosis over standard variety. Maximum negative value was observed in the hybrid Hraswa/Bhadra for standard heterosis. All the hybrids exhibited negative heterobeltiosis. Hybrid Hraswa/Karthika showed positive relative heterosis (Fig. 12).

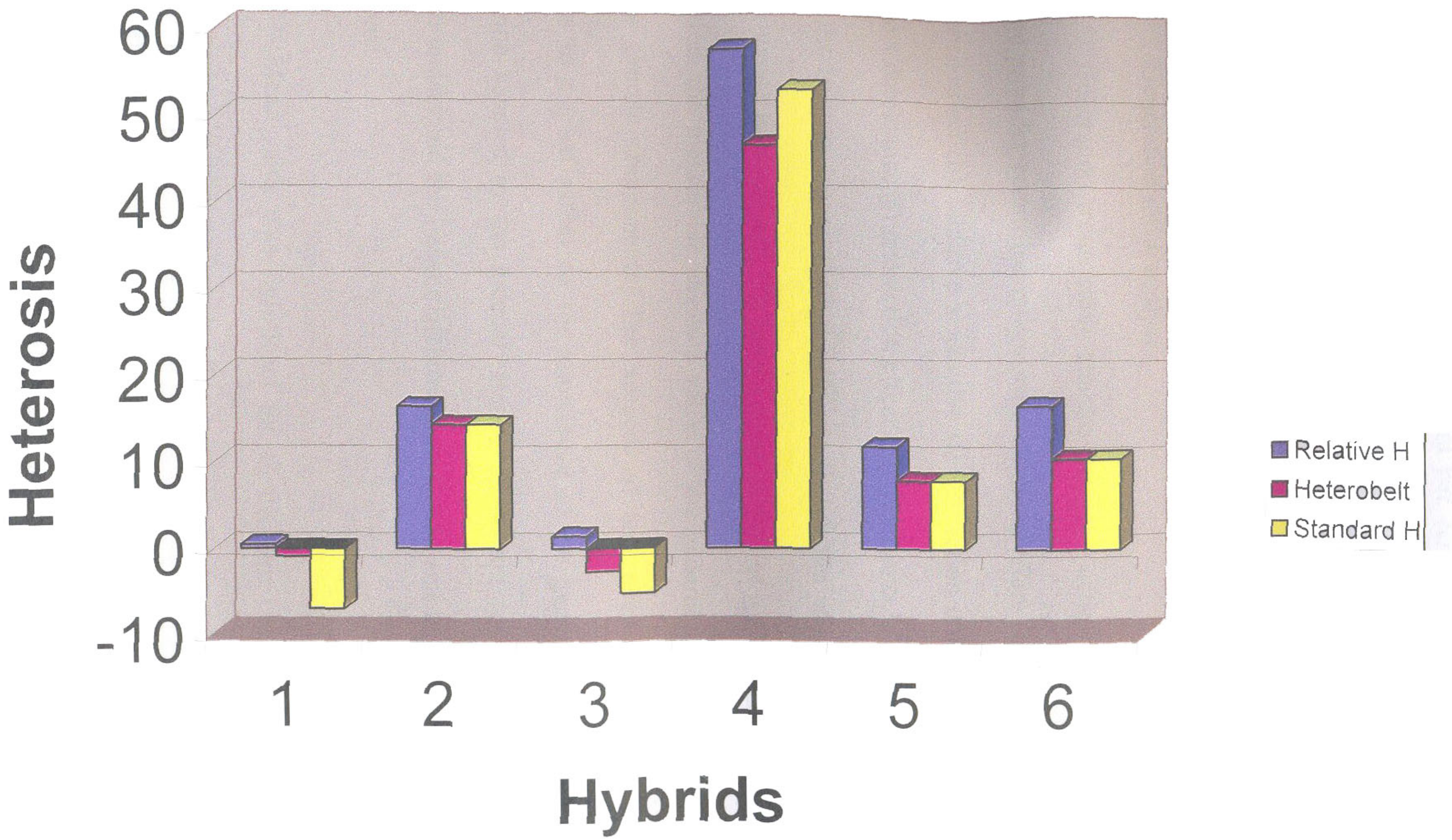
Positive values were obtained for all the six hybrids for standard heterosis for the character percentage pollen sterility. Maximum value was obtained in the hybrid Hraswa/Vytila-3. Negative heterobeltiosis was exhibited by IR 36/Mattatriveni. Negative relative heterosis was exhibited by Hraswa/Karthika (Fig. 13).

Cytoplasmic male sterile lines (CMS) of IR 36 under the background of Vytila-3 cytoplasm showing 100 percentage pollen sterility can be used as a commercial CMS line with its restorer Mattatriveni. This hybrid has 27 percentage standard heterosis over standard variety Bhadra with respect to grain yield per plant. Maximum standard heterosis was shown by the hybrid Hraswa/Karthika .The derived Hraswa CMS line under the background of Bhadra cytoplasm exhibited 72 percentage pollen sterility in the third backcross generation. The

7. Heterosis for spikelets per panicle



8. Heterosis for grain density



complete conversion of CMS line for cent per cent pollen sterility necessitates repeated backcrossing with pollen parents.

5.3 Experiment Number 3

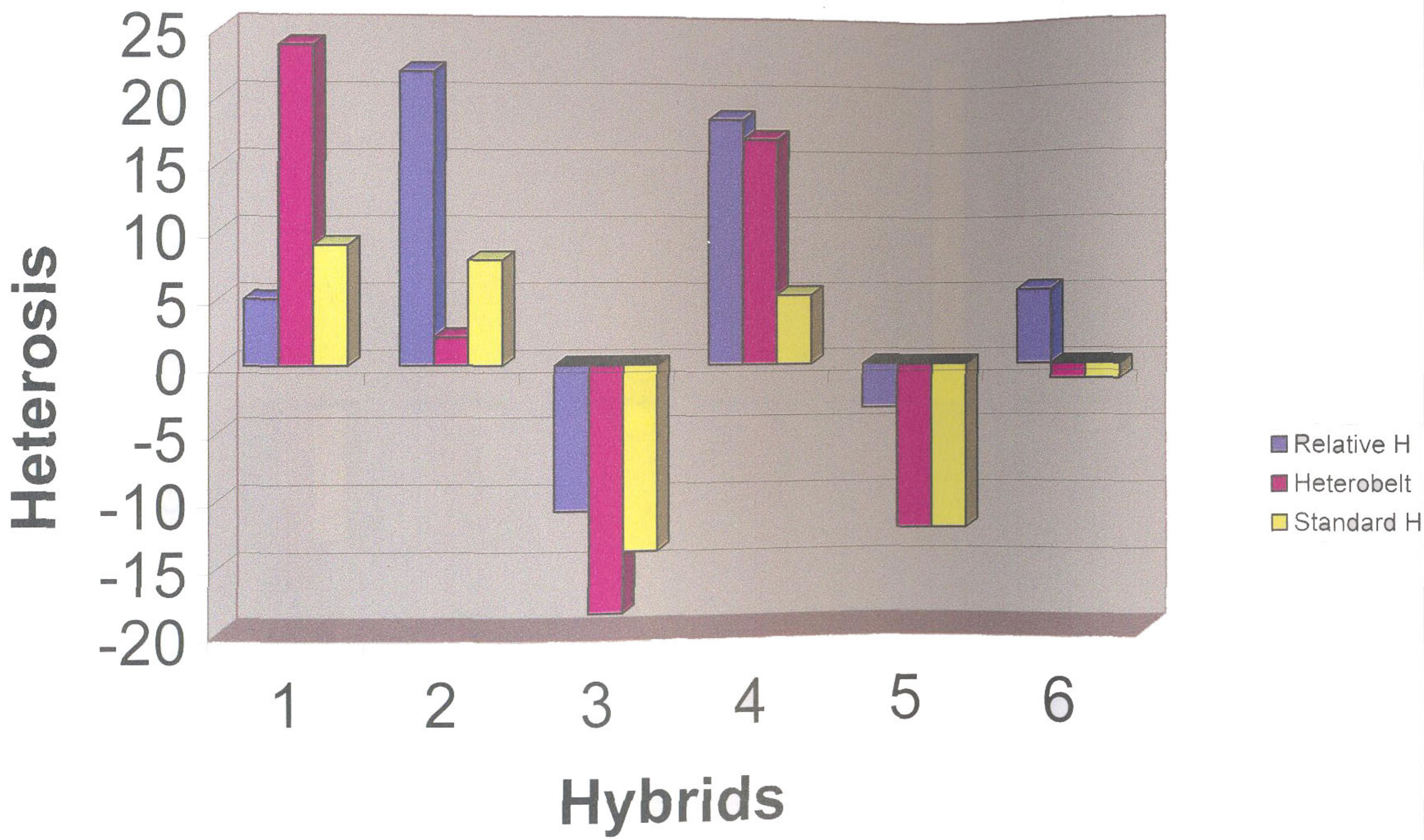
5.3.1 Genetic analysis of fertility restoration

5.3.1.1 Generation mean analysis

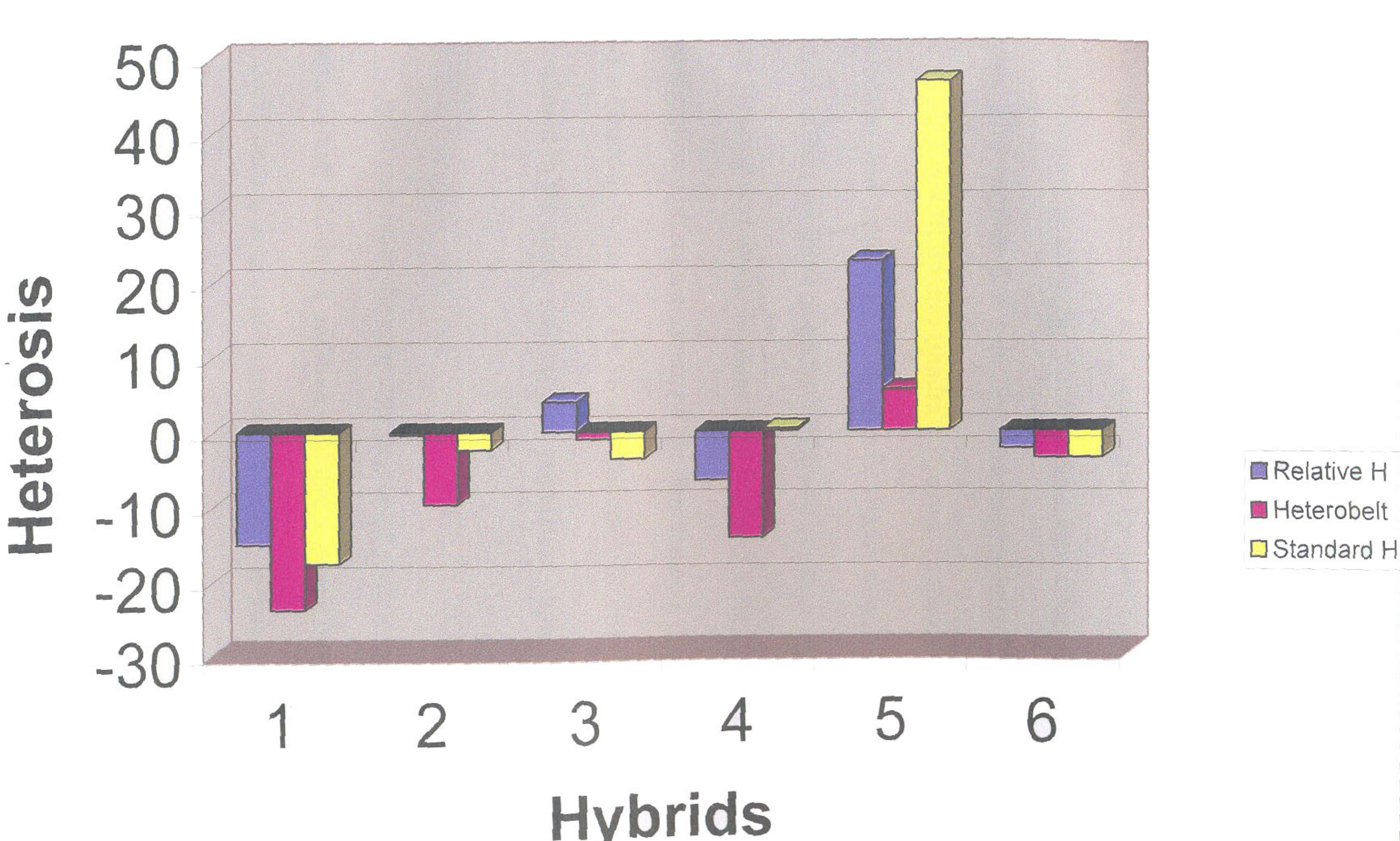
Generation mean study enables the gene action to be analysed cross wise and provides quantified information on mean effect (m), additive effect (d), dominance effect (h), additive x additive (i) interaction effect (which is fixable), additive x dominance (j) interaction effect and dominance x dominance interaction effect, the relative magnitudes of which will indicate whether developments of hybrids would be economic. To have a clear picture of genetic mechanism of the population, the measurable absolute value of the generation must be partitioned into its genetic components. The success of any plant breeding programme depends to a great extent on the knowledge of the genetic architecture of the population handled by the breeder. Hence an attempt was made in the present study to understand the genetic architecture of yield and its important component characters.

Mean value was significant for all the four crosses for the character tillers at harvest. Additive Genetic effect was negatively significant in all the four crosses and maximum negative value was obtained in the cross Vytila-3 x Hraswa. Higher positive dominance effect was observed in Vytila-3 x IR 36 followed by Bhadra x IR 60133 indicated the fact that by the utilization of heterosis breeding

9. Heterosis for 100 grain weight



Heterosis for grain L/B ratio

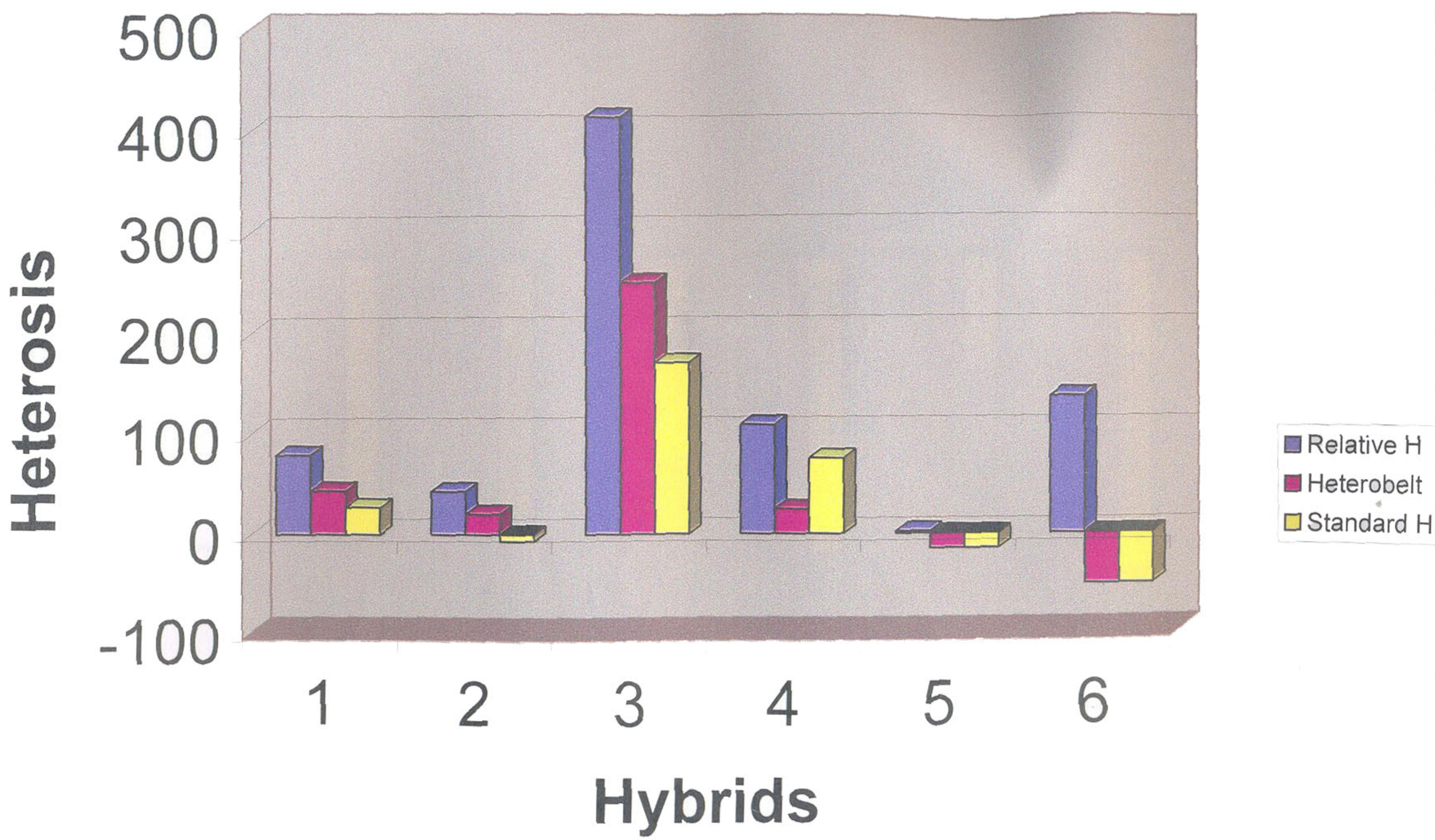


programmes, crop improvement may be done. Highest additive x additive interaction effect was observed in Vytila-3 x IR 36 emphasizing that this can be utilized for population improvement programmes.

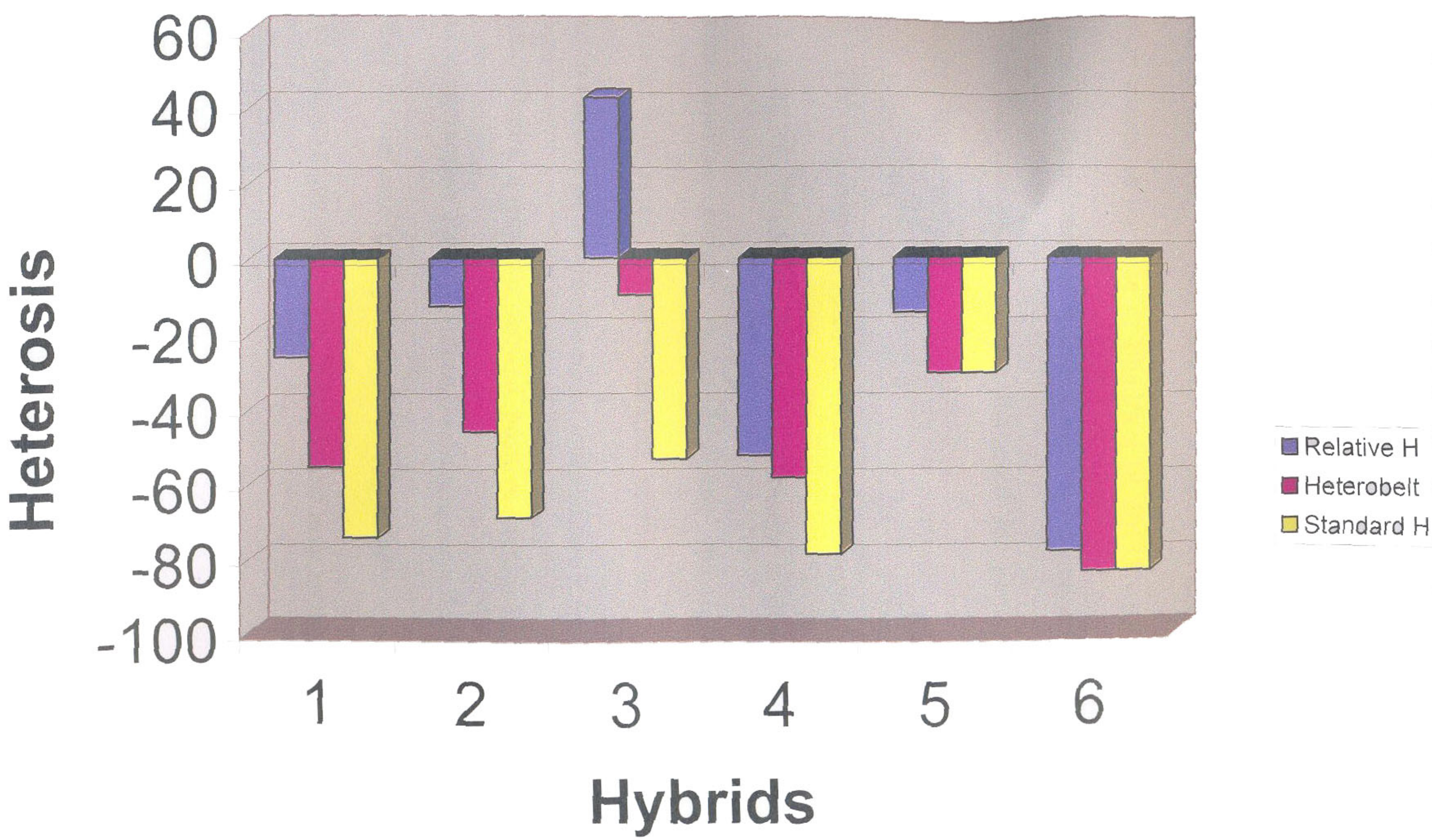
For panicle length, mean value was significant for all the crosses. Additive value was positive and significant for two crosses namely Vytila-3 x IR 36 and Bhadra x Hraswa. Significant dominance effect was observed in Bhadra x Hraswa. This implies that selection and improvement may be applied in the crosses Vytila – 3 x IR 36 and Bhadra x Hraswa. In the case of Bhadra x Hraswa, both selection and utilization of heterosis vigour may be done. In the case of interaction effects additive x additive showed positive significance in the cross Bhadra x Hraswa, additive x dominance in Vytila–3 x IR 36 and Bhadra x Hraswa. Positive significant effect was obtained for dominance x dominance for the crosses Vytila-3 x Hraswa, Vytila-3 x IR 36 and Bhadra x IR 60133. As interaction effect is predominant in the above said crosses, population improvement may be resorted to.

With respect to the character degree of panicle exsertion additive effect, dominance effect, additive x additive, additive x dominance were negative. In the case of dominance x dominance interaction effect, it was found that three crosses namely Vytila-3 x Hraswa, Bhadra x Hraswa and Bhadra x IR 60133 showed significant positive values. Hence in these cases, population improvement methods may be adopted.

11. Heterosis for grain yield per plant



12. Heterosis for % spikelet sterility

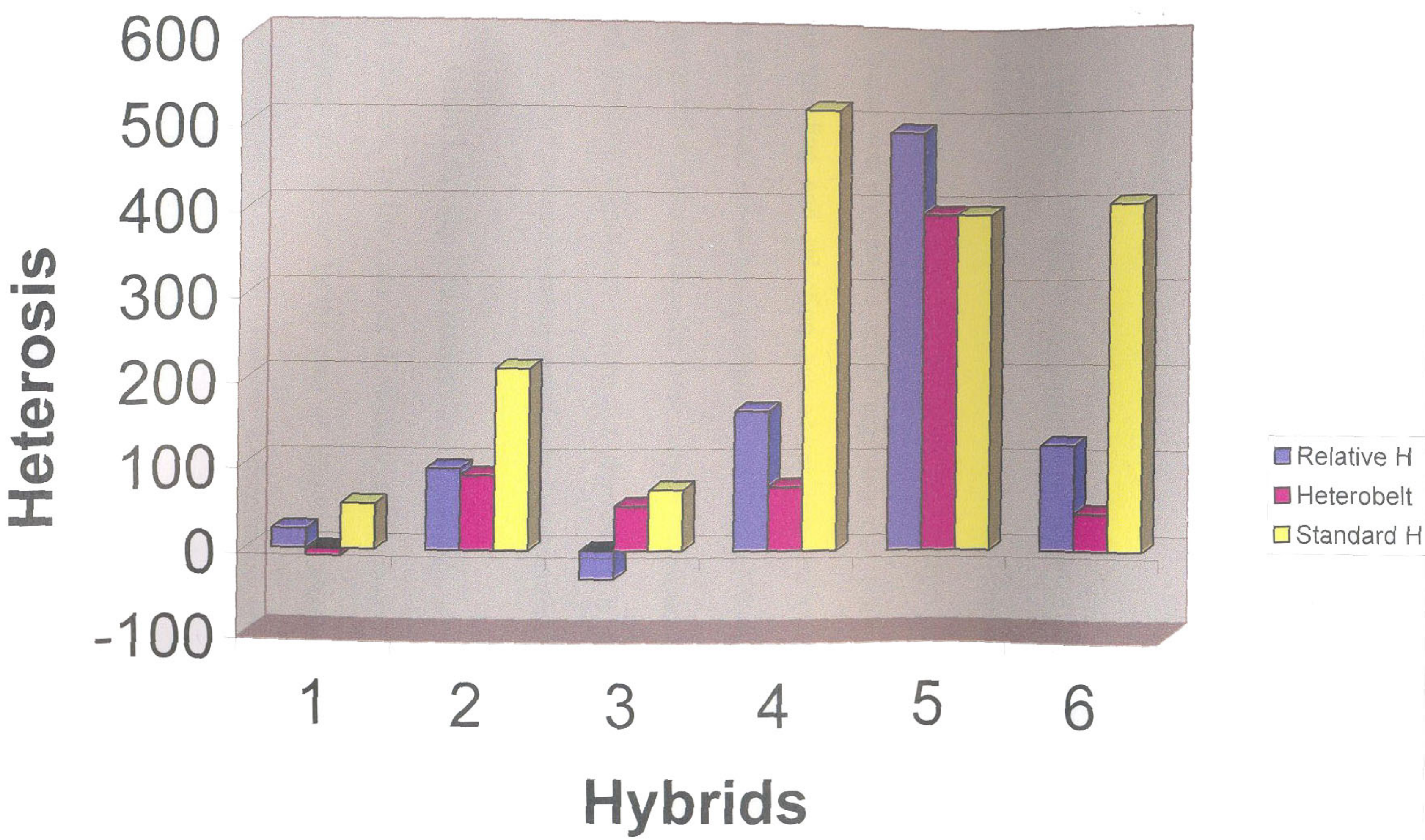


For angle of panicle exsertion, positive significant additive effect was obtained in the crossess Vytila-3 x Hraswa and Bhadra x IR 60133 suggesting further selection and improvement. Dominance effect attained negative values for three crosses except one, which was non-significant. Negative values were observed in the case of both additive x additive and additive x dominance interaction except in the case of Bhadra x IR 60133 which has taken a positive value. Positive significant dominance x dominance interaction effect was showen by all the four crosses, suggesting the need for population improvement by hybridization and selection.

For spikelets per panicle, four crosses namely Vytila-3 x Hraswa, Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133 took positively significant additive genetic values implying the fact that selection and improvement will result in the betterment of the crop. Negative values were observed in the case of dominance effect and additive x additive interaction effect. The cross Bhadra x Hraswa showed positive significant value for additive x dominance interaction. Positive values for dominance x dominance interaction was manifested in the case of Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133 implying that population improvement may be the better way for further improvement of this character.

Vytila-3 x Hraswa, Vytila-3 x IR 36 and Bhadra x IR 60133 showed positive additive effect for the character grain density suggesting selection and improvement. Dominance effect was positive and significant in two crosses

13. Heterosis for % pollen sterility



namely Vytila-3 x IR 36 and Bhadra x Hraswa. In Vytila-3 x IR 36, both selection and improvement and heterosis vigour may be utilized. Positive additive interaction effect was observed in one cross. In two crosses additive x dominance interaction effect was significantly positive. In Bhadra x Hraswa significant positive values were obtained for dominance x dominance interaction suggesting further enhancement by population improvement.

100 grain weight showed significant positive additive effect for three crosses namely Vytila-3 x Hraswa, Vytila-3 x IR 36, Bhadra x Hraswa suggesting selection and improvement may be the better way. Only Vytila-3 x IR 36 exhibited positive value for dominance effect implying that both development through heterosis breeding and selection procedures may be under taken. Additive x additive interaction effect was positive in the case of Vytila-3 x IR 36. Positive values for additive x dominance for three crosses have been observed. Two crosses exhibited positive significant values for dominance x dominance interaction suggesting further enhancement by population improvement.

Grain L/B ratio was positive and significant in Vytila-3 x Hraswa and Bhadra x Hraswa. In the case of dominance affect none of the crosses showed positive significant effect. In the case of Bhadra x Hraswa significant positive values were obtained for both additive x dominance effect and dominance x dominance effect. This suggests that for this particular cross selection as well as population improvement may be adopted.

For grain yield per plant two crosses showed significant values for additive effect and dominance effect. Vytila-3 x IR 36 showed significant positive values for both effects suggesting suitability of improvement by selection and utilization of heterosis vigour. Additive x additive interaction effect was significant in two crosses. Additive x dominance also showed positive significance in two crosses. Dominance x dominance interaction effect was significant in three crosses. This suggests enhancement by population improvement.

Significant negative additive effect was observed in three crosses namely Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133 in the case of percentage spikelet sterility. Some crosses exhibited significant negative values for dominance effect and additive x additive interaction effect. Selection, exploitation of heterosis and population improvement may be undertaken for the further decrease in this character.

For percentage of pollen sterility all the four crosses showed significant negative values suggesting that further decrease may be achieved by selection and improvement. Significant negative values were obtained for additive x dominance and dominance x dominance interaction, pointing towards population improvement for further increase of pollen sterility.

SUMMARY

6. SUMMARY

The salient findings of the study can be summarized as follows:

1. Four cross combinations of rice variety i.e., Vytila-3 x Hraswa, Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133 exhibited increase in male sterility with each step of backcrosses with pollen parent.
2. In the case of Vytila-3 x IR 36, 100 per cent male sterility was obtained in the F_2BC_3 generation. This points out the importance of backcrossing to evolve fully male sterile line in other crosses also.
3. The source of male sterile cytoplasm was confirmed to be that of saline tolerant rice variety Vytila-3 and Bhadra as per the result of backcrossing. Cytoplasmic male sterility exhibited by the cytoplasmic action of Vytila-3 and Bhadra was due to the nuclear interaction of IR 36, Hraswa and IR 60133. Crosses exhibiting cytoplasmic nuclear interaction and resulting in the manifestation of male sterility includes Vytila-3 x Hraswa, Vytila-3 x IR 36, Bhadra x Hraswa and Bhadra x IR 60133.
4. Cytoplasm of Vytila-3 and Bhadra were identified as alternative source of cytoplasmic male sterility suitable to warm humid tropical climate of Kerala. Varieties IR 36, Hraswa, IR 60133 are the derived maintainer lines.
5. With respect to grain yield contributing characters, the highest positive gca effect was observed in Bhadra followed by Mattatriveni. As the dominance variance of this character was higher than additive genetic variance, it can be assumed that there is scope for hybrid vigour exploitation.

6. The analysis of heterosis revealed that the extent of heterosis in rice was significant enough to explore the prospects of commercial hybrid suitable to warm tropical humid conditions.

7. Relative heterosis was positive and significant in the hybrids IR 36 x Mattatriveni, IR 36 x Karthika, Hraswa x Karthika, Hraswa x Vytila-3 and Hraswa x Bhadra for most of the yield contributing characters.

8. Heterosis over better parent was significant in IR 36 x Mattatriveni, IR 36 x Karthika, Hraswa x Karthika and Hraswa x Vytila-3 with respect to various characters.

9. Estimation of standard heterosis revealed that hybrids namely IR 36 x Mattatriveni, Hraswa x Karthika and Hraswa x Vytila-3 can be exploited as commercial rice hybrids.

10. Generation mean analysis revealed that the characters tillers at harvest, panicle length, spikelets per panicle, grain L/B ratio and percentage of pollen sterility were controlled by both allelic contributions and its interactive effects and hence for improving the characters hybridization and selection can be resorted to.

11. In the case of angle of panicle exsertion, grain density, 100-grain weight, percentage of spikelet sterility and grain yield per plant there is scope for improvement through both heterosis breeding and hybridization and selection.

12. Karthika and Mattatriveni were identified as possible fertility restorer for the evolved CMS lines like IR 36 under Vytila-3 cytoplasm.

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APPENDICES

APPENDIX – I

Meteorological data (monthly average) 1998

Month	Temperature (°C)		Mean (RH %)	Rainy days	Mean sunshine hours	Evaporation
	Maximum	Minimum				
January 1998	35.0	18.0	64	0	9.3	168.0
February	35.7	21.6	64	0	9.6	167.4
March	39.5	19.9	67	1	10.0	189.8
April	39.8	22.5	68	4	9.0	241.7
May	34.1	25.2	77	9	7.6	120.9
June	35.2	21.2	87	24	3.4	86.6
July	31.4	22.2	88	28	3.3	87.1
August	32.5	22.9	86	18	3.6	88.3
September	31.5	22.4	87	24	4.1	86.0
October	32.4	21.0	85	18	4.8	88.9
November	33.4	21.0	78	9	7.2	91.8
December	32.8	18.1	69	4	6.6	127.3

Meteorological data (monthly average) 1999

Month	Temperature (°C)		Mean (RH %)	Rainy days	Mean sunshine hours	Evaporation
	Maximum	Minimum				
January 1999	34.2	17.5	58	0	9.3	174.3
February	36.4	21.0	56	1	9.1	175.5
March	37.5	20.7	68	0	8.8	167.1
April	38.2	22.4	73	4	10.3	133.9
May	34.0	22.8	82	18	4.9	99.5
June	31.2	22.0	85	23	5.0	90.0
July	31.2	21.3	89	28	2.4	73.3
August	31.6	22.2	84	12	5.5	96.1
September	33.5	22.4	76	3	7.1	105.5
October	32.2	21.0	85	15	4.8	87.2
November	32.8	20.5	69	1	8.2	115.5
December	32.6	19.4	60	0	8.8	177.7

Meteorological data (monthly average) 2000

Month	Temperature (°C)		Mean (RH %)	Rainy days	Mean sunshine hours	Evaporation
	Maximum	Minimum				
January 2000	35.2	19.7	60	0	9.2	203.4
February	35.6	19.5	67	1	8.6	147.4
March	38.0	22.4	67	0	9.7	180.9
April	36.2	21.8	74	3	7.2	128.4
May	35.5	22.8	72	8	8.5	152.2
June	32.0	21.5	86	21	3.3	91.8
July	31.2	20.5	82	15	4.8	104.3
August	31.8	21.2	87	19	3.1	95.9
September	3.26	21.5	81	10	5.9	101.1
October	33.4	20.6	80	10	5.6	101.1
November	34.4	18.0	66	5	6.7	123.4
December	33.2	17.0	59	2	7.9	161.5

APPENDIX - II

Hybrid rice released in India

Hybrids	Year	State	Parentage	Duration	Yield	Character
APHR 1	1994	AP	IR 58025A/Vajram	130-135 days	7.14 t/ha	
APHR 2	1994	AP	IR 62829A/MTU 9992	120-125 days	7.52 t/ha	
CORH 1	1994	TN	IR 62829A/IR 10198-66.2R	110-115 days	6.50 t/ha	
CORH 2	1998	TN	IR 58025A/C20	125 days	6.10 t/ha	Saline tolerant
KRH 1	1994	Karnataka	IR 58025A/IR 9761	120-125 days	7.50 t/ha	
KRH 2	1995	,,	IR 58025A/KMR 3	135 days	9.30 t/ha	
CNRH 3	1995	WB	IR 62829A/Ajaya	125-130 days	7.49 t/ha	
DRRH 1	1996	DRR, HYD	IR 58025A/IR 40750	125-130 days	7.30 t/ha	
ADTRH 1	1999	TN	IR 58025A/IR 66R	115 days	6.40 t/ha	Moderately resistant to sheath blight, leaf folder, high tillering
Pant Sankar Dhan 1	1997	UP	IR 58025A/UPR-195-178A	115-120 days	6.5-7.0 t/ha	
Narendra Sankar Dhan 2	1998	UP	IR 58025A/NDR 3026-3-1-R	125-130 days	6.0-6.5 t/ha	
Sahyadri	1998		IR 58025A/BR 827-35-3-1-1-R	125-130 days	6.0-6.5 t/ha	

ALTERNATIVE SOURCES OF CYTOPLASMIC MALE STERILITY AND GENETIC ANALYSIS OF FERTILITY RESTORATION IN RICE (*Oryza sativa* L.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Investigation for alternative source of cytoplasmic male sterility suitable for warm humid tropical climatic conditions was conducted at Agricultural Research Station, Mannuthy and College of Horticulture, Vellanikkara (1998-2001). The study included the evolution of alternative source of cytoplasmic male sterility, potential CMS lines, screening of genotypes for fertility restoration and its genetic analysis. From the backcross experiments conducted, sterile cytoplasmic source was confirmed to be that of Bhadra and saline tolerant rice variety Vytila-3. The cytoplasmic nuclear interaction exhibited by various crosses studied, resulted in the manifestation of male sterility. The four cross combinations with Vytila-3 and Bhadra as cytoplasmic maternal sources exhibited increase in male sterility with each step of backcross. In the case of Vytila-3 x IR 36, 100 percentage male sterility was obtained in the F_2BC_3 generation. This points out the relevance of backcrossing to evolve fully male sterile line in other crosses also. With respect to grain yield and components, the highest positive gca effect was observed in Bhadra followed by Mattatriveni. Since the dominance variance of this character was greater than the additive genetic variance, there is scope for hybrid vigour exploitation. The estimation of heterosis in the case of hybrids produced was significant enough to explore the prospects of hybrid rice suited to warm humid tropics. Generation mean analysis revealed that the characters tillers at harvest, panicle length, spikelets per panicle, grain L/B ratio and pollen sterility percentage were controlled by both allelic contribution and its interactive effects and hence for improving the characters, hybridization followed by selection can be resorted to.