HETEROSIS AND COMBINING ABILITY STUDIES IN RICE (*Oryza sativa* L.) USING MALE STERILE LINES AS TESTERS

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Affectionately Dedicated to

My beloved Parents Sisters

and

BROTHERS

Department of Agricultural Botany,
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Bangalore

CERTIFICATE

This is to certify that the thesis entitled HETEROSIS AND COMBINING ABILITY STUDIES IN RICE (*oryza sativa* L.) USING MALE STERILE LINES AS TESTERS submitted by Mr. R.L. Ravi Kumar for the degree of MASTER OF SCIENCE (AGRICULTURE) in AGRICULTURAL BOTANY (Plant Breeding and Genetics) of the University of Agricultural Sciences, Bangalore, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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September 3 , 1983

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CONTENTS

LIST OF TABLES

LIST OF FIGURE

LIST OF PLATES

INTRODUCTION

I. INTRODUCTION

The exploitation of hybrid vigour is being extended to many crops following its success in crops such as maize, bajra and onion. The commercial utilization of heterosis requires some easy mechanism for F_1 seed production; among many such mechanisms tried so far, most attractive has been the use of male sterility. In fact, detection and use of male sterility has been rapidly increasing in the breeding of crop plants. Originally such attempts were somewhat confined to cross pollinated crops. But, of late it is being extended to self pollinated crops as well.

Rice, *Oryza sativa* L. is the main source of nourishment for over half the world's population, and even upto 80 per cent in south east Asia. About 414 million tonnes of rice is produced on about 145 million hectares of rice land all over the world. Asia tops the list in total rice production (376.2 million tonnes) and Australia in productivity (7179 kg/ha). In an area of about 40 million hectares, India produces 82 million tonnes, of which 2.3 million tonnes are produced in Karnataka, on 1.16 million hectares of rice land.

1960's saw a technical reform in rice production in India as well as in the world. Many changes have been introduced in the plant type, its duration, resistance to diseases and pests, response to manures, fertilizers etc., which made it possible to increase the production two fold. Also there was a steady increase in yield till late seventies. But the trend of yield increase is not maintained during the recent years in most important rice growing countries except China, giving an impression that there has been some plateauing in production. Exploitation of hybrid vigour is one possibility that would help to break this plateau and help further increase the rice production. Though reports of heterosis upto 186 per cent of the better parent were published as early as thirties, its commercial exploitation has been delayed for want of cheaper method of hybrid seed production.

Though male sterility in rice was reported as early as 1957, its practical use on commercial scale in the field started in late seventies in China (Lin and Yuan, 1980). In India too, rigorous search is being made in some institutions to identify male sterile lines, maintainers and restorers which would be economical under local conditions.

Male sterility was reported in Karnataka in early seventies (Mahadevappa, 1973a). But so far no attempt is made to develop sterility maintainers and to identify restorers for its commercial use. Therefore, in the present investigation, several varieties representing a wide genetic diversity were screened to identify maintainers and restorers, if any, to the male sterile lines included in this study.

In introducing the commercial cultivation of hybrids it is relevant to know the degree of outcrossing on male sterile lines, for it determines the amount of hybrid seed production which provides information to know the economic feasibility.

Heterosis of hybrids is important in any hybrid breeding programme. Understanding the magnitude of expression of heterosis for yield and yield contributing characters is a necessary step before embarking on hybrid rice breeding. This would help in the selection of potential parents, through general combining ability and specific combining ability effects.

Hence, the present investigation with three male sterile lines and 22 varieties was carried out with the following objectives.

i. to identify maintainers and restorers for male sterile lines;

ii. to estimate the magnitude of heterosis for yield and yield contributing characters;

iii. to estimate combining ability effects for different yield and yield contributing characters and

iv. to evaluate outcrossing rate on different male sterile lines due to different pollinators.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Literature on the subject of heterosis is vast. But that on the exploitation of hybrid vigour in self pollinated crops is limited. Hence a very brief and selected review on heterosis in general, and available literature on heterosis in rice and similar crops have been presented in this chapter.

Hybrid vigour, the manifest effect of heterosis has been one of the most interesting topics in the science of genetics as well as in plant breeding. Studies on hybrid vigour, in the beginning were mainly of academic interest. Various hypotheses have been advanced to explain the phenomenon. Theory of heterozygosity (Shull, 1908 and 1911; East, 1908), theory of dominance (Devenport, 1908; Bruce, 1910; Keeble and Pellow, 1910), theory of intra-allelic interaction (East, 1936), the super dominance or over dominance hypothesis (Hull, 1945), and physiological hypothesis (Ashby, 1930, 1932 and 1937) are some among the several hypotheses putforth. But consensus is that one or several of these hypotheses act alone or in combination for any given situation of heterotic effect.

Heterosis or hybrid vigour has been recorded in many crop plants; but it is successfully exploited only in a few of them due to limitations in large scale and economical hybrid seed production. The unisexual and monoecious nature of plant (maize), dichogamy (maize and bajra), male sterility (sorghum and bajra) and prolific seed production per hand pollination (tomato, brinjal, cotton and tobacco) have made large scale hybrid seed production possible and applicable under field conditions. Initially exploitation of hybrid vigour was restricted only to cross pollinated and often cross pollinated crops. But following the development of male sterile lines and of large scale hybrid seed production techniques, the exploitation of hybrid vigour is being attempted in self pollinated crops as well.

Rice is a self pollinated crop. Hence improvement in this crop has been largely through introduction, selection, mutation, hybridization. Recently, with the discovery of heterosis and male sterility, greater importance is being placed on the possibility of hybrids for commercial cultivation. Recent reports (Lin and Yuan, 1980; Viramani et al. 1981) have indicated that the rice hybrids in China and Philippines have shown 20-30% greater yield than non hybrid varieties under irrigated conditions. Lin and Yuan (1980) have reported that about 17 per cent of total rice area in China is currently under hybrids.

Singil'din (1978) outlined a scheme for producing a complex heterotic hybrid population using genetic male sterile plants, which performed best F_3 onwards in fertile population. However, to develop good hybrids it would be necessary to estimate the extent of heterosis and combining ability of the parents, to assess their potentiality. A brief review of the literature on heterosis and combining ability is presented below.

2.1. HETEROSIS

2.1.1. Plant height

Kadam et al. (1937) reported that in the varieties studied by them, the estimates of heterosis ranged from 2.00 to 2.39 per cent over the better parent and 7.48 to 84.05 over the inferior parent. Mitra (1962) in the crosses of winter varieties of rice, Patnai-23 and Bharamnik and summer varieties Charnock and Dharival observed hybrid vigour in F_1 generation. He further noticed that it persisted in F_2 generation and the mean height in F_2 generation exceeded tall parent. Heterosis for plant height was observed by Dzyuba (1975) in the F_1 and F_2 rice hybrids. He reported that the tallness is controlled by dominant gene and dwarfness by recessive gene. Mallick et al., (1978) reported that the heterosis was positive for this character in the crosses among six varieties. However, significant heterosis could not be detected for this character in some hybrids studied elsewhere (Dhulappanavar et al., 1970; Subbaiah Pillai, 1961).

In a diallel analysis, amongst number of varieties including IR 8 and Basmati 320, additive genetic effects were observed (Khan and Khan, 1980). Chan (1980) observed dominant effect for plant height in a diallel set between japonica and indica varieties.

2.1.2. Number of tillers per plant

Kadam et al. (1937) reported that the heterosis present for this character was 2.0 to 5.8 per cent over mid parent. Madhusudana Rao (1965), in a study of rice crosses, found that the hybrid with S1-013 as one of the parents showed high heterosis, hybrids producing 1.9 to 9.3 tillers more than the superior parent.

Marked heterosis was recorded in respect of number of tillers in three intervarietal hybrids by Dhulappanavar et al. (1970).

Khan and Khan (1980), in a diallel analysis amongst number of varieties including IR 8 and Basmathi 320, observed additive genetic effects to be in operation in controlling this character.

2.1.3. Number of panicle bearing tillers

Saini et al. (1974), in their study on panicle bearing tiller number in rice hybrids, reported that hybrid vigour in F_1 ranged from 0.14 per cent to 162.07 per cent over midparent and -8.73 to 71.85 per cent over better parent.

Shalaan et al. (1975) reported that the number of earbearing tillers per plant was quantitatively inherited and showed significant heterosis. Purohit (1972) and Singh and Singh (1978), in their study on rice hybrids, reported positive heterosis for this character in relation to better parent.

2.1.4. Length of the panicle

Dhulappanavar and Mensinkai (1967) reported that the panicle length in F_1s exceeded that of parents, indicating vigour to the extent of 13.79 per cent over the better parent and 29.14 per cent over the midparent. Maximum heterosis was recorded in S 199 x Warnar 1, next in order being T 65 x China 2 among the crosses studied by Dhulappanavar et al. (1970). Positive and significant heterosis was also observed for this character in the F_1 generation of the cross NC 1281 x Cauvery (Bardhan Roy et al., 1975). Similar results were also reported by Madhusudhana Rao (1965), Idsumi (1937) and Capinpin and Punyasingh (1938).

The length of the panicle exhibited significant heterosis in two rice corsses studied by Shalaan et al. (1975). Mallick et al. (1978) reported negative heterosis for the above chracter in the F_1 of crosses among six varieties. Shrivastava (1981) also observed significant heterosis for this character.

2.1.5. Days to maturity

In the F_1s of five crosses, Bardhan Roy et al. (1975) reported negative heterosis. Similar results were obtained by Purohit (1972) in the study of six crosses of rice. F_1 hybrids between Oryza glaberrima and Oryza sativa were found to be heterotic for earliness (Carpenter, 1975). Yap and Chang (1976) reported positive heterosis for this character.

2.1.6. Total spikelets per panicle

Dzyuba (1975) observed heterosis for number of spikelets per panicle in F_1 and F_2 hybrids of Redi x Cross 4428 and Krasanodar 424 x Ango. Similar reports were also obtained by Singil'din and Shilovskii (1977). Significant heterotic effect was found for the above character in a diallel cross among five varieties (Chatel and Dechanet, 1980). F_1 hybrids between two indica and two japonica varieties exhibited heterosis for the above character (Chan, 1980).

Mallick et al. (1978) reported negative heterosis for number of fertile grains per panicle in the F_1 of the crosses among six varieties, whereas Singh and Singh (1978) reported positive heterosis for this character.

2.1.7. Spikelet sterility

Rajagopalan et al. (1973), in their study of the tall and dwarf varieties reported that the spikelet sterility in the F_1s ranged from 12.9 to 81.8 per cent. Bardhan Roy *et al*. (1975) reported low but positive heterosis for spikelet sterility in the F_1s of four crosses of rice whereas Yap and Chang (1976), from a 5 x 5 diallel analysis, reported negative heterosis for this character. F_1 hybrids between *O. glaberrima* and *O. sativa* were found to be heterotic for spikelet sterility as reported by Carpenter (1975).

2.1.8. 1000 grain weight

Significant heterosis was observed for 1000 grain weight in crosses assessed by Dhulappanavar *et al*. (1970). Earlier reports by Capinpin and Punyasingh (1938) and Dhulappanavar and Menshinkai (1967) differ from each other, the first one failing to show heterosis and the second recording negative heterosis.

In one of the two crosses examined by Shalaan *et al*. (1975), significant heterosis for 1000 grain weight was observed. Chan (1980) reported heterotic effect for this character in the F_1s of the diallel cross between *indica* and *japonica* varieties.

2.1.9. Grain yield per plant

Shalaan *et al*. (1975) reported that the yield per plant was quantitatively inherited and heterosis for the

Table 1: Extent of heterosis and heterobeltiosis reported for various agronomic characteristics in rice

Character	No. of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	Reference
Yield	1	34.0	33.0	Pillai (1961)
	19		2.3 to 368.6	Rao (1965)
	20	-72.0 to 161.0	-81.0 to 57.0	Karunkaran (1968)
	19		-45.0 to 110.0	Carnahan *et al.* (1972)
	6	-8.05	- 5.06	Chang et al. (1973)
	12	-10.4 to 25.1		Mohanty and Mohapatra (1973)
	12	-16.6 to 48.5	-69.0 to 28.7	Sivasubramanian and Menon (1973)
	6	- 1.5 to 112.5		Saini and Kumar (1973)
	15	-90.72 to 156.7	-91.42 to 136.4	Saini *et al.* (1974)
	107	-61.6 to 167.4	-63.7 to 128.7	Parmar (1974)
	11	-40.0 to 71.0	-42.0 to 69.0	Murayama *et al.* (1974)
	1	91.9	- 8.7	Paramsivan (1975)
	45		-41.0 to 67.0	Davis and Rutger (1976)
	15	-58.6 to 55.5	-71.5 to 38.4	Khaleque *et al.* (1977)

Table 1 (contd.)

Character	No. of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	Reference
	6	1.9 to 21.9	-1.0 to 21.1	Mallick *et al.* (1978)
	21		37.0 to 125.0	Maurya and Singh (1978)
	2	33.32 to 64.3	1.9 to 22.0	Singh and Singh (1978)
Grain/panicle	1	133.1	127.0	Pillai (1961)
	4	3.4 to 20.2		Namboodiri (1963)
	19		-45.0 to 44.0	Carnahan *et al.* (1972)
	6	-2.3	-17.2	Chang *et al.* (1973)
	12	-35.5 to 43.2	38.1 to 8.8	Sivasubramanian and Menon (1973)
	12	-24.4 to 15.1		Mohanty and Mohapatra (1973)
	6	4.6 to 77.8		Saini and Kumar (1973)
	15	0.9 to 70.0	-6 to 19.7	Saini *et al.* (1974)
	1	-8.3	-12.3	Paramsivan (1975)
	19		-26.2 to 11.4	Rao (1965)
	22	-24.	-24.0 to 55.0	Davis and Rutger (1976)
	15	-39.4 to 73.0	-70.4 to 43.2	Khaleque *et al.* (1977)
	6	-34.2 to -7.3	-37.7 to -9.5	Mallick *et al.* (1978)

Table I (contd.)

Character	No. of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	References
Grain weight	1	105.1	99.1	Pillai (1961)
	4	0.6 to 3.8		Namboodiri (1963)
	11	-23.0 to 14.0	-26.0 to 14.0	Karunakaran (1968)
	19		-25.0 to 3.0	Carnahan <u>et al.</u> (1972)
	12	- 4.3 to 11.1		Mohanty and Mohapatra (1973)
	6	- 1.0 to 24.2		Saini and Kumar (1973)
	15	-15.9 to 23.7		Saini <u>et al.</u> (1974)
	107	- 4.8 to 17.4		Parmar (1974)
	1	-17.2	-23.3	Paramsivan (1975)
	22		-31.0 to 9.0	Davis and Rutger (1976)
	1	5.1		Pillai (1961)
	4	9.1 to 122.8		Namboodiri (1963)
	19		13.5 to 505.1	Rao (1965)
	1	71.9	16.6	Dhulappanavar and Mensinkai (1967)

Table 1 (contd.)

Character	No. of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	Reference
	11	-42.0 to 181.0	-43.0 to 128.0	Karunakaran (1968)
	19		-10.0 to 32.0	Carnahan <u>et al</u>. (1972)
	6	-18.3 to 20.3	-10.2 to -9.6	Chang <u>et al</u>. (1973)
	12	-14.7 to 84.8	-45.0 to -2.9	Sivasubramanian and Menon (1973)
	6	- 4.1 to -71.7		Saini and Kumar (1973)
	15	0.1 to 162.1	-8.7 to 71.9	Saini <u>et al</u>. (1974)
	107	- 5.8 to 192.0		Parmar (1974)
	12	-15.5 to 81.6		Mohanty and Mahapatra (1973)
	1	50.0	0.0	Parmsivan (1975)
	45		-31.0 to 19.0	Davis and Rutger (1976)
	6	5.8 to 76.9	-23.8 to 64.2	Mallick <u>et al</u>. (1978)
Plant height	1	100.2	99.8	Pillai (1961)
	4	14.9 to 42.7		Namboodiri (1963)
	19		-17.6 to 12.5	Rao (1965)
	1	20.5	4.8	Dhulappanavar and Mensinkai (1967)

Table 1 (contd)

Character	No. of hybrids studied	Heterosis (%)	Heterobeltiosis (%)	Reference
	20	-17.0 to 35.0	-37.0 to 33.0	Karunakaran (1968)
	6	10.8 to 10.2	- 2.1 to 1.8	Chang et al. (1973)
	12	0.9 to 15.9	-14.5 to 51.2	Sivasubramanian and Menon (1973)
	107	3.4 to 39.7		Parmar (1974)
	1	20.1	3.8	Paramsivan (1975)
	15	-20.6 to 40.3	-13.7 to 63.8	Khaleque et al. (1977)
	6	- 0.4 to 28.9	-14.9 to 25.1	Mallick et al. (1978)
Days to flower	4	- 0.6 to 10.1		Namboodiri (1963)
	1	- 6.2	-12.2	Dhulappanavar and Mensinkai (1967)
	20	-17.0 to 35.5	-37.0 to 27.0	Karunakaran (1968)
	6	-11.2 to -9.5	-19.8 to -16.4	Chang et al. (1973)
	15	-28.5 to 5.0	-12.9 to 12.3	Khaleque et al. (1977)
	6	-18.5 to 3.1	-19.8 to -4.7	Mallick et al. (1978)

character was significant in one of the two crosses. Singil'din (1978), while measuring heterosis for the main economic characters in hybrids, reported that the heterosis for the above character ranged from 11 to 23 per cent depending on the cross and the year. Similar findings have also been reported by Singh and Singh (1978) and Khaleque and Joarder (1978).

Maurya and Singh (1978) reported that eleven crosses exhibited heterosis over the better parent, although the yield components associated with this effect varied between crosses in several diallel sets. Srivastava (1981) observed heterosis and reported that yield per panicle and yield per plant were positively correlated with plant height. Noticeable heterosis over higher parent was also recorded in earlier reports (Kadam et al., 1937; Capinpin and Punyasingh, 1938; and Ramaiah, 1935).

Most of the available literature on extent of heterosis and heterobeltiosis in rice with respect of various characters is summarised in Table 1.

2.2. COMBINING ABILITY

Singh et al. (1977) in a study of six diallel crosses observed significant general combining ability and specific combining ability variances for panicle length, number of primary branches, spikelet number, 1000 grain weight and grain yield per plant. The highest general combining ability and specific combining ability effects for grain yield were produced by CH_4 and Badshahpasand x CH_4 respectively.

Singh et al. (1979) reported that specific combining ability variances were greater than those due to general combining ability, indicating the predominance of non-additive genes in the control of all the characters studied. Significant general combining ability effects were shown for all the characters except panicle length in most crosses involving IET 3618.

Rao et al. (1980) reported that the general and specific combining ability variances were significant for all 10 yield component characters in a diallel of seven varieties. Six agronomic and yield component characters were studied in the progeny of a 5 x 5 diallel and both additive and non-additive gene effects were detected for all the characters. Varieties with best general combining ability for different characters viz., number of days to heading, number of panicles, panicle length, height and yield per plant were identified. Similarly, varieties with good specific combining ability were also identified.

2.3. PERCENTAGE OF OUTCROSSING

Experience in China in hybrid seed production and hybrid cultivation has shown that raising male sterile lines (A and B) in one hectare would suffice to take up hybrid seed production in an area of 30 hectares (Anon. 1981) This would yield enough seeds for planting 1000 hectares. However, this ratio may vary based on technique employed in male sterile line, and hybrid seed production. Since paddy is a self pollinated crop, the percentage of outcrossing achieved plays an important role in commercialising hybrid rice cultivation.

Srinivasan and Subramanian (1961) reported that the percentage of natural cross pollination ranged from 0.04 to 0.03 and the distance upto which the natural cross pollination took place ranged from 6 to 7 feet from the pollinating agent.

The estimated natural cross pollination in two winter rice varieties by Palaniswamy and Rajagopalan (1964) ranged from 0.004% to 0.113%. Natural crosses were found in all directions and was not confined to any particular row indicating that the pollen travelled in all directions. The per cent natural crossing in the first row at one foot from the pollen parent in all the directions appeared to be similar.

Mahadevappa (1973b) observed 4 per cent of cross pollination when male sterile plants were grown along with the varieties. He also observed as high as 24 per cent seed set on the male sterile plant and about 50 per cent on some panicles by open anemophily and controlled pollination.

Repev *et al.* (1975) reported that among the hybridization methods tested, the one giving the best results involved emasculation and shaking the inflorescence of female parent together with 4-5 panicles of the males. The percentage success in crosses reached 41 in 21 crosses of Soviet varieties. The highest seed set was achieved at an air temperature of 24-27°C during pollination.

Viramani *et al.* (1980) during the dry season planted two cytosterile lines along with their respective maintainer lines as pollen source in two isolation plots with a planting ratio of 1:5. The outcrossing on male sterile plants ranged from 35 to 40 per cent. The male sterile line Zhenshan 97A showed higher seed set than V20A because of its better panicle exsertion and synchronised flowering in relation to the pollen parent. The higher seed set was observed on the male sterile plants planted across the wind direction.

Azzini and Rutger (1982) reported that the amount of outcrossing on three short statured male steriles of rice, when planted in alternate rows with tall cultivars was very poor in case of genetic male sterile lines, indicating that this type cannot be considered useful in hybrid seed production. But cytoplasmic male sterile lines showed average seed set of 5.4 per cent in 1978 and 32.5 per cent in 1979. The higher seed set in 1979 was due to better synchronisation.

Sharma et al. (1982) evaluated outcrossing potential of V20A, a cytosterile line, under open pollination using V20B as pollinator. Both were grown in isolated plots in two seasons and the B-line was staggered planted to provide male sterile plants a substantial pollen load for two to three weeks. There was no significant difference in seed set in two dry seasons (22.6 per cent in 1981 and 26.3 per cent in 1982). They opined that spraying gibberellic acid, flag leaf cutting and synchronised flowering may enhance the seed set potential of the male sterile line.

2.4. MALE STERILITY

In the entire plant kingdom, species flowering annually (which must reproduce by means of seed) tend to be easily, if not obligately, self fertilized (Rick and Butler, 1956; Watts, 1963; Rowlands, 1964). Some species tend to have mechanisms such as dioecism, monoecism, heterostyly, protandry, self-incompatibility and male sterility which promote cross pollination. Male sterility was exploited in many crops such as sorghum, bajra, maize, onion, sugarbeet etc., and as early as in 1962 the impact was so high that it was estimated that 23 per cent of all onions produced were hybrids; 60 per cent of total sugarbeet were hybrids; corn hybrids occupied 85 per cent of the total corn acreage, and hybrid grain sorghum was grown on 90 per cent of the total acreage. Earlier, the exploitation of advantages of male sterility were restricted to only cross pollinated crops. But now it has been successfully utilised in highly self-pollinated crops also such as wheat, tobacco, carrots, tomato etc., and rice is one among them.

Though the existence of male sterility in rice was discovered as early as 1927, it is only in 1950's that the genetic and cytological study of male sterility was initiated. Because the work on breeding of male sterile lines, maintainers and restorers was slow till 1972 and little information was known on pollen abortion (Anon. 1981). A brief review on male sterility in rice is given under different headings.

2.4.1. Genetic male sterility

Field observations over three years by Trees and Rutger (1978) on P, F_1, F_2 and F_3 of crosses with male sterile plants of five cultivars revealed that the male sterility from each source is controlled by a single recessive gene. Some male sterile lines showed little or no stainable pollen when tested with iodine, whereas others produced much stainable pollen and were considered to be functionally sterile due to morphological disorders.

Singh and Ikehashi (1979) reported that monogenic recessive male sterility can be induced by use of a chemical mutagen-ethylenimine. Thus male sterile lines have shown excelled crossability with their male fertile parent. A few male sterile lines showed good panicle exsertion and hence had high outcrossing percentage.

2.4.2. Cytoplasmic genic male sterility

Watanabe (1971) obtained a cytoplasmic-genetic male sterile line in the progenies of the cross between 'Lead' Burmese variety (indica) and 'Fujisabea-5" a Japanese variety (japonica). The sterile line with the nucleus of 'Fujisabea-5' in the cytoplasm of 'Lead' showed almost complete sterility.

Kinoshita et al. (1980) reported that reciprocal differencesof pollen and spikelet fertility were observed in the F_1 hybrids from a diallel between four Japanese and four Indian varieties. Hence hybrid male sterility was caused by the interaction between the cytoplasm and nuclear genes. True breeding male sterile lines were produced after seven to ten back crosses to the recurrent parent.

Parmer et al. (1981) conducted many reciprocal and various back crosses involving known sources of cytoplasmic male sterility. They attributed male sterility to nuclear genes in a few lines and they also reported cytoplasmic male sterility-fertility restorer system.

2.4.3. <u>Pollen abortion</u>

Pollen abortion occurred in most of the male sterile lines at the uninucleate stage, when tapetal cells degenerated abruptly as a result of the rapid enlargement and vacuole formation of the middle layer cells. Pan (1979) observed that the vascular bundles in the filaments were poorly differentiated with 50 per cent aborted pollen grains in the anthers, while in the anther with only 20 per cent aborted grains, the vascular bundle was apparently normal in filament. Anther culture was performed by Ling <u>et al</u>. (1981) with three diverse lines possessing cytoplasmic male sterility. Based on the stage at which microsporic abortion occurred, three groups of cytoplasmic lines were observed - pollen abortion during (i) the post meiotic tetrad stage, (ii) the pre-binucleate phase and (iii) after normal pollen development.

2.5. IDENTIFICATION OF MAINTAINERS AND RESTORERS

Yuan Long-ping started research on male-sterility and its utilization in rice as early as 1964. He found a common wild rice plant with abortive pollen on Hainan Island only in 1970. By repeatedly crossing to rice cultivars (♂), a male sterile line, maintainer line and restorer line were successfully developed by 1973, and a group of superior cross combinations were identified. The hybrid rice was planted experimentally with success in 1974 and hybrid rice was popularised in 1976 on a large scale (Anon. 1981).

In India, Mahadevappa (1973a) crossed 21 varieties to male sterile plants and indicated wide scope for obtaining both the fertility restorers as well as sterility maintainers to Karnataka male sterile line-1.

In Japan, of the 511 varieties crossed with a completely male sterile strain of Taichung-65 with cytoplasm from 'Lead' rice, 175 were identified as restorers and almost all of these being from Southern Japan (Ishimine and Shinjo, 1978). Ishimine and Shinjo (1978) reported that, of the 219 varieties crossed with a completely male sterile strain, 22 from North Japan and five fromthe South were restorers. of the non-restorers, 111 were from the North and 75 from the South. All the 214 varieties crossed with a completely male sterile line with cytoplasm _O. perennis_ (CMS_3) were non-restorers.

It is reported that out of many elite lines utilised, IR 747 B-6-3 and IR 10154-23-3-2 were effective maintainers of cytoplasmic male sterility while IR 279-105-2-3 were restorers of fertility of Zhenshan 97A and V20A (Anon. 1980). The IRRI varieties IR 24 and IR 26 were used extensively as restorers in hybrid rice breeding in China.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The present investigation was carried out in the wet lands of the Main Research Station (MRS), University of Agricultural Sciences, Hebbal, Bangalore during summer and *Kharif* seasons of 1982. The experiment included 22 varieties and three male sterile lines. The soil type of the experimental plot was sandy loam and pH 6.5. The irrigation was provided throughout the growth period. The monthly rainfall, average maximum and minimum temperature, relative humidity and sunshine hours during the experimental period are presented in appendix I.

3.1. Material

Twenty-two varieties commonly cultivated in the area were selected as male parents along with three male sterile lines as female parents (Table 2). Male sterile lines included were those developed from the cross IR 8 and C-435 (Jeerigesanna) at the Regional Research Station, Mandya and are being extensively used for many studies in different research institutions (The International Rice Research Institute, Tamil Nadu Agricultural University, Andhra Pradesh Agricultural University and also in different sections of the University of Agricultural Sciences, Bangalore).

3.2. Methods

3.2.1. Crossing technique

Rice is a highly self pollinated crop and the

Table 2: List of male and female parents included in the present investigation

Male parents

1. Bilikagga	9. KMP 104	17. Sona
2. Basumathi	10. KMP 249	18. TN 1
3. ES 18	11. Mangala	19. Telhamsa
4. IR 36	12. MR 365	20. Type 3
5. IET 7031	13. Pragathi	21. Vikram
6. IET 5909	14. Palguna	22. Vani
7. Intan mutant	15. Purple puttu	
8. KMP 39	16. Pushpa	

Female parents

1. KMS-1
2. KMS-4
3. KMS-5

percentage of outcrossing is very low. Hence, pollination is supplemented by many techniques of which the following two methods were employed in this study.

3.2.2. Top leaves cutting

Wherever the top leaves of the parents were prominent, erect and covering the panicle, the top leaves were cut and the panicle was better exposed thereby facilitating free pollen dispersal in order to increase the percentage of outcrossing.

3.2.3. Contact method

The panicles of the male parent were brought near the female panicle during anthesis. This increases the chances of pollen deposition on female plant.

Using these techniques, hybrids were produced and 66 true hybrids were identified by looking in the hybrid for one or two dominant characters of the male parent.

3.3. Experimental lay-out

3.3.1. Production of hybrids

The 22 varieties and 3 male sterile lines were raised and were transplanted in the main field as shown below during summer 1982, with a spacing of 20 cm between rows and between plants within each row.

x x x x x x x x x x x x x

x x x x x x x x x x x x x

▲▲ 0 0 ●●

x x x x x x x x x x x x x

x x x x x x x x x x x x x

x = male parent

0 = KMS-1

▲ = KMS-4

● = KMS-5

All the three male sterile lines were stubble planted with two rows of a male parent on either side. The crop was supplied with 62:62:62 kg of $N:P_2O_5:K_2O$ per hectare, as basal dose and 62 kg of N/ha as top dressing in two split doses of 31.00 kg/ha at 30th and 60th day after transplanting. The synchronisation in flowering was achieved by cutting the tillers which bloomed early.

3.3.2. Evaluation of hybrids

The 91 entries viz., 66 hybrids, 22 male parents and 3 female parents were evaluated in Kharif 1982. The hybrids were planted between male and female rows with a spacing of 20 cm both between rows and plants. Such rows of hybrids, males and females were randomized. The crop was supplied with 50:50:50 kg of $N:P_2O_5:K_2O$ per hectare as basal dose and 50 kg of N/ha as top dressing in two split doses of 25 kg/ha at 30th and 60th day after transplanting. All the practices recommended for the crop were followed.

3.4. Recording observations

Five randomly chosen plants in each of the hybrid, male and female parent were tagged for observation. The observation as per the recommendation given in 'Descriptor for rice' by IBPGR-IRRI Rice Advisory Committee were recorded. However, the detailed procedure is given below.

3.4.1. Percentage of outcrossing

Number of fertile spikelets and number of unfilled spikelets in each panicle of female parent in the first crop was counted. The ratio of number of fertile grains to the total number of grains was expressed as percentage of outcrossing due to each male parent.

3.4.2. Number of days to 50% flowering

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

3.4.3. Plant height

Plant height was measured in centimeters from the ground level to the base of the panicle after completion of heading.

3.4.4. Total number of tillers per plant

The number of tillers in each plant was counted after 45 days of transplanting.

3.4.5. Number of productive tillers per plant

The number of productive tillers per plant was recorded after full heading as the total number of panicle bearing tillers.

3.4.6. Length of the panicle

Length of the panicle was measured in centimeters from the base to the tip of the panicle at maturity.

3.4.7. Days to maturity

maturity was recorded as the duration in days from seeding to the time when more than 80 per cent of the grains on the panicles were fully ripened. This was also attained by adding 35 days to the number of days to 50% flowering.

3.4.8. Number of spikelets per panicle

The total number of filled and chaffy spikelets per panicle was counted.

3.4.9. Spikelet sterility

Spikelet sterility readings were obtained from counts of chaffy grains in proportion to total number of spikelets on panicles.

3.4.10. Pollen sterility

The pollen grains were stained with acetocarmine and the number of fertile and sterile pollen grains (as classified by Chaudhary *et al.* 1981) were counted in each microscopic field. The ratio of number of sterile pollen to the total number of pollen was expressed as percentage sterility.

3.4.11. Yield per plant

The filled grains obtained from each plant after threshing were dried and the weight was recorded in grams.

3.4.12. Thousand grain weight

A random sample of 1000 well developed, whole grains dried to 13 per cent moisture content was weighed for each hybrid and male parent and weight was recorded in grams.

Since there is no seed set in the female plants the yield per plant and 1000 grain weight was not recorded.

3.5. Statistical analysis

3.5.1. Analysis of variance:

The mean of five randomly selected plants in each cross and parental lines for the above said characters were utilised for statistical analysis and variance due to different sources were worked out and tables were constructed in the following pattern for each character separately.

ABOVA TABLE FOR PARENTS AND HYBRIDS

Source	d.f.	S.S.	Mean sum of squares
Treatments	(t-1)		
Parents	(p-1)		
Parents Vs Crosses	1		
Crosses	(mf-1)		
Lines	(m-1)		M_1
Testers	(f-1)		M_2
Lines x Testers	(m-1)(f-1)		M_3
Error	t(r-1)		M_4
Total	tr-1		

Where r = number of replications

m = number of male parents

f = number of female parents

p = parents

t = total treatments

3.5.2. <u>Estimation of combining ability</u>

Combining ability estimates were computed following the procedure given by Singh and Chaudhary (1977). The model used to estimate general combining ability (GCA) and specific combining ability (SCA) effects of ijk observation is given below.

$$X_{ij} = u + g_i + g_j + S_{ij} + e_{ijk}$$

Where u = population mean

g_j = GCA effect of j^{th} female effect

g_i = GCA effect of i^{th} male parent

S_{ij} = SCA effect of ij^{th} combination

j = Number of female parents

i = Number of male parents

k = Number of replications

The individual effects were estimated as indicated below.

(a) Estimation of GCA effects of lines (males)

$$g_i = \frac{X_{i...}}{fr} - \frac{X..........}{mfr}$$

Where $X_{i...}$ = total of i^{th} male parent over all female parents and replications and X... is grand total

(b) Estimation of GCA effects of testers (females)

$$g_j = \frac{X_j}{mr} - \frac{X...}{mfr}$$

Where X_j = total of j^{th} female parent over all female parents and replications.

(c) Estimation of SCA effects

$$S_{ij} = \frac{X_{ij}}{r} - \frac{X_{i...}}{fr} - \frac{X_{j...}}{mr} + \frac{X_{....}}{mfr}$$

Where ij = ijth combination total over all the replications

The following standard errors were used to test the significance of GCA and SCA effects

$$SE\ (\text{GCA for line or males}) = \sqrt{\frac{M_4}{r \times f}}$$

$$SE\ (\text{GCA for females}) = \sqrt{\frac{M_4}{r \times m}}$$

$$SE\ (\text{SCA effects}) = \sqrt{\frac{M_4}{r}}$$

3.5.3. Estimation of heterosis

The mean value for each character of each parent or hybrid was determined from over replications and taken for the estimation of heterosis. Heterosis over midparent (MP), better parent (bP) and Best parent (BP) were computed by the methods of Turner (1953) and Hayes et al. (1955). Heterosis was calculated as the percentage increase or decrease of mean F_1 performance.

$$\text{Midparent value (MP)} = \frac{\bar{P}_1 + \bar{P}_2}{2}$$

Where $\bar{P}_1$ = Parent 1, i.e., male parent

$\bar{P}_2$ = Parent 2, i.e., female parent

$$\text{Above midparent value} = \frac{F_1 - MP}{MP} \times 100$$

$$\text{Over that of Better parent value} = \frac{F_1 - bP}{bP} \times 100$$

$$\text{Over that of Best parent value} = \frac{F_1 - BP}{BP} \times 100$$

The following standard errors were used to etest the significance of heterosis:

$$SE\ (MP) = \sqrt{\frac{3M_4}{2r}}$$

$$SE\ (BP) = \sqrt{\frac{2M_4}{r}}$$

M_4 = Error mean sum of squares

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the experiment on identification of maintainers and restorers, estimation of combining ability effects, outcrossing and heterosis in hybrids involving 22 varieties, 3 male sterile lines and 66 hybrids are presented in this chapter under the following headings.

1. Analysis of variance for parents and crosses.
2. Magnitude of heterosis
3. Combining ability effects:
   (a) General combining ability effects
   (b) Specific combining ability effects
4. Percentage of seed set in different male sterile lines with different varieties.
5. Fertility restoration.

4.1. Analysis of variances for parents and crosses

The ANOVA showing mean sum of squares for the characters - plant height, total tillers, productive tillers, panicle length, spikelet sterility, number of spikelets per panicle and grain yield per plant are presented in Table 3.

The mean sum of squares for treatments was significant at one per cent level for all the characters.

Table 3: Variances due to treatments for characters in rice

Source	Characters						
	Plant height	Total tillers	Productive tillers	Panicle length	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant
Treatments	1147.06**	245.52**	163.87**	25.50**	6674.35**	5320.63**	334.87**
Parents	1455.98**	88.64	65.99	23.74**	5547.02**	5656.72**	162.08**
Crosses	1050.63**	198.24**	131.25**	24.93**	5631.26**	2874.26**	361.84**
Parents Vs Crosses	1153.99**	7084.13**	4633.41**	104.88**	101530.85**	156268.63**	2211.11**
Lines	1504.17**	97.59	66.32	25.54**	6016.02**	1501.16**	-
Testers	592.48**	11.83	26.24	3.93	3213.33	2.13	-
Lines x Testers	845.68**	257.45**	168.71**	25.58**	5554.03**	3697.58**	-
Error	16.39	84.79	49.90	2.13	1440.73	300.61	73.20
CD at 5%	7.66	8.07	6.19	1.28	23.52	10.74	7.49
CD at 1%	10.04	10.58	8.12	1.68	30.85	14.09	9.83

**Significant at 1% level

Hence, treatment sum of squares for all characters were further partitioned and the variances due to parents were found significant for all the characters except for two viz., total number of tillers and productive tillers. Variances due to crosses were found significant for all the characters studied. Significant variances were found for all the characters due to parents Vs crosses. The variances due to males (lines) were significant for the characters, plant height, panicle length, number of spikelets per panicle, sterility percentage and grain yield per plant at 1 per cent level, while for the total tillers and productive tillers the variability was not significant. But female lines (testers) were less variable in respect of all the characters studied and significant variance was found only in plant height. Mean sum of squares due to line x tester were significant for all the characters. So line x tester interaction was significant in the experiment.

The mean sum of square values were found significant for most of the characters studied due to males in comparison to testers. Similarly, males are less variable when compared to crosses, parents Vs crosses and lines x testers. Hence greater variability was found in crosses when compared to parents. Among parents the testers were found to be less variable, less diverse and more uniform than the males.

Due to sterility of hybrids, the seeds obtained were not sufficient hence the two characters, namely, days to maturity and 1000 grain weight were taken at random and not replicationwise. Hence these two characters were not included in the ANOVA table.

4.2. Magnitude of heterosis

Heterosis was studied for nine characters by comparing the mean values of F_1 with midparent (MP), better parent (bP) and the best parent (BP). The difference was multiplied by hundred and heterosis was expressed as percentage. The data obtained for the following characters viz., plant height, total tillers per plant, number of productive tillers per plant, panicle length, days to maturity, number of spikelets per panicle, spikelet sterility, yield per plant and 1000 grain weight are presented in Tables 4 to 12, respectively. The results are presented below for different characters.

4.2.1. Plant height: Type 3 had the highest (110.40) and KMS 249 had the lowest (52.10) plant height among male parents while KMS-1 and KMS-5 recorded the highest (72.52) and the lowest (52.00) plant height among females. Of the 66 hybrids, hybrid KMS-1 x Intan mutant recorded maximum plant height (116.80) and hybrid KMS-5 x ES 18 recorded the minimum (57.40). Heterosis ranged from -10 to 124.18 per cent for plant height.

TABLE 4 : Magnitude of heterosis for plant height (%)

Sl. No.		Mp	bp	Bp		Mp	bp	Bp		Mp	bp	Bp
1	KMS-1 X Bilikagga	02	27.96**	78.1**	KMS-4 X Bilikagga	14**	67.97**	80.4**	KMS-5 X Bilikagga	-07**	41.5**	41.5**
2	" X Basumathi	10**	35.96**	89.2**	" X Basumathi	-10**	30.8**	40.4**	" X Basumathi	05	56.9**	56.9**
3	" X ES18	36**	47.09**	75.04**	" X ES18	14**	19**	38.6**	" X ES18	04	10.3*	10.3*
4	" X IR36	54**	62.07**	103.4**	" X IR36	31**	41.17**	51.6**	" X IR36	08	18.4**	18.4**
5	" X IET7031	23**	40.65**	95.7**	" X IET7031	10**	41.17**	51.6**	" X IET7031	16**	56.9**	56.9**
6	" X IET5909	33**	47.54**	105.3**	" X IET5909	18**	52.6**	63.9**	" X IET5909	30**	71.9**	71.9**
7	" X Intan mutant	49**	59.9**	124.18**	" X Intan mutant	18**	47.9**	58.9**	" X Intan mutant	23**	58.20**	58.20**
8	" X KMP39	47**	73.86**	76.19**	" X KMP39	29**	32.19**	33.97**	" X KMP39	22**	19.23**	19.23**
9	" X KMP104	28**	28.25**	77.7**	" X KMP104	30**	47.96**	58.9**	" X KMP104	29**	50.0**	50.0**
10	" X KMP249	31**	56.6**	56.6**	" X KMP249	39**	43.95**	43.95**	" X KMP249	23**	19.6**	19.6**
11	" X Mangala	21**	21.3**	68.9**	" X Mangala	08**	23.48**	32.6**	" X Mangala	62**	90.3**	90.3**
12	" X MR365	15**	15.72**	58.54**	" X MR365	29**	46.17**	57.00**	" X MR365	04	20.3**	20.3**
13	" X Pragathi	30**	38.58**	65.45**	" X Pragathi	27**	34.02**	43.95**	" X Pragathi	20**	28.8**	28.8**
14	" X Palguna	27**	43.25**	58.9**	" X Palguna	29**	30.45**	40.11**	" X Palguna	22**	25.76**	25.76**
15	" X Purple puttu	35**	45.3**	73.5**	" X Purple puttu	12**	17.22**	25.9**	" X Purple puttu	24**	32.69**	32.69**
16	" X Pushpa	06	10.0**	53.16**	" X Pushpa	21**	44.74**	55.5**	" X Pushpa	12**	36.5**	36.5**
17	" X Sona	22**	33.5**	55.85**	" X Sona	09*	12.9**	21.3**	" X Sona	14**	20.38**	20.38**
18	" X TN1	-08*	-01	18.6**	" X TN1	18**	23.30**	32.4**	" X TN1	13**	21.03**	21.03**
19	" X Telhamsa	11**	15.6**	47.4**	" X Telhamsa	25**	35.8**	45.87**	" X Telhamsa	59**	75.96**	75.96**
20	" X Type3	18**	47.5**	106.14**	" X Type3	01	45.8**	56.6**	" X Type3	03	57.3**	57.3**
21	" X Vikram	30**	36.7**	72.7**	" X Vikram	41**	52.9**	64.29**	" X Vikram	10*	21.92**	21.92**
22	" X Vani	57**	79.09**	95.7**	" X Vani	31**	32.23**	42.02**	" X Vani	31**	33.46**	33.46**

* Significant at 5 per cent level.
** Significant at 1 per cent level.

KMS-5 had minimum plant height, and was considered as the best parent for the purpose of this analysis. All the 66 hybrids showed significant positive heterosis above the best parent and none exhibited negative heterosis. Though hybrid KMS-5 x ES 18 showed the least hybrid vigour (10.3) it was significant while hybrid KMS-1 x Intan mutant had maximum hybrid vigour over the best parent.

Minimum, non-significant, negative heterosis (-01) was observed in KMS-1 x TN 1 over better parent and the maximum (90.3) was in KMS-5 x Mangala; 65 hybrids manifested significant positive hybrid vigour and one hybrid showed negative but non significant heterosis over better parent.

Sixtythree hybrids exhibited positive heterosis out of which 55 exhibited significant hybrid vigour over midparent. Three hybrids recorded negative heterosis and all the three were significant over midparent. Heterosis over midparent ranged from -10 to 62.

Significant heterosis over MP, bP and BP was observed in 57 hybrids for this character. Fiftyfour out of 57 manifested significant positive heterosis in comparison with MP, bP and BP for plant height.

4.2.2. Total number of tillers per plant: Among male parents, variety Sona showed the highest tiller number (28.20) and variety IET 7031, the lowest (12.60). Of

TABLE 5 : Magnitude of heterosis for total tillers (%)

Sl. No.		Mp	bp	Bp		Mp	bp	Bp		Mp	bp	Bp
1	KMS-1 X Bilikagga	87**	51**	19.8	KMS-4 X Bilikagga	116**	81**	31.2*	KMS-5 X Bilikagga	96**	57**	31.20
2	" X Basumathi	35*	18*	-06	" X Basumathi	35**	22.3**	-11.3	" X Basumathi	91*	63.4**	36.17
3	" X ES18	46	45	15.6	" X ES18	73	64	30.4	" X ES18	36	32.76	10.63
4	" X IR 36	11	10.6	-11.3	" X IR36	-26	-30	-43.9	" X IR36	67**	63.4**	36.17
5	" X IET7031	67*	30.3	02	" X IET7031	43	14.5	-17	" X IET7031	29	-01	-17.7
6	" X IET5909	52*	36.7	07	" X IET5909	38	28.18	-07	" X IET5909	49*	31	09.2
7	" X Intan mutant	20	16.9	-08	" X Intan mutant	68**	64*	23	" X Intan mutant	34	27.65	06.3
8	" X KMP39	34	29	09	" X KMP39	69**	55*	31.9*	" X KMP39	63**	61**	37.58
9	" X KMP104	04	00	-21	" X KMP104	32	31	-04	" X KMP104	50*	41.27	17.7
10	" X KMP249	80**	58.2**	34.8	" X KMP249	57*	42.6	0.03	" X KMP249	113**	83.8**	53.19
11	" X Mangala	-02	-07	-18	" X Mangala	-01	-10	-20	" X Mangala	-21	-23	-31.9
12	" X MR365	26	10.6	-13	" X MR365	18	12.5	-18	" X MR365	56**	49.79*	24.8
13	" X Pragathi	51	16.9	-08	" X Pragathi	115**	73.19**	25.5	" X Pragathi	29	00	-16.3
14	" X Palguna	03	-10.9	-29	" X Palguna	33	18.39	-14	" X Palguna	25	05	-12.05
15	" X Purple puttu	37	19.60	-06	" X Purple puttu	65*	47.7	07	" X Purple puttu	89**	60.85**	34.05
16	" X Pushpa	52*	42*	28	" X Pushpa	44	27	13.5	" X Pushpa	05	01	-09
17	" X Sona	-08	-17	-18	" X Sona	-03	-17	-17	" X Sona	-09	00	-16.3
18	" X TN1	-03	-09	-18	" X TN1	-22	-30	-36.9	" X TN1	04	08	-09.2
19	" X Telhamsa	69**	65**	36.1*	" X Telhamsa	62**	52*	24.8	" X Telhamsa	39.3	39.63	16.13
20	" X Type3	13	-02	-22.6	" XType3	54	37.96	00	" X Type3	53*	30.21	08.51
21	" XVikram	26	19.6	-06	" X Vikram	43	40.9	02	" X Vikram	44	36.6	11.34
22	" X Vani	14	10.6	-11	" X Vani	00	-05	-24	" X Vani	21	0.19	-01.7

* Significant at 5 per cent level.
** Significant at 1 per cent level.

females, line KMS-5 showed the highest tiller number (23.50) and KMS-4 the lowest (20.44). Among hybrids KMS-5 x KMP-249 recorded the maximum (43.20) and hybrid KMS-4 x IR 36 recorded the minimum number of tillers (15.80). The parent having highest number of tillers was considered as the best parent. Out of 66 hybrids, 33 showed negative heterosis 32 positive heterosis and in one hybrid there was no heterosis over the best parent. But only three hybrids manifested significant positive heterosis.

Heterosis over better parent ranged from -30 to 83.80 per cent. Most of the hybrids except 12 showed positive heterosis. Eighteen out of 54 hybrids exhibited significant positive heterosis and none manifested significant negative heterosis.

As compared to mid parent none of the hybrids showed significant negative heterosis. Twentyfive hybrids recorded significant positive heterosis, while 57 hybrids recorded positive heterosis though not statistically significant. Heterosis ranged from -26 to 116 per cent over midparent. Nine hybrids recorded negative heterosis but none was significant.

The hybrids KMS-1 x Telhamsa, KMS-4 x Bilikagga and KMS-4 x KMP 39 manifested significant heterosis over MP, bP and BP. Significant heterosis over midparent and better parent was observed in 15 hybrids. All the six hybrids having Bilikagga and Basumathi as male parents manifested significant hybrid vigour over both mid parent and better parent. None of the 22 hybrids having KMS-5 as female parent showed significant heterosis over the best parent, while one having KMS-1 and two hybrids having KMS-4 as female parent manifested significant heterosis over the best parent.

4.2.3. Productive tillers per plant: Productive tillers number is an important character for yield. Heterosis for this character ranged from -46 to 139 per cent and all the hybrids showed positive heterosis over midparent except KMS-4 x IR 36, KMS-5 x Mangala and KMS-4 x Sona which showed negative but non-significant heterosis.

Thirty-three hybrids expressed significant positive hybrid vigour and 30 showed positive but non significant heterosis over midparent. As compared to midparent the maximum heterosis was observed in KMS-4 x Bilikagga (139%) while the minimum was in KMS-4 x Sona (-21). Hybrids having Bilikagga as male parent, manifested highest heterosis with all the female lines viz., KMS-1, KMS-4 and KMS-5 (131, 139 and 109 respectively) over midparent. Only three male parents Bilikagga, KMP 249 and Telhamsa produced hybrids with significant heterosis over midparent with all the female lines.

Compared to the best parent, 28 hybrids manifested

TABLE 6: Magnitude of heterosis for productive tillers (%)

Sl. No.			Mp	bp	Bp			Mp	bp	Bp			Mp	bp	Bp
1	KMS.1	X Bilikagga	131**	96.9**	10	KMS.4	X Bilikagga	139**	115.98**	09	KMS.5	X Bilikagga	109**	69.73**	18
2	"	X Basumathi	27	23	-26	"	X Basumathi	45**	33*	-18	"	X Basumathi	86**	79**	25
3	"	X ES18	71**	49*	12	"	X ES18	82	54	16	"	X ES18	124**	120**	66**
4	"	X IR36	12	-10.28	-17	"	X IR36	-17	-35*	-41*	"	X IR36	71**	53**	41*
5	"	X IET7031	79*	69.2*	-05	"	X IET7031	78.89*	78.5*	-09	"	X IET7031	31	16	-18
6	"	X IET5909	70**	51*	-09	"	X IET5909	50	28	-07	"	X IET5909	57*	55*	13
7	"	X Intan mutant	45	26	-05	"	X Intan mutant	97**	66**	25	"	X Intan mutant	47*	45*	09
8	"	X KMP39	45	18.8	03	"	X KMP39	88**	49**	30	"	X KMP39	83**	68**	46*
9	"	X KMP104	24	10.8	-21	"	X KMP104	60*	38	-01	"	X KMP104	59**	61**	16
10	"	X KMP249	30**	52*	08	"	X KMP249	65*	42	01	"	X KMP249	98.8**	98.78**	41*
11	"	X Mangala	08	-08	-27	"	X Mangala	32	-08	-12	"	X Mangala	-04	-08	-26
12	"	X MR365	18	06	-25	"	X MR365	30	12	-21	"	X MR365	101**	101**	42*
13	"	X Pragathi	35	25.4	-18	"	X Pragathi	43	27	-17	"	X Pragathi	27	25.92	-12
14	"	X Palguna	68*	53.07*	-08	"	X Palguna	60	59	16	"	X Palguna	28	16	-19
15	"	X Purple puttu	51	43	-10	"	X Purple puttu	92**	76.38**	09	"	X Purple puttu	71**	66.6**	02
16	"	X Pushpa	41	09	09	"	X Pushpa	59**	20	20	"	X Pushpa	16	00	00
17	"	X Sona	13	-06	-20	"	X Sona	-21	-35	-46**	"	X Sona	05	-02	-16
18	"	X TN1	60	49.23	-16	"	X TN1	31	29.25	-34*	"	X TN1	28	11.1	-22
19	"	X Telhamsa	155*	27.7	11	"	X Telhamsa	60**	28	11	"	X Telhamsa	55**	42*	24
20	"	X Type3	60	53.8	-14	"	X Type3	82*	81.6*	-06	"	X Type3	42	27.16	-11
21	"	X Vikram	53	46.15	-18	"	X Vikram	91.6**	91.5**	-03	"	X Vikram	109**	86.41**	30
22	"	X Vani	46	27.58	-04	"	X Vani	14	03	-32	"	X Vani	44*	42.5	07

* Significant at 5 per cent level
** Significant at 1 per cent level

significant positive hybrid vigour. Only one hybrid KMS-4 x IR 36 exhibited significant negative heterosis, though eight hybrids showed numerically negative heterosis. The hybrid vigour over better parent ranged from -35 to 120 per cent.

The parent having maximum number of productive tillers was considered as the best parent, and the highest hybrid vigour over this parent was observed in KMS-5 x ES 18 and the least hybrid vigour was observed in KMS-4 x Sona. Though 30 hybrids manifested positive heterosis only five hybrids manifested significant heterosis above the best parent. None of the hybrids having either KMS-1 or KMS-4 as their female parent showed significant positive heterosis over the best parent. Thirty-five hybrids showed negative heterosis and three hybrids recorded significant negative heterosis, while one hybrid exhibited neither positive nor negative heterosis over the best parent.

Pushpa had maximum (23.20) and Bilikagga had minimum number (9.20) of productive tillers among the male parents. KMS-4 and KMS-5 had minimum (11.76) and maximum (16.20) number of tillers among the female parents. Five hybrids manifested significant heterosis over MP, bP and BP.

4.2.4. <u>Panicle length</u>: The longest panicle was observed in Pushpa (26.13) and the shortest (15.73) in purple puttu

Plate 1: Crop stand of the hybrid (KMS-5 x Mangala)

Plate 2: Crop stand of the hybrid (KMS-1 x Pushpa)

Plate 3: Crop stand of the hybrid (KMS-1 x Telhamsa)

Plate-1.

Plate-3.

Plate-2.

TABLE 7: Magnitude of heterosis for panicle length (%)

Sl. No.		Mp	bp	Bp		Mp	bp	Bp		Mp	bp	Bp
1	KMS.1 X Bilikagga	05	02	-13**	KMS.4 X Bilikagga	14**	13**	-09*	KMS.5 X Bilikagga	-20**	-20**	-36**
2	" X Basumathi	00	-02	-12**	" X Basumathi	-12**	-17**	-25**	" X Basumathi	-03	-09*	-18**
3	" X ES18	11**	00	-15**	" X ES18	-14**	-20**	-37**	" X ES18	-14**	-20**	-37**
4	" X IR36	14**	06	-09**	" X IR36	-06	-09**	-28**	" X IR36	03	-01	-21**
5	" X IET7031	11**	09*	-07*	" X IET7031	-13**	-30**	-30**	" X IET7031	-03	-05	-29**
6	" X IET5909	05	03	-12**	" X IET5909	04	03	-16**	" X IET5909	-04	-05	-23**
7	" X Intan mutant	10**	08*	-08*	" X Intan mutant	00	-11	-19**	" X Intan mutant	-10*	-11**	-27**
8	" X KMP39	20**	04	-10**	" X KMP39	03	-07*	-26**	" X KMP39	09*	-02	-22**
9	" X KMP104	22*	10**	-05	" X KMP104	00	-05	-25**	" X KMP104	03	-04	-23**
10	" X KMP249	09*	00	-15**	" X KMP249	14**	08*	-14**	" X KMP249	-16**	-20**	-37**
11	" X Mangala	17**	08*	-08*	" X Mangala	-12**	-15**	-33**	" X Mangala	06	02	-20**
12	" X MR365	19**	09*	-07*	" X MR365	-01	-06	-26**	" X MR365	06	01	-33**
13	" X Pragathi	20**	10**	-08*	" X Pragathi	06*	00	-20**	" X Pragathi	-13**	-16**	-26**
14	" X Palguna	08*	-01	-15**	" X Palguna	01	-03	-20**	" X Palguna	-02	-07*	-31**
15	" X Purple puttu	19**	01	-14**	" X Purple puttu	13**	00	-20**	" X Purple puttu	-10	-13**	-31**
16	" X Pushpa	03	-05	-05	" X Pushpa	-11**	-20**	-20**	" X Pushpa	-12**	-21**	-21**
17	" X Sona	-06	-08*	-22**	" X Sona	-08*	-09*	-27**	" X Sona	01	01	-19**
18	" X TN1	-02	-11**	-24**	" X TN1	-01	-08*	-28**	" X TN1	-08*	-14**	-32**
19	" X Telhamsa	04	00	-14**	" X Telhamsa	05	04	-17*	" X Telhamsa	-01	-02	-22**
20	" X Type3	00	-02	-16**	" X Type3	-10**	-12**	-28**	" X Type3	-05	04	-15**
21	" X Vikram	11**	08*	-08*	" X Vikram	-02	-02	-21**	" X Vikram	-18**	-19**	-35**
22	" X Vani	12**	05	-10**	" X Vani	01	-01	-22**	" X Vani	-02	-05	-25**

* Significant at 5 per cent level
** Significant at 1 per cent level

among male parents. KMS-1 had the longest (22.32) and KMS-5 had the shortest panicle (20.75) among female parents. Among hybrids KMS-1 x Pushpa and KMS-4 x ES 18 recorded the longest (24.90) and the shortest (16.48) panicle length.

As against midparent positive heterosis was recorded in 33 hybrids and negative heterosis in 29 hybrids, while four hybrids showed no heterosis. Nineteen hybrids manifested significant positive hybrid vigour and 15 recorded significant negative hybrid vigour over the same parent. Minimum heterosis over midparent (-20%) was observed in KMS-5 x Bilikagga and maximum (22%) was in KMS-1 x KMP 104. Heterosis ranged from -30 to 13 per cent over better parent; minimum heterosis was observed in KMS-4 x IET 7031 and maximum in KMS-4 x Bilikagga; 21 hybrids showed positive heterosis of which nine were significant. Twenty-three out of 40 recorded significant negative heterosis over better parent. Five hybrids did not manifest heterosis over better parent.

The parent with longest panicle was taken as the best parent and all the 66 hybrids manifested negative heterosis over the best parent. Sixtyfour hybrids exhibited significant negative heterosis, the rest (2) showing negative but non significant heterosis while none showed positive heterosis.

TABLE: 8 Magnitude of heterosis for number of days to maturity (%)

Sl. No.		bp	Bp		bp	Bp		bp	Bp
1	KMS.1 X Bilikagga	-12.5	01.1	KMS.4 X Bilikagga	-07	06.7	KMS.5 X Bilikagga	-12.5	01
2	" X Basumathi	-11	6.7	" X Basumathi	02	22.03	" X Basumathi	-12	05
3	" X ES18	07	06.7	" X ES18	02	02.5	" X ES18	02	01.6
4	" X IR36	-01	18.6	" X IR36	18	41.5	" X IR36	-11	06.7
5	" X IET7031	-11	08.4	" X IET7031	-02	19.5	" X IET7031	-02	19.5
6	" X IET5909	-10	-19.5	" X IET5909	00	33.05	" X IET5909	-10	19.5
7	" X Intan mutant	-05	19.5	" X Intan mutant	-05	19.5	" X Intan mutant	-15	06.7
8	" X KMP39	-03	21.2	" X KMP39	-03	21.18	" X KMP39	-16	05.1
9	" X KMP104	04	25.4	" X KMP104	00	19.5	" X KMP104	00	19.5
10	" X KMP249	01	06.7	" X KMP249	01	06.7	" X KMP249	-02	03.3
11	" X Mangala	-02	02.5	" X Mangala	-06	-02	" X Mangala	-06	-01
12	" X MR365	09	12.7	" X MR365	00	03.3	" X MR365	00	03.3
13	" X Pragathi	-06	05.1	" X Pragathi	10	23.72	" X Pragathi	-08	02.5
14	" X Palguna	-10	23.7	" X Palguna	00	38.1	" X Palguna	-10	23.7
15	" X Purple puttu	07	19.5	" X Purple puttu	14	27.9	" X Purple puttu	09	22.09
16	" X Pushpa	-18	-01	" X Pushpa	-01	19.5	" X Pushpa	-06	27.96
17	" X Sona	-02	34.7	" X Sona	-02	34.7	" X Sona	-02	34.7
18	" X TN1	00	15.2	" X TN1	00	15.25	" X TN1	00	15.25
19	" X Telhamsa	-02	04.2	" X Telhamsa	00	06.7	" X Telhamsa	08	15.25
20	" X Type3	-09	08.4	" X Type3	-09	08.4	" X Type	02	22.03
21	" X Vikram	-07	26.3	" X Vikram	00	35.6	" X Vikram	-22	05.9
22	" X Vani	-10	19.5	" X Vani	02	34.7	" X Vani	-10	19.49

Twenty-three hybrids expressed significant heterosis over midparent, better parent and best parent, of which eight hybrids showed significant positive heterosis while 15 showed significant negative heterosis over mid and better parents.

4.2.5. Number of days to maturity: The significance of expression of heterosis for this character was not tested, and hybrid vigour over midparent was not determined since maturity of females could not be assessed correctly.

The number of days to maturity of male parent was taken as better parent and heterosis was worked out. Minimum heterosis over better parent was observed in KMS-5 x Vikram (-22.00%) and maximum heterosis in KMS-4 x IR 36 (19.00%). Positive heterosis was observed in 17 hybrids, negative heterosis in 38 hybrids, while 11 hybrids showed no hybrid vigour at all over better parent.

The parent ES 18 had minimum (118) number of days to maturity and was considered as the best parent. All the hybrids except three showed positive heterosis over the best parent indicating longer duration as compared to the best parent. Though three hybrids showed earliness as compared to ES 18, the differences were not statistically significant. The maximum heterosis was observed in KMS-4 x Palguna and the minimum in KMS-4 x Mangala over the best parent. Three hybrids manifested negative heterosis over both best and better parents.

TABLE 9: Magnitude of heterosis for number of spikelet per panicle (%)

Sl. No.			Mp	bp	Bp			Mp	bp	Bp			Mp	bp	Bp
1	KMS.1	X Bilikagga	14	11.6	-14.1	KMS.4	X Bilikagga	03	-09	-32.9**	KMS.5	X Bilikagga	01	00	-25*
2	〃	X Basumathi	13	-14.1	-33.9*	〃	X Basumathi	31	13.63	-36.3**	〃	X Basumathi	05	-10	-48.5**
3	〃	X ES18	55**	28.3*	-0.01	〃	X ES18	21*	15.34	-35.4**	〃	X ES18	-12	-16.7	-52.3**
4	〃	X IR36	116*	60.8**	23.15*	〃	X IR36	42	23.06	-31.1**	〃	X IR36	27	09	-37.5**
5	〃	X IET7031	24	-05	-27.7*	〃	X IET7031	28	09.4	-38.7**	〃	X IET7031	75**	48**	-15.26**
6	〃	X IET5909	12	-01	-01	〃	X IET5909	-17	-35**	-35**	〃	X IET5909	08	-13	-12.27
7	〃	X Intan mutant	20	12.5	-14	〃	X Intan mutant	38*	27	-15.9	〃	X Intan mutant	21	12	-25.64*
8	〃	X KMP39	06	-09.5	-30.90**	〃	X KMP39	70**	65.9**	-06.8	〃	X KMP39	25	20.6	-30.9**
9	〃	X KMP104	32*	15.58	-11.76	〃	X KMP104	09	09	-38.0**	〃	X KMP104	13	17.44	-32.76**
10	〃	X KMP249	55*	23.9	-05	〃	X KMP249	89**	71.36**	-04	〃	X KMP249	01	00	-42.5**
11	〃	X Mangala	35**	24.2*	-05	〃	X Mangala	08	01	-35.2**	〃	X Mangala	15	09	-30.5**
12	〃	X MR365	38	16.58	-11	〃	X MR365	26	17	23.1**	〃	X MR365	12	05	-31.2**
13	〃	X Pragathi	29*	17.4	-10.3	〃	X Pragathi	38*	32*	-16.6	〃	X Pragathi	27	20	-23.66*
14	〃	X Palguna	-05	-14.75	-34.9**	〃	X Palguna	36*	29	-20.3	〃	X Palguna	06	02	-37.22**
15	〃	X Purple puttu	-06	-15.6	-35.6**	〃	X Purple puttu	36*	31*	-20.55	〃	X Purple puttu	19	16	-29.96**
16	〃	X Pushpa	38	-08.4	-30.08**	〃	X Pushpa	97**	89**	15.39	〃	X Pushpa	15	11	-31.99**
17	〃	X Sona	-18	-21.7	-33.3**	〃	X Sona	-17	-31**	-41.22**	〃	X Sona	05	-12	-24.68*
18	〃	X TN1	-09	-33.10**	-48.9**	〃	X TN1	38**	14.43	-35.9**	〃	X TN1	18	-04	-45.29**
19	〃	X Telhamsa	-11	-13.4	-33.9**	〃	X Telhamsa	16	02	-25.2*	〃	X Telhamsa	29*	15	-16.03
20	〃	X Type3	-01	-19.5	-38.5**	〃	X Type3	43*	28.7	-27.9**	〃	X Type3	43*	-27.5	-27.50*
21	〃	X Vikram	14	09.9	-16.09	〃	X Vikram	16	03	-26.74*	〃	X Vikram	05	-05	-32.3**
22	〃	X Vani	34**	26.3*	-03	〃	X Vani	33*	21	-18.4	〃	X Vani	13	05	-29.38**

* Significant at 5 per cent level
** Significant at 1 per cent level

Among the males, Palguna and ES18 took maximum (163) and minimum (116) number of days to maturity. Hybrids KMS-4 x IR 36 and KMS-4 x Mangala matured taking maximum (167) and minimum (116) number of days among hybrids.

4.2.6. <u>Number of spikelets per panicle</u>: Maximum (157.20) and minimum (57.50) number of spikelets per panicle was observed in IET 5909 and TN 1 respectively among male parents, whereas KMS-1 and KMS-4 showed maximum (120) and minimum (88) spikelet number per panicle respectively among female parents. Hybrid KMS-1 x IR 36 had maximum (193.6) number of spikelets per panicle and the hybrid KMS-5 x ES 18 had the minimum (74.9). Heterosis for this character ranged from -52.3 to 110 per cent.

Positive heterosis was observed over midparent in 57 hybrids and 21 of them possessed significant positive heterosis. Negative heterosis was observed in nine hybrids but none reached level of significance. The heterosis ranged from -18 to 110 per cent over midparent.

The heterosis ranged from -35 to 89 per cent over better parent; the minimum hybrid vigour was observed in KMS-4 x IET 5909 and the maximum was in KMS-4 x Pushpa. Positive heterosis was observed in 43 hybrids and negative heterosis in 21 hybrids; two hybrids showed no heterosis over better parent. Significant heterosis was observed in 13 hybrids out of which three were negative and 10 were positive as compared to better parent.

The parent having maximum number of spikelets per panicle was taken as the best one (IET 5909). Only two hybrids namely, KMS-1 x IR 36 and KMS-4 x Pushpa exhibited positive heterosis over the best parent. Negative heterosis was shown by 64 hybrids of which 43 hybrids were significant over the best parent. Only one hybrid manifested significant positive hybrid vigour. All the 22 hybrids having KMS-5 as female parent showed negative heterosis over the best parent. The minimum heterosis (-52.3) as compared to the best parent was observed in the hybrid KMS-5 x ES 18 and the maximum (23.15) was in KMS-1 x IR 36.

Two hybrids namely KMS-1 x IR 36 and KMS-4 x Pushpa manifested positive heterosis over MP, bP and BP, KMS-1 x IR 36 was the only hybrid which exhibited significant positive hybrid vigour over BP, bP and MP. Though nine hybrids exhibited negative heterosis over MP, bP and BP, none was significant.

4.2.7. Sterility percentage: Sterility is a highly variable character particularly in paddy. Sterility ranged from 16.05 to 62.42 per cent among male parents. Sterility is highly influenced by environmental conditions. Low temperature during flowering increases sterility.

TABLE 10: Magnitude of heterosis for spikelet sterility (%)

Sl. No.		Mp	bp	Bp		Mp	bp	Bp		Mp	bp	Bp
1	KMS-1 X Bilikagga	12	103**	404.7**	KMS-4 X Bilikagga	22*	113**	431.2**	KMS-5 X Bilikagga	-05	67**	315.5**
2	" X Basumathi	-03	251**	251**	" X Basumathi	36**	391**	390**	" X Basumathi	41**	408**	408.4**
3	" X ES18	31**	338**	378**	" X ES18	51**	405**	452**	" X ES18	34**	347**	388.47**
4	" X IR36	12	79**	394.3**	" X IR36	08	50**	314.3**	" X IR36	23	100**	452.02**
5	" X IET7031	-05	90**	294.1**	" X IET7031	29**	160**	432.7**	" X IET7031	11	124**	260.15**
6	" X IET5909	-02	26*	394.3**	" X IET5909	-07	21	369.15**	" X IET5909	-03	27*	392.83**
7	" X Intan mutant	35**	191**	497**	" X Intan mutant	31**	183**	432.08**	" X Intan mutant	38**	199**	461.3**
8	" X KMP39	18*	91**	432**	" X KMP39	15	86**	419.61**	" X KMP39	-13	55**	334.26**
9	" X KMP104	32**	128**	476.9**	" X KMP104	12	94**	392.21**	" X KMP104	08	88**	376.63**
10	" X KMP249	33**	98**	481.9**	" X KMP249	22*	98**	436.45**	" X KMP249	21*	98**	428.97**
11	" X Mangala	14	184**	348.6**	" X Mangala	01	155**	291.12**	" X Mangala	-67**	-15	29.59
12	" X MR365	01	110**	320.5**	" X MR365	-04	90**	298.75**	" X MR365	46**	188**	505.6**
13	" X Pragathi	-12	77**	265.7**	" X Pragathi	18	140**	392.21**	" X Pragathi	-02	97**	304.98**
14	" X Palguna	-23**	22	248.7**	" X Palguna	21*	92**	450.78**	" X Palguna	-42**	-08	164.79**
15	" X Purple puttu	-06	56**	319.9**	" X Purple puttu	24**	105**	453.89**	" X Purple puttu	24**	104**	452.52**
16	" X Pushpa	-24*	40*	219.6**	" X Pushpa	-50**	-02	113.08**	" X Pushpa	-24*	46*	217.13**
17	" X Sona	14	98**	437**	" X Sona	23**	98**	481.19**	" X Sona	26**	98**	498.13**
18	" X TN1	-47.32**	-14	134.3*	" X TN1	18	91**	423.3**	" X TN1	38**	126**	517.44**
19	" X Telhamsa	45**	410**	426.4**	" X Telhamsa	33	369**	384.1**	" X Telhamsa	-21	179**	484.47**
20	" X Type3	10	284**	302.5**	" X Type3	05	26.3**	280.68**	" X Type3	38**	380**	402.8**
21	" X Vikram	-05	221.3**	12	" X Vikram	-41**	-16	182.86**	" X Vikram	-26**	06	258.87**
22	" X Vani	12	96**	387.2**	" X Vani	34**	135**	483.8**	" X Vani	-17	45**	258.87**

* Significant at 5 per cent level.
** Significant at 1 per cent level.

The lowest sterility was observed in Basumathi and the highest in IET 5909 among male parents. Among hybrids sterility ranged from 20.80 to 99.10 per cent.

Basumathi was considered as the best parent for it showed minimum sterility. Significant positive heterosis was observed in all the hybrids over the best parent except in KMS-5 x Mangala. Negative heterosis was not at all observed indicating none of the hybrids showed less sterility than the best parent. The maximum heterosis was (517.44) observed in KMS-5 x TN 1 and the minimum hybrid vigour (29.59) was in KMS-5 x Mangala over the best parent.

The parent having the lowest sterility in each combination was considered as better parent. Sixty hybrids showed positive heterosis over the better parent and 57 out of 60 exhibited significant positive heterosis. None of the six hybrids showed significant negative heterosis as compared to better parent. The hybrid vigour ranged from -16 to 410 over the better parent.

As compared to midparent the lowest hybrid vigour (-67.0) was observed in KMS-5 x Mangala and the highest (51.00%) in KMS-4 x ES 18. Positive hybrid vigour was observed in 43 hybrids, of which 25 exhibited significant increase over midparent. Though 23 hybrids manifested negative heterosis, only 10 hybrids showed significant

TABLE 11: Magnitude of heterosis for grain yield per plant.(%)

Sl. No.		bp	Bp		bp	Bp		bp	Bp
1	KMS.1 X Bilikagga	-72**	-87**	KMS.4 X Bilikagga	-68*	-82**	KMS.5 X Bilikagga	-61*	-78**
2	" X Basumathi	19	-31	" X Basumathi	-71**	-84**	" X Basumathi	-84**	-90**
3	" X ES18	-38	-62	" X ES18	-80**	-88**	" X ES18	-03*	-78**
4	" X IR36	-36	-65**	" X IR36	-80**	-88**	" X IR36	-86**	-92**
5	" X IET7031	12	-71**	" X IET7031	-57	-88**	" X IET7031	-16	-79**
6	" X IET5909	-01	-64**	" X IET5909	-24	-73**	" X IET5909	-23	-73**
7	" X Intan mutant	-71**	-79**	" X Intan mutant	-55**	-68**	" X Intan mutant	-87**	-91**
8	" X KMP39	-52	-79**	" X KMP39	-27	-68**	" X KMP39	+21	-65**
9	" X KMP104	-51	-25**	" X KMP104	-42	-71**	" X KMP104	-03	-62**
10	" X KMP249	-70*	-90**	" X KMP249	-67*	-85**	" X KMP249	-80*	-91**
11	" X Mangala	-42	-63**	" X Mangala	-48*	-67**	" X Mangala	99**	26
12	" X MR365	-28	-59**	" X MR365	-46	-69**	" X MR365	+97*	-98**
13	" X Pragathi	14	-38*	" X Pragathi	-53	-74**	" X Pragathi	-40	-68**
14	" X Palguna	98	-49**	" X Palguna	-70*	-92**	" X Palguna	32	-66**
15	" X Purple puttu	24	-57**	" X Purple puttu	-89	-96**	" X Purple puttu	-75	-92**
16	" X Pushpa	-38*	-38*	" X Pushpa	-02	-02	" X Pushpa	-06	-06
17	" X Sona	-58	-86**	" X Sona	-45	-82**	" X Sona	-89	-97**
18	" X TN1	71	-57**	" X TN1	-06	-91**	" X TN1	-95	-24**
19	" X Telhamsa	-77*	-77**	" X Telhamsa	-48**	-48**	" X Telhamsa	29	28
20	" X Type3	14	-48**	" X Type3	15	-47**	" X Type	54	-79**
21	" X Vikram	141**	-21	" X Vikram	63	-47**	" X Vikram	204**	-01
22	" X Vani	-40	-66**	" X Vani	-94**	-97**	" X Vani	09	-38*

*Significant at 5 per cent level.
** Significantat 1 per cent level.

difference as compared to midparent.

Twenty-seven hybrids showed significant heterosis over MP, bP and BP. Forty-three hybrids exhibited positive heterosis over MP. bP and BP. None showed negative heterosis over MP, bP and BP.

4.2.8. Grain yield per plant: Heterosis over midparent was not worked out since the yield of female parent was always zero. The yield of male parent was always taken as better parent yield. The maximum yield among male parents was observed in Pushpa (29.84) and minimum (7.34) in TN 1. The grain yield observed in hybrids ranged from 0.37 to 38.13. The lowest grain yield was obtained from the hybrid KMS-5 x TN 1 and the highest from KMS-5 x Telhamsa.

As compared to better parent hybrid vigour varied from -99 to 204% and 15 hybrids manifested positive heterosis over better parent. Three hybrids exhibited significant positive heterosis while 22 hybrids showed significant negative heterosis over better parent. Fifty-one hybrids had negative heterosis for the character.

Pushpa produced the highest yield among male parents and was taken as the best parent. Heterosis ranged from -98 to 28 over the best parent. Though two hybrids were on positive side, the differences were not

TABLE 12: Magnitude of heterosis for 1000 grain weight (%)

Sl. No.			bp	Bp			bp	Bp			bp	Bp
1	KMS.1	X Bilikagga	-25.9	-25.9	KMS.4	X Bilikagga	-02	-02	KMS.5	X Bilikagga	-51	-51.7
2	"	X Basumathi	01	-38.5	"	X Basumathi	02	-37.8	"	X Basumathi	01	-38.9
3	"	X ES18	70	-02.3	"	X ES18	01	-41.7	"	X ES18	48	-15.3
4	"	X IR36	-19	-37	"	X IR36	-50	-60.6	"	X IR36	01	-21.2
5	"	X IET7031	15	-12.6	"	X IET7031	-43	-56.7	"	X IET7031	24	-05
6	"	X IET5909	11	-37.8	"	X IET5909	22	-31.8	"	X IET5909	11	-11
7	"	X Intan mutant	20	-14.1	"	X Intan mutant	10	-21.25	"	X Intan mutant	22	-13.3
8	"	X KMP39	01	-29.5	"	X KMP39	22	-14.2	"	X KMP39	-05	-33.4
9	"	X KMP104	07	-37.0	"	X KMP104	01	-40.15	"	X KMP104	64	-03
10	"	X KMP249	06	-16.5	"	X KMP249	00	-21.25	"	X KMP249	12	-11.8
11	"	X Mangala	05	-12.6	"	X Mangala	-20	-33.8	"	X Mangala	16	-04
12	"	X MR365	-09	-78.3	"	X MR365	-32	-46.45	"	X MR365	00	-21.2
13	"	X Pragathi	08	-14.9	"	X Pragathi	00	-21.2	"	X Pragathi	21	-04
14	"	X Palguna	59	-11	"	X Palguna	24	-29.9	"	X Palguna	10	-37.8
15	"	X Purple puttu	20	-21.2	"	X Purple puttu	20	-21.2	"	X Purple puttu	-04	-37
16	"	X Pushpa	36	-10.2	"	X Pushpa	-11	-41.7	"	X Pushpa	-08	-38.9
17	"	X Sona	-16	-43.3	"	X Sona	-20	-46.45	"	X Sona	21	-17.7
18	"	X TN1	-01	-33	"	X TN1	09	-26.7	"	X TN1	30	-12.6
19	"	X Telhamsa	-06	-21.25	"	X Telhamsa	-06	-19.29	"	X Telhamsa	-25	-37
20	"	X Type3	-06	-33.8	"	X Type3	-09	-36.6	"	X Type	-15	-40
21	"	X Vikram	04	-10.2	"	X Vikram	-06	-21.2	"	X Vikram	-37	-46.06
22	"	X Vani	20	-17.3	"	X Vani	-07	-35.8	"	X Vani	09	-24.8

significant. Fiftynine out of 64 hybrids exhibited significant negative heterosis over the best parent.

Superiority of hybrids over the best and better parent was observed only in two hybrids KMS-5 x Telhamsa and KMS-5 x Mangala, while significant negative heterosis over better and the best parent was observed in 22 hybrids. None of the hybrids showed significant positive heterosis over the best parent, indicating none of the hybrids yielded significantly higher yield than the best parent, while 22 hybrids recorded significant negative heterosis both over better parent and the best parent.

4.2.9. 1000 grain weight: There was no seed set in female lines, hence the 1000 grain weight of male parent was always taken as the better parent and heterosis over midparent was not determined. The highest 1000 grain weight was observed in Bilikagga and the lowest in IET 5909 among the parents. The lowest 1000 grain weight was observed in KMS-4 x IR 36 and the highest in KMS-4 x Bilikagga among hybrids. The 1000 grain weight ranged from 14.20 to 25.40 among parents and from 10.00 to 24.80 among hybrids.

As compared to better parent maximum hybrid vigour (70%) was observed in KMS-1 x ES 18 and maximum negative hybrid vigour (-51%) was observed in KMS-5 x Bilikagga. Twenty-five hybrids manifested negative heterosis and 41 hybrids showed positive heterosis over better parent.

None of the hybrids exhibited positive hybrid vigour, both maximum and minimum heterosis over the best parent were negative. Heterosis ranged from -60.60 to -02.00 as observed in KMS-4 x IR 36 and KMS-4 x Bilikagga respectively. Bilikagga had the highest 1000 grain weight and was considered as the best parent. Twenty-five hybrids showed negative heterosis both over better and best parents while none showed positive heterosis.

4.3. Combining ability effects

The general combining ability effects of 25 parents pertaining to seven characters are presented in Table 13.

As for plant height, significant GCA effect was manifested in 21 out of 25 parents. Parents MR 365, Pushpa, Telhamsa and Vikram did not show significant GCA effect for this character. Eleven parents manifested positive GCA effect and 14 showed negative GCA effect while 10 were positively significant and 11 were negatively significant. Intan mutant had the highest (14.07) and TN 1 the lowest (-15.33) GCA effect for plant height.

The GCA effect ranged from -8.08 to 8.85 for total tillers. The highest GCA effect was observed in ES 18 and the lowest (8.08) in Mangala for total tillers. Twelve parents exhibited positive GCA effects for this character

Table 13: Estimates of general combining ability effect

Parent	Characters						
	Plant height	Total tillers	Productive tillers	Panicle length	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant
1. Bilikagga	11.67**	6.85**	3.10	0.25	0.60	4.00	-4.84*
2. Basumathi	4.53**	0.85	-1.36	0.50	-23.67**	-2.84	-0.96
3. BS 18	-8.07**	8.85**	7.44**	-2.42**	-8.34	7.70*	-3.03
4. IR 36	2.47*	-2.68	-1.09	0.12	14.73*	5.06	-4.70*
5. IET 7031	7.73**	-3.88	-2.8	0.35	-4.20	0.27	-4.02
6. IET 5909	8.07**	0.05	1.37	1.19**	12.8	3.39	-1.10
7. Intan mutant	14.07**	2.05	2.44	0.69	9.33	14.31**	-3.88
8. KMP 39	-5.40**	7.32**	5.77**	0.12	2.43	6.23*	-1.29
9. KMP 104	4.53**	0.39	-0.35	0.71	-4.80	9.47**	-0.00
10. KMP 249	-7.00**	6.79**	3.97*	-0.33	11.20	14.83**	-6.68**
11. Mangala	4.80**	-8.08**	-4.76**	0.18	1.63	-21.73**	9.74**
12. MR 365	-1.93	-1.48	-0.10	0.93*	10.90	2.83	-2.72
13. Pragathi	-4.07**	-4.94*	-3.43	0.13	11.90	-5.01	1.93
14. Palguna	-6.20**	-3.28	-3.23	-0.33	-10.03	-11.27**	-0.74
15. Purpleputtu	-5.00**	2.45	1.70	-0.51	-6.37	8.16**	-5.30
16. Pushpa	-1.80	1.78	2.64	0.68	27.33**	-27.96**	15.69**
17. Sona	-10.27**	-5.63*	-5.83**	-0.60	-13.53	18.55**	-6.77**
18. TN 1	-15.33**	-7.28**	-5.50**	-2.60**	-32.10**	0.45	-4.89*
19. Telhamsa	0.20	6.32**	3.76*	0.68	-0.03	-6.42*	10.02**
20. Type 3	10.33**	-2.21	-2.23	0.10	-10.53	-4.51	2.47
21. Vikram	- 0.33	-0.15	0.56	-0.25	-0.77	-19.37**	7.51**
22. Vani	-3.00**	-4.08	-1.96	0.33	11.57	3.32	3.40
23. KMS-1	12.35**	-1.10	-1.63*	2.14**	11.22**	-1.99	1.15
24. KMS-4	-4.42**	-1.53	-1.23	-0.78	-1.22	3.06**	-2.31*
25. KMS-5	-7.93**	2.63**	2.86**	-1.36**	-10.00**	-1.07	1.16
CD at 5% - Female	0.75	1.76	1.32	0.27	5.01	2.29	1.59
CD at 1% "	0.99	2.23	1.73	0.36	6.57	3.00	2.09
CD at 5% - Male	2.04	4.66	3.57	0.74	13.57	6.20	4.33
CD at 1% "	2.68	6.11	4.68	0.96	17.80	8.13	5.67

*Significant at 5 per cent level
**Significant at 1 per cent level

of which only six were significant; 13 manifested negative of which only four were significant.

The highest GCA effect (7.44) was observed in ES 18 and the lowest GCA effect (-5.83) in Sona for productive tillers. Nine parents exhibited significant GCA effect out of which four were positively significant five were negatively significant for productive tillers, while 11 parents showed positive GCA effects and 14 showed negative GCA effect. All the female lines namely KMS-1, KMS-4 and KMS-5 showed significant GCA effect for productive tillers.

The GCA effect ranged from -2.60 (TN 1) to 2.14 (KMS-1) for panicle length. Significant GCA effect for panicle length was observed in seven parents, of which three were positive and four were negative.

Though 12 parents exhibited positive GCA effect, only in respect of three parents (IR 36, Pushpa and KMS-1) the effects were significant; similarly three parents Basumathi, TN 1 and KMS-5 out of 13 manifested significant negative GCA effect for total number of spikelets per panicle. TN 1 manifested the lowest and Pushpa the highest GCA effect for total number of spikelets per panicle.

Pushpa and Sona recorded the lowest (-27.96) and the highest (18.55) GCA effect for per cent sterility.

Positive GCA effect was observed in 15 parents of which 8 were significant. Out of 10 showing negative GCA effect, only 5 were significant.

Significant GCA effect for grain yield per plant was observed in 11 parents while four showed significant positive and seven showed significant negative. The GCA effect ranged from -6.77 to 15.99 and the highest and lowest GCA effect for yield per plant were observed in Pushpa and Sona respectively.

None of the varieties showed positive GCA effect for all the seven characters and only one parent Palguna showed negative GCA effect for all the characters. Parent TN 1 had significant GCA effect for all characters except per cent sterility. Three parents Bilikagga, IET 5909 and Intan mutant manifested positive GCA effect for all the characters except for grain yield per plant. KMS-4 and Sona had negative GCA effect for all the characters except for sterility. KMP-249, Mangala and Sona had significant GCA effect for characters - plant height, total tillers, productive tillers, per cent sterility and grain yield per plant, whereas non significant GCA effects were observed for panicle length and total spikelets.

The specific combining ability effects of different cross combinations are shown in Tables 14, 15 and 16.

A majority of hybrids showed significant SCA effect for plant height; 12 varieties in combination with KMS-1, 14 varieties with KMS-4 and 13 varieties with KMS-5 showed significant effect for this character. Two varieties IET 5909 and Intan mutant manifested significant SCA effect in combination with all female lines. The SCA effects were positive in combination with KMS-1 and negative with KMS-4 for plant height. Thirty-three combinations showed positive SCA effect and the rest showed negative SCA effect for this character.

KMS-5 showed significant positive SCA effect in combination with IR 36 for total tillers, whereas KMS-4 in combination with IR 36 showed significant negative SCA effect. None of the other combinations manifested significant SCA effect for this character. The genotypes IET 7031, IET 5909, KMP 249, Mangala, Pragathi, Palguna, Pushpa, Sona, TN 1, Telhamsa and Vani incombination with KMS-1 manifested positive but non-significant SCA effect for total tillers; 13 male parents with KMS-4 and nine male parents with KMS-5 also exhibited the same trend. None of the varieties showed positive SCA effect with the three testers.

IR 36 and MR 365 in combination with KMS-5, and IR 36 in combinationwith KMS-4 manifested significant SCA effect for productive tillers; IR 36 with KMS-4 exhibited negative while the other two exhibited positive SCA effects. Positive SCA effect was observed in 34 cross combinations, 12 varieties with KMS-1, 10 with

Table 14. Estimates of specific combining ability effects in crosses of KMS-1

Crosses	Plant height	Total tillers	Productive tillers	Panicle length	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant
1. KMS-1 x Bilikagga	2.84	-1.09	1.10	-0.49	4.24	4.80	-2.58
2. " x Basumathi	1.78	-2.49	-2.83	-0.51	-2.49	-12.06*	9.89**
3. " x BS 18	6.98**	-4.28	-2.37	1.46*	33.17**	-2.20	2.78
4. " x IR 36	1.84**	-0.29	-1.10	0.59	49.17**	-6.35	3.96
5. " x IET 7031	2.38	4.91	3.43	1.09	-12.16	-10.34	1.35
6. " x IET 5909	5.64**	2.38	2.63	-1.25	12.44	2.17	0.50
7. " x Intan mutant	10.44**	-4.02	-1.83	0.51	-4.19	2.36	-1.08
8. " x KMP 39	4.91**	-4.29	-3.17	0.19	-23.89*	7.86	-3.63
9. " x KMP 104	-4.22**	-0.35	-2.83	1.09	13.54	12.03	-3.87
10. " x KMP 249	-3.69*	0.74	-0.37	-0.27	7.54	7.42	-1.64
11. " x Mangala	0.91	1.30	0.56	1.07	17.51	21.76**	-10.92
12. " x MR 365	-0.76	-1.89	-3.39	0.98	19.01	-6.58	3.87
13. " x Pragathi	-2.02	2.97	1.03	1.46*	-0.96	-5.42	5.54
14. " x Palguna	-3.29	1.70	3.03	-0.46	-17.73	-4.08	4.67
15. " x Purple puttu	3.11	-3.82	-1.30	0.05	-22.39	-12.73	6.16
16. " x Pushpa	-9.09**	5.24	1.56	-0.64	-7.39	7.90	-8.28*
17. " x Sona	-0.82	0.90	3.03	-2.00**	-11.63	-3.57	-0.50
18. " x TN 1	-15.12**	2.50	3.49	-2.40**	-17.63	-34.13**	6.19
19. " x Telhamsa	-15.69**	4.10	0.63	-1.28*	-26.03	19.80	-14.54**
20. " x Type 3	4.78**	-3.95	0.83	-1.12	-22.93	-2.22	1.87
21. " x Vikram	-2.16	-1.29	-3.97	1.38*	2.71	-0.23	4.67
22. " x Vani	10.24**	1.10	2.76	0.14	10.11	3.98	-4.38

*Significant at 5 per cent level
**Significant at 1 per cent level

Table 15: Estimates of specific combining ability effects in crosses of KMS-4

Crosses	Plant height	Total tillers	Productive tillers	Panicle length	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant
1. KMS-4 x Bilikagga	7.22**	2.53	0.47	3.51**	-12.71	4.90	2.42
2. " x Basumathi	-6.83	-3.46	-1.63	-0.95	6.56	-0.17	-2.13
3. " x BS 18	-0.44	0.34	-2.44	-1.09	-7.68	3.69	-1.18
4. " x IR 36	1.02	-9.06*	-6.91*	-1.59*	-23.98*	-24.86**	0.26
5. " x IET 7031	-4.24*	-0.27	2.62	-1.87**	-17.01	8.84	-0.51
6. " x IET 5909	-15.97**	-1.39	-1.57	0.69	-28.80	-4.90	1.46
7. " x Intan mutant	-6.79**	-7.80	4.76	0.58	5.36	-5.17	5.69
8. " x KMP 39	-0.31	2.33	2.62	-0.94	26.46*	0.72	3.08
9. " x KMP 104	2.76	-0.73	1.62	-1.07	15.30	-6.70	0.75
10. " x KMP 249	6.49**	-5.12	-2.38	2.83**	22.09	-5.15	3.43
11. " x Mangala	-13.11**	3.13	3.42	-2.65	-16.34	8.07	-7.76*
12. " x MR 365	8.22**	-3.07	-3.30	-1.46*	-7.64	-15.42**	4.16
13. " x Pragathi	3.16	0.20	-1.02	0.72	1.62	7.88	-2.00
14. " x Palguna	3.69*	1.93	0.82	0.32	17.82	22.74**	-4.29
15. " x Purple puttu	-4.90**	0.20	1.89	1.23	14.66	4.46	-2.04
16. " x Pushpa	7.29**	2.68	3.56	0.06	36.56**	-14.14**	7.02
17. " x Sona	-0.03	1.53	-2.37	-0.26	-11.58	-1.58	3.95
18. " x TN 1	8.[illegible]2**	-3.66	-1.10	1.58*	5.32	7.80	-0.32
19. " x Telhamsa	-3.50	1.33	0.22	0.97	-0.17	7.79	-2.29
20. " x Type 3	-4.24	2.87	2.22	-1.39*	6.32	-10.80*	5.66
21. " x Vikram	10.42**	1.33	0.22	0.77	-0.64	-11.57*	-4.53
22. " x Vani	1.22	-1.46	-4.23	-0.03	-0.84	14.03*	-10.62**

*Significant at 5 per cent level
**Significant at 1 per cent level

Table 10. Estimates of specific combining ability effects in crosses of KMS-5

Crosses	Plant height	Total tillers	Productive tillers	Panicle length	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant
1. KMS-5 x Bilikagga	-10.07**	-1.63	-1.61	-2.99**	8.48	-9.70	0.18
2. " x Basumathi	5.07**	5.76	4.48	1.47*	-4.06	12.28*	-7.75
3. " x BS 18	-6.53**	3.77	5.28	-0.56	-25.49*	-1.47	-1.58
4. " x IR 36	-12.87**	9.36*	8.03*	0.98	-25.29*	1.24	-4.21
5. " x IET 7031	1.87	-4.62	-6.06	0.59	29.18*	1.50	-0.83
6. " x IET 5909	9.33*	-0.96	-1.06	0.40	16.38	2.68	-1.94
7. " x Intan mutant	-3.67*	-3.76	-2.92	-1.09	- 1.15	2.84	-4.61
8. " x KMP 39	-4.60*	1.96	0.53	0.73	-2.55	-8.56	0.56
9. " x KMP 104	1.47	1.10	1.28	-0.02	1.78	-5.33	3.10
10. " x KMP 249	-2.80	4.70	2.73	-2.57**	-29.62*	-2.25	-1.81
11. " x Mangala	22.20**	-4.43	-3.86	1.57*	-1.15	-29.81**	18.66**
12. " X MR 365	- 7.46**	4.97	7.20*	0.47	-11.45	22.01**	-8.00*
13. " x Pragathi	-1.12	-3.16	-2.06	-2.19**	-0.59	-2.38	-3.51
14. " x Palguna	-0.40	-3.63	-3.86	0.14	-0.09	-13.58**	-0.36
15. " x Purple puttu	1.80	-3.63	-0.59	-1.28*	7.74	8.35	-4.11
16. " x Pushpa	1.80	-7.89	-5.12	0.55	-29.15*	6.17	1.25
17. " x Sona	0.87	-2.43	-0.66	2.27**	23.21	5.24	-3.47
18. " x TN 1	6.33**	1.16	-2.39	0.81	12.41	26.40**	-5.86
19. " x Telhamsa	19.20**	-5.43	0.80	0.30	26.20*	-27.48**	16.82**
20 " x Type 3	-0.53	1.10	-3.06	2.51**	16.61	12.99*	-7.44
21. " x Vikram	-8.26**	0.23	3.73	-2.15**	-2.05	11.89*	-0.11
22. " x Vani	-11.67**	0.37	0.27	-0.09	-9.25	-17.95**	15.02**

*Significant at 5 per cent level
**Significant at 1 per cent level

KMS-4 and 12 with KMS-5; but Telhamsa was the only common parent which produced positive SCA effect in combination with all the female parents for productive tillers.

Twenty-three hybrids manifested significant SCA effect for panicle length. KMS-1 in combination with three varieties (IR-36, Pragathi and Vikram), KMS-4 with three varieties (Bilikagga, KMP 249 and TN 1) and KMS-5 in combination with four varieties (Type 3, Sona, Basumathi and Mangala) exhibited significant positive SCA effect. Bilikagga and KMP 249 showed negative SCA effect in combination with KMS-1 and KMS-5 for panicle length. Highest (3.51) and lowest (-2.99) SCA effects for panicle length were recorded in the crosses KMS-4 x Bilikagga and KMS-5 x Bilikagga, respectively.

IR 36 in combination with KMS-1 and KMP 249 in combination with KMS-5 recorded the highest (49.17) and the lowest (-29.62) SCA effects for number of spikelets per panicle. The genotypes ES 18, IR 36, Mangala, MR 365, Vikram and Vani in combination with KMS-1 manifested positive SCA effect, while negative SCA effect was evident in combination with KMS-4 and KMS-5, for this character. Thirty-seven combinations expressed negative SCA effect, while 10 varieties in combination with KMS-1, 10 varieties with KMS-4 and nine varieties with KMS-5 expressed positive SCA effect for this character. Only IR 36 showed significant SCA effect with all the female lines for number of spikelets per panicle, while none showed positive effect with all females.

None of the varieties showed significant SCA effect in combination with all female lines for sterility, while hybrid KMS-5 x TN 1 and KMS-1 x TN 1 exhibited the highest (26.40) and the lowest (-34.13) SCA effects respectively. Significant negative SCA effects were observed in 11 hybrids and significant positive SCA effects in 10 hybrids. None of the varieties showed positive SCA effect with all female lines for sterility; similarly none showed negative SCA effect with all female lines for this character.

Significant SCA effect was observed in 11 hybrids for grain yield per plant. Telhamsa in combination with KMS-1 and Mangala in combination with KMS-5 recorded the lowest (-15.54) and the highest (18.66) SCA effect for grain yield per plant. Basumathi with KMS-1, Mangala, Telhamsa and Vani in combination with KMS-5 exhibited significant positive SCA effect, while 7 other hybrids exhibited significant negative SCA effect for the character.

None of the hybrids manifested significant SCA effects for all the characters. The cross KMS-4 x IR 36 showed significant SCA effect for 5 characters viz., total tillers, productive tillers, panicle length, total spikelets and spikelet sterility. The hybrid KMS-1 x IET 5909 showed negative SCA effect only for panicle length, while KMS-1 x Vani and KMS-4 x Palguna showed negative SCA effect only for yield per plant. The variety Pushpa in combination with KMS-4 manifested negative SCA effect only for sterility per cent. So was KMS-4 x Bilikagga for number of spiklelets per panicle. The hybrid KMS-5 x Pragathi exhibited negative SCA effect for all the characters.

4.4. Percentage of seed set in different male sterile lines with different varieties

The experiment conducted with three male sterile lines and 22 genotypes to assess outcrossing under natural conditions provided the following results. The percentage of outcrossing was recorded based on seed set on female lines. The female panicles when bagged did not set seeds confirming that any seed set on open panicles of female line is due to fertilisation through foreign pollen. The data on percentage seed set on different male sterile lines namely KMS-1, KMS-4 and KMS-5 due to different varieties are given in Table 17 and graphically represented in Fig. 1. The percentage seed set on different male sterile lines ranged from 4.4 to 44.77. It ranged from 10.56 to 29.26 per cent in KMS-1, from 11.05 to 44.77 per cent on KMS-4 and from 4.4 to 22.90 on KMS-5. Minimum seed set on KMS-1, KMS-4 and KMS-5 was due to Puspa, IET 5909 and ES 18, while maximum was due to Intan mutant, Basumathi and

Table 17: Percentage of seed set on different male sterile lines with different varieties (pollinators)

Sl. No.		Male sterile lines		
		KMS-1	KMS-4	KMS-5
1.	Bilikagga	16.01	32.75	11.60
2.	Basumathi	27.25	44.77	8.78
3.	ES 18	12.80	23.14	4.40
4.	IR 36	21.35	39.93	11.88
5.	IET 7031	18.91	20.66	7.16
6.	Intan mutant	29.26	31.87	8.69
7.	IET 5909	12.75	11.05	8.47
8.	KMP 29	19.57	20.30	14.28
9.	KMP 104	13.15	44.16	5.49
10.	KMP 249	28.36	33.14	17.83
11.	Mangala	27.14	38.32	5.21
12.	MR 365	18.18	26.05	4.46
13.	Pragathi	16.38	42.99	22.90
14.	Palguna	25.00	35.32	6.60
15.	Purple puttu	20.33	33.33	9.45
16.	Pushpa	10.56	22.82	13.83
17.	Sona	16.48	37.50	11.14
18.	TN 1	16.4	41.66	15.00
19.	Telhamsa	21.03	18.13	8.71
20.	Type 3	26.13	18.05	11.44
21.	Vikram	19.08	34.17	6.13
22.	Vani	24.13	32.25	15.63

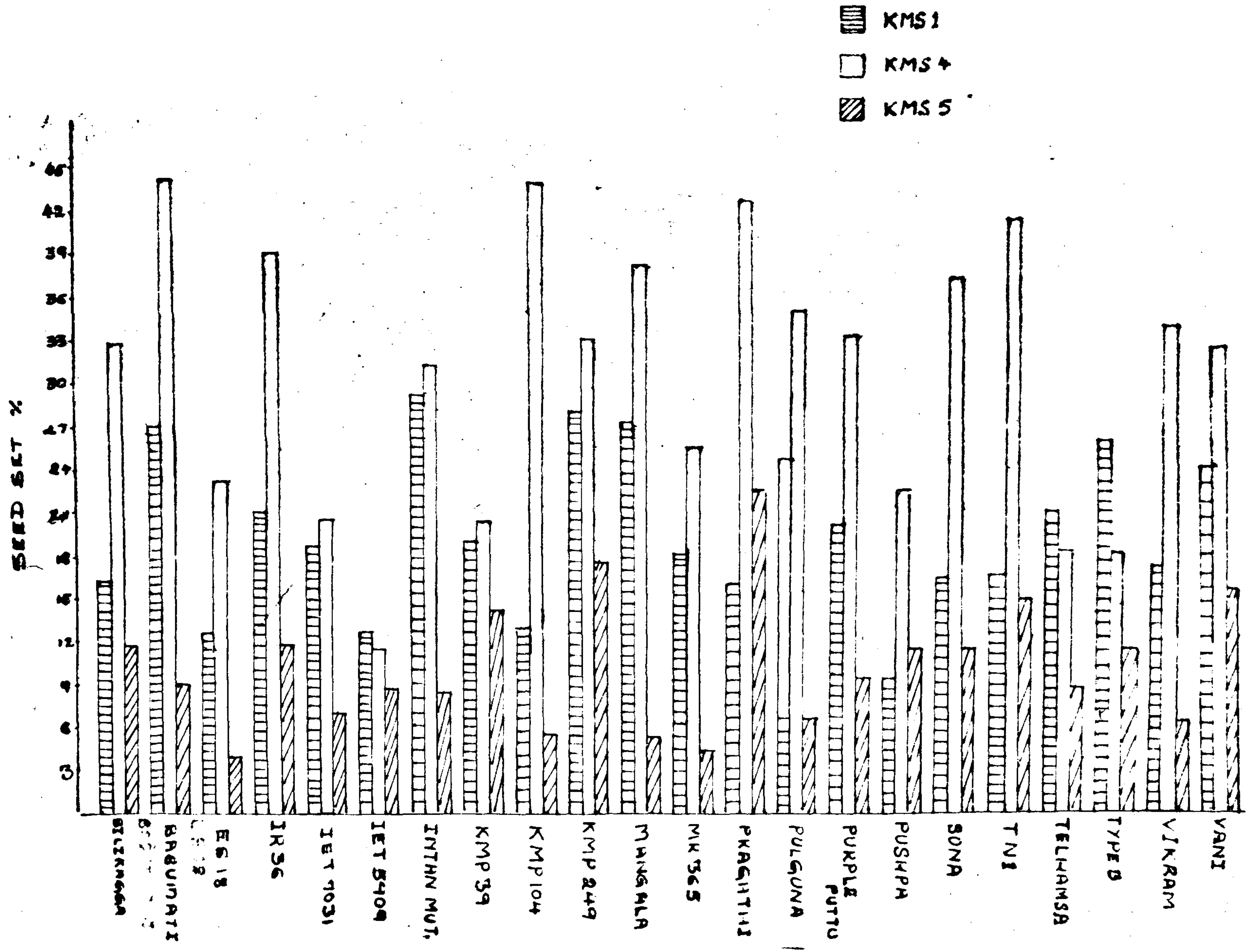

Fig. 1: Percentage of seed set in different male sterile lines with different varieties

Pragathi respectively. On an average, KMS-4 observed highest seed set (31.01%) followed by KMS-1 (19.25%) and KMS-5 (9.50%).

There is no definite scale adopted in the past for classifying seed set per cent. In the present investigation, the amount of seed set was classified for convenience into three classes namely:

(a) Very high seed set	24%
(b) High seed set	15-24%
(c) Low seed set	15%

Fifteen varieties showed very high seed set on KMS-4 where as seven varieties showed high seed set on KMS-1, while none showed on KMS-5. Eleven varieties with KMS-1, six varieties with KMS-4 and four varieties with KMS-5 observed high seed set. Eighteen varieties with KMS-5, four with KMS-1 and only one variety with KMS-4 showed low seed set. None of the varieties produced very high seed set on all female lines but Basumathi, Intan mutant, KMP 249, Mangala, Palguna and Vani caused for very high seed set on both KMS-4 and KMS-1 indicating their potentiality to be pollinators for high rate of outcrossing. Pushpa indicated low potentiality with KMS-1 and KMS-5 but produced high seed set on KMS-4.

Table 18: Mean values of percentage pollen sterility of different hybrids

	Hybrids	Per cent sterility	Hybrids	Per cent sterility	Hybrids	Per cent sterility
1.	KMS-1 x Bilikagga	61.97	KMS-4 x Bilikagga	42.43	KMS-5 x Bilikagga	92.00
2.	" x Basumathi	67.47	" x Basumathi	37.66	" x Basumathi	88.53
3.	" x ES 18	89.13	" x ES 18	59.69	" x ES 18	60.84
4.	" x IR. 36	60.88	" x IR 36	72.47	" x IR. 36	60.11
5.	" x IET 7031	58.48	" x IET 7031	52.54	" x IET 7031	41.07
6.	" x IET 5909	53.06	" x IET 5909	49.88	" x IET 5909	33.86
7.	" x Intan mutant	60.83	" x Intan mutant	88.79	" x Intan mutant	35.27
8.	" x KMP 39	58.70	" x KMP 39	53.25	" x KMP 39	58.38
9.	" x KMP 104	60.20	" x KMP 104	52.12	" x KMP 104	32.37
10.	" x KMP 249	73.77	" x KMP 249	45.38	" x KMP 249	67.86
11.	" x Mangala	62.83	" x Mangala	56.10	" x Mangala	20.23
12.	" x MR 365	42.63	" x MR 365	54.11	" x MR 365	33.82
13.	" x Pragathi	43.73	" x Pragathi	55.72	" x Pragathi	37.67
14.	" x Palguna	48.44	" x Palguna	65.60	" x Palguna	37.02
15.	" x Purple puttu	44.37	" x Purple puttu	45.70	" x Purple puttu	58.51
16.	" x Pushpa	57.36	" x Pushpa	19.89	" x Pushpa	16.14
17.	" x Sona	76.91	" x Sona	68.74	" x Sona	80.72
18.	" x TN 1	70.06	" x TN 1	34.63	" x TN 1	91.09
19.	" x Telhamsa	69.61	" x Telhamsa	70.10	" x Telhamsa	49.56
20.	" x Type 3	24.21	" x Type 3	16.15	" x Type 3	70.19
21.	" x Vikram	17.31	" x Vikram	32.08	" x Vikram	46.32
22.	" x Vani	49.25	" x Vani	67.72	" x Vani	49.04

4.5. Fertility restoration

The pollen grains were stained with acetocarmine and the number of fertile and sterile grains were counted. The percentage sterility of hybrids is presented in Table 18.

Hybrid KMS-1 x ES 18 showed the highest (89.13%) and the hybrid KMS-1 x Vikram (17.31%) the lowest pollen sterility with an average of 56.9% among KMS-1 Crosses. Fifteen of the 22 KMS-1 hybrids showed more than 50% sterility. Hybrids KMS-1 x Vikram (17.31%), KMS-1 x Type 3 (24.27) manifested low and the hybrids KMS-1 x ES 18 (89.13%) KMS-1 x KMP 249 (73.77%) KMS-1 x Sona (76.91%) and KMS-1 x TN 1 (70.05%) manifested high pollen sterility among crosses involving KMS-1.

The pollen sterility ranged from 16.15% to 88.79% among KMS-4 crosses with an average of 51.8%. The genotypes Type 3, Vikram, TN 1 and Basumathi in combination with KMS-4 produced hybrids with low sterility. While the genotypes Intan mutant, IR 36 and Telhamsa produced high sterility.

Among KMS-5 hybrids, KMS-5 x Bilikagga showed the maximum (92.00%) and KMS-5 x Pushpa the minimum pollen sterility. Eleven out of 22 hybrids manifested more than 50% sterility. In combination with KMS-5 the genotypes Pushpa, Palguna, Pragathi, MR 365, Mangala

KMP 104, Intan mutant and IET 5909 produced hybrids with low sterility while Bilikagga, Basumathi, Sona, TN 1 and type 3 produced hybrids with high sterility. the average of 22 KMS-4 hybrids being 52.7%.

In general, the genotypes ES 18, IR 36 and Sona produced consistently high sterility with all the three female lines. Vikram showed low sterility with all the male sterile lines. The behaviour of the three male sterile lines which have the same source of cytoplasm is inconsistent in respect of pollen sterility.

DISCUSSION

V. DISCUSSION

The primary goal of any plant breeder is essentially to improve the genetic potentiality of crop more particularly the yielding ability or productivity of a genotype. This is being achieved in several ways, the most attractive one being heterosis breeding. This has been largely exploited in cross pollinated crops. Recently it is also successfully exploited in rice in China though work on hybrid rice is still in the initial stages in other countries. However, studies have been initiated towards development of hybrids in many countries including India and Philippines. In the present study, an attempt was made to identify the lines which can be used as maintainers and restorers for the three male sterile lines developed at the University of Agricultural Sciences, Bangalore.

In any hybrid breeding, choice of parents is important. The parents to be used are determined by two factors: (i) *per se* performance of lines and (ii) its behaviour in hybrid combination. Therefore, in the present investigation, general and specific combining ability of the 22 lines included in the study were also assessed. The work was also extended to study the rate of outcrossing of these 22 lines in association with the three male sterile lines. The results obtained are discussed below under the following head lines:

(i) Magnitude of heterosis

(ii) Fertility restoration

(iii) Rate of outcrossing

(iv) *Per se* performance and combining ability

5.1. Magnitude of heterosis

One of the objectives of the present study is to measure the expression of heterosis in rice. In crops like rice where a great number of varieties are being cultivated, and commercial exploitation of heterosis is new, comparison of hybrids with released varieties is more important rather than their performance above midparent. In the present investigation, therefore, three methods viz., deviation from mid, better and best parents were employed to measure the magnitude of heterosis.

5.1.1. Plant height

For plant height, 45 hybrids manifested significant positive heterosis over mid parent value ranging from 8 to 62 per cent indicating non additive gene action in these crosses. This is in conformity with the results obtained by Dzyuba (1975) and Chan (1980) who stated that the tallness is controlled by dominant gene and dwarfness is by recessive gene. In eight hybrids non significant positive heterosis was observed indicating additive genetic effects (Khan and Khan 1980). Three hybrids showed significant negative heterosis indicating partial dominance. All the hybrids were taller than the best parent since shortest among the parents was taken as best parent. Several workers (Kadam et al. 1937; Mitra, 1962; Dhulappanavar et al., 1970; Dzyuba, 1975; Mallick et al., 1978; Singh et al., 1980; Purohit, 1972) have observed increased height of hybrids over midparent, better parent and often even over the best parent. With the discovery of dwarfing gene and new plant type concept in rice, it is desirable to breed hybrids which are dwarf or intermediate plant statured. Though, in the present experiment hybrids expressed heterosis over midparent, elimination of these parents from any hybrid programme may not be justified for three reasons; (i) majority of the hybrids studied were intermediate between their parents and did not exceed the height of many of the popular varieties presently being cultivated; (ii) the female parents included in this experiment was considered to be extremely dwarf; (iii) in certain areas in India straw yield is also an important criterion for selection; thus medium tall hybrids are preferred. Considering all these characters, many hybrids having medium plant height looked desirable. The heterosis observed for plant height was high in magnitude and the variance observed in crosses, parents, parents Vs crosses, lines and testers was high and could be attributed to genotypic variance for this character.

5.1.2. Days to flowering

Heterosis for this character was positive, negative or was absent as compared to better parents. But Dhulappanavar and Mensinkai (1967), Purohit (1972) and Bardhan Roy et al. (1975) observed only negative heterosis for days to flowering. So earliness is one of the frequently observed economical characters of the hybrids. But in the present investigation, except on hybrid (KMS-5 x Mangala) all the other hybrids showed positive heterosis over the best parent. The magnitude of heterosis observed was low, perhaps due to low genetic diversity that existed among parents for maturity duration. When comparisons were made with the best parent (ES 18), hybrids were late by 20 days and few hybrids by a day or two. Majority of the hybrids showed negative heterosis over male parent or better parent indicating additive or partial dominance gene action. A few hybrids manifested positive heterosis as compared to better parent indicating over dominance or dominance. Complete dominance was also found for this character; where the duration of hybrids were equal to male parent.

Dwarfness and earliness are mostly desired in an hybrid. The nature of gene action found for these characters was additive and dominance respectively. So intermediate height and earliness can be expected in the hybrids.

5.1.3. Grain yield per plant

As for grain yield per plant, some hybrids showed significant positive heterosis over better parent indicating complete dominance for the character. Similar reports are made by Maurya and Singh (1978); Capinpin and Punyasingh (1938); and Ramaiah (1935). A few hybrids did not show significant heterosis over better parent indicating partial dominance or additive gene action. Since sterility in hybrids affected the yield, the gene action for yield per plant could not be assessed clearly. Though sterility was present a few hybrids produced more yield than the best parent indicating possible scope for the exploitation of the character. The hybrids KMS-5 x Telhamsa and KMS-5 x Mangala were found superior to the best variety and hence seem to be promising.

Many hybrids showed heterosis for components of yield. Considering this and the fact that some hybrids were sdwarf and earlier, the feasibility of a hybrid breeding is promising. Similar conclusions have been reached by Singil'din (1978) and Shalaan et al. (1975).

5.1.4. Total tillers

For total tillers, three hybrids, KMS-1 x Telhamsa, KMS-4 x Bilikagga and KMS-4 x KMP 39 showed significant heterosis over the best parent indicating over dominance to be operative in governing this character. A majority of hybrids did not manifest significant heterosis over midparent indicating additive gene action; a few hybrids exhibited significant heterosis over better parent revealing likely dominant gene action governing this character. Maximum heterotic effects recorded over MP, bP and BP were 116.0, 83.80 and 53.19, respectively. Additive gene action for this chracter was also observed by Khan and Khan (1980). Heterosis for number of tilers per plant was observed by Kadam et al. (1937), Madhusudana Rao (1965), Dhulappanavar et al. (1970), Ramaiah (1935) and Dhulappanavar and Mensinkari (1967). All the male parents showed consistent results with all female lines viz., KMS-1, KMS-4 and KMS-5. Manifestation of high heterosis for this important yield component is indicative of the potentiality of hybrids for increasing yield.

5.1.5. Number of productive tillers

Shalaan et al. (1975) reported that the trait panicle bearing tiller is quantitatively inherited. Positive heterosis was observed by Purohit (1972), Singh and Singh (1978) and Saini et al. (1974) for this character. Similarly, in the present investigation, positive heterosis has been observed for this chaacter in 63 hybrids. A few hybrids showing negative heterosis were non significant indicating enormous scope for the exploitation of this character. Half the number of hybrids showed significant heterosis over mid parent indicating non additive gene action. Hence, the character is controlled by both additive as well as non additive type of gene action. Over dominance and dominance type of gene action was also observed in many hybrids. Most of the hybrids showed higher number of total tillers as well as productive tillers and manifestation of high heterosis indicated greater diversity of parents for total and productive tillers. Excepting a few hybrids most of the hybrids exhibited heterosis in desirable direction.

5.1.6. Panicle length

Though about half the number of hybrids showed positive heterosis and increased panicle length over mid parent, a few and none of the hybrids showed positive heterosis over better and the best parent respectively. But significant increase in panicle length over better parent was reported by Dhulappanavar and Mensinkai (1967), significant heterosis over midparent was observed by

Bardhan Roy *et al*. (1975); Madhusudhana Rao (1965); Idsumi (1937); Capinpin and Punyasingh (1938), Shalaan *et al*. (1975) and Srivastava (1981). All these indicated non additive gene action for panicle length and similar conclusions emerge from the present study, since 34 hybrids showed significant deviation from midparent. Most of the hybrids deviated significantly from the best parent and therefore over dominance type of gene action was also present. Only two hybrids having either KMS-4 or KMS-5 as female parent showed significant increase over better parent. Hence care should be taken while using these female lines in hybrid rice breeding.

5.1.7. Number of spikelets per panicle

None of the hybrids exhibited significant negative heterosis for number of spikelets per panicle indicating that there was no significant decrease in spikelet number in the hybrids. Twenty one hybrids manifested significant heterosis over midparent indicating non additive gene action. But majority of the hybrids did not differ from the midparent showing additive gene action. Only three hybrids having KMS-5 as female parent showed significant heterosis, while only one hybrid having KMS-5 showed negative heterosis and two having KMS-4 and six having KMS-1 showed negative heterosis. Only one (KMS-1 x IR 36) showed significant heterosis over the best parent indicating overdominant gene action, which can be exploited in heterosis breeding. Ten hybrids indicated dominant gene action by expressing heterosis over better parent, but additive gene action predominates for number of spikelets per panicle. Dzyuba (1975), Singil'din and Shilovskii (1977), Chatel and Dachanet (1980), Chan (1980) and Singh and Singh (1978) reported positive heterosis for the character as observed in the present experiment. A few hybrids showed negative heterosis as was also observed earlier by Mallick *et al.*, (1978). More spikelets were produced per panicle in hybrids which is an indication for higher yields, though corresponding high grain yield could not be realised because of sterility in the hybrids. Hence, it can be concluded that the spikelet number is an important yield attribute through which we can expect high yields in hybrids.

5.1.8. Sterility percentage

Sterility is the most vulnerable character in paddy. It is easily affected by environmental factors and nuclear manipulations. Earlier reports indicated that F_1 sterility ranged from 12.9 to 81.0 per cent (Rajagopalan *et al.* 1973). Carpenter (1975) and Bhardhan Roy *et al.* (1975) reported positive heterosis but Yap and Chang (1976) reported negative heterosis. Similarly, both significant positive and significant negative heterosis was found in the present experiment. Thirty-five hybrids showed significant deviation from midparent indicating non additive gene action while 31 hybrids did not exhibit significant heterosis revealing additive tgene action but non additive gene action predominated. The male parent was chosen as better parent and some hybrids (KMS-1 x TN 1, KMS-1 x Vikram, KMS-4 x Pushpa, KMS-5 x Mangala and KMS-5 x Palguna) manifested negative heterosis indicating more fertility than their male parent. Hence these male parents could be considered as good restorers. Since the best parent was least sterile, all the hybrids showed higher positive heterosis. One hybrid KMS-5 x Mangala did not show significant heterosis over the best parent; the fertility of this hybrid was just on par with the best parent. It is known that sterility is inversely related to yield and may not be directly useful. However, the genotypes showing high sterility can be utilised for developing maintainers. The results obtained for the above character reveal plenty of scope for developing maintainers and restorers to the male sterile lines KMS-1, KMS-4 and KMS-5 which is one of the objectives of the present investigation.

5.1.9. Thousand grain weight

Many contradictory results have been reported for this character. Dhulappanavar *et al.* (1970), Shalaan *et al.* (1975) and Chan (1980) reported significant heterotic effect for this character, while Capinpin and Punyasingh (1938) did not observe heterosis and Dhulappanavar and Mensinkari (1967) observed negative heterosis for this character. In the present investigation too all three types of heterosis were observed. But in most of the hybrids positive heterosis over better parent (male parent) was observed which may be due to dominance or additive gene effect. None of the hybrids showed positive heterosis over the best parent. Number of spikelets per panicle did not have any influence on 1000 grain weight. No correlations were observed for 1000 grain weight and yield since sterility had hazardous effect on yield. But it was found in several other crops that 1000 grain weight was highly influenced by crop growth period and environmental conditions prevailed during crop growth (Shankaregowda, 1970). Shankaregowda (1970) observed an inverse relationship between 1000 grain weight and total spikelets (grain) in sorghum; hence yield was not much affected by 1000 grain weight and hence much emphasis was not given during selection of hybrids. Some more studies of the present kind and a probe into the relationship between this character and grain yield, which should definitely be strong if the influence of sterility is eliminated, may throw more light on the relevance of this in hybrid breeding programme.

5.2. Fertility restoration

The commercial exploitation of heterosis was achieved in any crop only after the development of technique that enabled large scale hybrid seed production possible at cheaper costs. Sterility is one of the mechanisms that has helped in cheap and large scale hybrid seed production. In rice, though male sterility was observed as early as in 1964, successful hybrid rice was developed only after the discovery of maintainers and restorers in 1973 (Anon. 1981). In Karnataka also a male sterile line was identified (Mahadevappa, 1973a, Mahadevappa et al. 1980). Though wide scope was indicated for obtaining both the fertility restorers and sterility maintainers no constant attempts were made to accomplish this. The data generated on pollen sterility in the 66 hybrids studied here (Table 17) reveal unexpected inconsistency in the sterility behaviour. Of the 22 varieties crossed to all the three male sterile lines, ES 18, IR 36 and Sona showed high sterility thereby offering scope to develop maintainers. Sterility maintainers can be developed through back crossing and selecting for male steritlity and desirable characters of the recurrent parent. Similarly Vikram in combination with all the three male sterile lines produced hybrids with least sterility and this may be useful in a programme for developing restorers. None of the other varieties in combination with all the three male sterile lines manifested consistent fertility or sterility, though the cytoplasmic background of all male sterile lines was the same. This discrepancy in the sterility behaviour among the crosses of KMS lines of the same cytoplasmic background needs to be studied in depth through a study specially designed, eliminating seasonal effects and involving known restorers and maintainers.

5.3. Seed set on different male sterile lines (rate of outcrossing)

Large scale commercial planting of hybrids in self pollinated crops depends on cost of hybrid seed production, which in turn is determined by percentage outcrossing. The amount of seed set observed on male sterile lines KMS-1, KMS-4 and KMS-5 varied from 10.56-28.36 per cent, 11.05-44.77 per cent, 4.4-22.90 per cent respectively. The average amount of seed set was 19.25, 31.01 and 9.50 on KMS-1, KMS-4 and KMS-5 respectively. The seed set among panicles of the same plant varied considerably. This seems to have happened because of panicles emerging on different dates which is the characteristics of a vegetatively propagated crop, the case here with KMS lines.

The height of the male sterile lines varied from 52.00 to 72.52 cm, whereas the height of male parents ranged from 52.10 to 110.40 cm. On an average all the male parents were taller than KMS-5 whereas only two parents were dwarf than KMS-4. KMS-1 was taller than 16 male parents. Since all the male parents were much taller than KMS-5, the pollen distribution on KMS-5 was obstructed. The panicles were not properly exposed and also were covered by the leaves of the male parent. The plant habit of KMS-5 was also not erect and the tillers were somewhat spreading. Even though KMS-1 had good number of tillers the plant was taller than many male parents, hence the seed set was less than in KMS-4. The panicle emergence in KMS-1 was continuous hence lack of pollen for pre-emerged or late emerged panicles, probably was the main factor contributing to the low seed set. The flowering also started very early in KMS-1. KMS-4 had optimum height in the sense it was slightly shorter or equivalent to that of male parents. Hence it had better chances for pollen reception. The heading time of KMS-4 is also late as compared to KMS-1 thereby causing better synchronisation. The panicles were better exposed in case of KMS-4 and the spikelets were well distributed. The plants of KMS-5 were covered by male plants and hence were not properly exposed to wind for effective pollination and fertilization.

Though, in general, plant height played an important role, there was no definite correlation between plant height and seed set. The highest seed set on KMS-4 was also due to better panicle exsertion. Hence, KMS-4 plant type was found desirable for hybrid seed production with the set of male parents used in this study.

5.4. *Per se* performance and combining ability

In case of females, KMS-1 had the highest GCA effect for plant height and its *per se* performance was also high. The *per se* performance was found to be correlated with the GCA effects observed for plant height. However, no conclusion can be drawn, since all the female lines were less divergent as they were derived from the same cross. Similar correlations were found for productive tillers in case of KMS-5 (high GCA effect and more number of productive tillers). The GCA effect of females, in general, were consistent with their *per se* performance. It was observed from total tillers and productive tillers that the line KMS-5 showed the highest GCA effect and the highest *per se* performance. KMS-1 exhibited highest *per se* performance and GCA effect in respect of plant height, panicle length and spikelet number per panicle. Similarly, KMS-4 showed the highest sterility and GCA effect.

Thus from the studies for GCA effect and their relative *per se* performance, some conclusions can be drawn. All the desirable characters are not present in the same female line. The characters like good tillering higher panicle number and dwarf plant height were found in KMS-5 while characters like better panicle length, good spikelet number, least sterility and better yields were found in KMS-1 whereas KMS-4 was not found desirable in any of the characters observed. Hence it is always better to use male parents which can complement the characters absent in the female parent. In any hybrid breeding programme with KMS-1 as female parent pollinators selected should possess high GCA effect for tillering, productive tillers and dwarf habit.

KMS-1 was found to be the best female parent since it had high GCA effect for yield components, viz., panicle length, spikelet number and least sterility in their crosses. It is very important to have fertile hybrid to exploit heterosis for grain yield. KMS-1 had negative GCA effect for sterility and it restored fertility of hybrids. KMS-5 was the next best female line since it had good GCA effects for characters like productive tillers and dwarf plant type which are highly correlated with yield. While using KMS-5 as a parent, since it has very low GCA effect for total spikelets, pollinators with high GCA effect for these characters should be selected. KMS-4 is the least desirable female as it had lowest GCA effect for yield and highest GCA effect for sterility. Hence finding a good restorer would be a problem. In addition, it had negative GCA effects for total tillers, productive tillers, panicle length and number of spikelets per panicle.

No definite correlations exist between per se performance and GCA effect in case of males. The parents having maximum and moderate number of tillers showed negative and least GCA effects. Sona had maximum number of tillers followed by TN 1, Puspa and Mangala; their GCA effects were negative and Mangala showed highest negative GCA effect whereas male parents like Bilikagga and KMP-249 had minimum per se performance but good combining ability effects. But in some parents, viz., ES 18, Telhamsa, KMP 39 correlations were found having better per se performance and better GCA effects. Similar results were obtained for productive tillers. There was no correlation between per se performance and GCA effects in many of the males for productive tillers. Parents ES 18, KMP 39 and Telhamsa showed significant positive GCA effects for both total tillers and productive tillers. But consistency in GCA effects among males was found for total tillers and productive tillers.

As far as correlations between per se performance and GCA effects were concerned, similar picture was seen for all the characters. Puspa showed maximum yield and highest GCA effect followed by Telhamsa in yield as well as in GCA effect; hence it can be successfully used as a ale parent with any of the female lines. Male parents

Telhamsa, KMP-249, KMP 39, ES 18 are preferred for KMS-1 since they showed better GCA effect for total tillers and productive tillers and had negative GCA effect for plant height while KMS-1 lacks the same but has good combining ability effect for rest of the characters. For KMS-5 parents Telhamsa, Pushpa, Pragathi and Managala are more preferred as these combinations would be having desirable general combining ability for all the yield contributing characters.

In general, male parents, viz., Pushpa and Telhamsa had desirable combining ability effects for all the characters; hence can be preferred in any breeding programme. Parents ES 18, KMP 39, KMP 249 and Telhamsa had highest combining ability values for total tillers and productive tillers and least values for plant height; hence they can be used to develop varieties or hybrids with good tillers, panicle and medium or dwarf plant height. Good combiners for sterility were ES 18, Inter mutant, KMP 249, Purple puttu, Sona, KMP 104, KMP 39 which can be further utilised to develop maintainers. Good combiners for all the characters were found individually but except pushpa and Telhams rest of the varieties can be used for incorporating a few desirable characters. So based on the character to be incorporated or based on the female and objective, male parents have to be chosen carefully. Parents Vikram, Vani, Type 3, Pragathi, MR 365, IET 7031 and IR 36 had very less GCA effect for most of the characters and hence they may not be included in further breeding programme.

None of the hybrids having KMS-1 as female parent showed significant SCA effect either for total tillers or for productive tillers. The best combiner for total tillers was KMS-5 x IR 36 which showed significant positive SCA effect while KMS-4 x IR 36 showed significant negative SCA effect for the same character. Similarly, KMS-5 x IR 36 showed significant positive SCA effect for productive tillers followed by KMS-5 x MR 365, hence, the hybrid KMS-5 x IR 36 produced better tillers and panicles which is primarily correlated with yield while KMS-4 x IR 36 showed undesirable SCA effect for both the characters.

For plant height large number of hybrids showed significant SCA effects while hybrids KMS-1 x Intan mutant KMS-1 x Type 3, KMS-1 x IET 5909 and KMS-1 x IR 36 had greater plant height and were significant for tallness. So these combinations can be utilised where fodder yield also plays an important role and water logging is a problem. Many other hybrids also showed SCA effect for tallness. For dwarfness many hybrids showed significant SCA effects. The hybrid KMS-1 x TN 1, KMS-1 x Telhamsa, KMS-1 x Pushpa, KMS-4 x IET 5909, KMS-4 x Mangala, KMS-5 x Mani, KMS-5 x IR 36 and KMS-5 x Bilikagga had significant SCA effect for dwarfness. Hence these combinations play an important role in developing hybrids which suits to modern plant type concept. Only a few hybrids were tall and most of the hybrids were medium tall and dwarf as observed in parents, hence there is a scope for obtaining plants of any height.

Hybrids KMS-1 x ES 18, KMS-1 x Pragathi, KMS-1 x TN 1, KMS-5 x Basumathi, KMS-5 x Sona, KMS-5 x Type 3 showed significant SCA effect for panicle length. Only hybrid KMS-1 x ES 18 showed significant positive SCA effect for panicle length and number of spikelets per panicle. So correlations existed between higher panicle length and higher spikelet number in this hybrid. Even though many of the hybrids showed increased panicle length they did not show increased spikelet number indicating sparse distribution of spikelet in the hybrid. But some hybrids showed decreased panicle length and increased spikelet number indicating panicles with dense spikelets. Very few hybrids showed significant increase in spikelet number.

In hybrids KMS-1 x Basumathi, KMS-5 x Mangala, KMS-5 x Telhamsa, KMS-5 x Vani there was significant decrease in sterility but significant increase in yield, similarly in hybrids KMS-1 x Mangala, KMS-1 x Telhamsa, KMS-4 x Vani, KMS-5 x Basumathi, KMS-5 x MR 365 increased sterility was correlated with decreased yield indicating inverse relationship between yield and sterility. This indicates that there is a wide scope to develop both maintainers and restorers for the male sterile lines.

As revealed above, progenies of all the three sterile lines appeared to be capable of producing high sterile and less yielding hybrids. So there is wide scope for maintaining the sterility and also for producing fertile and high yielding hybrids so that a few fertility restorers can also be developed and further used in heterosis breeding.

The female lines used in this experiment are not yet stabilized for all the agronomic characters and they are also not divergent, hence definite trends in GCA effect and SCA effects were not obtained. Similarly, definite correlations were not obtained between yield contributing characters and yield.

SUMMARY

VI. SUMMARY

The present study was undertaken with a view to identify maintainers and restorers for the three male sterile lines of rice, viz., KMS-1, KMS-4 and KMS-5. The identification was done based on the pollen sterility of the hybrids. The magnitude of heterosis for nine quantitative characters namely plant height, total tillers, productive tillers, panicle length, number of spikelets per panicle, sterility percentage, days to maturity, grain yield per plant and 1000 grain weight in 66 crosses involving 3 male sterile lines and 22 inbred lines as male parent was calculated. Since all the three male sterile lines were derived from the same cross, they are cytoplasmically alike. The male parents were selected from cultivated varieties and breeding lines and were highly divergent. The study was also aimed at finding out the general combining ability of females and males and specific combining ability effects along with relative importance of additive and non-additive gene action governing the above characters. The amount of seed set on female lines due to different pollinators which in turn determine the potentiality for hybrid seed production was also determined.

The hybrids were produced during summer of 1982; the crosses along with female and male parents were evaluated for different traits in complete randomised design during Kharif of 1982 at the main research station, Hebbal, Bangalore.

The important findings are summarised below:

1. Some genotypes were found to be sterility maintainers for all the three male sterile lines and some as restorers. A scope to obtain both restorers and sterility maintainers was also indicated.

2. Sterility of the F_1 showed wide variations from 20.5 to 99.7 per cent based on seed set. Pollen sterility ranged from 16.14 to 92.00 per cent.

3. Great diversity was found among male parents and the crosses when compared to female lines for all the characters.

4. Significant heterosis over midparent was observed for many characters in some hybrids though majority of them did not show significant heterosis over midparents for characters such as total tillers, number of panicle bearing tillers, number of spikelets per panicle indicating additive gene action.

5. Over the best parent, significant positive heterosis was observed in most of the hybrids for characters viz., plant height, days to flowering and sterility percentage.

6. Two hybrids KMS-5 x Telhamsaand KMS-5 x Mangala were found superior to the best variety for yield and hence promising, while many hybrids showed heterosis for yield components.

7. The GCA effect of females in general was consistent over their *per se* performance. Hence, these lines could be made use of in producing hybrids.

8. Very few hybrids showed significant SCA effects for the characters studied.

9. The seed set on KMS-1, KMS-4 and KMS-5 ranged from 10.56 to 28.36, 11.05 to 44.77 and 4.4 to 22.90; the average seed set was 19.25, 31.01 and 9.50 respectively due to different pollinators. KMS-4 showed high seed set hence the plant type of KMS-4 is desirable for economical hybrid seed production.

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APPENDICES

APPENDIX I: Meteorological data for the year 1982, as recorded at meteorological observatory, Agricultural College, Farm, Hebbal, Bangalore

Month	Rainfall (mm)	Sunshine hrs/day	Temperature (°C)		Relative humidity	
			Maximum	Minimum	07.20 hrs	14.20 hrs
January	-	10.9	26.6	14.5	94	41
February	-	10.9	30.2	15.3	82	31
March	0.9	9.9	33.0	19.4	96	29
April	10.3	8.8	34.1	21.8	78	37
May	96.3	5.5	33.1	21.7	85	44
June	158.0	5.1	29.2	20.2	94	64
July	61.4	5.2	29.2	19.7	90	58
August	44.3	7.5	28.9	19.6	91	57
September	325.0	8.1	29.5	19.1	90	54
October	39.7	7.1	29.7	19.1	91	53
November	36.3	8.2	27.4	21.6	91	59
December	0.5	8.3	27.3	15.5	87	45

APPENDIX 2: Mean values of different characters of parents

Parents	Characters								
	Plant height (cm)	Total tillers	Productive tillers	Panicle length (cm)	Days to maturity	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant (g)	1000 grain weight (g)
1. Bilikagga	109.80	14.00	9.20	21.17	136	117.0	39.90	17.08	25.40
2. Basumathi	107.60	16.80	14.20	23.45	141	64.00	16.05	17.12	15.40
3. RS 13	62.00	22.40	17.40	17.69	118	80.10	17.55	17.95	14.60
4. IR 36	65.40	22.60	21.40	19.27	142	64.80	44.35	16.40	19.71
5. IET 7031	88.40	12.60	11.60	21.45	144	62.90	32.98	7.62	19.31
6. IET 5909	99.00	17.80	16.80	21.25	157	157.20	62.42	10.71	14.20
7. Intan mutant	85.00	21.20	17.40	21.60	148	104.00	30.16	21.49	18.10
8. KMP 39	52.80	24.00	20.20	17.46	148	84.30	44.84	13.22	17.80
9. KMP 104	72.20	20.50	16.60	18.36	141	89.30	40.67	14.91	15.00
10. KMP 249	52.10	17.00	16.40	18.52	124	71.60	40.67	13.63	20.00
11. Mangala	72.80	25.20	18.80	19.30	124	100.60	24.60	18.84	21.11
12. MR 365	71.40	18.80	16.40	18.50	122	103.40	33.70	17.26	20.00
13. Pragathi	62.20	1[illegible].00	15.20	18.60	132	99.20	33.02	16.29	19.99
14. Palguna	57.80	16.20	12.20	18.57	163	96.70	46.05	7.67	14.30
15. Purple putta	62.20	16.50	14.40	15.73	132	95.30	43.30	10.29	16.70
16. Pushpa	78.00	25.20	23.20	26.13	142	95.00	34.78	29.84	16.80
17. Sona	60.80	28.20	19.80	31.01	103	134.00	51.58	9.65	17.21
18. TN 1	62.20	25.60	11.20	17.86	135	57.50	43.85	7.34	17.10
19. Telhamsa	66.40	23.20	20.20	20.54	126	114.60	16.58	29.53	21.21
20. Type 3	110.40	16.40	12.00	21.25	141	75.00	16.81	13.73	17.80
21. Vikram	65.80	20.20	11.80	21.00	160	112.30	54.12	9.73	22.00
22. Vani	57.40	22.60	17.40	19.39	156	105.90	33.78	17.06	17.50
23. KMS-1	72.52	22.24	13.00	22.32	-	120.00	98.90	-	-
24. KMS-4	55.96	20.44	11.76	20.82	-	88.00	99.70	-	-
25. KMS-5	52.00	23.50	16.20	20.[illegible]	-	90.00	99.70	-	-

APPENDIX 3 : Mean values of different characters in crosses of KMS-1

Crosses			Characters								
			Plant height (cm)	Total tillers	Productive tillers	Panicle length (Cm)	Days to maturity	No. of spikelets per panicle	Spikelet sterility (%)	Yield per plant (g)	1000 grain weight (g)
1.	KMS-1	x Bilikagga	92.80	33.80	25.60	22.70	119	134.90	81.01	3.82	18.80
2.	"	x Basumathi	98.60	26.40	17.60	22.95	126	103.80	56.37	20.38	15.60
3.	"	x BS 18	91.20	32.60	26.00	22.21	126	154.80	76.79	11.05	24.80
4.	"	x IR 36	106.00	25.00	19.20	33.76	140	193.60	79.35	10.51	16.00
5.	"	x IET 7031	102.00	29.00	22.00	24.39	128	113.60	63.23	8.57	22.20
6.	"	x IET 5909	107.00	30.40	25.40	22.95	141	155.20	79.35	10.63	15.80
7.	"	x Intan mutant	116.80	26.00	22.00	24.06	141	135.10	87.90	6.29	21.80
8.	"	x KMP 39	91.80	31.00	24.00	23.28	143	108.50	85.40	6.30	17.90
9.	"	x KMP 104	92.60	22.20	18.20	24.77	148	138.70	92.60	7.37	16.00
10.	"	x KMP 249	81.60	35.20	25.00	22.25	126	148.70	93.40	2.92	21.20
11.	"	x Mangala	88.00	23.20	17.20	24.25	121	149.10	71.20	10.94	22.20
12.	"	x MR 365	82.60	24.60	17.40	24.28	133	139.90	67.50	12.38	18.20
13.	"	x Pragathi	86.20	26.00	19.00	24.57	124	140.90	58.70	18.71	21.60
14.	"	x Palguna	82.80	19.80	21.20	22.20	146	102.30	55.97	15.16	22.60
15.	"	x Purple puttu	90.40	26.60	20.80	22.59	141	101.20	67.40	12.79	20.00
16.	"	x Pushpa	79.80	36.00	25.60	24.90	117	109.90	51.30	18.65	22.80
17.	"	x Sona	81.20	23.20	18.60	20.35	159	104.80	86.20	4.09	14.40
18.	"	x TN 1	61.80	23.20	19.40	19.71	136	80.20	37.60	12.54	17.00
19.	"	x Telhamsa	76.80	38.40	25.80	22.36	123	103.90	84.50	6.73	20.00
20.	"	x Type 3	107.40	21.80	20.00	21.86	128	96.60	64.60	15.59	16.80
21.	"	x Vikram	90.00	26.60	19.00	24.12	149	131.90	51.58	23.42	22.80
22.	"	x Vani	102.80	25.00	22.20	23.34	141	151.60	78.20	10.25	21.00

APPENDIX 4. Mean values of different characters in crosses of KMS-4

Crosses	Plant height (cm)	Total tillers	Productive tillers	Panicle length (cm)	Days to maturity	No. of spikelets per panicle	Spikelets sterility (%)	Yield per plant (g)	1000 grain weight (g)
1. KMS-4 x Billikagga	94.00	37.00	25.40	23.83	126	105.40	85.30	5.35	24.80
2. " x Basumathi	73.20	25.00	18.80	19.50	144	110.10	78.80	4.87	15.80
3. " x ES 18	67.00	36.80	26.80	16.48	121	101.50	88.60	3.55	14.80
4. " x IR 36	79.00	15.80	13.80	18.76	167	108.30	64.50	3.34	10.00
5. " x IET 7031	79.00	23.40	21.00	18.40	141	96.30	85.50	3.25	11.00
6. " x IET 5909	85.40	26.20	21.60	21.97	157	101.50	75.30	8.13	17.30
7. " x Intan mutant	82.80	34.80	29.00	21.20	141	132.20	85.40	9.59	20.00
8. " x KMP 39	69.80	37.20	30.20	19.21	143	146.40	83.40	9.57	21.80
9. " x KMP 104	82.80	27.00	23.00	19.60	141	97.40	79.00	8.53	15.20
10. " x KMP 249	75.00	29.20	23.40	22.50	126	150.80	86.10	4.53	20.00
11. " x Mangala	69.10	22.60	20.40	17.58	116	101.80	62.80	9.77	16.80
12 " x MR 365	81.90	23.00	18.40	19.40	122	120.80	64.00	9.24	13.60
13. " x Pragathi	75.00	35.40	19.40	20.91	146	131.00	79.10	7.70	20.00
14. " x Palguna	73.00	24.20	19.40	20.02	163	125.30	88.40	2.33	17.60
15. " x Purple puttu	65.60	30.20	25.40	20.71	151	124.90	88.90	1.09	20.00
16. " x Pushpa	81.00	32.00	28.00	21.00	141	181.40	34.20	30.49	14.80
17. " x Sona	63.20	23.40	12.60	19.15	159	92.40	93.40	[illegible]	13.50
18. " x TN 1	69.00	17.80	15.20	19.04	136	100.70	84.90	2.53	18.60
19. " x Telhamsa	76.00	35.20	25.80	21.69	126	117.30	77.70	15.41	25.50
20. " x Type 3	81.60	25.20	21.80	19.80	128	113.30	61.10	15.82	1610
21. " x Vikram	85.60	25.90	22.60	20.58	160	116.10	45.40	15.82	20.00
22. " x Vani	74.00	21.40	16.80	20.42	159	128.20	93.70	0.87	16.30

APPENDIX 5: Mean values of different characters in crosses of KMS-5

Crosses	Plant height (cm)	Total tillers	Productive tillers	Panicle length (cm)	Days to maturity	No. of spikelets per panicle	Spikelets sterility (%)	Yield per plant (g)	1000 grain weight (g)
1. KMS-5 x Billikagga	73.60	27.00	27.40	16.75	119	117.40	66.70	6.59	12.50
2. " x Basumathi	81.60	38.40	29.00	21.43	124	81.00	81.60	2.73	15.50
3. " x BS 18	57.40	31.20	38.60	16.50	120	74.90	78.40	6.64	21.50
4. " x IR 36	61.60	38.40	32.80	20.56	126	98.20	88.60	2.34	20.00
5. " x IET 7031	81.60	23.20	13.80	20.40	141	133.20	74.00	6.39	24.00
6. " x IET 5909	89.40	30.80	26.20	20.11	141	137.90	79.10	8.2	22.60
7. " x Intan mutant	82.30	30.00	25.40	19.55	126	116.90	90.10	2.59	22.0C
8. " x KMP 39	62.00	38.80	34.00	20.32	124	108.60	69.70	10.42	16.90
9. " x KMP 104	78.00	33.20	26.80	20.15	141	105.70	76.50	14.35	24.60
10. " x KMP 249	62.20	43.20	32.60	16.55	122	90.30	84.90	2.76	22.40
11. " x Mangala	99.00	19.20	17.20	21.25	117	109.20	20.80	37.66	24.40
12. " x MR 365	62.60	35.20	33.00	20.87	122	108.20	97.20	0.49	20.00
13. " x Pragathi	67.00	23.60	20.40	17.45	121	120.00	65.00	9.66	23.20
14. " x Palguna	65.40	24 90	18.80	19.27	146	98.60	42.50	10.14	15.80
15. " x Purple puttu	69.00	37.80	27.00	18.02	144	110.10	88.68	2.50	16.00
16. " x Pushpa	71.00	25.50	23.40	20.70	151	106.90	50.90	28.00	20.90
17. " x Sona	62.60	23.60	19.40	21.13	159	113.40	96.00	1.01	20.90
18. " x TN 1	62.94	25.60	18.00	17.68	136	86.00	99.10	0.37	22.20
19. " x Telhamsa	91.50	32.75	28.75	20.40	136	132.00	46.30	33.13	16.00
20. " x Type 3	81.80	30.60	20.60	22.12	144	114.80	80.70	6.28	15.20
21. " x Vikram	63.40	31.40	30.20	17.05	125	106.40	57.60	29.67	13.70
22. " x Vani	69.40	28.00	24.80	19.70	141	111.00	57.60	18.64	19.10