

"STUDIES ON COMBINING ABILITY AND HETEROSIS  
IN F<sub>1</sub> RICE HYBRIDS USING CYTOPLASMIC  
MALE STERILE LINES"

M.Sc. (Ag.) THESIS

by

**ABHINAV SAO**

DEPARTMENT OF PLANT BREEDING AND GENETICS  
COLLEGE OF AGRICULTURE  
INDIRA GANDHI AGRICULTURAL UNIVERSITY  
RAIPUR (C.G.)

2002

**"STUDIES ON COMBINING ABILITY AND HETEROSIS  
IN F<sub>1</sub> RICE HYBRIDS USING CYTOPLASMIC  
MALE STERILE LINES"**

*Thesis*

Submitted to the

**Indira Gandhi Agricultural University, Raipur**

by

**ABHINAV SAO**


**IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE  
DEGREE OF**

**Master of Science  
in  
Agriculture  
(Plant Breeding and Genetics)**

Roll No : 1798

I D No: **AG/96/01**

**SEPTEMBER, 2002**



*Dedicated to  
my respected parents  
and  
teachers*

## CERTIFICATE - I

This is to certify that the thesis entitled "**STUDIES ON COMBINING ABILITY AND HETEROSIS IN F<sub>1</sub> RICE HYBRIDS USING CYTOPLASMIC MALE STERILE LINES**" submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE (Plant Breeding and Genetics)** of the Indira Gandhi Agricultural University, Raipur (C.G.) is a record of the bonafide research work carried out by **Shri Abhinav Sao** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

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

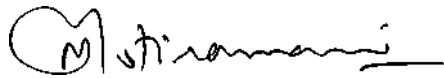
Date : 02/09/2002 .



**Chairman  
Advisory Committee**

### THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman: Dr. N. K. Motiramani



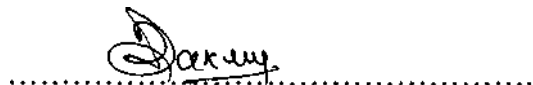
Member: Dr. V. S. Thrimurti



Member: Dr. A. K. Sarawgi

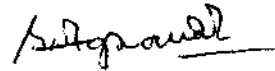


Member: Dr. R.R. Saxena



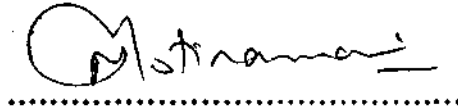
## CERTIFICATE - II

This is to certify that the thesis entitled "STUDIES ON COMBINING ABILITY AND HETEROSIS IN F<sub>1</sub> RICE HYBRIDS USING CYTOPLASMIC MALE STERILE LINES" submitted by **Shri Abhinav Sao** to the Indira Gandhi Agricultural University, Raipur (C.G.) in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** in the **DEPARTMENT OF PLANT BREEDING AND GENETICS** has been approved by the student's Advisory Committee after oral examination in collaboration with the external examiner.



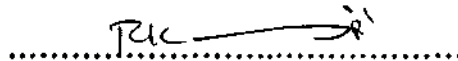
**EXTERNAL EXAMINER**

Dr. N.K. MOTIRAMANI  
MAJOR ADVISOR



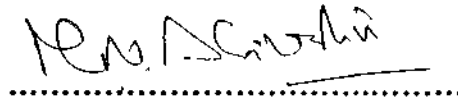
.....

Dr. R.K. MISHRA  
HEAD OF THE DEPARTMENT



.....

Dr. M.N. SHRIVASTAVA  
DIRECTOR OF INSTRUCTIONS



.....

Date: 10/2002.

## ACKNOWLEDGEMENT

*I feel it to be a privilege to express my deepest sense of gratitude towards Chairman of my advisory committee Dr. N.K. Motiramani, Principal Scientist, who is a blend of austerity and fortitude reflecting in his integrity, acuity and simplicity. I feel proud to have guide of such a stature and I shall ever remain grateful to him for his competent and affectionate guidance, continued inspiration, research insight, unique supervision, knowledge and enthusiastic interest, which he provided me throughout my post graduation and research investigation despite his heavy schedule of work.*

*I would like to express my deep sense of indebtedness towards members of my Advisory Committee Dr. V.S. Thrimurti, Head, Department of Plant Pathology, Dr. A.K. Sarawgi, Senior Scientist (Plant Breeding and Genetics) and Dr. R.R. Saxena, Associate Professor (Department of statistics) for their co-operation, valuable suggestions and healthy criticism towards completion of my thesis work.*

*My sincere thanks to Dr. R.K. Mishra, Prof. and Head, Department of Plant Breeding and genetics, College of Agriculture, IGAU, Raipur for his abled guidance and wholehearted co-operation during my research work.*

*I wish to record my sincere thanks to Dr. V.K. Patil, Hon'ble Vice Chancellor, Dr. R.S. Tripathi, DRS, IGAU, Raipur and Dr. M.N. Shrivastava, Director of Instructions and Dean, College of Agriculture, Raipur for providing necessary facilities during the course of my research work and approval.*

*My wholehearted thanks are also due to Dr. R.K. Sahu, Professor, Department of Plant Breeding and Genetics for his support and valuable suggestions during whole course of my research work.*

*I am also thankful to Dr. R.L. Pandey, Dr. S.S. Rao, Dr. V.N. Sahu, Shri M.W. Chitle, Dr. Deepak Sharma, Dr. O.P. Kashyap, Dr. M. Yasin, Dr. R.N. Sharma, Dr. R.K. Yadav, Dr. L.K. Mishra, Shri Arvind Kumar, Dr. P.K. Chandrakar, Dr. N.K. Rastogi, Shri G.R. Sahu, and other staff members of Department of Plant Breeding and Genetics.*

*I wish to express thanks to my seniors Mangala Choudhary, Richa Shukla, Mrs. Ritu Ravi Saxena, Mrs. Payal Vaishnava, Narendra Gannamani, Amit Aradhey, G. Raju, Praveen Patil, Praveen Jadhav, Gawai, Kulkarni, Sanjeev, B.S. Asati, Santosh Jha, Shekhar Rao and Vivek Mishra.*

*I am thankful to god for giving me such a loving friend, Asha, whose inspirations, valuable suggestions, criticism, co-operations and moral support are not having words to express during the whole course of my research work.*

*I am thankful to my friends Deepak, O.P., Paramjeet, Jitendra, Amit, Satish, Devendra, Raja, Rama, Nitish, Kamlesh, Deepak Gauraha, Mahendra, Nitin, Abhijeet, Krishna, Sudhanshu, Sajid, Tarun, Yogesh, Golu, Golu Sir, Akhilesh, Ishwari, Rita, Deepti, Param, Geetu, Mrs. Anshu, Savita, Sahida, and my Juniors, Arvind, Dhananjay, Lakesh, Ghanshyam, Bala, Subodh, Sudarshan, Pyare, Smita, Prabha for their encouragement. I am also thankful to field aids Pathi Ram, Shravan and Parmanand for their help in conduction of my research work.*

*I am very pleased, from the core of my heart, to admit that all my love and affection goes to my parents, Alok, Shilpa, Nanaji-Naniji, Dr. K.K. Sahu (Jijaji)-Didiji, Gaurav, Garima, relatives, friends, my teachers and alma matters for the constant love, affection, motivation and knowledge they have been providing. Lastly I am also thankful to Dewangan Brothers and Yogesh Pal (Pal STD) for their valuable help in preparation of this manuscript.*

*Department of Plant Breeding and Genetics,  
College of Agriculture, Raipur*

**(Abhinav Sao)**

*Date: 02/09/2002 ,*

## CONTENTS

CHAPTER NO.	PARTICULARS	PAGE NO.
I.	<b>Introduction</b>	1-5
II.	<b>Review of Literature</b>	6-27
	Combining ability	6
	Heterosis	15
	Genetic Variability	18
	Heritability	20
	Genetic advance	22
	Isolation of Restorer and Maintainer lines	24
III.	<b>Materials and Methods</b>	28-42
	Materials	28
	Methods	28
	Statistical Analysis	32
	Combining ability Studies	35
	Heterosis	40
IV.	<b>Results</b>	43-92
	Evaluation of genotypes	43
	Variability, Heritability and genetic advance	55
	Combining Ability Analysis	57
	Heterosis	71
	Isolation of Maintainers and Restorers	92
V.	<b>Discussion</b>	93-110
	Analysis of Variance	94
	Evaluation of Genotypes	94
	Studies on Variability, Heritability and Genetic Advance	107
	Isolation of Maintainers and Restorers	109
VI.	<b>Summary, Conclusion and Suggestions for Future Work</b>	111-115
VII.	<b>Abstract</b>	116-117
VIII.	<b>Bibliography</b>	118-127

## LIST OF TABLES

TABLE NO.	PARTICULARS	PAGE NO.
1.	Hybrids released in India.	5
2.	Details of parents used in study	29
3.	Mean performance of parents	44
4.	Mean performance of hybrids.	50-51
5.	Analysis of Variance for different characters.	56
6.	GCV, PCV, Heritability ( $h^2$ ), Genetic Advance and Components of Variance.	56
7.	Analysis of variance for Line x tester analysis.	59
8.	General combining ability effects of lines and testers.	60
9.	Specific combining ability effects of hybrids.	61-62
10.	Magnitude of gca variance and sca variance for different characters	72
11.	Percent Relative heterosis, heterobeltiosis and standard heterosis for different characters.	74-79
12.	Best general combiners and specific combiners for different characters.	105
13.	sca effects of hybrid combinations and gca effects of the parents for grain yield per plant.	106
14.	<i>Per se</i> performance, sca effects and heterosis of F <sub>1</sub> hybrids and gca effects of the parents for grain yield per plant.	108
15.	Restorers and Maintainers for four CMS lines.	108

# INTRODUCTION

# CHAPTER I

## INTRODUCTION

Rice (*Oryza sativa* L.) is one of the important food crop of the world both in terms of area (147.3 million ha) and production (518.4 million tons). It is consumed by more than half of the world's population living in the developing countries. About 90 per cent of world's rice is grown and consumed in Asia and about 2.8 billion people derive their 50 per cent of the total calorie intake from this crop (Anonymous, 1996).

Rice contributes around 45 per cent of India's cereal production and is the main staple food for over 60 per cent of the population in the country. Rice is cultivated in about 43 million ha with a total production of 86 million tons (Singh *et al.*, 2001). Chhattisgarh the newly born state known as 'rice bowl of India', occupies an acreage of 4.0 million ha of rice with a production of 4.6 million tons is noted with a productivity of 1.15 tons per ha, much below the nation's average of 1.9 tons per ha.

Rice production in India has shown remarkable increase in the past two decades due to the adoption of high yielding modern varieties. The green revolution achieved in rice was mainly due to the introduction of dwarfing gene in the development of high yielding varieties through breeding, combined with the adoption of integrated fertilizer and pest management. However, of the 414 rice growing districts, about 70 per cent are with yields below than the national average. Even by moderate estimates, the yield level of rice has to increase by 25-30 per cent from the present level of 1.9 tons per ha if the country is to remain self sufficient by 2010. thereby stressing the necessity for innovative breeding techniques. (Siddiq, 2000).

In the irrigated ecosystem rice production has shown a plateauing trend. In order to increase production and productivity in this ecosystem, innovative breeding approaches are needed with respect to i) a new plant type concept, ii) new biotechnological tools to increase potential yields and iii) yield heterosis in hybrid rice. Out of these, hybrid rice technology is a proven technology in china and a more practical one to raise production.

Heterosis in rice was first reported by Jones (1926) and Ramaiah (1933). Since then several workers have reported heterosis for various economically important characters. Commercial exploitation of heterosis has been made possible by the use of cytoplasmic genetic male sterility and fertility restoration system. A number of cytosterile **maintainer** and restorer lines in rice has been developed in China and at IRRI, Philippines. Additional cytosterile lines are being developed to diversify the genetic and cytoplasmic base of commercial F<sub>1</sub> rice hybrids. Chinese and IRRI scientists have reported upto 45 per cent natural out crossing on male sterile lines in rice, which is sufficient to produce bulk quantities of hybrid seed. High hybrid seed yield has been important for hybrid rice production. Technology is available to obtain hybrid seed production of over 1.5- 2.0 tons per ha. Recent average hybrid seed yield in China has been 2.4 tons per ha.

Chinese scientists for the first time in 1976 reported successful development and release of hybrids in rice. Since then, the area under hybrid rice production in China has increased from 2.1 million ha in 1977 to 15.3 million ha in 1997. Hybrid rice has a yield advantage of more than 15-20 per cent over conventional improved varieties (Lin and Yuan, 1980).

Hybrid rice enabled China to increase rice production during 1977 to 1997 by more than 312 million tons to feed its ever-increasing population. Recently hybrid rice has yielded about 6.6 tons per ha compared with 5 tons per ha for conventional cultivars. Yields of 11.2 tons per ha from a single hybrid crop on a large scale (1,000 ha) and 17.1 tons per ha in a small plot (0.1 ha ) have also been reported (Bai and Luo, 1996). Similar yield superiority of F<sub>1</sub> hybrids has been confirmed under tropical conditions at IRRI, Philippines. Hybrid rice varieties developed so far are grown under irrigated conditions.

India's hybrid rice project started in the late 1980's and its potential for the development and commercialization of hybrid rice is encouraging. Since 1991, India's research network has involved 12 research centers. Over 400 hybrids were developed and evaluated between 1990 and 1994. The best 35 hybrids exceeded the yield of the best check by over 1 ton per ha. Several hybrid cultivars have been released to farmers, whose salient features are given in Table-1. Besides government research networks some private sector companies such as Hybrid Rice International, MAHYCO, Pioneer and E.I.D. Parry Ltd. are also engaged in the development and commercialization of hybrid rice technology. India's current hybrid seed yield is about 0.5-2.0 tons per ha under standardized hybrid seed production package. A total of 1.300 tons of hybrid rice seed was produced for 60,000 ha of the cultivated area under hybrid rice in 1996. (Ahmad, 1997).

The CMS lines introduced from China are unsuitable to use as such in developing hybrid rice in India. Therefore, it is necessary to identify maintainers and restorers among the lines developed through conventional

breeding procedures which could be converted into CMS lines for wider adaptability. Identification of restorers, which show consistently high degree of restoration of CMS lines, would be of great value in commercial hybrid breeding programme if restoring ability is combined with higher combining ability.

Keeping the above facts in view, the present study was undertaken with the following objectives.

1. To assess the variability for yield and yield components in selected rice hybrid.
2. To estimate **heritability** and genetic advance for yield and yield components.
3. Estimation of **gca** of parents and **sca** of hybrids for yield and yield components.
4. To determine the magnitude of heterosis for yield and yield components.
5. Isolation of effective maintainers restorers for CMS lines 22A, **IR 62829A**, **IR 67684A** and **IR 68899A**.

**Table-1 : Hybrids rice released in India**

Name of Hybrids (Year of release)	Cross	Duration (days)	Yield in <b>OFT@t/ha</b>		Yield adv. over check <b>(%)</b>	Released for state
			Hybrid	Check		
APRH-1 (1994)	IR 58025A/ Vajram	130-135	7.14	5.27 <b>(Chaitanya)</b>	35.4	Andhra Pradesh
APRH-2 (1994)	IR 62829A/ MTU-9992	120-125	7.52	5.21 (Chaitanya)	44.2	Andhra Pradesh
CORH-1 (1994)	IR 62829A/ IR- 10198	110-115	6.08	5.23 <b>(IR-50)</b>	16.2	Tamil Nadu
KRH-1 (1994)	IR 58025A/ IR-9761	120-125	6.02	4.58 <b>(Mangala)</b>	31.4	Karnataka
CNRH-3 (1995)	IR 62829A/ Ajaya	125-130	7.49	5.45 <b>(Khitish)</b>	37.4	West Bengal
DRRH-1 (1996)	IR 58025A/ IR- 40750	125-130	7.30	5.50 <b>(Tellahansa)</b>	32.7	Andhra Pradesh
KRH-2 (1996)	IR 58025A/ KMR-3	130-135	7.40	6.10 (Jaya)	21.3	Karnataka
Pant Sankar Dhan-1(1997)	IR 58025A/	115-120	6.80	6.20 (Pant Dhan-4)	9.7	Uttar Pradesh
CORH-2 (1998)	IR 58025A/	115-120	6.25	5.20 (ADT-39)	20.2	Tamil Nadu
ADRH-1 (1998)	IR 58025A/ IR-66	115-120	7.10	4.90 <b>(ASD-18)</b>	44.9	TamilNadu
Sahyadri (1998)	IR 58025A/ BR- 827-35	125-130	6.64	4.89 (Jaya)	35.8	Maharashtra
Narendra Sankar Dhan-2 (1998)	IR 58025A/ NDR- 3026	125-130	6.15	4.94 <b>(Sarjoo-52)</b>	24.5	Uttar Pradesh
PHB 71 (1997)*	-	130-135	7.86	6.14 (PR 106)	28.0	Haryana, U.P., Tamil Nadu
PA 6201 (2000)*		125-130	6.18	5.03 (Jaya)	22.9	Eastern and some parts of Southern India
HRI-120 (2000)*		135-140	6.11	4.91 (Jaya)	24.4	U.P., Bihar, Orissa, A.P., Karnataka, MH
Pusa RH-10 (2001)	Pusa 6A/ PRR-78	120-125	4.35	3.11 (Pusa Basmati-1)	39.9	Haryana, Punjab, Western U.P., Delhi

@OFT= On-farm trials. \* Private bred hybrid released by Central Variety Release Committee.

## REVIEW OF LITERATURE

---

## CHAPTER - II

### REVIEW OF LITERATURE

Rice (*Oryzasativa* L.) holds the key to sustained food sufficiency in the country. Hybrid rice technology has proved to be a viable option to increase the rice productivity over the current levels. India's hybrid rice research was started in the late 1980s and its potential for the development and commercialization of hybrid rice is encouraging. In the year 1991 more than 400 hybrids were developed and evaluated. The best 35 hybrids exceeded the yield of the best check by over 1 ton per ha. Since then several hybrid cultivars have been released to the farmers for commercial cultivation.

The literature relevant to the present study is reviewed here under the following heads:

1. Combining ability.
2. Heterosis.
3. Genetic variability.
4. Heritability.
5. Genetic advance.
6. Isolation of effective restorer and maintainer lines.

#### **2.1. COMBINING ABILITY :**

The knowledge regarding the nature of combining ability of parents and hybrids facilitates the choice of parents in a breeding programme. The combining ability is the ability of an inbred or a parent in transfer of desirable character to its hybrid progenies. The average performance of a parent

or inbred in a series of cross combinations is known as its "general combining ability" and the performance of two specific inbred in a particular cross combination is known as its "specific combining ability".

Davis (1927) suggested the use of inbred variety top cross to test the general combining ability of inbred. Sprague and Tatum (1942) made a distinction between general and specific combining abilities. They defined general combining ability (gca) as the average performance of a line in a series of crosses and further assumed that gca was dependent on the additive effects of genes. The specific combining ability (sca) was used for those cases in which certain cross combinations do relatively better or worse than would be expected on the basis of average performance of lines involved. The sca depends on genes with dominance and epistatic effects.

The review of literature pertaining to combining ability in rice is as follows :

#### 2.1.1. The gca and **sca** effects :

Zhou *et al.* (1982) found that general combining ability of parents was prominent than the specific combining ability. Each character in hybrids was influenced by the gca of both male sterile lines and restorers and also by the sca of the cross combination.

Kumar and Rangaswami (1984) adopting line x tester analysis obtained significant gca and sca effects for the characters studied. High gca for yield per plant was shown by cultivars 07414 and 07107. Three crosses were reported as superior on the basis *of per se* performance and sca effects.

Sharma *et al.* (1987) reported that in a line x tester analysis of rice, the good combiner for economic yield was PL 16 among the tall parents, and IR 54 and IR 36 among semi-dwarf parents. The crosses IR 36/Safri-17 and IR 54/Pankaj showed significant sca effects for economic yield.

Tseng and Huang (1987) observed that gca as compared to sca play a prominent role in the performance of the hybrid. They identified Tainugsenynh-172 as good combiner.

Peng and Virmani (1990) in their combining ability studies conducted at IRRI, Philippines indicated that gca effect of parents and sca effects of hybrids for yield were highly significant.

Banumathy and Prasad (1991) studied twelve rice hybrids involving four CMS lines and three testers for their combining ability for six quantitative characters. Among the parents evaluated, IR 62829 A was found to be a good general combiner for grain yield, plant height and number of filled grains. The cross IR 62829 A/ IR 50 manifested high positive significant sca effect for plant height.

Watanesk (1993) studied gca for four 'A' lines and five 'R' lines and sca of 20 hybrids in a line x tester design. Among 'A' lines CNTA-10 and CNTA-1 for yield, plant height and panicle length, CNTA-7 for spikelets per panicle and CNTA-34 for days to 50 per cent flowering, 1000-grain weight and low per cent for unfilled grains, were good general combiner. Among testers, SPRLR-75055-352-2-1, SPRLR-77034 and PSL-17-1-1-1 were identified as good general combiner.

Kumar and Chanrappa (1994) reported from the combining ability studies derived from data on 9 yield related traits in 14 rice crosses and their parents (7 line x 2 testers) that variance due to gca was higher than variance due to sca for all characters except number of productive tillers, grain yield per panicle and grain yield per plant.

Ramalingam *et al.* (1997) in their study found CMS line IR 58025 A and restorer IR 54742 to possess favourable genes for one or more characters. The hybrid combination IR 58025 A/IR24 showed superior sca effects for all the 7 characters studied. It was followed by IR 58025 A/IR 24723 and IR 62829 A/IR 54742 with good sca effects for six characters.

Anand *et al.* (1999) studied combining ability for eight quantitative characters through line x tester analysis involving four CMS lines and 10 testers. The combining ability analysis revealed significant sca effects for all the characters. Among the parents, Pragathi A, BR203-70-B-2, IR31406-MS and IR 50400-64-1-2-2-2 were found to be good general combiners for grain yield.

Dwivedi *et al.* (1999) studied combining ability for grain yield and its contributing characters in a 10 parent F<sub>1</sub> diallel in rice over three environments: E1: normal sowing time (NS) and high fertility (HF), E2: NS and optimum fertility (OF) and E3: late sowing (LS) and HF. The parental lines included four tropical Japonica lines having wide compatibility genes and six *indica* lines. Both gca and sca were influenced by environments. The magnitude of sca variance was relatively higher than gca variance.

Meenakshi and **Amirthadevarathinam** (1999) studied combining ability and genetic variance for yield and 8 yield and physiological components in 10 genotypes and revealed that **Annada** and **Kallurundaikar** were the best general combiner for all the characters except 100-grain weight. **Annada/Kallurundaikar** and **Annda/Chandikar** were the best specific combiner.

Kalitha and Upadh aya (2000) studied combining ability of 14 characters through a line x testers approach involving 11 lines and 3 testers and reported the predominance of non-additive gene action for all the characters except panicle length. Among the lines, Rangadoria, ARC 10372 and Nilajee, and among the testers, Annada were the good combiners for grain yield per plant and some other adaptive characters. Seven crosses were identified as the good specific combinations for grain yield per plant and some other adaptive characters.

**Munhot *et al.*** (2000) carried out combining ability analysis for yield, yield attributes and quality traits through line x tester approach and revealed that the parents Mahamaya, RP 2151-33-2, Dubraj, Abhaya and R302-111 were good general combiners for grain yield and its components. The crosses RP 2151-33-2/Pusa Basmati-1, R302-111/Dubraj, RP 2151-33-2/Dubraj, Mahamaya/Basmati-370, PR-111/Pusa Basmati-1 and PR106/Tarori Basmati showed high specific combining ability for yield.

**Satyanarayana *et al.*** (2000) studied combining ability for grain yield and its component characters through line x tester approach involving three CMS lines and 33 restorer lines and reported that CMS line V 20A was found as

good general combiner for earliness whereas. IR 58025A and IR 62829A were found good general combiners for yield. The restorers, viz., IR 9761-19-IR, MTU 5249, IR 46 R, IR 1349-3-13-IR, IR 28178-70-2-3, Chianungsenyu, Suweon 318 R, IR 2797 - 125, UPR 254-84-ITCA. Suweon 287R were found as good general combiners for yield.

Sreeramachandra Babu *et al.* (2000) carried out combining ability analysis with 4 CMS lines and 8 testers by adopting line x tester approach and found that among the four CMS lines, IR 58025 A and IR 62829 A and among the 8 testers WGL 3962, IET 9762 and IET 10021 were found as good general combiners for yield and other yield attributes. The hybrids, IR 62829A/WGL 3962, IR 62829A/IR 276-301-06-01 R, IR 62829A/MTU 9992, APMS 2A/IET 9762, IR 58025A/IET 10021 and APMS 1A /IET 10021 were found as good heterotic combinations for grain yield.

### **2.1.2. Gene Action:**

Fisher (1918) was the first who divided the genetic variance into three components i.e. additive, dominance and epistatic variances. Additive variance arises from differences between the two homozygous for each gene governing a polygenic trait. Dominance variance arises due to the deviation of heterozygote from the average of the two homozygotes for each gene affecting a polygenic trait; sometimes referred to as intra-allelic interaction component. Epistatic variance arises due to the deviations as a consequence of inter-allelic interactions. Riaymun & Mather (1955) further divided the epistatic variance into three components: (1) additive x additive. (2) additive x dominance,

(3) dominance \ dominance interactions. Line x tester analysis (Kempthorne, 1957) has been found to be the best in estimation of unbiased additive and dominance components in the absence of epistasis. The studies on estimation of genetic variance by line x tester analysis in rice is reviewed as under:

Haque *et al.* (1981) reported the predominance of additive gene action for yield, effective tillers per plant, grains per panicle and predominance of non additive gene action for days to flowering, plant height and spikelets fertility.

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

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

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

Manuel and Palanisami (1989) observed the ratio of  $gca/sca$  variance and indicated the predominance of additive gene action for days to flowering, plant height and panicles per plant and prevalence of non-additive gene action for flag leaf area, grains per panicle, spikelets sterility 100-grain weight and grain yield per plant. Both additive and non-additive gene actions were equally important for panicle length in their study.

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

Sarawgi *et al.* (1991) reported the importance of non-additive components for number of tillers per plant, fertile spikelets per panicle, spikelets sterility and grain yield per plant. However plant height, panicle length and test weight were reported to be governed by additive gene action.

Gravois and McNew (1993) reported non-additive gene action for plant height, panicle length and yield per plant whereas, additive gene action was reported for productive tillers per plant.

Uma (1994) reported that non-additive gene action contributed more for days to flowering, number of productive tillers per plant, panicle length, spikelets per panicle, 1000-grain weight and yield per plant whereas, additive gene action contributed more for plant height, filled grains per panicle and spikelets fertility.

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

Manonmani and Ranganathan (1998) studied the nature of gene action for **earliness** and other traits in line x testers approach and observed that the ratio of gca:sca variances showed the importance of non-additive gene action for days to flowering, plant height, number of productive tillers, panicle length number of grains per primary ears, 100-grainsweight and yield.

Dwivedi *et al.* (1999) observed that both additive and non-additive gene action were important in their study. The magnitudes of **sca** variances were relatively higher than the **gca** variances and thus the predominance of non-additive gene action was indicated for all the characters except for 100-seed weight. Additive gene action played major role for 100-seed weight.

Meenakshi and Amirthadevarathinam (1999) reported preponderance of additive gene action for days to flowering and grain yield per plant. Both additive and non-additive gene action were observed for productive tillers.

Lavanya (2000) reported dominant gene effects for traits like productive tiller per plant, filled grains per panicle, spikelets fertility per cent, harvest index, grains protein and grain yield. Additive gene effects were found for days to 50 per cent flowering, plant height, panicle length and test weight.

Munhot *et al.*, (2000) observed the predominance of dominance gene action for plant height, panicle length, spikelets fertility per centage, harvest index, milling per cent, head rice recovery per cent, kernel breadth, elongation ratio and allali value and additive gene action for fertile spikelets, spikelets density, kernel length and length: breadth ratio and kernel elongation.

Satyanarayana *et al.*, (2000) reported that the **sca** variances were higher than **gca** variances for all the characters, indicating the predominance of non-additive gene interaction in governing yield and related traits.

## 2.2. HETEROSIS:

Heterosis refers to the phenomenon in which the hybrid of two genetically dissimilar parents show an **increased/ decreased** vigour at least over mid parental value. Heterosis in rice was first reported by Jones (1926). Literature related to heterosis is reviewed as under:

Rao *et al.*, (1980) reported negative heterosis for spikelets fertility. They also reported standard heterosis of hybrids ranging from - 18.0 to 51.0 for number of spikelets per panicle.

Shrivastava and Seshu (1982) recorded high heterosis for spikelets per panicle, plant height and grain yield per plant. Highest heterobeltiosis (62.5 per cent) for yield was recorded in cross IR-36/Cr 1002.

Zhang and Xu (1986) observed positive heterosis for the traits effective tillers, number of filled grains, spikelets fertility per centage and 1000-grain weight but, negative heterosis was recorded for tillering ability.

Kalaimani and Kadambavanasundaram (1987) reported significant heterosis for yield due to positive heterosis for grains per panicle and 100-grain weight.

Tseng and Huang (1987) reported positive heterosis for grain yield, spikelets per panicle, 1000-grain weight, plant height and negative heterosis for panicles per plant and percentage of grain set.

Sasmal (1988) observed that heterosis for grain yield was associated with heterosis for grain length, grain breadth, panicle length and rachillas per panicle.

Young and Virmani (1990) noticed negative heterosis, heterobeltiosis and standard heterosis in direct and reciprocal crosses for days to flowering. They also reported that hybrids were taller than the parents and showed standard heterosis for grain yield.

Sharma and Mani (1990) produced four hybrids by utilizing CMS lines and computed heterosis and standard heterosis for yield and yield contributing characters. Heterosis for grain yield per plant was mainly due to high number of effective tillers per plant, long panicle, higher number of grains and 1000-grain weight. Hybrids IR 46830A/Mahsuri and IR 46830A/Basmati-370 revealed significant heterosis and standard heterosis for grain yield per plant.

Peng and Virmani (1991) evaluated 75 F<sub>1</sub> hybrids of which 31 showed significant standard heterosis for days to 50 per cent flowering and plant height.

Nguyen and Bui (1993) reported heterosis for yield over mid parent ranging from 23.0-63.6 per cent and heterosis for yield over better parent ranging from 6.8-62.0 per cent in rice hybrids.

Watanesk (1993) reported heterosis, heterobeltiosis and standard heterosis for yield of 20 F<sub>1</sub> rice hybrids and observed that hybrids CNTA-10/ CNTLR-80140-14-1-1-1 had highest heterosis (44.5 per cent), CNTA10/ spLR-77034-PSL-17-11-1 had highest heterobeltiosis (41.8 per cent) and standard heterosis (51.7 per cent).

Bobby and Nadarajan (1994) studied 50 F<sub>1</sub>, out of which 14 showed significantly longer panicles over variety IR 50. Positive heterosis for number of productive tiller per plant and standard heterosis for 1000-grain weight was recorded for six out of fifty hybrids.

Yang and Song (1994) revealed heterosis for plant height, flag leaf length and width, total number of grains per main panicle and number of effective tillers. Heterosis was highest for number of effective tillers (59.06 per cent) and high for total grain number (42.44 per cent).

Ramalingam *et al.* (1994) from a study on heterosis revealed that the two hybrids IR 58025A/IR 29723 and V20A/IR24 can be used in hybrid programme. Since they showed higher heterosis with high out crossing rate.

Ramesha *et al.* (1996) studied 8 rice hybrids and observed significant commercial heterosis for grain yield in hybrids IR 58025A/Swarna, PMS 3A/PR103 and IR 58025A/IR 32809. However hybrids IR 58025A/IR 52256 and IR 62829A/ IR 53390 showed negative commercial heterosis.

Mishra and Pandey (1998) utilized V20A and IR 62829A to develop hybrid with 19 elite genotypes. About 17-20 per cent of all the hybrids manifested significant and positive heterobeltiosis and standard heterosis for seed yield in the range of 44.7 to 230.9 per cent and 42.4 to 81.4 per cent, respectively. Heterosis for seed yield was due to the positive and significant heterosis for components like, panicle length, number of spikelets per panicle and 1000-grain weight.

Panwar *et al.* (1998) studied 22 F<sub>1</sub> hybrids using five male sterile lines and eighteen restorers. Observations for grain yield per plant, panicle per plant, grains per panicle and 1000-grain weight were recorded. They reported that six hybrids for grain yield per plant, twelve hybrids for

panicles per plant and seven hybrids for grains per panicle showed positive and significant heterosis. All the twenty-two hybrids showed negative significant heterosis in their study.

Singh and Haque (1999) reported positive heterosis for grain yield per plant, ear bearing tillers per plant and number of grains per panicle in a study made in 10x10 diallel crosses.

Sreeramachandra Babu *et al.* (2000) evaluated 32 rice hybrids in a line x testers analysis. The hybrids IR 62829A/WGL 3962, IR 62829A/IR 276-301-66-01R, IR 62829A/MTU 992, APMS 2A/IET9762, IR 58025A/IET 10021 and APMS 1A/IET 10021 were found to be good heterotic combinations for grain yield.

### **2.3. GENETIC VARIABILITY :**

Genetic improvement of any character is difficult without having sufficient genetic variability. Therefore, the existence of genetic variability in population is pre-requisite for any crop improvement programme.

Shukla *et al.* (1972) evaluated 179 rice varieties and observed a high genetic coefficient of variation for number of effective tillers per plant. 100-grain weight and grain yield per plant.

Kaul and Kumar (1982) in their study noticed that genotypic coefficient of variation was found to be the highest for plant height followed by tiller number and grain yield.

Li *et al.* (1991) studied yield components in 9 rice cultivars and reported that the genetic coefficient of variation was highest for panicles per plant, followed by grain weight per plant and grain density and lowest for plant height and spikelets fertility.

Bai *et al.* (1992) reported that phenotypic coefficient of variations were higher than genotypic coefficient of variations for plant height and grain yield per plant.

Babu (1996) conducted experiment on twenty two advanced generation, salt tolerant genotypes and reported that genotypic and phenotypic coefficients of variations were high for number of unfilled grains, number of filled grains and grain yield per plant.

Singh and Choudhary (1996) derived information on genetic variability from data on 12 characters in 45 F<sub>1</sub> progeny, 45 F<sub>2</sub> progeny and their 10 parents and reported that estimates of genotypic coefficient of variations and phenotypic coefficient of variations were high for number of panicles per plant, number of grains per panicle, grain yield per plant and 1000-grain weight.

Choudhary and Das (1998) worked out estimates of variability in eleven deep-water rice varieties and its attributing characters. High genotypic coefficient of variation was observed for grains per panicle followed by grain yield.

Kaw *et al.* (1999) evaluated ninety-four rice genotypes (38 *japonica I indica* F<sub>1</sub>, 36 *indica I indica* F<sub>1</sub> and 20 parents) for genetic variability under three cold stress environment at three locations in Philippines, Korea and

Pakistan. High genotypic variations were observed at all locations for fertility percentage and number of fertile spikelets per panicle and low genotypic variations were found for flowering duration and panicle length.

Shivani and Sree Rama Reddy (2000) conducted experiment involving 10 hybrids and two varieties of rice for morphological and physiological traits. They reported moderate to high genotypic and phenotypic coefficients of variations for plant height, productive tillers per plant, spikelets sterility, 1000-grain weight, grain yield per plant and harvest index.

Sadhukhan and Chattopadhyay (2000) studied twenty six aromatic genotypes and observed high GCV for grains per panicle, test weight, plant height and kernel length.

Iftakharuddaula *et al.*(2001) evaluated nineteen rice hybrids in order to determine variability and it was observed that all the tested characters had significant variation. The highest genotypic coefficient of variation was found for panicles per plant followed by spikelets per panicles, grain yield, 1000-grain weight

#### **2.4. HERITABILITY :**

Alias (1985) in a field experiment with six genotypes observed 26-50 per cent broad sense heritability for plot yield and 60-90 per cent heritability for grain number per panicle and 1000-grain weight.

De and Rao (1988) observed high heritability for ear bearing tillers per hill, sterility percentage, hundred-grain weight, and length of grain and breadth of grain.

Choubey and Singh (1994) reported high heritability estimates for total number of spikelets followed by grain yield per plant and 100-grain weight.

Sarawgi and Soni (1994) conducted experiment on 16 cultivars of rice and 72  $F_1$ 's which were grown under irrigated and rainfed conditions. Heritability estimates were highest for plant height, grain length, 100 seed weight, spikelets density, panicle length and fertile spikelets per panicle.

Babu (1996) reported high heritability estimates for number of filled grains, grain yield per plant and number of productive tillers per plant.

Rao *et al.* (1997) evaluated twenty high quality genotypes of rice for 8 yield components and reported that broad sense heritability estimates for spikelets per panicle, 1000 grains weight and panicle length ranged from 0.70 to 0.93.

Borbora and Hazarika (1998) conducted experiments on thirty genotypes of rice including 16 local varieties and 14 high yielding varieties/advanced lines under 2 sowing dates. High to moderate heritability was recorded for number of chaffy grains per panicle, number of filled grains per panicles, 1000-grain weight and grain yield per panicle.

Choudhary and Das (1998) studied heritability estimates in eleven deep-water rice varieties for yield and its attributing characters. High heritability was found for grains per panicle and grain yield.

Kaw *et al.*(1999) reported that heritability estimates over locations ranged from 82.60 per cent for panicle length to 93.10 per cent for plant height.

Sadhukhan and Chattopadhyay (2000) observed high genetic gain as percentage of mean for yield per plant, test weight, plant height, number of grain per panicle, kernel length after cooking and amylose content.

Shivani and Sree Rama Reddy (2000) conducted experiment involving 10 hybrids and two varieties of rice for studying certain genetic parameters for morphological and physiological traits. They found high heritability for productive tillers per plant, panicle length, number of spikelets per panicle, filled grains per panicle, grain yield per plant, 1000-grain weight, harvest index.

Iftikharuddaula *et al.*(2001) evaluated nineteen rice hybrids and reported high heritability and genetic advance for panicles per plant, spikelets per panicle and 1000-grain weight.

## 2.5. GENETIC ADVANCE :

Genetic advance is the improvement in the mean genotypic value of selected plants over the parental population. It is the measure of genetic gain under selection. The success of genetic advance under selection depends on three factors:

Genetic variability

Heritability

Selection intensity.

The genetic advance is generally high with the characters having high heritability.

Johnson *et al.* (1955) emphasized that in cases where heritability is mainly due to non-additive gene effects the expected genetic gain will be low, but if it is due to additive effect, high genetic gain is expected.

Genetic advance studies made in rice and their salient findings are reported here in :

Maurya *et al.* (1986) reported high genetic advance for grain length, grain length:breadth ratio, plant height, grains per panicle, 100 grains weight and panicle length.

Bai *et al.* (1992) reported moderate to high estimates of genetic advance for plant height and grain yield per plant.

Manuel and Prasad (1993) observed that plant height, grain per panicle and grain yield showed moderate/high genetic advance indicating selection for these traits based on phenotypic value would results in greater efficiency.

Ramalingam *et al.* (1994) reported that total filled grains and grain yield showed high genetic advance and as such selection for these traits would be effective.

Babu (1996) studied twenty-two advanced generation, salt tolerant genotypes and observed high genetic advance for number of filled grains, grain yield per plant and number of productive tillers per plant.

Mani *et al.* (1997) studied 24 genotypes of Basmati rice for six panicle characters and observed high genetic advance for number of filled grains per panicle.

Choudhary and Das (1998) estimated genetic advance in eleven deep-water rice varieties for yield and its attributing characters. High genetic advance was reported for grains per panicle followed by grain yield.

Shivani and Sree Rama Reddy (2000) observed high genetic advance for number of spikelets per panicle, filled grains per panicle and grain yield per plant. They also reported a low genetic advance for productive tillers per plant, panicle length and 1000-grain weight.

## **2.6. ISOLATION OF RESTORER AND MAINTAINER LINES :**

Jones and Emsweller (1937) first discovered that cytoplasmic genetic male sterility is governed by the interaction of cytoplasmic and nuclear genes in onion. Sampath and Mohanty (1954) first reported the role of cytoplasm in causing male sterility in rice. For the F<sub>1</sub> hybrids development involving CMS lines, it is essential to identify effective restorers (R) i.e., which restores the fertility of cytoplasmic male sterile (CMS) lines and maintainers (B) i.e., which maintains the male sterility of the CMS lines. The progress made in the development and isolation of maintainer and restorer lines is reviewed as under:

Yuan (1980) reported that among 256 late photosensitive *indica* varieties screened in a test cross nursery in Jiangxi province, 19.7 per cent were restorers. In another test cross nursery in Jiangxi province, among 438 early photosensitive and medium weakly photosensitive *indica* varieties, only 7.5 per cent were restorers. In another experiment with 345 *japonica* varieties screened, no restorer was found. It was concluded from the study that frequency of restorers were more in *indica* varieties than *japonica* varieties and also the frequency of restorer was more in late varieties as compared to early and medium duration varieties.

Virmani (1985) reported from the results of a collaborative study conducted at IRRI, Philippines and China that 15 and 24 per cent of the elite breeding materials developed at IRRI were affective restorers in China and IRRI, respectively, but only 6 per cent were effective restorers at both the sites. The restoration ability of remaining restorers lines was location specific. The study also revealed that the frequency of restorer genotypes was higher in tropical environment than in sub tropical environment.

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

Mandal *et al*, (1990) studied the F<sub>1</sub> hybrids obtained from the crosses between CMS line IR 46830 A and six local cultivars. The F<sub>1</sub> hybrids were screened for fertility restorer, partial restorer and maintainers of the CMS line. A suitable maintainer Br-8 was identified which was further backcrossed to BC3 in order to obtain a fully stabilized CMS line. At this stage about 90 per cent of the progeny were found to be completely sterile.

Prasad *et al*. (1992) crossed twenty-one short and medium duration *indica* cultivars with eight CMS lines to identify maintainers and restorers. Hybrids IR 62829A/ CO 45, IR 62829A/CO43, IR 58025A/IR50, MS 37A/IET 11752 and Mangala A/IR-62 showed 10 per cent pollen fertility. These hybrids are being used in back cross programme to develop new CMS lines. Heera and MS 10 were identified as restorer and are being used to develop new hybrid combinations.

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

Padmavathi *et al.* (1997) selected 44 genotypes for study of restoration ability of different CMS lines derived from WA and 577A cyto-steriles. five genotypes were able to restorer fertility of two CMS lines derived from WA cyto-sterile source and five genotypes were identified as effective maintainers.

Ganeshan *et al.* (1998) studied four CMS lines in crosses involving 8 rice cultivars. Among the cultivars tested IR 54742-22-19-3 R . AS 78113, C37, CBT 04001 and PMK2 were found to be effective restorers for WA source of CMS lines and no restorer could be identified for CMS lines IR 66707A with *Oryzaperennis* as source of cytoplasm. Nine genotypes were identified as potential maintainers.

Hemareddy *et al.* (2000) studied 132 rice genotypes for testing their ability to restore fertility in test crosses with two WA cyto-sterile lines (IR 58025 A, IR 62829A). One of *Oryza perennis* (IR 66707A) and five MS 577A cyto-sterile lines (Pushpa A, Mangala A, ES 18A, Intan Mutant A and Madhuri A) to identify restorers. The genotypes ARC 11353, IR 9761-19-1 R, IR 25924-95, IR 29723-143-3-2 and IR 30864R restored complete fertility for two cyto-sterile lines of WA system whereas, for cyto-sterile lines of MS 577A source none of the genotypes showed consistency in fertility restoration except for the genotype IR 50360-12-1, which restored the fertility completely in the three cyto-sterile lines of MS 577A source. The genotypes IR 64, IR 2797-105R, IR 25924-95 and Mandya Vijaya were found to be good maintainers for the MS 577A cytosterile systems.

Gannamani (2001) studied 24 rice hybrids involving two CMS lines *viz.*, IR 68886A and IR 68888A and 12 improved varieties as testers. Testers Culture-100 and R-11 were found effective maintainers for CMS line IR 68886A whereas, testers, Culture-100, Indira-9 and R-15 were found effective maintainers for CMS line IR 68888A. Based on high spikelet fertility percentage shown by hybrids, testers Rajshri and R-714-13 were rated as effective restorers for CMS line IR 68886A whereas, testers Kishori, Rajshri, R-741-552 and Swarna were found effective restorers for CMS line IR 68888A.

Ushakumari *et al.* (2002) studied the performance of different hybrids and segregating populations using *indica*, *japonica* subspecies and wide compatible varieties for pollen fertility. Among the hybrids pollen fertility ranged from 60 per cent (Norin PL 9 x IR 50) to 96.67 per cent (Palawan x Akihikari).

## MATERIALS AND METHODS

---

## CHAPTER III

### MATERIALS AND METHODS

The present study was conducted at the Research farm, Department of Plant Breeding and Genetics, Indira Gandhi Agricultural University, Raipur (Chhattisgarh) during *Kharif*2000 and *Kharif* 2001. This study broadly comprises the following objectives:-

1. Assessment of the variability present.
2. Estimation of the heritability and genetic advance.
3. Estimation of the general combining ability of the parents and specific combining ability of the hybrids for yield and yield components.
4. Determination of the magnitude of heterosis for yield and yield components.
5. Isolation of the effective maintainers and restorers for the four CMS lines under study.

#### 3.1. MATERIALS :

The biological material used in the study comprised of four CMS lines *viz.* 22A, IR 62829A, IR 67684A and IR 68899A, having the WA cytoplasmic back ground as lines and thirteen promising varieties of rice *viz.* Kranti, Indira, Swarna, Annada, R-827-287, Shyamala, IR-64, Pusa Basmati, R-574-11, R-15, BG-380, Abhaya and Safri-17 as testers. The source and parentage of the lines and testers is presented in Table-2.

#### 3.2 METHODS :

The parents were raised is different seeding dates during *Kharif* 2000. in such a way to ensure synchronization in flowering for the purpose of hybridization.

**Table-2 : Details of parents used in the study**

Genotypes	Parentage	Source
Lines		
22A	-	DRR, Hyderabad.
IR 62829A	-	WA cytoplasm, IRRI, Philippines.
IR 67684A	-	WA cytoplasm, IRRI, Philippines.
IR 68899A	-	WA cytoplasm, IRRI, Philippines.
Testers		
Kranti	Cross-116/IR-8	Raipur (C.G.)
Indira	Tainan 3 Mutant	CRR, Cuttack.
Swarna	Vasishtha/Mahsuri	Maruteru (A.P.)
Armada	MTU-15/Waikaku	CRR, Cuttack.
R-827-287	R-310-37/AS-688	Raipur (C.G.)
Shyamala	R-60-2712/R-1389	Raipur (C.G.)
IR-64	IR-5657-33-2-1/IR-2061-465-1-5-5	IRRI. Phillipines.
Pusa Basmati	Pusa 150/Karnal Local	IARI, New Delhi.
R-574-11	Asha/Kranti	Raipur (C.G.)
R-15	Indigenous selection from Chinoor	Batargoda, Shri Lanka.
BG-380	BG-9-2/Obs-677	Raipur (C.G.)
Abhaya	CR-157-392/OR-57-21	Raipur (C.G.)
Safri-17	Indigenous selection from Safri	Raipur(C.G.)

### **3.2.1 Hybridization :**

In *Kharif* 2000, the selected thirteen male parents were crossed to each of the four CMS lines to generate a set of fifty-two hybrids. In order to increase the seed settings the spikelets of the CMS plants that were expected to flower the next day were clipped one-third at the top. The clipped panicles were completely covered with butter paper bags for the purpose of avoiding entry of outside pollen grains into the clipped panicles. In the next morning at near about 8.30 A.M. panicles from the male parents were collected at anthesis and pollen grains were dusted over clipped spikelets with proper precaution. The pollinated panicles were immediately bagged again and labeled properly with date and cross name. In this way fifty-two crosses were made for the present study. The bagged panicles were harvested separately from mother plants after thirty days of hybridization. The seeds of each cross were collected separately and were sun dried. The seeds were also treated with bavistin as a precautionary measure against fungal attack before storing the seeds in paper bags.

### **3.2.2 Seeding of F<sub>1</sub>'s and parents :**

During *Kharif* 2001, seeds of fifty-two hybrids made during the previous season were carefully germinated in petriplates lined with moist filter paper. These petriplates were kept in germinator and later germinated seeds were transferred to wooden trays after 3 days. The four lines and 13 tester parents were also sown on the same day when seeds of hybrids were planted in petriplates.

### **3.2.3 Planting of F<sub>1</sub>'s and parents :**

About 25 days old seeding of 52 hybrids and their 17 parents were planted in Randomized Complete Block Design (RCBD) with two replications during *Kharif* 2001. A standard spacing of 20x20 cm. was adapted for planting and ten plants were planted in a single row. Single seedling per hill was planted. Recommended packages of practices were followed.

### 3.2.4 Recording of observations :

In each treatment, observations were recorded on five plants in both the replications for following traits. The mean values for five plants were considered for analysis.

#### (i) Pollen sterility percentage :

This observation was taken by microscopic study of pollen grains. The florets were first preserved in 70 percent alcohol. The pollen sterility and fertility counts were taken later by using acetocarmine stain. The stained pollen grains were counted as fertile and the unstained as sterile pollen grains. The total counts of sterile pollen grains were seen in relation to the total pollen grains in the three microscopic fields. The mean of the three microscopic fields was then calculated. These mean values for sterile pollens and total pollens were used for calculating the pollen sterility percentage. The pollen sterility percentage was calculated as below :

$$\text{Pollen sterility percentage} = \frac{\text{Number of sterile pollen grains}}{\text{Total no. of pollen grains}} \times 100$$

#### (ii) Plant Height :

Height of the plant was measured in centimeters from the ground level to the tip of primary panicle at the time of harvest.

#### (iii) Number of Productive tillers per plant :

The total number of panicle bearing tillers in each plant was recorded at the time of harvest.

**(iv) Panicle length :**

The length of main panicle of each plant was measured in centimeters from the base to the tip of the panicle excluding awns, if any, at the time of harvest.

**(v) Total number of filled spikelets per panicle :**

Total number of well filled spikelets per panicle of each plant were counted and recorded.

**(vi) Total number of chaffy spikelets per panicle :**

Total number unfilled spikelets (chaffy) per panicle of each plant were counted and recorded.

**(vii) 100-grain weight :**

The weight of one hundred well filled grains in grams for each plant was recorded.

**(viii) Grain yield per plant :**

Weight of grains of each plant in grams was recorded.

**(ix) Spikelet fertility percentage :**

The ratio of total number of filled spikelets per panicle to the total number of spikelets per panicle for each plant was calculated and expressed in percentage.

**3.2 Statistical analysis :**

The means were worked out for all the ten traits for each genotype. These mean data were subjected to further statistical analysis.

### 3.3.1 Analysis of variance :

The mean data were subjected to valance analysis and test of significance as per the method of Panse and Sukhatme (1961).

Table: Analysis of variance:

Source of variation	D.F.	M.S.	Expected M.S.
Replication	$r - 1$	$M_r$	
Treatments	$t - 1$	$M_g$	$a_e + r\sigma_g$
Error	$(r-1)(t-1)$	$M_e$	$\sigma_e$

Where,

$r$  = Number of replications and

$t$  = Number of treatment

### 3.3.2 Studies on Variability, Heritability and Genetic Advance :

#### 3.3.2.1 Variability :

Genotypic coefficient of variation (gcv) and phenotypic coefficient of variation (pcv) were calculated by the method suggested by Singh and Choudhary (1985).

$$M_g - M_e$$

Where,

$a_g$  = Genotypic variance

$M_g$  = Treatment mean square

$M_e$  = Error mean square

**a. Phenotypic coefficient of variation (pcv) :**

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

$$\text{pcv} = \frac{\sigma p}{X} \times 100 \quad (\text{ap} = \sqrt{\sigma^2 p})$$

Where,

$\sigma^2 p$  = Phenotypic variance

ap = Phenotypic standard deviation

$\sigma^2 g$  = Genotypic variance

ag = Genotypic standard deviation

$\sigma^2 e$  = Environmental variance

X = General mean

**b. Genotypic coefficient of variation (gcv) :**

$$\text{gcv} = \frac{\sigma g}{X} \times 100 \quad \{\sigma g = \sqrt{\sigma^2 g}\}$$

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

<10 per cent = Low

10-20 per cent = Moderate, and

> 20 per cent = High.

**3.3.2.2 Heritability :**

Heritability estimates (broad sense) for yield and yield components were worked out as per the method suggested by Singh and Choudhary (1985) as follows :

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

The broad sense heritability estimates were classified as low, moderate and high as follows :

0-30 per cent = low

31-60 per cent = moderate, and

> 60 per cent = high

### 3.3.2.3. Genetic Advance :

Genetic Advance was estimated by adopting the method suggested by Johnson *et al.* (1955) using the formula:

$$GA = K.h^2 \sigma_p$$

Where,

GA = Genetic Advance

K = Selection Differential (at 5 per cent K= 2.06)

$h^2$  = Heritability, and

$\sigma_p$  = Phenotypic standard deviation

GA was reported as percentage of mean and it was calculated as follows :

$$GA \text{ as percentage of mean} = \frac{\text{Genetic Advance}}{\text{General mean}} \times 100$$

The GA was categorized as :

> 20 per cent = high

10-20 per cent - moderate, and

< 10 per cent = low

## 3.4 COMBINING ABILITY ANALYSIS :

Combining ability analysis was carried out by the method suggested by Kempthorne (1957). Mean sum of squares that arises due to

different sources of variation were estimated and their expected genetic values were also calculated. A model analysis of variance (ANOVA) table of Line x tester analysis is given below:

ANOVA table for line x tester Analysis:

Source of variation	Degree of freedom	Sum of squares	Mean squares	Expected mean squares
Replication	(r-1)	RSS	-	-
Hybrids	(l t - 1)	SS	-	-
Lines	(M)	SS (l)	M l	Me + r [Cov. (FS)- 2 Cov. (HS)] + rt [Cov. (HS)]
Tester	(t-1)	SS (t)	Mt	Me + r [Cov. (FS) -2 Cov. (HS)] + r/l [Cov. (HS)]
Lines x testers	(l-1) (t-1)	SS (l x t)	M (l x t)	Me + r [Cov. (FS) - 2 Cov. (HS)]
Error	(r-1)(t-1)	ESS	Me	-
Total	(rt-1)	-	-	-

Where,

r = Number of replications

l = Number of lines

t = Number of testers, and

r = Number of genotypes

Estimates of full sib's and half sib's covariance were calculated

from mean squares, using following formula :

$$\text{Cov. (HS)} = \frac{M l + Mt - 2M (l \times t)}{r (l \times t)}$$

$$\text{Cov. (FS)} = - \frac{\text{Me} + \text{Mt} + \text{M} (\text{t} \times \text{t}) - 3 \text{Me} + 6r \text{Cov. (HS)} - r (\text{t} \times \text{t}) \text{Cov. (HS)}}{3r}$$

Cov. (HS) and Cov. (FS) were utilized to estimate variance due to general combining ability (gca) and variance due to specific combining ability (sca) as under:

$$\begin{aligned} \text{Variance of gca} &= \text{Cov. (FS)} - \text{Cov. (HS)} \\ \text{Variance of sca} &= \text{Cov. (FS)} - 2 \text{Cov. (HS)} \end{aligned}$$

### 3.4.1 Estimation of gca and sca effects :

The gca and sca effects of  $ijk$ th observations were estimated by adopting the following model.

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

Where,

$N$  = population mean

$g_i$  = gca effect of  $i$ th line

$g_j$  = gca effect of  $j$ th tester

$s_{ij}$  = sca effect of hybrid of  $i$ th line with  $j$ th tester

$e_{ijk}$  = Error effect associated with  $ijk$ th observation

$i$  = Number of lines

$j$  = Number of testers

$k$  = Number of replications

The individual effects of gca and sca were estimated from the data obtained from two way table of lines vs. testers as given below. In this each data was totaled over replications:

Two way table for lines vs. tester:

Lines	Tester				Total
	1	2	3	4	
1.	X <sub>ij</sub>	-	-	-	X <sub>i.</sub>
2.	-	-	-	-	-
3.	-	-	-	-	-
4.	-	-	-	-	-
Total	X <sub>.j.</sub>	-	-	-	X...

$$\mu = \frac{X...}{r/t}$$

$$o_i = \frac{X_{i.}}{rt} - \frac{X...}{r/t} \quad \{ \text{Check } \sum o_i = 0 \}$$

$$g_j = \frac{X_{.j.}}{rt} - \frac{X...}{r/t} \quad \{ \text{Check } \sum g_j = 0 \}$$

$$s_{ij} = \frac{X_{ij.}}{rt} - \frac{X_{i.}}{rt} - \frac{X_{.j.}}{rt} + \frac{X...}{r/t} \quad \{ \text{Check } \sum_i \sum_j s_{ij} = 0 \}$$

Where.

X... = Total of all hybrid combination.

X<sub>i.</sub> = Total of ith line over 't' Testers and 'r' replications

X<sub>.j.</sub> = Total of jth tester over 'l' lines and 'r' replication and

X<sub>ij.</sub> = Total of the hybrid between ith line and jth tester over replications

Significance of gca effects of lines is tested as :

$$t = \frac{g_i}{\text{S.E. (g}_i\text{)}}$$

Significance of gca effects of testers is tested as :

$$t = \frac{g_j}{\text{S.E. (g}_j\text{)}}$$

Significance of sca effects of hybrids is tested as :

$$t = \frac{S_{ij}}{\text{S.E. (S}_{ij}\text{)}}$$

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

(i) Standard error for testing the gca effects of tester:

$$\text{S.E. (g}_i\text{)} = \frac{\sqrt{Me}}{rt}$$

(ii) Standard error for testing the significance of difference between gca effect of two lines:

$$\text{S.E. (g}_i\text{-g}_j\text{)} = \frac{\sqrt{2Me}}{rt}$$

(iii) Standard error for testing the gca effect of testers

$$\text{S.E. (g}_j\text{)} = \frac{\sqrt{Me}}{rt}$$

(iv) Standard error for testing significance of difference between gca effects of two testers:

$$\text{S.E. (Sij)} = \frac{\sqrt{2Me}}{rt}$$

(v) Standard error for testing the sca effects of hybrids:

$$\text{S.E. (Sij)} = \frac{\sqrt{Me}}{rt}$$

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

$$\text{S.E. (Sij-Sk l)} = \frac{\sqrt{2Me}}{rt}$$

### 3.5 HETEROISIS :

Heterosis for each trait was worked out by utilizing the overall mean of each hybrid over replications for each trait. The mean data of isogenic maintainer lines (of respective CMS lines) were used as  $\bar{P}$  values for female parents. Relative heterosis was estimated as percent deviation of hybrid values from its mid parental value. The formula used for estimating relative heterosis is as under:

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

Where.

di = Heterosis over mid parental value (relative heterosis)

$\bar{F}_1$  = Mean hybrid performance, and

MP = Mid parental value, i.e. the arithmetic mean of two parents involved in the respective cross combination

Heterobeltiosis was calculated as the deviation of the hybrid from the better parent as under:

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

Where,

dii = Heterobeltiosis i.e. heterosis over better parent, and

BP = Average performance of better parent in the respective cross combination

Standard heterosis was calculated as the deviation of the hybrid from the check variety (Swarna) in the present study as under :

$$diii = \frac{F_1 - \text{Check variety}}{\text{Check variety}} \times 100$$

Where,

diii = Standard heterosis i.e. heterosis over check variety.

The significance of different types of heterosis was carried out by adopting 't' test as suggested by Wynne *et al.* (1970).

$$t \text{ (relative heterosis)} = \frac{F_{ij} - MP_{ij}}{\sqrt{(3/8)Me}}$$

$$t \text{ (heterobeltiosis)} = \frac{F_{ij} - BP_{ij}}{\sqrt{(3/8) Me}}$$

$$t \text{ (standard heterosis)} = \frac{F_{ij} - \text{Check variety}}{\sqrt{3/8 Me}}$$

Where,

$F_{ij}$  = Mean of  $i, j$  th cross

$MP_{ij}$  = Mid parental value for  $i, j$ th cross

$BP_{ij}$  = Mean of the better parent for  $i, j$ th cross and

$M_e$  = Estimate of error variance

## RESULTS

---

## **CHAPTER IV**

### **RESULTS**

The present investigation was undertaken with the objectives of :  
(i) estimation of the variability, genetic advance and heritability, (ii) estimation of gca of parents and sca of hybrids for yield and yield components, (iii) estimation of the magnitude of heterosis, heterobeltiosis and standard heterosis for yield and its component characters and (iv) identification of promising maintainer and restorers for CMS lines 22A, IR 62829A, IR 67684A and IR 68899A.

The results obtained from the present study with respect to mean performances, combining ability, gene action, gene effects and heterosis are presented here under:

#### **4.1 EVALUATION OF GENOTYPES :**

The different genotype i.e. four lines, thirteen testers and their fifty-two  $F_1$ 's were first evaluated based on their mean performance for 10 different characters.

##### **4.1.1 MEAN PERFORMANCES :**

The observations on five plants for the sixty-nine genotypes i.e. parents and hybrids in two replications for ten different characters were used for calculating the mean performances. The observations were first averaged for five plants taken randomly for each genotype in each replication and were later averaged over both the replications. The mean performances of parents and hybrids are presented in Table -3 and Table -4, respectively

Table-3: Mean performance of parents

PARENTS	CHARACTERS									
	Plant height (cm)	Panicle length (cm)	Total no. of prod tillers/ plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
Female parents										
22A	106.40	24.15	13.20	151.95	6.65	145.30	4.34	100.00	1.66	5.26
IR 62829A	106.00	23.43	10.40	145.29	6.80	138.49	4.68	100.00	1.70	7.17
IR 67684A	109.90	23.97	11.20	110.60	14.77	95.70	13.63	100.00	1.79	6.66
IR 68899A	106.20	25.91	8.30	129.70	6.00	123.70	4.61	100.00	1.83	11.27
Average of Female parents	107.13	24.36	10.77	134.38	8.55	125.80	6.82	100.00	1.74	7.59
Male parents										
Kranti	108.80	23.59	12.80	143.29	131.60	11.70	91.83	4.80	2.63	24.71
Indira	114.50	21.81	11.80	206.10	129.40	76.70	62.90	2.18	1.96	19.11
Swarna	101.00	21.49	9.70	164.70	135.00	29.70	81.96	2.87	1.73	19.89
Annada	104.93	22.81	9.30	199.60	140.64	58.96	70.43	5.17	2.09	12.18
R-827-287	93.50	21.01	9.40	173.40	138.00	34.60	80.10	2.87	1.46	11.69
Shyamala	93.17	22.93	9.90	116.40	81.90	34.50	70.46	3.17	2.36	20.49
IR-64	102.96	25.83	8.86	149.06	114.03	35.03	76.46	4.09	2.30	19.51
Pusa Basmati	99.04	24.33	10.55	109.70	76.22	33.47	69.49	8.48	7.94	21.24
R-574-11	110.83	23.35	9.27	155.20	118.46	36.73	76.45	12.43	2.66	31.56
R-15	176.90	23.65	12.10	174.00	143.00	31.00	82.20	2.37	1.73	19.16
BG-380	106.50	23.13	8.64	136.50	103.90	32.60	76.23	3.98	2.60	16.31
Abhaya	97.10	23.54	9.40	118.30	93.10	25.20	78.67	1.94	2.06	16.66
Safri-17	173.58	26.04	10.10	157.80	135.80	20.50	86.96	6.10	2.32	18.94
Average of male parents	114.06	23.35	10.14	154.16	118.60	35.44	77.24	4.65	2.14	19.34
Overall parental Avg.	112.43	23.59	10.29	149.51	92.71	56.70	60.67	22.05	2.05	16.57
SE	1.34	1.27	1.66	13.34	9.97	7.31	3.34	1.97	0.14	2.56
CD at 5%	2.66	2.52	3.30	24.55	19.84	14.55	6.64	3.92	0.27	5.09
CD at 1%	3.55	3.36	4.39	32.70	26.42	19.37	8.85	5.22	0.37	6.78
CV	3.15	5.41	14.47	7.70	10.63	10.94	5.86	5.62	7.05	21.10

#### **4.1.1.1 Mean performance of parents :**

The mean performances of four lines, thirteen testers and overall mean of seventeen parents for ten different characters is presented in Table -3.

The mean performances of individual characters are described as below:

##### **4.1.1.1.1 Plantheight :**

Parents for plant height ranged from 93.17 cm. (Shyamala) to 176.90 cm (R-15) with an overall mean of 112.43 cm. The average female parent plant height was 107.13 cm. with line IR 67684A recording a highest height of 109.90 cm. and line IR 62829A showing lowest height of 106.00 cm.

R-15 (176.90 cm) was found tallest, among the male parents, followed by Safri-17 (173.58 cm), Indira (114.50 cm), R-574-11 (110.83 cm), Kranti (108.80) and BG-380 (106.50 cm). The average male parent height was 114.06 cm. with minimum height recorded for Shyamala (93.17 cm). «

##### **4.1.1.1.2. Panicle length :**

The mean of panicle length, among the parents, ranged from 21.01 cm. (R-827-287) to 26.04 cm. (Safri-17) with an overall mean of 23.59 cm. Lines. IR 62829A (23.43 cm) had shortest panicle while. IR 68899A (25.91 cm) had longest panicle as compared to lines mean of 24.36 cm. The testers overall mean was found to be 23.35 cm. Tester Safri-17 (26.04 cm) showed the longest panicle followed by testers 1R-64 (25.83 cm), Pusa Basmati (24.33 cm), R-15 (23.65 cm). Kranti (23.59 cm) and Abhaya (23.54 cm). Tester R-827-287 (21.01 cm) had the lowest mean value for this trait.

#### **4.1.1.1.3 Total number of productive tillers / plant :**

The mean of total number of productive tiller per plant ranged from 8.30 (IR 68899A) to 13.20 (22A) with an overall mean of 10.29. Among the lines, 22A (13.20) recorded the highest mean value for this trait while, IR 68899A (8.30) showed the lowest mean value. The testers, overall mean for this trait was 10.14 with tester Kranti (12.80) recording the highest mean value for this trait. The lowest number of productive tillers per plant was observed for tester BG-380 (8.64).

#### **4.1.1.1.4 Total number of spikelets per panicle :**

The total number of spikelets per panicle ranged from 109.70 (Pusa Basmati) to 206.10 (Indira), with an overall average of 149.51. Among the lines, 22A (151.95) showed highest number of spikelets per panicle while, IR 67684A (110.60) showed least number of spikelets per panicle as compared to the mean of lines 134.38. Among the testers, Indira (206.10) recorded highest number of spikelets per panicle followed by Annada (199.60), R-15 (174.00), R-827-287 (173.40) and Swarna (164.70). Tester Pusa Basmati (109.70) had the lowest mean value for this trait as compared to overall testers mean of 154.16.

#### **4.1.1.1.5 Total number of filled spikelets per panicle :**

Among the parents, mean of total number of filled spikelets per panicle ranged from 6.00 (IR 68899A) to 143.00 (R-15) with an overall mean of 92.71. Among the lines, IR 67684A (14.77) had highest number of filled spikelets per panicle while, IR 68899A (6.00) showed least number of filled spikelets per panicle as compared to lines mean of 8.55. Among the testers, highest mean value for this trait was recorded for R-15 (143.00) followed by

Annada (140.64), R-827-287 (138.00), Safri-17 (135.80) Swarna (135.00) and Kranti (131.60) while, lowest mean value was recorded for Pusa Basmati (76.22) as compared to the overall testers mean of 118.60.

#### **4.1.1.1.6 Total number of chaffy spikelets per panicle :**

Among the parents, the mean total number of chaffy spikelets per panicle ranged from 11.70 (Kranti) to 145.30 (22A) with an overall parental mean of 56.70. Among the females, 22A (145.30) had highest total number of chaffy spikelets per panicle while, IR 67684A (95.70) recorded least mean value for this character as compared to the lines mean 125.80. Among the testers, Indira (76.70) showed the highest mean total number of chaffy spikelets per panicle while, Kranti (11.70) recorded the least mean value for this trait as compared to the overall testers mean of 35.44.

#### **4.1.1.1.7 Spikelet fertility percentage :**

The mean of spikelet fertility percentage ranged from 4.34 per cent (22A) to 91.83 per cent (Kranti) with an overall parental mean of 60.67 per cent. Among the lines, the highest mean value for this trait was recorded for IR 67684A (13.63per cent) and the lowest mean value was recorded for 22A (4.34 per cent) in comparison to lines mean of 6.82 per cent. Among the testers, highest spikelet fertility percentage was shown by Kranti (91.83 per cent) followed by Safri-17 (86.96 per cent), R-15 (82.20 per cent) Swarna (81.96 per cent) and R-827-287 (80.10 per cent) while, the lowest mean value was obtained for Indira (62.90 per cent) as compared to the overall testers mean of 77.24 per cent.

#### **4.1.1.1.8 Pollen sterility percentage :**

The mean pollen sterility percentage ranged from 1.94 per cent (Abhaya) to 100.00 per cent (22A, IR 62829A, IR 67684A and IR 68899A) with an overall parental mean of 27.05 per cent. All the female parents are characterized by an overall mean of 100.00 per cent for this trait. Among the testers, R-574-11 (12.43 per cent) showed the highest percentage of pollen sterility followed by Pusa Basmati (8.48 per cent), Safri-17 (6.10 per cent) and Annada (5.17 per cent), while Abhaya (1.94 per cent) recorded the lowest mean value for this trait as compared to overall testers mean of 4.65 per cent for this character.

#### **4.1.1.1.9 100-grain weight :**

The parents for 100- grain weight ranged from 1.46g (R-827-287) to 2.66g (R-574-11) with an over all mean of 2.05g. Among the lines, highest mean value for this trait was recorded for IR 68899A (1.83g) and the lowest mean value was recorded for 22A (1.66g) as compared to the overall lines average of 1.74g. Among the testers, R-574-11 (2.66g) had the highest mean value for 100-grain weight followed by Kranti (2.63g), BG-380 (2.60g), Shyamala (2.36g) and Safri-17 (2.32g) and the lowest mean value was recorded for R-827-287 (1.46g) as compared to overall testers mean of 2.14g.

#### **4.1.1.1.10 Grain yield per plant :**

The mean grain yield per plant ranged from 5.26g (22A) to 31.56g (R-574-11) as compared to the overall parental mean of 16.57g. Among the lines, highest grain yield per plant was recorded for IR 68899A (11.27g) while, the lowest mean for 22A (5.26g) in comparison to lines mean of 7.59g. Among the testers, highest mean value for grain yield per plant was noted for R-574-11

(31.56g), followed by Kranti (24.71g), Pusa Basmati (21.24g), Shyamala (20.49g) and Swarna (19.89g) while, the lowest mean value was recorded for R-827-287 (11.69g). The testers over all mean for this trait was found to be 19.34g.

#### **4.1.1.2 Mean performance of hybrids :**

The mean performance of the fifty two hybrid for ten different characters is presented in Table-4.

##### **4.1.1.2.1. Plant height :**

Mean for plant height, among the hybrids, ranged from 87.90 cm. (IR 62829A/Pusa Basmati) to 153.60 cm. (IR 67684A/Safri-17) with an overall hybrids mean of 108.07 cm. A reduced plant height was observed for the crosses involving 22A as female parent (overall mean 105.49 cm) while, the crosses involving IR 68899A as female parent showed the highest overall mean plant height of 109.28cm. Lowest mean height was shown by IR 62829A/Pusa Basmati (87.90 cm.) followed by IR 62829A/Annada (88.90 cm), IR67684A/R-574-11 (89.12 cm.), IR 68899A/Annada (90.60 cm.), IR 68899A/R-827-287 (91.83 cm.), IR 68899A/R-574-11 (91.88 cm.), and IR 62829A/Kranti (91.90 cm.).

##### **4.1.1.2.2. Panicle length :**

Hybrid performance for panicle length ranged from 19.39 cm. (IR 68899A/Annada) to 26.83 cm. (IR 68899A/Safri-17) with an overall average of 23.61cm. Longest panicle length was recorded for IR 68899A/Safri-17 (26.83 cm), followed by 22A/Annada (26.25 cm) IR 67684A/R-15 (26.25 cm). IR 62829A/Pusa Basmati (25.88 cm.), 22A/BG-380

**Table-4: Mean performance of Hybrids**

Hybrids	CHARACTERS									
	Plant height (cm)	Panicle length (cm)	Total no. of prod tillers/plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/plant (g)
<b>22A</b>										
Kranti	93.85	25.39	12.50	211.99	122.05	89.90	57.59	4.97	2.28	12.70
Indira	100.92	21.51	6.20	144.10	5.30	138.80	3.71	91.00	1.70	2.15
Swarna	107.15	23.93	15.45	122.75	96.45	26.30	78.88	8.39	1.96	21.46
Annada	106.40	26.25	12.25	133.50	6.99	126.50	5.32	99.10	2.12	2.98
R-827-287	92.30	24.67	11.05	171.75	145.75	26.00	84.88	2.40	1.50	5.03
Shyamala	103.20	23.05	15.25	157.00	130.50	26.50	83.13	13.60	2.46	8.40
IR-64	96.03	21.98	14.86	181.67	155.70	25.97	85.75	9.48	2.00	13.31
Pusa Basmati	102.02	25.85	10.18	182.45	7.76	174.70	8.31	98.60	1.63	2.78
R-574-11	111.95	22.22	11.75	108.55	3.02	105.53	2.88	97.37	2.07	6.73
R-15	113.80	23.94	11.00	113.30	11.60	101.70	10.26	60.87	2.67	3.07
BG-380	98.80	25.87	11.45	170.80	124.50	46.30	72.79	5.34	2.19	19.24
Abhaya	101.00	23.15	8.70	176.70	117.29	59.41	66.32	2.89	1.77	5.34
Safri-17	143.98	23.65	7.24	166.96	119.99	46.96	71.89	14.00	2.16	11.22
Average	105.49	23.95	11.37	145.95	80.53	76.50	48.57	39.07	2.03	8.80
<b>IR 62829A/</b>										
Kranti	91.90	24.27	16.50	172.00	131.03	40.97	76.30	3.69	2.10	21.93
Indira	108.37	22.37	12.40	213.14	37.77	175.38	18.74	90.45	2.04	8.00
Swarna	106.35	20.00	12.52	197.30	163.96	33.37	83.04	8.95	2.01	19.80
Annada	88.90	21.11	13.80	125.68	13.77	111.90	7.44	94.96	1.91	6.93
R-827-287	92.88	24.23	11.48	137.42	11.74	125.67	8.47	87.74	1.88	18.21
Shyamala	94.58	22.95	14.50	206.83	177.17	29.67	85.63	26.19	2.22	8.39
IR-64	106.00	24.23	11.10	177.33	150.29	27.03	84.62	5.23	2.06	17.93
Pusa Basmati	87.90	25.88	11.30	213.40	46.20	167.20	21.49	72.02	2.03	9.18
R-574-11	103.30	21.52	9.90	157.80	118.60	39.20	75.12	33.19	1.88	4.69
R-15	153.40	22.78	14.85	148.85	142.15	56.70	71.55	15.45	2.01	14.96
BG-380	100.38	24.26	11.53	137.47	99.43	38.03	72.36	2.79	2.10	35.11
Abhaya	95.16	24.28	11.90	206.53	121.85	84.70	59.03	16.00	1.82	16.05
Safri-17	150.30	25.21	10.20	147.60	99.83	47.76	67.70	35.40	2.07	15.10
Average	106.12	23.29	12.46	172.41	101.06	75.19	56.26	37.85	2.01	15.09

Conti.....

**CHARACTERS**

Hybrids	CHARACTERS									
	Plant height (cm)	Panicle length (cm)	Total no. of prod tillers/plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
<b>IR 67684A/</b>										
Kranti	101.60	22.11	12.10	143.00	126.03	16.97	88.24	7.50	2.21	11.42
Indira	111.70	23.38	15.40	161.00	153.40	7.60	95.32	13.89	1.93	6.45
Swarna	115.70	25.16	11.30	203.39	179.99	23.40	88.33	1.90	2.12	41.61
<b>Annada</b>	102.70	23.67	16.00	157.90	31.78	126.12	20.06	86.57	2.43	16.68
R-827-287	98.10	25.28	13.0	217.29	197.79	19.49	91.04	3.70	1.67	12.61
Shyamala	101.75	23.73	11.60	147.20	105.60	41.60	71.72	4.01	2.35	13.85
IR-64	98.92	21.89	11.59	136.83	95.17	34.93	74.37	20.00	2.12	16.64
Pusa Basmati	101.30	23.44	10.80	158.18	147.75	10.43	93.45	4.25	1.76	11.24
R-574-11	89.12	21.31	11.60	102.81	10.43	92.37	10.15	93.92	2.45	5.35
R-15	141.80	26.25	9.80	191.80	154.30	37.50	79.80	5.15	1.76	15.27
BG-380	102.40	23.85	17.65	192.50	2.50	190.00	1.30	97.81	1.61	4.03
Abhaya	102.03	24.65	12.10	154.30	100.30	54.10	64.89	20.31	2.16	9.47
Safri-17	153.60	23.90	10.71	236.20	46.10	190.10	19.47	95.51	2.15	2.50
Average	109.28	23.74	12.58	169.46	103.93	64.97	61.39	34.96	2.06	12.85
<b>IR 68899A/</b>										
Kranti	112.60	24.38	10.30	121.50	109.80	11.69	90.29	12.84	2.22	4.20
Indira	111.40	19.97	12.30	195.00	7.00	188.02	3.52	90.60	1.95	7.66
Swarna	113.55	23.99	12.07	166.80	142.30	24.50	85.18	8.87	2.20	13.28
<b>Annada</b>	90.60	19.39	10.70	122.60	3.50	119.10	2.82	96.93	2.03	2.29
R-827-287	91.83	23.08	14.25	156.75	131.38	25.38	83.91	5.73	1.75	4.65
Shyamala	131.45	24.17	8.35	183.80	160.30	23.49	87.17	29.24	1.78	4.31
IR-64	104.95	25.10	11.00	140.70	83.20	57.50	59.12	13.44	2.28	8.27
Pusa Basmati	102.80	22.84	8.10	192.60	185.00	7.60	96.06	22.41	2.28	7.78
R-574-11	91.88	21.40	11.88	64.88	10.50	54.38	16.18	94.90	2.15	2.31
R-15	143.13	24.00	5.67	178.90	123.55	55.35	69.11	10.07	2.07	7.11
BG-380	101.35	25.03	14.77	174.57	3.50	171.07	1.98	95.97	1.60	2.55
Abhaya	102.60	24.27	7.60	128.00	96.90	31.10	75.68	10.90	2.08	8.02
Safri-17	150.15	26.83	17.67	194.07	127.36	66.70	65.50	14.01	2.16	20.12
Average	111.40	23.41	11.12	155.39	91.10	64.29	56.65	38.91	1.89	7.12
Overall hybrid Avg	108.07	23.61	11.89	163.57	94.16	70.24	55.73	37.70	2.04	10.97
SE	1.34	1.22	1.66	12.34	9.97	7.31	3.34	1.97	0.14	2.06
CD at 5%	2.66	2.52	3.30	24.55	19.84	14.55	6.64	3.92	0.27	5.09
CD at 1%	3.55	3.36	4.39	32.70	26.42	19.37	8.85	5.22	0.37	6.78
CV	3.15	5.41	14.47	7.70	10.63	10.94	5.86	5.62	7.05	21.10

(25.87 cm), 22A/Pusa Basmati (25.85 cm), 22A/Kranti (25.39 cm.), IR 67684A/R-827-287 (25.28 cm.), IR 62829A/Safri-17 (25.21 cm), IR 67684A/Swarna (25.16 cm.), IR 68899A/IR-64 (25.10 cm.) and IR 68899A/BG-380 (25.03 cm.). The lowest panicle length was recorded for hybrid IR 68899A/Annada (19.39 cm.).

#### **4.1.1.2.3 Total number of productive tillers per plant :**

Hybrid mean for this trait has ranged from 5.67 (IR 68899A/R-15) to 17.67 (IR 68899A/Safri-17) with an overall average of 11.89. Highest number of productive tillers per plant was observed for IR 68899A/Safri-17 (17.67), followed by IR 67684A/BG-380 (17.65), IR 62829A/Kranti (16.50), IR 67684A/Annada (16.00), 22A/Swarna (15.45), IR 67684A/Indira (15.40) and 22A/Shyamala (15.25). More average number of productive tillers per plant were observed when CMS line IR 67684A was used as female parent.

#### **4.1.1.2.4 Total number of spikelets per panicle :**

The mean of total number of spikelets per panicle, among the hybrids ranged from 102.81 (IR 67684A/R-574-11) to 236.20 (IR 67684A/Safri-17) with an overall hybrid mean of 163.57. Highest total number of spikelets per panicle were recorded for IR 67684A/Safri-17 (236.20), followed by IR 67684A/R-827-287 (217.29). IR 62829A/Pusa Basmati (213.40), IR 62829A/Indira (213.14), 22A/Kranti (211.99), IR 62829A/Shyamala (206.83), IR 62829A/Abhaya (206.53) and IR 67684A/Swarna (203.39). More total number of spikelets per panicle were observed when CMS lines IR 62829A and IR 67684A were used as female parents.

#### **4.1.1.2.5 Total number of filled spikelets per panicle :**

Among the hybrids, mean value for this trait ranged from 2.50 (IR 67684A/BG- 380) to 197.79 (IR 67684A/R827-287), with an overall hybrid mean of 94.16. Highest number of filled spikelets per panicle was shown by IR 67684A/R-827-287 (197.79), followed by IR 68899A/Pusa Basmati (185.00), IR 67684A/Swarna (179.99), IR 62829A/Shyamala (177.17), IR 62829A/Swarna (163.96), IR 68899A/Shyamala (160.30) and 22A/IR-64 (155.70), IR 67684A/R-15 (154.30), IR 67684A/Indira (153.40) and IR 62829A/IR-64. Total number of more filled spikelets per panicle were observed when CMS lines IR 67684A and IR 62829A were used as female parents.

#### **4.1.1.2.6 Total number of chaffy spikelets per panicle :**

The hybrids mean value of number of chaffy spikelets per panicle ranged from 7.60 (IR 67684A/Indira), and (IR 68899A/Pusa Basmati) to 190.10 (IR 67684A/Safri-17) with an overall average of 70.24. Lowest mean value for this characters was observed for IR 67684A/ Indira and IR 68899A/Pusa Basmati (7.60), followed by IR 67684A/Pusa Basmati (10.43), IR 68899A/Kranti (11.69), IR 67684A/Kranti (16.97) and IR 67684A/R-827-287 (19.49).

#### **3.1.1.2.7 Spikelet fertility percentage :**

Mean of spikelet fertility percentage among the hybrids, ranged from 1.30 per cent (IR 67684A/BG-380) to 96.06 per cent (IR 68899A/Pusa Basmati) with an overall average of 55.73 per cent. Several hybrids like IR 67684A/Indira (95.32 per cent). followed by IR 67684A/Pusa Basmati (93.45 per cent), IR 67684A/R-827-287 (91.04 per

cent), IR 68899A/Kranti (90.29 per cent), IR 67684A/Swarna (88.33 per cent), IR 67684A/Kranti (88.24 per cent) and IR 68899A/Shyamala (87.17 per cent) recorded higher mean values for this trait. Lowest spikelet fertility was observed for hybrid IR 67684A/BG-380, followed by IR 68899A/BG-380, IR 68899A/Annada, 22A/R-574-11, IR 68899A/Indira and 22A/Indira.

#### **4.1.1.2.8. Pollen sterility percentage :**

Mean pollen sterility percentage, among the hybrids, ranged from 1.90 per cent (IR 67684A/Swarna) to 99.10 per cent (22A/Annada) with an overall average of 37.70 per cent. Lowest mean value for this character was observed for IR 67684A/Swarna (1.90 per cent) followed by 22A/R-827-287 (2.40 per cent), IR 62829A/BG-380 (2.79 per cent), 22A/Abhaya (2.89 per cent), IR 62829A/Kranti (3.69 per cent), IR 67684A/R-827-287 (3.70 per cent), IR 67684A/Shyamala (4.01 per cent), IR 67684A/Pusa Basmati (4.25 per cent) and 22A/Kranti (4.97 per cent).

#### **4.1.1.2.9 100-grain weight :**

The range for this trait varied from 1.50g (22A/R-827-287) to 2.67g (22A/R-15) with an overall hybrid mean of 2.04g. Highest mean value for this trait was recorded for 22A/R-15 (2.67g). followed by 22A/Shyamala (2.46g), IR 67684A/R-574-11 (2.45g), IR 67684A/Annada (2.43g) and IR 67684A/Shyamala (2.35g).

#### **4.1.1.2.10 Grain yield per plant :**

Mean of grain yield per plant, among the hybrids ranged from 2.15g. (22A/Indira) to 41.61g. (IR 67684A/Swarna) with an overall mean of

10.97g. Highest mean value for this trait was observed for the hybrid IR 67684A/Swarna (41.61g.), followed by IR 62829A/BG-380 (35.11g.) IR 62829A/Kranti (21.93g.), 22A/Swarna (21.46g.), IR 68899A/Safri-17 (20.12g.), IR 62829A/Swarna (19.80g.), 22A/BG-380 (19.24g) and IR 62829A/R-827-287 (18.21g).

#### **4.2 VARIABILITY, HERITABILITY AND GENETIC ADVANCE :**

These parameters were calculated for 69 genotypes (17 parents and 52 hybrids) under combining ability analysis for ten different traits.

##### **4.2.1 Variability :**

The genotypic and phenotypic coefficient of variations are presented in Table–6. High genotypic as well as phenotypic coefficient of variations were recorded for traits *viz.*, spikelet fertility percentage (111.91 and 112.06 per cent), total number of filled spikelets per panicle (78.49 and 79.25 per cent), 100-grain weight (65.69 and 68.99 per cent), total number of spikelets per panicle (61.76 and 62.67 per cent), total number of chaffy spikelets per panicle (58.09 and 58.38 per cent), total number of productive tillers per plant (20.15 and 21.58 per cent), panicle length (19.21 and 24.05 per cent ) and grain yield per plant (17.80 and 18.08 per cent). Moderate genotypic and phenotypic coefficient of variations were observed for pollen sterility percentage (12.63 and 14.47 per cent) whereas, low genotypic and phenotypic coefficient of variations were observed for plant height (5.67 and 7.84 per cent).

Table-5: Analysis of variance for different characters

Source of Variation	Degree of Freedom	Characters									
		Plant height (cm)	Panicle length (cm)	Total no. of productive tillers/ plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
Replication	1	196.50	2.617	22.152	302.00	50.00	224.18	48.84	3.078	0.000061	25.617
Treatment	68	766.63*	5.213*	12.510*	2234.55*	6811.41*	5569.15*	2199.31*	3085.96*	0.153*	134.36*
Error	68	11.84	1.634	2.769	152.33	6770.01	53.57	11.136	3.898	0.0207	6.592

\* Significant at P = 0.05 level.

Table-6: Genotypic and Phenotypic Coefficients of Variations (gcv and pcv), Heritability ( $h^2$ ), Genetic Advance and components of variance.

	Characters									
	Plant height (cm)	Panicle length (cm)	Total no. of productive tillers/ plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
Heritability (%)	52.20	63.80	87.20	97.10	98.10	99.00	99.70	76.20	90.60	97.00
Genetic advance as % of mean	1.82	15.38	540.29	73.45	114.22	101.33	141.85	1.31	772.41	324.09
GCV %	5.67	19.21	20.15	61.76	78.49	58.09	111.91	12.63	65.69	17.80
PCV %	7.84	24.05	21.58	62.67	79.25	58.38	112.06	14.47	68.99	18.08
Genotypic Variance	38.29	20.54	5.35	9775.27	5419.90	1510.25	4060.36	19.61	1.76	4.68
Phenotypic Variance	73.20	32.20	6.14	10066.91	5525.84	1524.90	4070.44	25.70	1.96	4.79
Environmental Variance	34.91	11.66	0.79	291.64	105.94	14.45	10.08	6.09	0.20	0.11

#### **4.2.2. Heritability:**

The broad sense heritability estimates have been presented in Table -6. All the characters except plant height showed high broad sense heritability estimates. Among the character studied, highest heritability estimate was recorded for spikelet fertility per cent (99.70 per cent) followed by total number of chaffy spikelets per panicle (99.00 per cent), total number of filled spikelets per panicle (98.10 per cent), total number of spikelets per panicle (97.10 per cent), grain yield per plant (97.00 per cent), total number of productive tillers per plant (87.20 per cent), pollen sterility percentage (76.20 per cent) and panicle length (63.80 per cent). The moderate heritability was shown by plant height (52.20 per cent).

#### **4.2.3 Genetic advance :**

Genetic advance expressed as percentage of mean is presented in Table-6. The 100-grain weight recorded highest genetic advance as percentage of mean (772.41 per cent) followed by total number of productive tillers per plant (540.29 per cent) and grain yield per plant (324.09 per cent). Genetic advance in general was high for most of the characters studied except plant height, panicle length and pollen sterility percentage, which showed low genetic advance and total number of spikelets per panicle showed moderate genetic advance.

#### **4.3. COMBINING ABILITY ANALYSIS :**

Data recorded on fifty-two hybrids, four lines and thirteen testers were used for combining ability analysis by following the line X tester approach of Kempthorne (1957).

### **4.3.1 Analysis of variance :**

Analysis of variance for all the traits under study has been presented in Table-7. The result showed significant variance for all the characters studied for parents, hybrids as well as parents vs. hybrids. The variance due to hybrid was partitioned into variance due to lines, testers and lines X testers for all the characters. The variance due to lines was significant for the characters *viz.*, plant height, panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelet fertility percentage and grain yield per plant whereas, the variance due to lines was non significant for the remaining two characters i.e. 100-grain weight and pollen sterility percentage. The variance due to testers as well as lines x testers were significant for all the characters studied.

### **4.3.2 Combining ability effects :**

The estimates of general combining ability (gca) effects of four lines, thirteen testers and specific combining ability (sca) effects of fifty-two hybrids for all the ten characters under study are presented in Table-8 and Table-9, respectively, and described as under :

#### **4.3.2.1.Plant height :**

The gca effects of the lines ranged from 2.58 (22A) to 3.33 (IR 68899A). The gca effects of two lines 22A (-2.58) and IR 68899A (3.33) were significant with former showing negative gca effect and latter a positive gca effect. The remaining two lines showed non-significant gca effects. The testers except Indira and Shyamala recorded significant gca effects. Among the testers, gca effects ranged from -14.30 (R-827-287) to 41.43 (Safri-17).

**Table-7: Analysis of Variance for line x tester Analysis**

Source	Degree of freedom	Characters										
		Plant height (cm)	Panicle length (cm)	No. of productive tillers/plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/plant (g)	
Replication	1	196.98	2.64	22.153	302.608	49.739	224.173	48.840	3.057	0.000283	25.608	
Parents	16	1186.72**	4.12**	4.262**	1625.941**	5433.424**	3705.306**	1994.460**	3477.538**	0.276**	125.025**	
Hybrids	51	640.33**	5.65**	14.070**	2369.976**	7376.234**	6170.941**	2294.389**	2966.586**	0.117**	128.027**	
Parent vs. Hybrids	1	486.68**	97.65**	65.461**	5065.375**	53.656**	4699.883**	625.953**	2909.057**	0.0032**	607.310**	
Lines	3	200.31**	2.28**	14.380**	1922.064**	2931.768**	1100.026**	729.685**	94.310**	0.0093**	347.753**	
Testers	12	2228.44**	9.03**	11.743**	3624.979**	13899.969**	9631.692**	4465.961**	6903.724**	0.180**	198.265**	
Line x tester	36	147.63**	4.81**	14.820**	1988.967**	5572.030**	5439.936**	1700.924**	1893.563**	0.105**	86.304**	
Error	68	11.83	1.634	2.769	152.337	99.558	52.576	11.137	3.898	0.0207	6.592	

\* Significant at P = 0.05 level

\*\* Significant at P = 0.01 level

Table-8: gca effects of Lines and Testers

PARENTS	Plant height (cm)	Panicle length (cm)	Total no. of productive tillers/ plant	Total no. of spikelets/ panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets/ panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
<b>Lines</b>										
22A	-2.58*	0.35	-0.51	-6.53	-13.63*	6.26*	-7.14*	1.38*	0.00	-2.17*
IR 62829A	-1.96	-0.29	0.57	8.85*	6.91*	4.96*	0.54	0.15	-0.03	4.13*
IR 67684A	1.21	0.13	0.70	5.85	9.78*	-5.27*	5.67*	-2.74*	0.02	1.89*
IR 68899A	3.33*	-0.19	-0.76	-8.17*	-3.06	-5.95*	0.93	1.21	0.00	-3.85*
<b>Testers</b>										
Kranti	-8.09*	0.42	0.96*	-1.44	28.07*	-30.36*	22.38*	-30.45*	0.16*	1.60*
Indira	0.02	-1.80*	-0.31	14.74*	-43.29*	57.21*	-25.41*	33.78*	-0.13*	-4.90*
Swarna	2.61*	-0.34	0.95*	8.99*	51.52*	-43.35*	28.13*	-30.68*	0.03	13.07*
Annada	-10.92*	-1.00*	1.30*	-28.65*	-80.14*	50.66*	-46.81*	59.69*	0.09*	-3.75*
R-827-287	-14.30*	0.71*	0.56	7.24	27.51*	-21.11*	11.35*	-12.81*	-0.33*	-0.84
Shyamala	-0.33	-0.13	0.54	10.14*	49.23*	-39.93*	23.18*	-19.64*	0.17*	-2.23*
IR-64	-6.60*	-0.31	0.25	-4.43	26.93*	-33.88*	20.23*	-25.66*	0.08	3.07*
Pusa Basmati	-9.57*	0.90*	-1.79*	23.09*	2.52	19.74*	-0.90	11.62*	-0.11*	-3.22*
R-574-11	-9.01*	-2.00*	-0.61*	-55.06*	-58.52*	2.63*	-29.65*	42.14*	0.10*	-6.20*
R-15	29.96*	0.63	-1.56*	-5.35	13.74*	-7.43*	1.95	-14.82*	0.09*	-0.87
BG-380	-7.34*	1.15*	1.96*	5.27	-36.67*	41.11*	18.62*	12.78*	-0.16*	4.26*
Abhaya	-7.88*	0.48	-1.81*	2.82	14.93*	-12.92*	10.75*	-25.18*	-0.08	-1.25
Safri-17	41.43*	1.39*	-0.44	22.64*	4.17	17.64*	0.41	2.03*	0.10*	1.27
SE (lines)	0.54	0.18	0.25	1.95	1.65	1.10	0.52	0.33	0.02	0.38
SE (testers)	1.08	0.35	0.49	3.90	3.29	2.19	1.04	0.65	0.05	0.76

\* Significant at P= 0.05 level

Table-9: sca effects of Hybrids

Hybrids	Plant height (cm)	Panicle length (cm)	Total no. of productive tillers/ plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
<b>22A/</b>										
Kranti	-3.56	1.01	0.16	56.40*	13.45*	43.75*	-13.38*	-3.66*	0.07	2.30
Indira	-4.60*	-0.65	-4.86*	-27.69*	-31.95*	5.09	-19.47*	18.14*	-0.21*	-1.75
Swarna	-0.96	0.31	3.12*	-43.28*	-35.60*	-6.85	2.16	-0.02	-0.11	-0.41
Annada	11.83*	3.29*	-0.43	5.11	6.61	-0.66	3.55*	3.33*	0.00	-2.07
R-827-287	1.10	0.01	-0.88	7.47	37.71*	-29.60*	24.95*	-23.87*	-0.21*	-2.93*
Shyamala	-1.96	-0.78	3.34*	-10.18	0.73	-10.08*	8.35*	-6.04*	0.25*	1.83
IR-64	-2.86	-1.67*	3.24*	29.06*	48.24*	-16.66*	16.92*	-3.93*	-0.12	1.44
Pusa Basmati	6.10*	0.99	0.60	2.32	-75.29*	78.46*	-39.39*	47.90*	-0.30*	-2.80*
R-574-11	15.47*	0.25	0.98	6.57	-18.99*	26.40*	-16.07*	16.15*	-0.07	4.13*
R-15	-21.65*	-0.65	1.18	-38.39*	-82.67*	32.63*	-40.29*	36.61*	0.54*	-4.86*
BG-380	0.65	0.76	-1.89*	8.49	80.64*	-71.31*	42.82*	-46.51*	0.31*	6.18*
Abhaya	3.38	-1.29*	-0.86	16.84*	21.83*	-4.18	6.97*	-11.01*	-0.19*	-2.21
Safri-17	-2.95	-1.60*	-3.71*	-12.72	35.30*	-47.18*	22.88*	-27.11*	0.02	1.15
<b>IR 62829A/</b>										
Kranti	-6.12*	0.54	3.08*	1.03	1.90	-3.87	-2.35	-3.71*	-0.07	5.24*
Indira	2.24	0.25	0.25	25.99*	-20.00*	42.97*	-12.12*	18.82*	0.16*	-2.20
Swarna	-2.37	-2.98*	-0.89	15.89*	11.38*	1.52	-1.36	1.77	-0.03	-8.37*
Annada	-6.29*	-1.20*	0.04	-18.09*	-7.14	-13.96*	-2.01	0.43	-0.18*	-4.42*
Shyamala	-11.20*	-0.23	1.50	24.28*	26.87*	-5.61	3.18	7.78*	0.05	-4.48*
IR-64	6.49*	1.22*	-1.61	9.35	22.30*	-14.28*	8.11*	-6.96*	-0.03	-0.23
R-827-287	1.06	0.21	-1.54	-42.23*	-116.83*	71.58*	-59.15*	62.70*	0.21*	3.95*
Pusa Basmati	-8.64*	1.67*	0.63	17.90*	-57.38*	72.26*	-33.88*	22.55*	0.13	-2.69*
R-574-11	6.20*	0.20	-1.95*	40.45*	76.06*	-38.62*	48.50*	-46.80*	-0.23*	-4.21*
R-15	17.33*	-1.17*	3.95*	-18.21*	27.34*	-11.07*	13.33*	-7.58*	-0.09	0.73
BG-380	1.61	-0.20	-2.89*	-40.21*	35.05*	-78.27*	34.71*	-47.84*	0.25*	15.75*
Abhaya	-3.07	0.48	1.25	31.30*	5.86	22.42*	-7.99*	3.32*	-0.11	2.20
Safri-17	2.76	0.60	-1.83*	-47.45*	-5.39	-45.08*	11.02*	-4.48*	-0.04	-1.26

Conti.....

Hybrids	Plant height (cm)	Panicle length (cm)	Total no. of productive tillers/plant	Total no. of spikelets / panicle	Total no. of filled spikelets/ panicle	Total no. of chaffy spikelets / panicle	Spikelet fertility percentage	Pollen sterility percentage	100-grain weight (g)	Grain yield/ plant (g)
<b>IR 67684A/</b>										
Kranti	0.40	-2.05*	-1.45	-24.97*	-5.98	-17.64*	4.47*	2.99*	-0.01	-3.03*
Indira	2.39	1.44*	3.12*	-23.16*	92.76*	-114.58*	59.33*	-54.86*	0.00	-1.50
Swarna	3.80*	1.76*	-2.24*	24.98*	24.54*	1.78	-1.19	-2.39*	0.03	15.68*
Annada	4.34*	0.93	2.11*	17.13*	7.99	10.48*	5.48*	-5.08*	0.29*	7.58*
R-827-287	3.11	0.83	-0.14	40.64*	66.35*	-24.37*	18.30*	-18.46*	-0.05	0.60
Shyamala	-7.21*	0.12	-1.53	-32.36*	-47.57*	16.56*	-15.86*	-11.51*	0.13	3.23*
IR-64	-3.77*	-1.54*	-1.25	-28.15*	-35.70*	3.85	-7.27*	10.70*	-0.01	0.71
Pusa Basmati	1.58	-1.19*	0.00	-34.33*	41.29*	-74.28*	32.96*	-42.33*	-0.18*	1.61
R-574-11	-11.15*	-0.43	-0.38	-11.55	-34.98*	24.77*	-21.60*	16.81*	0.29*	-1.31
R-15	2.56	1.88*	-1.23	27.74*	36.62*	-20.04*	16.46*	-14.99*	-0.39*	3.28*
BG-380	0.46	-1.04	3.10*	17.82*	-64.76*	83.92*	-41.48*	50.07*	-0.29*	-13.09*
Abhaya	0.62	0.43	1.32	-17.93*	-18.56*	2.05	-7.26*	10.53*	0.18*	-2.14
Safri-17	2.88	-1.13	-1.44	44.14*	-62.00*	107.49*	-42.34*	58.52*	0.00	-11.62*
<b>IR 68899A</b>										
Kranti	9.28*	0.50	-1.79*	-32.46*	-9.37	-22.24*	11.26*	4.38*	0.01	-4.52*
Indira	-0.03	-1.65*	1.49	24.86*	-40.81*	66.52*	-27.73*	17.90*	0.04	5.45*
Swarna	-0.47	0.91	0.00	2.41	-0.32	3.55	0.39	0.63	0.12	-6.91*
Annada	-9.88*	-3.02*	-1.73*	-4.51	-7.46	4.14	-7.02*	1.32	-0.10	-1.08
R-827-287	-5.28*	-1.05	2.57*	-5.88	12.77*	-17.81*	15.91*	-20.38*	0.05	-1.62
Shyamala	20.37*	0.89	-3.31*	18.26*	19.97*	-0.87	4.32*	9.76*	-0.43*	-0.58
IR-64	0.14	1.99*	-0.38	-10.26	-34.83*	27.09*	-17.77*	0.19	0.16*	-1.92
Pusa Basmati	0.96	-1.47*	-1.23	14.11*	91.38*	-76.44*	40.31*	-28.12*	0.35*	3.88*
R-574-11	-10.52*	-0.02	1.35	-35.46*	-22.08*	-12.53*	-10.83*	13.84*	0.01	1.39
R-15	1.76	-0.05	-3.90*	28.86*	18.71*	-1.52	10.50*	-14.03*	-0.06	0.85
BG-380	-2.72	0.47	1.68*	13.90*	-50.93*	65.66*	-36.05*	44.28*	-0.28*	-8.84*
Abhaya	-0.93	0.37	-1.71*	-30.21*	-9.13	-20.28*	8.28*	-2.84*	0.12	2.15
Safri-17	-2.69	2.12*	6.97*	16.01*	32.10*	-15.23*	8.44*	-26.93*	0.02	11.74*
SE (Hybrids)	1.88	0.61	0.85	6.76	5.70	3.80	1.80	1.13	0.08	1.31

\* Significant at P= 0.05 level.

The sca effects ranged from -21.65 (22A/ R-15) to 20.37 (IR 68899A/Shyamala). Twenty-two out of fifty-two hybrids showed significant sca effects. Twelve of these twenty-two viz., 22A/ Indira, 22A/ R-15, IR 62829A/Kranti, IR 62829A/Annada, IR 62829A/Shyamala, IR 62829A/Pusa Basmati, IR 67684A/Shyamala, IR 67684A/IR-64, IR 67684A/R-574-11, IR 68899A/Annada, IR 68899A/R-827-287, IR 68899A/R-574-11 showed negative sca effects whereas, ten hybrids viz. 22A/Annada, 22A/Pusa Basmati, 22A/R-574-11, IR 62829A/IR-64, IR 62829A/R-574-11, IR 62829A/R-15, IR 67684A/Swarna, IR 67684A/Annada, IR 68899A/Kranti and IR 68899A/Shyamala showed positive sca effects. The remaining thirty hybrids had shown non-significant sca effects.

#### **4.3.2.2. Panicle length :**

The gca effects of the lines were found to be non-significant. Seven testers, R-574-11 (-2.00), Indira (-1.80), Armada (1.00), R-827-287 (0.71), Pusa Basmati (0.90), BG-380 (1.15) and Safri-17 (1.39) showed significant gca effects. Four testers, viz., R-827-287, Pusa Basmati, BG-380 and Safri-17 showed positive significant gca effects whereas, the remaining three showed negative gca effects. The testers range for gca effects was from - 2.00 (R-574-11) to 1.39 (Safri-17).

The sca effects for panicle length ranged from -3.02 (IR 68899A/Annada) to 3.29 (22A/Annada). Eight hybrids, viz., 22A/Annada, IR 62829A/IR-64, IR 62829A/Pusa Basmati, IR 67684A/Indira, IR 67684A/ Swarna, IR 67684A/R-15, IR 68899A/IR-64 and IR 68899A/Safri-17 showed significant positive sca effects whereas, twelve hybrids viz., 22A/IR-64,

22A/Abhaya, 22A/Safri-17, IR 62829A/Swarna, IR 62829A/Annada, IR 62829A/R-15, IR 67684A/Kranti, IR 67684A/ IR-64, IR 67684A/Pusa Basmati, IR-68829A/Indira, IR 68899A/Annada and IR 68899A/Pusa Basmati showed significant negative sca effects. Thirty-two remaining hybrids showed non-significant sca effects.

#### 4.3.2.3. Total number of productive tillers per plant :

The gca effects of the lines were found to be non significant. Among the testers, BG-380 (1.96), Annada (1.30), Kranti (0.96), Swarna (0.95), R-574-11 (-0.61), R-15 (-1.56), Pusa Basmati (-1.79) and Abhaya (-1.80) showed significant gca effects with former four testers showed positive and later four showed negative gca effects.

Among the fifty-two hybrids, the sca effects for the total number of productive tillers per plant ranged from -4.86 (22A/Indira) to 6.97 (IR 68899A/Safri-17). Twenty three hybrids out of the fifty-two hybrids showed significant sca effects. Eleven hybrids 22A/Swarna, 22A/Shyamala, 22A/IR-64, IR 62829A/Kranti, IR 62829A/R-15, IR 67684A/Indira, IR 67684A/Annada, IR 67684A/BG-380, IR 68899A/R-827-287, IR 68899A/BG-380 and IR 68899A/Safri-17 showed positive significant sca effects while, twelve hybrids viz., 22A/ Indira, 22A/BG-380, 22A/Safri-17, IR 62829A/R-574-11, IR 62829A/BG-380, IR 62829A/Safri-17, IR 67684A/Swarna, IR 68899A/Kranti, IR 68899A/Annada, IR 68899A/Shyamala, IR 68899A/R-15 and IR 68899A/Abhaya showed negative significant sca effects. The remaining twenty-nine hybrids showed non-significant sca effects.

#### **4.3.2.4. Total number of spikelets per panicle :**

Two lines IR 62829A (8.85) and IR 68899A (-8.17) showed significant gca effects. Seven testers *viz.*, R-574-11 (-55.06), Annada (28.65), Pusa Basmati (23.09), Safri-17 (22.64), Indira (14.74), Shyamala (10.14) and Swarna (8.99) showed significant gca effects. Tester R-574-11 was the only one which showed significant negative gca effects whereas, remaining six showed positive significant gca effects.

Out of fifty-two hybrids, thirty-eight hybrids showed significant sca effects. Twenty-one hybrids *viz.* 22A/Kranti, 22A/IR-64, 22A/Abhaya, IR 62829A/ Indira, IR 62829A/Swarna, IR 62829A/Shyamala, IR 62829A/Pusa Basmati, IR 62829A/R-574-11, IR 62829A/Abhaya, IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/R-15, IR 62829A/BG-380, IR 67684A/Safri-17, IR 68899A/Indira, IR 68899A/Shyamala, IR 68899A/Pusa Basmati, IR 68899A/R-15, IR 68899A/BG-380 and IR 68899A/Safri-17 showed positive significant sca effects. The seventeen hybrids showing negative significant sca effects were of the line 22A with testers Indira, Swarna, R-15, of the line IR 62829A with testers Annada, R-827-287, R-15, BG-380, Safri-17, of the line IR-67684 A with testers Kranti, Indira, Shyamala, IR-64, Pusa Basmati, Abhaya and of the line IR 68899A with testers Kranti, R-574-11, and Abhaya. The sca effects ranged for this trait from -47.45 (IR 62829A/ Safri-17) to 56.40 (22A/Kranti).

#### **4.3.2.5 Total number of filled spikelets per panicle :**

The gca effects of lines ranged from -13.63 (22A) to 9.78 (IR 67684A). All the four lines except IR 68899A showed significant gca effects of which line 22A showed negative and IR 62829A and IR 67684A showed

positive gca effects. All the testers except Pusa Basmati and Safri-17 showed significant gca effects for this trait. Seven testers *viz.*, Kranti, Swarna, R-827-287, Shyamala, IR-64, R-15 and Abhaya showed positive significant gca effects whereas, four testers *viz.*, Indira, Armada, R-574-11 and BG-380 showed negative significant gca effects. The range of gca effects varied between -80.14 (Armada) to 57.52 (Swarna).

Forty hybrids out of fifty-two hybrids recorded significant sca effects. Twenty-two hybrids *viz.* 22A/Kranti, 22A/R-827-287, 22A/IR-64, 22A/BG-380, 22A/Abhaya, 22A/Safri-17, IR 62829A/Swarna, IR 62829A/Shyamala, IR 62829A/IR-64, IR 62829A/R-574-11, IR 62829A/R-15, IR 62829A/BG-380, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/R-827-287, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 68899 A/R-827-287, IR 62829A/Shyamala, IR 68899A/Pusa Basmati, IR 62829A/R-15 and IR 68899A/Safri-17 showed positive significant sca effects whereas, eighteen hybrids involving CMS line 22A with Indira, Swarna, Pusa Basmati, R-574-11, R-15; CMS line IR 62829A with Indira, R-827-287, Pusa Basmati; CMS line IR 67684A with Shyamala, IR-64, R-574-11, BG-380, Abhaya, Safri-17; CMS line IR 68899A with Indira, IR-64, R-574-11 and BG-380 showed negative significant sca effects. The range of sca effects for this trait varied between- 116.83 (IR 62829A/R-827-287) to 92.76 (IR 67684A/Indira).

#### 4.3.2.6 Total **number of chaffy spikelets per panicle** :

All the four lines showed significant gca effects ranging from -5.95 (IR 68899A) to 6.26 (22A) for this trait. Lines 22A and IR 62829A showed positive gca effects whereas, lines IR 67684A and IR 68899A showed negative

gca effects. All the testers recorded significant gca effects. Seven testers (**Kranti**, Swarna, R-827-287, Shyamala, IR-64, R-15 and Abhaya) showed negative significant gca effects whereas, six testers (Indira, Annada, Pusa Basmati, R-574-11, BG-380 and Safri-17) showed significant positive gca effects. The gca effects of testers ranged from -43.35 (Swarna) to 57.21 (Indira).

Thirty-eight hybrids out of fifty-two hybrids showed significant sca effects. Out of these sixteen hybrids viz. 22A/Kranti, 22A/Pusa Basmati, 22A/R-574-11, 22A/R-15, IR 62829A/Indira, IR 62829A/R-827-287, IR 62829A/Pusa Basmati, IR 62829A/Abhaya, IR 67684A/Annada, IR 67684A/Shyamala, IR 67684A/R-574-11, IR 67684A/BG-380, IR 67684A/Safri-17, IR 68899A/Indira, IR 68899A/IR-64 and IR 68899A/BG-380 recorded positive significant sca effects whereas, twenty-two hybrids involving CMS line 22A with R-827-287, Shyamala, IR-64, BG-380, Safri-17; CMS line IR 62829A with Annada, IR-64, R-574-11, R-15, BG-380, Safri-17; CMS line IR 67684A with Kranti, Indira, R-827-287, Pusa Basmati, R-15; CMS line IR 68899A with Kranti, R-827-287, Pusa Basmati, R-574-11, Abhaya and Safri-17 showed negative significant sca effects. The sca effects for this trait ranged from -114.58 (IR 67684A/Indira) to 107.49 (IR 67684A/Safri-17).

#### 4.3.2.7 Spikelet **fertility** percentage :

Two lines 22A and IR 67684A showed significant gca effects of which former showed negative and later a positive gca effect. The range of gca effects of lines varied from -7.14 (22A) to 5.67 (IR 67684A). The gca effects of all the testers except Pusa Basmati, R-15 and Safri-17 were significant ranging from -46.81 (Annada) to 28.13 (Swarna). Positive significant gca effects were shown by Kranti, Swarna, R-827-287, Shyamala, IR-64 and Abhaya whereas, testers Indira, Annada, R-574-11 and BG-380 showed negative significant gca effects.

All the hybrids except seven hybrids viz., 22A/Swarna, IR 62829A/Kranti, IR 62829A/Swarna, IR 62829A/Annada, IR 62829A/Shyamala IR 67684A/Swarna, IR 68899A/Swarna showed significant sca effects. Twenty-five of these hybrids viz. 22A/Annada, 22A/R-827-287, 22A/Shyamala, 22A/IR-64, 22A/BG-380, 22A/Abhaya, 22A/Safri-17, IR 62829A/IR-64, IR 62829A/R-574-11, IR 62829A/R-15, IR 62829A/BG-380, IR 62829A/Safri-17, IR 67684A/Kranti, IR 67684A/Indira, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 67684A/Kranti, IR 68899A/R-827-287, IR 68899A/Shyamala, IR 68899A/R-15, IR 68899A/Abhaya, IR 68899A/Pusa Basmati and IR 68899A/Safri-17 showed positive significant sca effects whereas, twenty hybrids involving CMS line 22A with Kranti, Indira, Pusa Basmati, R-574-11, R-15; CMS line IR 62829A with Indira, R-827-287, Pusa Basmati, Abhaya; CMS line IR 67684A with Shyamala, IR-64, R-574-11, BG-380, Abhaya, Safri-17; CMS line IR 68899A with Indira, Armada, IR-64, R-574-11 and BG-380 showed negative significant sca effects. The sca effects of hybrids ranged between -59.15 (IR 62829A/R-827-287) to 59.33 (IR-67684 A/Indira).

#### 4.3.2.8 Pollen sterility percentage :

The gca effects for two lines 22A and IR 67684A were significant with former showing a positive and later a negative gca effect. GCA effects for lines ranged between -2.74 (IR 67684A) to 1.38 (22A). All the testers showed significant gca effects ranging from -30.68 (Swarna) to 59.69 (Annada). Seven testers viz., Kranti, Swarna, R-827-287, Shyamala, IR-64, R-15 and Abhaya showed negative gca effects whereas, six testers Indira, Annada, Pusa Basmati, R-574-11, BG-380 and Safri-17 showed positive gca effects.

Among the fifty-two hybrids, except for hybrids IR 22A/Swarna, IR 67829A/Swarna IR 62829A/Annada, IR 68899A/Swarna, IR 68899A/Annada and IR 68899A/IR-64, remaining forty-six hybrids showed significant sca effects. Positive significant sca effects were noted for twenty-one hybrids involving CMS line 22A with Indira, Annada, Pusa Basmati, R-574-11, R-15; CMS line IR 62829A with Indira, R-827-287, Shyamala, Pusa Basmati, Abhaya; CMS line IR 67684A with Kranti, IR-64, R-574-11, BG-380, Abhaya, Safri-17 and CMS line IR 68899A with Kranti, Indira, Shyamala, R-574-11 and BG-380 whereas, remaining twenty-five hybrids 22A/Kranti, 22A/R-827-287, 22A/Shyamala, 22A/IR-64, 22A/BG-380, 22A/Abhaya, 22A/Safri-17, IR 62829A/Kranti, IR 62829A/R-574-11, IR 62829A/IR-64, IR 62829A/R-15, IR 62829A/BG-380, IR 62829A/Safri-17, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/Shyamala, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 68899A/R-827-287, IR 68899A/Pusa Basmati, IR 68899A/R-15, IR 68899A/Abhaya and IR 68899A/Safri-17 showed negative significant sca effects. The range of sca effects, among the hybrids, for this trait varied between -54.86 (IR 67684A/Indira) to 62.70 (IR 62829A/R-827-287).

#### **4.3.2.9 100-grain weight :**

The lines effects were non-significant ranging from -0.03 (IR 62829A) to 0.02 (IR 67684A). All the testers except Swarna, IR-64 and Abhaya showed significant gca effects ranging between -0.33 (R-827-287) to 0.17 (Shyamala). Six testers *viz.*, Kranti, Annada, Shyamala, R-574-11 and Safri-17 showed positive gca effects whereas, four testers Indira, R-827-287, Pusa Basmati and BG-380 showed negative gca effects.

Among the fifty-two hybrids, twenty-two hybrids showed significant *sca* effects. Eleven hybrids *viz.*, 22A/Shyamala, 22A/R-15, 22A/BG-380, IR 62829A/Indira, IR 62829A/R-827-287, IR 62829A/BG-380, IR 67684/Annada, IR 67684A/R-574-11, IR 67684A/Abhaya, IR 68899A/IR-64 and IR 68899A/Pusa Basmati showed positive significant *sca* effects and eleven hybrids involving CMS line 22A with Indira, R-827-287, Pusa Basmati, Abhaya; CMS line IR 62829A with Annada, R-574-11; CMS line IR 67684A with Pusa Basmati, R-15, BG-380 and CMS line IR 68899A with Shyamala, BG-380 showed negative significant *sca* effects. The *sca* effects of hybrids ranged between -0.43 (IR 68899A/Shyamala) to 0.54 (22A/R-15).

#### 4.3.2.10 Grain yield per plant :

The *gca* effects for this trait for all the lines were significant ranging between -3.85 (IR 68899A) to 4.13 (IR 62829A). Two lines 22A and IR 68899A showed negative *gca* effects whereas, two lines IR 62829A and IR 67684A showed positive *gca* effects. All the testers except R-827-287, R-15, Abhaya and Safri-17 showed significant *gca* effects of which only four testers Kranti, Swarna, IR-64 and BG-380 showed positive *gca* effects whereas, five testers Indira, Annada, Shyamala, Pusa Basmati and R-574-11 showed negative *gca* effects. The *gca* effects of testers ranged between -6.20 (R-574-11) to 13.07 (Swarna).

Among all the fifty-two hybrids, twenty six hybrids showed significant *sca* effects with the range varying between -13.09 (IR 67684A/BG-380) to 15.75 (IR 62829A/BG-380). Out of the twenty six hybrids, twelve hybrids *viz.*, 22A/R-574-11, 22A/BG-380, IR 62829A/Kranti, IR 62829A/R-827-287, IR 62829A/Shyamala, IR 62829A/BG-380,

IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/Shyamala, IR 67684A/R-15, IR 68899A/Indira, IR 68899A/Pusa Basmati and IR 68899A/Safri-17 recorded positive *sca* effects. Hybrids involving CMS line 22A with R-827-287, Pusa Basmati, R-15; CMS line IR 62829A with Swarna, Annada, Shyamala, Pusa Basmati, R-574-11; CMS line IR 67684A with Kranti, BG-380, Safri-17 and CMS line IR 68899A with Kranti, Swarna and BG-380 showed negative significant *sca* effects for this trait.

#### 4.3.3 MAGNITUDE OF GCA VARIANCE AND SCA VARIANCE FOR DIFFERENT CHARACTERS :

The magnitude of *gca* variance and *sca* variance and their ratios for different traits are presented in Table-10. The *sca* variances were higher than the *gca* variances for all the traits. Positive *gca* variance and *sca* variance ratios were found for all the characters.

#### 4.4 HETEROSIS :

Heterosis was estimated for all the fifty-two hybrids for all ten characters. *viz.*, plant height, panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelet fertility percentage, pollen sterility percentage, 100-grain weight and grain yield per plant.

All the three types of heterosis, *viz.*, relative heterosis, heterobeltiosis and standard heterosis (over Swarna) were estimated and are presented in Table-11.

The results obtained for different characters have been described below.

**Table-10: Magnitude of gca variance and sca variance for different characters.**

Characters	Variance of gca	Variance of sca	variance of gca/ variance of sca
Plant height (cm)	62.74	67.09	0.93
Panicle length (cm)	0.040	1.68	0.029
Total no. of productive tillers/ plant	0.103	5.60	0.018
Total no. of spikelets / panicle	46.15	906.89	0.050
Total no. of filled spikelets/ panicle	167.28	2389.20	0.070
Total no. of chaffy spikelets/ panicle	4.35	2674.90	0.0016
Spikelet fertility percentage	52.75	844.28	0.062
Pollen sterility percentage	94.43	944.35	0.099
100 g rain weight (g)	0.00065	0.037	0.017
Grain yield/ plant (g)	10.98 <sup>*</sup>	39.85	0.27

#### 4.4.1 Plant height :

The relative heterosis for this trait ranged from -19.66 per cent (22A/R-15) to 31.85 per cent (IR 68899A/Shyamala). Thirty-nine out of fifty-two heterosis showed significant relative heterosis of which twenty-six hybrids showed negative heterosis and thirteen hybrids showed positive heterosis. The hybrids 22A/Kranti, 22A/Indira, 22A/R-827-287, 22A/IR-64, 22A/R-15, 22A/BG-380, IR 62829A/Kranti, IR 62829A/Indira, IR 62829A/Annada, IR 62829A/Shyamala, IR 62829A/Pusa Basmati, IR 62829A/R-574-11, IR 62829A/BG-380, IR 62829A/Abhaya, IR 67684A/Kranti, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/IR-64, IR 67684A/Pusa Basmati, IR 67684A/R-574-11, IR 67684A/BG-380, IR 68899A/Annada, IR 68899A/R-827-287, IR 68899A/R-574-11 and IR 68899A/BG-380 showed negative significant relative heterosis whereas, hybrids 22A/Swarna, 22A/Shyamala, 22A/R-574-11, 22A/Safri-17, IR 62829A/Swarna, IR 62829A/R-15, IR 62829A/Safri-17, IR 67684A/Swarna, IR 67684A/Safri-17, IR 68899A/Kranti, IR 68899A/Swarna, IR 68899A/Shyamala and IR 68899A/Safri-17 showed positive significant relative heterosis.

The heterobeltosis ranged from -5.66 per cent (IR 62829A/Pusa Basmati) to 64.86 (IR 67684A/Safri-17). Amongst forty-five hybrids showing significant heterobeltiosis, four hybrids viz., IR 62829A/Annada, IR 62829A/Pusa Basmati, IR 67684A/R-574-11 and IR 68899A/Annada exhibited negative significant heterobeltiosis and remaining forty-one hybrids showed positive significant heterobeltiosis.

Table-11: Percent Relative heterosis, Heterobeltiosis and standard heterosis for different characters.

Hybrids.	Plant Height (cm.)			Panicle length (cm.)			Total no. of productive tillers/plant			
	MP	BP	Check	MP	BP	Check	MP	BP	Check	
22A/										
Kranti	-12.78*	0.73	-7.08*	6.37*	-2.50*	18.14*	-3.85*	-5.30*	18.14*	28.86*
Indira	-8.63*	8.32*	-0.08	-6.40*	-17.40*	0.09	-50.40*	-53.03*	0.09	-36.08*
Swarna	3.32*	15.00*	15.00*	4.86*	-8.10*	11.35*	34.93*	17.05*	11.35*	59.27*
Annada	0.70	14.20*	5.34*	11.80*	0.81	22.15*	8.89*	-7.20*	22.15*	26.28*
R-827-287	-7.65*	-0.93	-8.61*	9.28*	-5.26*	14.79*	-2.21*	-16.29*	14.79*	13.91*
Shyamala	3.42*	10.77*	2.18*	-2.08*	-11.48*	7.25*	32.03*	15.53*	7.25*	57.21*
IR-64	-8.27*	3.07*	-4.92*	-12.05*	-15.59*	2.28	34.74*	12.58*	2.28	53.19*
Pusa Basmati	-0.68	9.50*	1.01	6.65*	-0.73	20.28*	-14.27*	-22.88*	20.28*	4.94
R-574-11	3.07*	20.16*	10.84*	-6.46*	-14.67*	3.39*	4.58*	-10.98*	3.39*	21.13*
R-15	-19.66*	22.14*	12.67*	0.17	-8.06*	11.40*	-13.04*	-16.67*	11.40*	13.40*
BG-380	-7.19*	6.04*	-2.18*	9.43*	-0.65	20.38*	4.88*	-13.26*	20.38*	18.04*
Abhaya	-0.74	8.40*	0.00	-2.91*	-11.10*	7.72*	-23.01*	-34.09*	7.72*	-10.30*
Saffi-17	2.85*	54.53*	42.55*	-5.76*	-9.18*	10.05*	-37.90*	-45.15*	10.05*	-25.36*
IR 62829A/										
Kranti	-14.43*	-1.36	-9.01*	3.25*	-6.80*	12.93*	42.24*	25.00*	12.93*	70.10*
Indira	-1.71*	16.31*	7.29*	-1.11	-14.09*	4.09*	11.71*	-6.06*	4.09*	27.83*
Swarna	2.75*	14.15*	14.15*	-10.95*	-23.20*	-6.93*	24.63*	-5.15*	-6.93*	29.07*
Annada	-15.71*	-4.58*	-11.98*	-8.69*	-18.93*	-1.76	40.10*	4.55*	-1.76	42.26*
R-827-287	-6.89*	-0.31	-8.04*	9.05*	-6.95*	12.75*	15.91*	-13.03*	12.75*	18.35*
Shyamala	-5.03*	1.51	-6.35*	-0.99	-11.87*	6.79*	42.86*	9.85*	6.79*	49.48*
IR-64	1.45	13.77*	4.95*	-1.65*	-6.95*	12.75*	15.23*	-15.91*	12.75*	14.43*
Pusa Basmati	-14.26*	-5.66*	-12.97*	8.39*	-0.61	20.42*	7.88*	-14.39*	20.42*	16.49*
R-574-11	-4.72*	10.87*	2.27*	-7.99*	-17.36*	0.14	0.66	-25.00*	0.14	2.06
R-15	8.45*	64.65*	51.88*	-3.25*	-12.52*	6.00*	32.00*	12.50*	6.00*	53.09*
BG-380	-5.52*	7.74*	-0.61	4.23*	-6.84*	12.89*	21.20*	-12.65*	12.89*	18.86*
Abhaya	-6.29*	2.14*	-5.78*	3.39*	-6.76*	12.98*	20.20*	-9.85*	12.98*	22.68*
Saffi-17	7.52*	61.32*	48.81*	1.92*	-3.19*	17.31*	-0.49	-22.73*	17.31*	5.15

Conti.....

Hybrids.	Plant Height (cm.)			Panicle length (cm.)			Total no. of productive tillers/ plant		
	MP	BP	Check	MP	BP	Check	MP	BP	Check
<b>IR 67684A/</b>									
Kranti	-7.09*	9.05*	0.59	-7.02*	-15.09*	2.88*	0.83	-8.33*	24.74*
Indira	-0.45	19.89*	10.59*	2.14*	-10.22*	8.79*	33.91*	16.67*	58.76*
Swarna	9.72*	24.18*	24.18*	10.69*	-3.38*	17.08*	8.13*	-14.39*	16.49*
Annada	-4.39*	10.23*	1.68	1.20	-9.10*	10.14*	56.10*	21.21*	64.94*
R-827-287	-3.54*	5.29*	-2.87*	12.41*	-2.92*	17.63*	26.21*	-1.52	34.02*
Shyamala	0.21	9.21*	0.74	1.19	-8.87*	10.42*	9.95*	-12.12*	19.59*
IR-64	-7.06*	6.17*	-2.06	-12.10*	-15.94*	1.86	15.47*	-12.20*	19.48*
Pusa Basmati	-3.03*	8.73*	0.29	-2.91*	-9.98*	9.07*	-0.69	-18.18*	11.34*
R-574-11	-19.25*	-4.35*	-11.76*	-9.93*	-18.16*	-0.83	13.34*	-12.12*	19.59*
R-15	-1.12	52.19*	40.39*	10.25*	0.81	22.15*	-15.18*	-25.76*	1.03
BG-380	-5.36*	9.91*	1.38	1.27	-8.41*	10.98*	77.97*	33.71*	81.96*
Abhaya	-1.42	9.51*	1.02	3.77*	-5.34*	14.70*	17.48*	-8.33*	24.74*
Safri-17	8.37*	64.86*	52.08*	-4.42*	-8.22*	11.21*	0.56	-18.86*	10.41*
<b>IR 68899A/</b>									
Kranti	4.73*	20.85*	11.48*	-1.70*	-6.57*	13.21*	-2.37*	-21.97*	6.18*
Indira	0.94	19.57*	10.29*	-16.30*	-23.31*	-7.07*	22.39*	-6.82*	26.80*
Swarna	9.59*	21.66*	21.66*	1.22	-7.87*	11.63*	34.17*	-8.56*	-8.56*
Annada	-14.18*	-2.76*	-10.29*	-20.40*	-25.54*	-9.77*	21.59*	-18.94*	10.30*
R-827-287	-8.04*	-1.44	-9.08*	-1.64*	-11.37*	7.40*	61.02*	-7.95*	46.90*
Shyamala	31.85*	41.09*	30.15*	-1.02	-7.11*	12.47*	-8.24*	-36.74*	-13.92*
IR-64	0.34	12.64*	3.91*	-2.99*	-3.61*	16.80*	22.17*	-16.67*	13.40*
Pusa Basmati	0.17	10.34*	1.78	-9.07*	-12.29*	6.28*	-14.06*	-38.64*	-16.49*
R-574-11	-15.34*	-1.38	-9.03*	-13.11*	-17.82*	-0.42	35.17*	-10.00*	22.47*
R-15	1.11	53.62*	41.71*	-3.15*	-7.83*	11.68*	-44.41*	-57.05*	-41.54*
BG-380	-4.71*	8.78*	0.35	2.08*	-3.88*	16.47*	74.43*	11.89*	52.27*
Abhaya	0.92	10.12*	1.58	-1.84*	-6.80*	12.94*	-14.12*	-42.42*	-21.65*
Safri-17	7.33*	61.16*	48.66*	3.29*	3.04*	24.84*	92.01*	33.86*	82.16*

Conti.....

Hybrids	Total no. of spikelets/ panicle			Total no. of filled spikelets/ panicle			Total no. of chaffy spikelets / panicle		
	MP	BP	Check	MP	BP	Check	MP	BP	Check
22A/									
Kranti	43.61*	2.86*	28.71*	76.56*	-14.65*	-9.59*	14.52*	668.38*	202.69*
Indira	-19.51*	-30.08*	-12.50*	-92.22*	-96.29*	-96.07*	25.05*	1086.32*	367.34*
Swarna	-22.47*	-40.44*	-40.44	36.18*	-32.55*	-32.55*	-69.94*	124.79*	124.79*
Annada	-24.05*	-35.23*	-18.94*	-90.50*	-95.11*	-94.82*	23.87*	981.20*	325.92*
R-827-287	5.58*	-16.67*	4.28*	100.41*	1.92*	7.96*	-71.10*	122.22*	-12.45*
Shyamala	17.01*	-23.82*	-4.67*	194.75*	-8.74*	-3.34	-70.52*	126.50*	-10.77
IR-64	20.70*	-11.85*	10.30*	158.04*	8.88*	15.34*	-71.20*	121.97*	-12.56*
Pusa Basmati	39.46*	-11.48*	10.78*	-81.26*	-94.57*	-94.25*	95.44*	1393.16*	488.21*
R-574-11	-29.32*	-47.33*	-34.09*	-95.17*	-97.89*	-97.76*	15.95*	801.97*	255.32*
R-15	-30.48*	-45.03*	-31.21*	-84.50*	-91.89*	-91.40*	15.37*	769.23*	242.42*
BG-380	18.43*	-17.13*	3.70	125.24*	-12.94*	-7.78*	-47.95*	295.73*	55.89*
Abhaya	30.77*	-14.26*	7.28*	135.16*	-17.98*	-13.12*	-30.31*	407.78*	100.03*
Safri-17	7.81*	-18.99*	1.37	68.47*	-16.09*	-11.18*	-43.35*	301.37*	58.15*
IR 62829A/									
Kranti	19.20*	-16.55*	4.43*	89.36*	-8.32*	-2.94	-45.44*	250.17*	37.94*
Indira	21.32*	3.42*	29.41*	-44.54*	-73.59*	-72.02*	62.99*	1398.97*	490.50*
Swarna	27.29*	-4.27*	-4.27*	131.77*	14.65*	14.65*	-60.33*	185.21*	185.21*
Annada	-27.12*	-39.02*	-23.69*	-81.31*	-90.37*	-89.80*	13.34*	856.41*	276.76*
R-827-287	-13.76*	-33.32*	-16.56*	-83.87*	-91.79*	-91.30*	45.20*	974.10*	323.13*
Shyamala	58.07*	0.35	25.58*	299.49*	23.90*	31.28*	-65.70*	153.59*	-0.10
IR-64	20.49*	-13.96*	7.67*	148.77*	5.10*	11.32*	-68.84*	131.03*	-8.99
Pusa Basmati	67.38*	3.54*	29.57*	11.30*	-67.69*	-65.78*	94.45*	1329.06*	462.96*
R-574-11	5.03*	-23.44*	-4.19*	89.37*	-17.06*	-12.15*	-55.26*	235.04*	31.98*
R-15	-6.76*	-27.78*	-9.62*	89.79*	-0.59	5.29	-33.10*	384.62*	90.91*
BG-380	-2.43*	-33.30*	-16.53*	79.66*	-30.47*	-26.35*	-55.54*	225.04*	28.04*
Abhaya	56.71*	0.21	25.39*	143.96*	-14.79*	-9.74*	3.49*	623.93*	185.18*
Safri-17	-2.60*	-28.38*	-10.38*	40.03*	-30.19*	-26.05*	-39.42*	308.21*	60.81*

Conti.....

Hybrids	Total no. of spikelets/ panicle			Total no. of filled spikelets/ panicle			Total no. of chaffy spikelets/ panicle		
	MP	BP	Check	MP	BP	Check	MP	BP	Check
<b>IR 67684A/</b>									
Kranti	12.64*	-30.32*	-13.17*	72.21*	-11.87*	-6.64*	-68.40*	45.04*	-42.86*
Indira	1.67*	-21.88*	-2.24	112.80*	7.27*	13.63*	-91.18*	-35.04*	-74.41*
Swarna	47.76*	-1.31	-1.31	140.36*	25.87*	25.87*	-69.68*	100.00*	100.00*
Annada	1.81*	-23.39*	-4.13*	-59.10*	-77.78*	-76.45*	63.09*	977.95*	324.64*
R-827-287	53.02*	5.43*	31.93*	157.60*	-31.62*	-27.56*	-70.08*	66.58*	-34.37*
Shyamala	29.69*	-28.58*	-10.62*	118.48*	-26.15*	-21.78*	-36.10*	255.56*	40.07*
IR-64	5.39*	-33.61*	-16.92*	47.77*	-33.45*	-29.50*	-46.55*	198.55*	17.61*
Pusa Basmati	43.60*	-23.25*	-3.96*	224.74*	3.32*	9.44*	-83.86*	-10.85*	-64.88*
R-574-11	-22.64*	-50.12*	-37.58*	-84.34*	-92.71*	-92.27*	39.50*	689.49*	211.01*
R-15	34.79*	-6.94*	16.54*	95.60*	7.90*	14.29*	-40.81*	220.51*	26.26*
BG-380	55.81*	-6.60*	16.88*	-95.79*	-98.25*	-98.15*	196.18*	1523.93*	539.73*
Abhaya	34.82*	-25.13*	-6.31*	85.96*	-29.86*	-25.70*	-10.50*	362.39*	82.15*
Safri-17	76.01*	14.60*	43.41*	-38.77*	-67.76*	-65.85*	227.19*	1524.79*	540.07*
<b>IR 68899A/</b>									
Kranti	-10.99*	-41.05*	-26.23*	59.59*	-23.22*	-18.67*	-82.73*	-0.09	-60.64*
Indira	16.14*	-5.39*	18.39*	-89.66*	-95.10*	-94.81*	87.64*	1507.01*	533.06*
Swarna	13.32*	-19.07*	-19.07*	101.84*	-0.49	-0.49	-68.06*	109.10*	109.40*
Annada	-25.54*	-40.51*	-25.56*	-95.23*	-97.55*	-97.40*	30.41*	917.95*	301.01*
R-827-287	3.43*	-23.94*	-4.82*	81.46*	-8.13*	-2.68	-67.94*	116.92*	-14.54*
Shyamala	49.37*	-10.82*	11.59*	264.73*	12.10*	18.74*	-70.30*	100.77*	-20.91*
IR-64	0.95	-3173*	-14.57*	38.63*	-41.82*	-38.37*	-27.55*	391.45*	93.60*
Pusa Basmati	60.40*	-6.55*	16.94*	349.98*	29.37*	37.04*	-90.33*	-35.04*	-74.41*
R-574-11	-54.46*	-68.52*	-60.61*	-83.13*	-92.66*	-92.22*	-32.21*	364.79*	83.09*
R-15	17.81*	-13.20*	8.62*	65.84*	-13.60*	-8.48*	-28.45*	373.08*	86.36*
BG-380	31.15*	-15.30*	5.99*	-93.63*	-97.55*	-97.40*	118.89*	1362.14*	475.99*
Abhaya	3.23*	-37.89*	-22.28*	95.56*	-32.24*	-28.22*	-58.23*	165.81*	4.71
Safri-17	35.00*	-5.84*	17.83*	79.64*	-10.94*	-5.67	-7.49*	470.09*	124.58*

Conti.....

Hybrids	Spikelet fertility percentage			Pollen sterility percentage			100-grain weight (g)			Grain yield/ plant (g)		
	MP	BP	Check	MP	BP	Check	MP	BP	Check	MP	BP	Check
22A/												
Kranti	19.76*	-37.29*	-29.73*	-90.51*	156.19*	73.17*	6.05*	-14.29*	31.79*	-15.22*	-59.76*	-36.15*
Indira	-88.96*	-95.96*	-95.47*	78.20*	4590.72*	3070.73*	-5.93*	-36.09*	-1.73	-82.36*	-93.19*	-89.19*
Swarna	82.81*	-14.10*	-14.10*	-83.69*	332.47*	332.47*	15.63*	-26.32*	-26.32*	70.69*	-32.00*	-32.00*
Annada	-85.76*	-94.21*	-93.51*	88.55*	5008.25*	3352.96*	13.18*	-20.30*	22.54*	-65.83*	-90.56*	-85.02*
R-827-287	101.05*	-7.57*	3.56	-95.33*	23.71*	-16.37*	-4.00*	-43.61*	-13.29*	-40.69*	-84.06*	-74.71*
Shyamala	122.29*	-9.47*	1.43	-73.62*	601.03*	373.86*	22.24*	-7.52*	42.19	-34.74*	-73.38*	-57.77*
IR-64	112.27*	-6.62*	4.62*	-81.78*	388.66*	230.31*	0.88	-24.81*	15.60*	7.53*	-57.83*	-33.08*
Pusa Basmati	-77.50*	-90.95*	-89.86*	81.88*	4982.47*	3335.54*	-9.29*	-38.72*	-5.78*	-79.06*	-91.19*	-86.02*
R-574-II	-92.88*	-96.86*	-96.48*	73.29*	4919.07*	3292.68*	-4.28*	-22.18*	19.65*	-63.41*	-78.68*	-66.16*
R-15	-76.29*	-88.83*	-87.48*	18.98*	3037.63*	2020.90*	57.29*	0.38	54.36*	-74.85*	-90.77*	-84.56*
BG-380	80.69*	-20.73*	-11.19*	-89.72*	175.26*	86.06*	2.82*	-17.67*	26.59*	78.44*	-39.04*	-3.26
Abhaya	59.79*	-27.78*	-19.08*	-94.32*	48.97*	0.69	-4.97*	-33.46*	2.31	-51.27*	-83.08*	-73.15*
Safri-17	57.47*	-21.71*	-12.28*	-73.60*	621.65*	387.80*	8.52*	-18.80*	24.85*	-7.29*	-64.45*	-43.59*
IR 62829A/												
Kranti	58.10*	-16.91*	-6.90*	-92.94*	90.21*	28.57*	-3.11*	-21.05*	21.38*	62.96*	-30.51*	10.25
Indira	-44.56*	-79.59*	-77.13*	77.47*	4562.37*	3051.57*	11.48*	-23.31*	17.91*	-24.97*	-74.65*	-59.78*
Swarna	91.68*	-9.57*	-9.57*	-82.56*	361.34*	361.34*	17.37*	-24.44*	-24.44*	79.19*	-37.26*	-37.26*
Annada	-80.18*	-91.90*	-90.92*	81.02*	4794.85*	3208.71*	1.06	-28.20*	10.40*	-3.79*	-78.04*	-65.16*
R-827-287	-80.03*	-90.78*	-89.67*	71.01*	4422.68*	2957.14*	19.30*	-29.32*	8.67*	162.01*	-42.30*	-8.45
Shyamala	127.92*	-6.75*	4.48*	-49.11*	1250.00*	812.54*	9.61*	-16.54*	28.32*	-26.12*	-73.42*	-57.81*
IR-64	108.57*	-7.85*	3.24	-89.93*	169.59*	82.23*	3.00*	-22.56*	19.07*	65.15*	-43.19*	-9.85
Pusa Basmati	-42.06*	-76.60*	-73.78*	33.09*	3612.37*	2409.40*	11.26*	-23.68*	17.34*	-21.72*	-70.91*	-53.84*
R-574-II	85.19*	-18.20*	-8.34*	-40.83*	1610.82*	1056.44*	-13.99*	-29.32*	8.67*	-72.19*	-85.14*	-76.42*
R-15	64.70*	-22.08*	-12.70*	-69.73*	696.39*	432.32*	17.20*	-24.44*	16.18*	40.01*	-52.60*	-24.78*
BG-380	78.85*	-21.20*	-11.71*	-94.62*	43.81*	-2.78	-2.21*	-21.05*	21.38*	279.06*	11.25*	76.52*
Abhaya	41.63*	-35.72*	-27.98*	-68.53*	724.74*	457.49*	-3.19*	-31.58*	5.20*	70.06*	-49.14*	-19.30*
Safri-17	47.74*	-26.28*	-17.40*	-33.11*	1724.74*	1133.45*	2.86*	-22.18*	19.65*	42.79*	-52.15*	-24.08*

Conti.....

Hybrids	Spikelet fertility percentage			Pollen sterility percentage			100-grain weight (g)			Grain yield/plant (g)		
	MP	BP	Check	MP	BP	Check	MP	BP	Check	MP	BP	Check
<b>IR 67684A/</b>												
Kranti	67.34*	-3.91*	7.66*	-85.66*	286.60*	161.32*	-0.11	-16.92*	27.74*	-27.16*	-63.81*	-42.58*
Indira	149.09*	3.80*	16.30*	-72.76*	615.98*	383.97*	2.93*	-27.44*	11.56*	-49.92*	-79.56*	-67.57*
Swarna	84.83*	-3.81*	-3.81*	-96.30*	-2.06*	-2.06	20.34*	-20.36*	22.54*	21.35*	31.84*	31.84*
Annada	-52.26*	-78.16*	-75.52*	64.94*	4362.37*	2916.37*	25.26*	-8.65*	40.46*	77.03*	-47.15*	-16.14*
R-827-287	94.26*	-0.86	11.08*	-92.80*	90.72*	28.92*	3.08*	-37.22*	-3.47	37.46*	-60.04*	-36.60*
Shyamala	70.60*	-21.90*	-12.49*	-92.20*	106.70*	39.72*	13.25*	-11.65*	35.84*	2.04*	-56.12*	-30.37*
IR-64	65.10*	-19.01*	-9.26*	-61.50*	930.93*	596.86*	3.67*	-20.30*	22.54*	27.14*	-47.28*	-16.34*
Pusa Basmati	124.86*	1.76*	14.02*	-92.15*	119.07*	48.08*	-5.36*	-33.83*	1.73	-19.46*	-64.39*	-43.49*
R-574-11	-77.46*	-88.95*	-87.61*	67.37*	4741.24*	3172.47*	9.89*	-7.89*	41.62*	-72.03*	-83.05*	-73.10*
R-15	66.56*	-13.10*	-2.63*	-89.91*	165.46*	79.44*	0.00	-33.83*	1.73	18.26*	-51.62*	-23.23*
BG-380	-97.11*	-98.58*	-98.41*	88.49*	4941.75*	3308.01*	-26.80*	-39.47*	-6.93*	-64.97*	-87.23*	-79.74*
Abhaya	40.60*	-29.34*	-20.82*	-60.06*	946.91*	607.67*	11.95*	-18.80*	24.85*	-18.84*	-69.99*	-52.39*
Safri-17	-61.30*	-78.80*	-76.24*	80.39*	4823.20*	3227.87*	4.74*	-19.17*	24.27*	-80.47*	-92.08*	-87.43*
<b>IR 68899A/</b>												
Kranti	87.24*	-1.68*	10.16*	-75.46*	561.86*	347.38*	-0.67	-16.54*	28.32*	-70.36*	-86.69*	-78.88*
Indira	-89.57*	-96.17*	-95.70*	77.59*	4570.10*	3056.79*	3.30*	-26.69*	12.71*	-32.62*	-75.73*	-61.49*
Swarna	96.79*	-7.24*	-7.24*	-82.73*	357.22*	357.22*	23.66*	-17.29*	27.17*	12.90*	-57.92*	-57.92*
Annada	-92.49*	-96.93*	-96.56*	84.58*	4896.39*	3277.35*	3.70*	-23.68*	17.34*	-71.05*	-92.74*	-88.49*
R-827-287	98.10*	-8.62*	2.38	-88.84*	195.36*	99.65*	6.85*	-34.21*	1.56	-39.25*	-85.27*	-76.62*
Shyamala	132.22*	-5.07*	6.36*	-43.24*	1407.22*	918.81*	-15.17*	-33.08*	2.89	-64.27*	-86.34*	-78.33*
IR-64	45.85*	-35.62*	-27.86*	-74.14*	592.78*	368.29*	10.30*	-14.29*	31.79*	-28.54*	-73.80*	-58.42*
Pusa Basmati	159.25*	4.61*	17.20*	-58.62*	1055.15*	680.83*	21.12*	-14.29*	31.79*	-37.46*	-75.35*	-60.88*
R-574-11	-60.08*	-82.38*	-80.26*	69.04*	4791.75*	3206.62*	-4.12*	-19.17*	24.28*	-86.87*	-92.68*	-88.38*
R-15	59.21*	-24.74*	-15.68*	-80.31*	419.07*	250.87*	16.74*	-22.18*	19.65*	-37.66*	-77.47*	-64.25*
BG-380	-95.09*	-97.84*	-97.58*	84.86*	4846.91*	3243.90*	-27.60*	-39.85*	-7.51*	-74.49*	-91.92*	-87.18*
Abhaya	81.76*	-17.59*	-7.66*	-78.59*	461.86*	279.79*	7.08*	-21.80*	20.23*	-20.92*	-74.59*	-59.68*
Safri-17	43.06*	-28.67*	-20.08*	-73.55*	622.16*	388.15*	4.10*	-18.80*	24.85*	78.29*	-36.25*	1.15

\* Significant at P=0.05 level

The range of standard heterosis of this trait varied from -12.97 per cent (IR 62829A/Pusa Basmati) to 52.08 per cent (IR 67684A/Safri-17). Among fifty-two hybrids, thirty-eight showed significant standard heterosis. Fifteen of these thirty-eight hybrids viz., 22A/Kranti, 22A/R-827-287, 22A/IR-64, 22A/BG-380, IR 62829A/Kranti, IR 62829A/Annada, IR 62829A/R-827-287, IR 62829A/Shyamala, IR 62829A/Pusa Basmati, IR 62829A/Abhaya, IR 67684A/R-827-287, IR 67684A/R-574-11, IR 68899A/Annada, IR 68899A/R-827-287 and IR 68899A/R-574-11 showed significant negative standard heterosis and remaining twenty-three hybrids showed significant positive standard heterosis.

#### **4.4.2 Panicle length :**

The range of relative heterosis for this trait varied from -20.40 per cent (IR 68899A/Annada) to 12.41 per cent (IR 67684A/R-827-287). Among the forty-four hybrids showing significant relative heterosis, nineteen hybrids involving line 22A with testers Kranti, Swarna, Annada, R-827-287, Pusa Basmati, BG-380; line IR 62829A with testers Kranti, R-827-287, Pusa Basmati, BG-380, Abhaya, Safri-17; line IR 67684A with testers Indira, Swarna, R-827-287, R-15, Abhaya and line IR 68899A with testers BG-380 and Safri-17 showed positive significant relative heterosis while, the remaining twenty four hybrids exhibited negative significant relative heterosis.

The heterobeltiosis ranged from -25.54 per cent (IR 68899A/Annada) to 3.04 per cent (IR 68899A/Safri-17). Out of fifty-two hybrids forty-seven showed significant heterobeltiosis. of which only one hybrid, viz.. IR 68899A/Safri-17 showed positive significant heterobeltiosis and remaining forty-six hybrids showed negative significant heterobeltiosis.

The range for standard heterosis varied from  $-9.77$  per cent (IR 68899A/Annada) to 24.84 per cent (IR 68899A/Safri-17). Forty-five hybrids showed significant standard heterosis of which forty-two hybrids viz., 22A/Kranti, 22A/Swarna, 22A/Annada, 22A/R-827-287, 22A/Shyamala, 22A/Pusa Basmati, 22A/R-574-11, 22A/R-15, 22A/BG-380, 22A/Abhaya, 22A/Safri-17, IR 62829A/Kranti, IR 62829A/Indira, IR 62829A/R-827-287, IR 62829A/Shyamala, IR 62829A/IR-64, IR 62829A/Pusa Basmati, IR 62829A/R-15, IR 62829A/BG-380, IR 62829A/Abhaya, IR 62829A/Safri-17, IR 67684A/Kranti, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/Shyamala, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 67684A/BG-380, IR 67684A/Abhaya, IR 67684A/Safri-17, IR 68899A/Kranti, IR 68899A/Swarna, IR 68899A/R-827-287, IR 68899A/Shyamala, IR 68899A/IR-64, IR 68899A/Pusa Basmati, IR 68899A/R-15, IR 68899A/BG-380, IR 68899A/Abhaya and IR 68899A/Safri-17 exhibited significant positive standard heterosis while, only three hybrids IR 62829A/Swarna, IR 68899A/Indira and IR 68899A/Annada showed significant negative standard heterosis.

#### **4.4.3. Total number of productive tillers per plant :**

The value of relative heterosis for this trait ranged from  $-50.40$  per cent (22A/Indira) to 92.01 per cent (IR 68899A/Safti-17). Thirty-four hybrids viz., 22A/Swarna, 22A/Annada, 22A/Shyamala, 22A/IR-64, 22A/R-587-11, 22A/BG-380, IR 62829A/Kranti, IR 62829A/Indira, IR 62829A/Swarna, IR 62829A/Annada, IR 62829A/R-827-287, IR 62829A/Shyamala, IR 62829A/IR-64, IR 62829A/Pusa Basmati, IR 62829A/R-15, IR 62829A/BG-380.

IR 62829A/Abhaya, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/Shyamala, IR 67684A/IR-64, IR 67684A/R-574-11, IR 67684A/BG-380, IR 67684A/Abhaya, IR 68899A/Indira, IR 68899A/Swarna, IR 68899A/Annada, IR 68899A/R-827-287, IR 68899A/IR-64, IR 68899A/R-574-11, IR 68899A/BG-380 and IR 68899A/Safri-17 showed significant positive relative heterosis while, thirteen hybrids *viz.*, 22A/Kranti, 22A/Indira, 22A/R-827-287, 22A/Pusa Basmati, 22A/R-15, 22A/Abhaya, 22A/Safri-17, IR 67684A/R-15, IR 68899A/Kranti, IR 68899A/Shyamala, IR 68899A/Pusa Basmati, IR 68899A/R-15 and IR 68899A/Abhaya exhibited significantly negative relative heterosis for this trait.

The heterobeltiosis for this trait ranged from -57.05 per cent (IR 68899A/R-15) to 33.86 per cent (IR 68899A/Safri-17). Fifty-one of the fifty-two hybrids showed significant heterobeltiosis of which twelve hybrids *viz.*, 22A/Swarna, 22A/Shyamala, 22A/IR-64, IR 62829A/Kranti, IR 62829A/Annada, IR 62829A/Shyamala, IR 62829A/R-15, IR 67684A/Indira, IR 67684A/Annada, IR-67684A/BG-380, IR 68899A/BG-380 and IR 68899A/Safri-17, showed positive significant heterobeltiosis while remaining thirty-nine hybrids exhibited negative significant heterobeltiosis. The hybrid IR 67684A/R-827-287 was the only one out of fifty-two hybrids which showed non-significant heterosis.

The range for standard heterosis varied between -36.08 per cent (22A/Indira) to 82.16 per cent (IR 68899A/Safri-17). Forty-eight hybrids showed significant standard heterosis of which forty hybrid, involving CMS line 22A with Kranti, Swarna, Annada, R-827-287, Shyamala, IR-64, R-574-11, R-15, BG-380; of CMS line IR 62829A with Kranti, Indira, Swarna, Annada,

R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, BG-380, Abhaya; of CMS line IR 67684A with all the thirteen testers except R-15 and CMS line IR 68899A with Kranti, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, BG-380, Abhaya and Safri-17 showed positive significant standard heterosis while, eight hybrids *viz.*, 22A/Indira, 22A/Abhaya, 22A/Safri-17, IR 68899A/Swarna, IR 68899A/Shyamala, IR 68899A/Pusa Basmati, IR 68899A/R-15 and IR 68899A/Abhaya exhibited negative significant standard heterosis.

#### **4.4.4 Total number of spikelets per panicle :**

The relative heterosis for this trait ranged from -54.46 per cent (IR 68899A/R-574-11) to 76.01 per cent (IR 67684A/Safri-17). Fifty one hybrids showed significant relative heterosis of which thirty seven hybrids involving CMS line 22A with Kranti, R-827-287, IR-64, Pusa Basmati, BG-380, Abhaya, Safri-17; CMS line IR 62829A/ with Kranti, Indira, Swarna, Shyamala, IR-64, Pusa Basmati, R-574-11, Abhaya; CMS line IR 67684A with Kranti, Indira, Swarna, Annada, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, BG-380, Abhaya, Safri-17 and CMS line IR 68899A with Indira, Swarna, R-827-287, Shyamala, Pusa Basmati, R-15. BG-380, Abhaya and Safri-17 showed significant positive heterosis whereas, rest of the fifteen hybrids except IR 68899A/IR-64 showed significant negative heterosis.

The heterobeltiosis for this trait ranged from -68.52 per cent (IR 68899A/R-574-11) to 14.60 per cent (IR 67684A/Safri-17). Out of fifty-two hybrids forty-nine showed significant heterobeltiosis and of which only five hybrids *viz.* 22A/Kranti, IR 62829A/Indira, IR 62829A/Pusa Basmati.

IR 67684A/R-827-287 and IR 67684A/Safri-17 showed positive significant heterobeltiosis whereas, forty-four hybrids showed negative significant heterobeltiosis. Heterobeltiosis shown by three hybrids viz., IR 62829A/Shyamala, IR 62829A/Abhaya and IR 67684A/Swarna was non-significant.

The value of standard heterosis for this trait varied from -60.61 per cent (IR 68899A/R-574-11) to 43.41 per cent (IR 67684A/Safri-17). Twenty-one hybrids 22A/Krant, 22A/R-827-287, 22A/IR-64, 22A/Pusa Basmati, 22A/Abhaya, IR 62829A/Kranti, IR 62829A/Indira, IR 62829A/Shyamala, IR 62829A/IR-64, IR 62829A/Pusa Basmati, IR 62829A/Abhaya, IR 67684A/R-827-287, IR 67684A/R-15, IR 67684A/BG-380, IR 67684A/Safri-17, IR 68899A/Indira, IR 68899A/Shyamala, IR 68899A/Pusa Basmati, IR 68899A/R-15, IR 68899A/BG-380 and IR 68899A/Safri-17 showed positive significant standard heterosis while, twenty-eight hybrids involving CMS line 22A with Indira, Swarna, Annada, Shyamala, R-574-11, R-15; CMS line IR 62829A with Swarna, Annada, R-827-287, R-574-11, R-15, BG-380, Safri-17; CMS line IR 67684A with Kranti, Annada, R-827-287, Shyamala, IR-64, Pusa Basmati, R-574-11, Abhaya and CMS line IR 68899A with Kranti, Swarna, Annada, R-827-287, IR-64, R-574-11 and Abhaya showed significant negative standard heterosis.

#### **4.4.5 Total number of filled spikelets per panicle :**

Relative heterosis for this trait ranged from -95.79 per cent (IR 67684A/BG-380) to 349.91 per cent (IR 68899A/Pusa Basmati). All the fifty-two hybrids showed significant relative heterosis. Out of these fifty-two hybrids, thirty-six hybrids involving CMS line 22A with Kranti, Swarna, R-827-287,

Shyamala, IR-64, BG-380, Abhaya, Safri-17; CMS line IR 62829A with Kranti, Swarna, Shyamala, IR-64, Pusa Basmati, R-574-11, R-15, BG-380, Abhaya, Safri-17; CMS line IR 68899A with Kranti, Indira, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, Abhaya and CMS line IR 68899A with Kranti, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, Abhaya and Safri-17 showed positive significant relative heterosis whereas, remaining sixteen hybrids exhibited negative significant relative heterosis.

The range of heterosis over better parent varied between -98.25 per cent (IR 67684A/BG-380) to 29.37 per cent (IR 68899A/Pusa Basmati). Fifty hybrids out of fifty-two hybrids showed significant heterobeltiosis of which only eleven hybrids viz., 22A/R-827-287, 22A/IR-64, IR 62829A/Swarna, IR 62829A/Shyamala, IR 62829A/IR-64, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 68899A/Shyamala and IR 68899A/Pusa Basmati showed significant positive heterobeltiosis while, the rest of the hybrids except IR 62829A/R-15 and IR 68899A/Swarna showed significant negative heterosis.

The value for standard heterosis ranged between -98.15 per cent (IR 67684A/BG-380) to 37.04 per cent (IR 68899A/Pusa Basmati). Forty-six hybrid combinations showed significant standard heterosis. of them only eleven hybrids viz., 22A/R-827-287, 22A/IR-64, IR 62829A/Swarna, IR 62829A/Shyamala, IR 62829A/IR-64, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 68899A/Shyamala and IR 68899A/Pusa Basmati showed positive significant standard heterosis while, thirty-five hybrids

exhibited negative significant standard heterosis. The hybrid combinations 22A/Shyamala, IR 62829A/Kranti, IR 62829A/R-15, IR 68899A/Swarna, IR 68899A/R-827-287 and IR 68899A/Safri-17 showed non-significant standard heterosis.

#### **4.4.6 Total number of chaffy spikelets per panicle :**

The range of relative heterosis varied for this trait between -91.18 per cent (IR 67684A/Indira) to 227.19 per cent (IR 67684A/Safri-17). All the hybrids showed significant relative heterosis and of these, thirty-four hybrids involving CMS line 22A with Swarna, R-827-287, Shyamala, IR-64, BG-380, Abhaya, Safri-17; CMS line IR 62829A with Kranti, Swarna, Shyamala, R-574-11, R-15, BG-380, Safri-17; CMS line IR 67684A with Kranti, Indira, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, Abhaya and CMS line IR 68899A with Kranti, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-574-11, R-15, Abhaya and Safri-17 showed significant relative heterosis while, the rest of the eighteen hybrids showed significant positive relative heterosis.

The value for heterobeltiosis ranged from -35.04 (IR 67684A/Indira and IR 68899A/Pusa Basmati) to 1524.79 (IR 67684A/Safri-17). All the Fifty-two hybrids except IR 68899A/Kranti showed significant heterobeltiosis. Only three hybrids viz., IR 67684A/Indira, IR 67684A/Pusa Basmati and IR 68899A/Pusa Basmati showed significant negative heterobeltiosis whereas, rest of the forty-eight hybrids showed significant positive heterobeltiosis.

Standard heterosis for this trait ranged between -74.41 per cent (IR 67684A/Indira and IR 68899A/Pusa Basmati) to 540.07 per cent (IR 67684A/Safri-17). Out of fifty-two hybrids, forty-eight hybrids showed significant standard heterosis and of these only ten hybrids viz., 22A/R-827-287, 22A/IR-64. IR 67684A/Kranti, IR 67684A/Indira, IR 67684A/R-827-287, IR 67684A/Pusa Basmati, IR 68899A/Kranti, IR 68899A/R-827-287, IR 68899A/Shyamala and IR 68899A/Pusa Basmati showed negative significant standard heterosis while, remaining thirty-eight hybrids exhibited positive significant standard heterosis. The hybrid combinations 22A/Shyamala, IR 62829A/Shyamala, IR 62829A/IR-64 and IR 68899A/Abhaya showed non-significant standard heterosis.

#### **4.4.7 Spikelet fertility percentage :**

The relative heterosis range for spikelets fertility percentage varied from -97.11 per cent (IR 67684A/BG-380) to 159.25 per cent (IR 68899A/Pusa Basmati). All the fifty-two hybrids showed significant relative heterosis of which thirty-five hybrid combinations involving CMS line 22A with Kranti. Swarna, R-827-287, Shyamala, IR-64, BG-380, Abhaya, Safri-17; CMS line IR 62829A with Kranti, Swarna, Shyamala, IR-64, R-574-11, R-15, BG-380, Abhaya, Safri-17; CMS line IR 67684A with Kranti, Indira, Swarna, R-287-287, Pusa Basi, R-15, Abhaya and CMS line IR 68899A with Kranti, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, Abhaya and Safri-17 showed positive significant relative heterosis while, the remaining seventeen hybrids exhibited negative significant relative heterosis.

The value of heterobeltiosis for this trait varied from -98.58 per cent (IR 67684A/BG-380) to 4.61 per cent (IR 68899A/Pusa Basmati). Fifty-one of the fifty-two hybrids showed significant heterobeltiosis and of these only three hybrids *viz.*, IR 67684A/Indira, IR 67684A/Pusa Basmati and IR- 68899A/Pusa Basmati showed significant positive heterobeltiosis while, remaining forty-eight hybrids exhibited negative significant heterobeltiosis. The only hybrid IR 67684A/R-827-287 showed non-significant heterobeltiosis.

Standard heterosis for this trait ranged from -98.41 per cent (IR 67684A/BG-380) to 17.20 per cent (IR 68899A/PusaBasmati). Forty-eight hybrids showed significant standard heterosis and of these only nine hybrids *viz.*, 22A/IR-64, IR 62829A/Shyamala, IR 67684A/Kranti, IR 67684A/Indira, IR 67684A/R-827-287, IR 67684A/Pusa Basmati, IR 68899A/Kranti, IR 68899A/Shyamala and IR 68899A/Pusa Basmati showed positive significant standard heterosis while, remaining thirty-nine hybrids exhibited negative significant standard heterosis. The four hybrid combinations 22A/R-827-287, 22A/Shyamala, IR 62829A/IR-64 and IR 68899A/R-827-287 showed non-significant standard heterosis.

#### 4.4.8 Pollen sterility percentage :

Relative heterosis for this trait ranged from -96.30 IR 67684A/Swarna) to 88.55 (22A/Annada). All the fifty-two hybrids showed significant relative heterosis of which thirty-five hybrids *viz.* 22A/Kranti, 22A/Swarna, 22A/R-827-287, 22A/Shyamala, 22A/IR-64, 22A/BG-380, 22A/Abhaya, 22A/Safri-17, IR 62829A/Kranti, IR 62829A/Swarna, IR 62829A/Shyamala,

IR 62829A/IR-64, IR 62829A/R-574-11, IR 62829A/R-15, IR 62829A/BG-380, IR 62829A/Abhaya, IR 62829A/Safri-17, IR 67684A/Kranti, IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/R-827-287, IR 67684A/Shyamala, IR 67684A/IR-64, IR 67684A/Pusa Basmati, IR 67684A/R-15, IR 67684A/Abhaya, IR 68899A/Kranti, IR 68899A/Swarna, IR 68899A/R-827-287, IR 68899A/Shyamala, IR 68899A/IR-64, IR 68899A/Pusa Basmati, IR 68899A/R-15, IR 68899A/Abhaya and IR 68899A/Safri-17 exhibited negative significant relative heterosis whereas, remaining seventeen hybrids showed significant positive relative heterosis.

The range for heterobeltiosis for this trait varied between -2.06 per cent (IR 67684A/Swarna) to 5008.25 per cent (22A/Annada). All the fifty-two hybrids showed significant heterobeltiosis and of these fifty-one hybrids showed positive significant heterobeltiosis whereas, only one hybrid IR 67684A/Swarna exhibited negative significant heterobeltiosis.

Standard heterosis for pollen sterility percentage ranged between -16.37 per cent (22A/R-827-287) to 3352.96 per cent (22A/Annada). Out of fifty-two hybrids, fifty-one hybrids showed significant standard heterosis. Forty-eight of these fifty-one hybrids showed positive significant standard heterosis while, only one hybrid 22A/R-827-287 exhibited negative significant standard heterosis. The three hybrid combinations 22A/Abhaya, IR 62829A/BG-380 and IR 67684A/Swarna showed non-significant standard heterosis.

#### 4.4.9 100-grain weight :

Relative heterosis for 100-grain weight ranged from -27.60 per cent (IR 68899A/BG-380) to 57.29 per cent (22A/R-15). A total of forty-seven out of fifty-two hybrids showed significant relative heterosis, of which thirty-three hybrids involving CMS line 22A with Kranti, Swarna, Annada, Shyamala, R-15, BG-380, Safri-17; CMS line IR 62829A with Indira, Swarna, R-827-287, Shyamala, IR-64, Pusa Basmati, R-15, Safri-17; CMS line IR 67684A with Indira, Swarna, Annada, R-827-287, Shyamala, IR-64, R-574-11, Abhaya, Safri-17 and CMS line IR 68899A with Indira, Swarna, Annada, R-827-287, IR-64, Pusa Basmati. R-15, Abhaya and Safri-17 showed positive significant relative heterosis and fourteen hybrids showed negative significant relative heterosis. The five hybrids combinations 22A/IR-64, IR 62829A/Annada, IR 67684A/Kranti, IR 67684A/R-15 and IR 68899A/Kranti showed non-significant relative heterosis.

Heterobeltiosis for 100-grain weight ranged from -43.61 per cent (22A/R-827-287) to 0.38 per cent (22A/R-15). Fifty-one hybrids out of fifty-two hybrids showed significant negative heterobeltiosis. The hybrid 22A/R-15 showed non-significant heterobeltiosis.

Standard heterosis for 100-grain weight varied from -26.32 per cent (22A/Swarna) to 54.36 per cent (22A/R-15). Forty-five hybrids showed significant standard heterosis of which thirty-nine hybrids involving CMS line 22A with Kranti, Annada, Shyamala, IR-64, R-574-11, R-15, BG-380, Safri-17; CMS line IR 62829A with Kranti, Indira, Annada, R-827-287, Shyamala, IR-64, Pusa Basmati, R-574-11, R-15, BG-380, Abhaya, Safri-17; CMS line IR 67684A

with Kranti, Indira, Swarna, Annada, Shyamala, IR-64, R-574-11, Abhaya, Safri-17 and CMS line IR 68899A with Kranti, Indira, Swarna, Annada, IR-64, Pusa Basmati, R-574-11, R-15, Abhaya and Safri-17 showed positive significant standard heterosis whereas, six hybrids *viz.*, 22A/Swarna, 22A/R-827-287, 22A/Pusa Basmati, IR 62829A/Swarna, IR 67684A/BG-380 and IR 68899A/BG-380 showed significant negative standard heterosis.

#### **4.4.10 Grain yield per plant :**

Among the fifty-two hybrids, relative heterosis ranged from -82.36 per cent (22A/Indira) to 279.06 per cent (IR 62829A/BG-380). All the fifty-two hybrids showed significant relative heterosis of which only nineteen hybrids *viz.*, 22A/Swarna, 22A/IR-64, 22A/BG-380, IR 62829A/Kranti, IR 62829A/Swarna, IR 62829A/R-827-287, IR 62829A/IR-64, IR 62829A/R-15, IR 62829A/BG-380, IR 62829A/Abhaya, IR 62829A/Safri-17, IR 67684A/Swarna, IR 67684A/Annada, IR 67684A/R-827-287, IR 67684A/Shyamala, IR 67684A/IR-64, IR 67684A/R-15, IR 68899A/Swarna and IR 68899A/Safri-17 showed positive significant relative heterosis whereas, remaining thirty-three hybrids showed negative significant relative heterosis for this trait.

Heterobeltiosis for this trait ranged from -93.19 per cent (22A/Indira) to 31.84 per cent (IR 67684A/Swarna). All the fifty-two hybrids showed significant heterobeltiosis of which only two hybrids *viz.*, IR 62829A/BG-380 and IR 67684A/Swarna showed positive significant heterobeltiosis whereas, remaining fifty hybrids showed significant negative heterobeltiosis.

The range of standard heterosis for this trait varied from –89.19 per cent (22A/Indira) to 76.52 per cent (IR 62829A/BG-380). Forty-seven hybrids out of fifty-two hybrids showed significant standard heterosis and of these only two hybrids IR 62829A/BG-380 and IR 67684A/Swarna showed positive significant standard heterosis whereas, forty-five hybrids showed significant negative standard heterosis. The five hybrid combinations *viz.*, 22A/BG-380, IR 62829A/Kranti, IR 62829A/R-827-287, IR 62829A/IR-64 and IR 68899A/Safri-17 showed non-significant standard heterosis.

#### **4.5 ISOLATION OF MAINTAINERS AND RESTORERS :**

The fertility restoration among fifty-two hybrids ranged from 1.30 per cent (IR 67684A/BG-380) to 95.32 per cent (IR 67684A/Indira), thereby suggesting partial restoration to high restoration of fertility of CMS lines. Many of the hybrids *viz.*, 22A/Indira, 22A/R-574-11, IR 67684A/BG-380, IR 68899A/Indira, IR 68899A/Annda and IR 68899A/BG-380 showed near to complete sterility. The testers (male parents) of these hybrids could be treated as effective **maintainers** for their respective CMS lines. These hybrids showed pollen sterility and spikelet fertility in the order of 91.00 per cent and 3.71 per cent, 97.37 per cent and 2.88 per cent, 97.81 per cent and 1.30 per cent, 90.60 per cent and 3.52 per cent, 96.93 per cent and 2.82 per cent, 95.97 per cent and 1.98 per cent, respectively.

Some of the testers of the hybrids IR 67684A/Indira, IR 67684A/Swarna, IR 67684A/R-827-287 and IR 67684A/Pusa Basmati could be treated as effective restorers for the respective CMS lines as their hybrids registered pollen sterility and spikelet fertility percentage in the order of 13.89 per cent and 95.53 per cent, 1.90 per cent and 88.33 per cent, 3.70 per cent and 91.04 per cent, 4.25 per cent and 93.45 per cent, respectively.

## DISCUSSION

## CHAPTER V

### DISCUSSION

In the coming decades, to sustain the future demands, the levels achieved in rice production has to be increased further every year by almost 2 million tons. This is a challenging task in view of the plateauing trend observed is yield potential of the present day high yielding varieties of rice. This increase in production should be achieved through sustainable environment friendly methods.

Among the many genetic approaches available to break the yield barrier in rice, hybrid rice technology appears to be the most feasible and adaptable one amongst the farmers. China has pioneered the release of hybrid rice for commercial cultivation to meet increasing demands for rice. During the last 25 years, an additional 300 million tons of rice was produced due to adoption of hybrid rice on large scale. The use of hybrid rice has spared 6 million ha of land from rice cultivation thereby, helping to divert the land for cultivation of high value cash crops (Singh *et al.*, 2001).

The problem of adaptability of Chinese male sterile lines to the alien environment, instability of yield of hybrids, unavailability of large number of affective restorers and inadequacy of the magnitude of standard heterosis are reported to be the main handicaps in hybrid rice programme.

22A, IR 62829A, IR 67684A and IR 68899A are the male sterile lines developed at IRR1, Philippines, having 'wildabortive' (WA) cytoplasm and are most stable and adaptable. It was, therefore felt appropriate to use these lines as source material in this investigation.

In the present investigation four CMS lines, thirteen testers and the resulting fifty two hybrids were evaluated by their mean performances, variances, combining ability and magnitude of heterosis. The results obtained are discussed here under :

### **5.1. Analysis of Variance:**

The analysis of variance for the parental genotypes and hybrids suggested significant variability between the parents and hybrids for all the characters studied. Thus the base genotypes showed high genetic variability for different characters, which is essential requirement for the success of any breeding programme. The variance due to line x tester interaction was also significant, which satisfy the requirement for comparison of different genotypes with respect to combining ability.

### **5.2 Evaluation of Genotypes :**

#### **5.2.1 Plant height :**

The sca variance was greater than the gca variance for plant height, indicating the predominance of non-additive gene action for this trait. This result is similar to the findings of Banumathy and Prasad (1991), Ramalingam *et al.* (1997), Sreeramachandra Babu *et al.* (2000), Satyanarayana *et al.* (2000) and Munhot *et al.* (2000). However, preponderance of additive gene action for this trait was reported by Manuel and Palanisamy (1989), Peng and Virmani (1990), Sarawgi *et al.* (1991), Sharma and Koranne (1995), and Lavanya (2000V

The tester Shyamala registered lowest mean plant height among the test varieties whereas, lowest mean height among the female parents was shown by IR 68899A. The female parent 22A showed highest negative gca effect for this trait. Among the testers, R-827-287 showed the highest negative gca effect. The negative gca effect indicated their usefulness in breeding of dwarf lines.

Among the hybrids, IR 62829A/Pusa Basmati was shortest followed by IR 62829A/Annada, IR 67684A/R-574-11, IR 68899A/Annada and IR 68899A/R-827-287. Highest negative sca effect was shown by 22A/R-15. The tester of this cross had significant positive gca effect and the line 22A had significant negative gca effect. The present findings indicate that the *per se* performance of the hybrids appeared not to be dependent on the sca effect. This is in accordance to the observations of Bobby and Nadarajan (1994).

Highest negative relative heterosis was shown by 22A/R-15 followed by IR 67684A/R-574-11 and IR-67829A/Annada. Highest negative heterobeltiosis was shown by IR 62829A/Pusa Basmati followed by IR 62829A/Annada and IR 67684A/R-574-11. Highest negative standard heterosis was shown by IR 62829A/Pusa Basmati followed by IR 62829A/Annada and IR 67684A/R-574-11.

Twenty-eight, four and fifteen hybrids had shown significant negative relative heterosis, heterobeltiosis and standard heterosis, respectively for this trait. Similar results have been reported by Young and Virmani (1990), Peng and Virmani (1991) and Yang and Song (1994).

### 5.2.2 Panicle Length :

The variance due to sca was higher than the gca variance for panicle length, indicating the preponderance of non-additive gene action for this trait. These results are similar to the findings of Gravois and Mc New (1993), Manonmani ~~and~~ Ranganathan (1998) and Munhot<sup>et al.</sup>(2000) and Satyanarayana *et al.* (2000).

All the lines registered non-significant gca effects. Highest positive gca effect among the testers, was shown by Safri-17, which is reflected in its *per se* performance. This was followed by BG-380 and Pusa Basmati with their positive gca effects.

Among the hybrids, high positive sca effects were recorded for 22A/Annada, followed by IR 68899A/Safri-17, IR 67684A/R-15 and IR 62829A/Pusa Basmati. These findings indicate that the high mean performance of the crosses is associated with positive sca effects with hybrids having none or one of the parents showing high gca effect, thereby suggesting the presence of non-additive gene effects.

Highest positive relative heterosis was shown by IR 67684A/R-827-287. followed by 22A/Annada, IR 62829A/R-827-287 and 22A/BG-380. Highest positive heterobeltiosis was shown by IR 68899A/Safri-17. Highest positive standard heterosis was shown by IR 68899A/Safri-17, followed by 22A/Annada, IR 67684A/R-15 and IR 62829A/Pusa Basmati. These findings are similar to the findings of Bobby and Nadarajan (1994). Ramalingam *et al.* (1994) and Mishra and Pandey (1998).

### 5.2.3 Total number of productive tillers per plant:

Higher sca variance than the gca variance was observed for this trait. Similar results have been reported by Cheema *et al.* (1988), Manonmani and Ranganathan (1998), Meenakshi and Amirthadevarathinam (1999), Kalitha and Upadhaya (2000), Lavanya (2000) and Satyanarayana *et al.* (2000). The preponderance of dominance gene action for number of productive tillers per plant, offers the scope for exploitation of heterosis in rice.

All the four lines showed non-significant gca effects. BG- 380, among testers, showed highest positive gca effect, followed by Annada, Kranti and Swarna.

Among the hybrids, high *per se* performances and positive sca effects were observed for hybrids IR 67684A/Annada and IR 67684A/BG-380. The testers of these two hybrids showed positive gca effects. These findings indicate the predominance of additive and non-additive gene action. The crosses IR 68899A/Safri-17 and IR 62829A/R-15 showed high positive sca effects whereas, the testers of these two hybrids had non-significant gca effect and negative significant gca effect, respectively. These findings suggest that the of non-additive gene action for these crosses resulted in their heterotic performance.

High positive relative heterosis, heterobeltiosis and standard heterosis were shown by the hybrids IR 68899A/Safri-17, followed by IR 68899A/BG-380, IR 67684A/BG-380, IR 67684A/Indira, IR 62829A/Kranti and 22A/Swarna. Similar results have been reported by Ramalingam *et al.* (1994), Yang and Song (1994), Bobby and Nadarajan (1994) and Singh and Haque (1999).

#### 5.2.4 Total number of spikelets per panicle:

The variance due to *sca* is greater than the *gca* variance, indicating the predominance of non-additive gene action for this trait. Similar results were suggested by Anand *et al.* (1999) Uma (1994), Dwivedi *et al.* (1999) and Satyanarayana *et al.* (2000). However, Haque *et al.* (1981) have suggested the importance of additive gene action for this trait.

Among the lines, IR 62829A exhibited high *gca* effect. Among the testers, **Annada** showed high positive *gca* effect, followed by Pusa Basmati and Safri-17. Among the hybrids, 22A/Kranti showed highest positive *sca* effect, followed by IR 67684A/R-15, 22A/Abhaya and IR 68899A/Indira. One of the parents of **all** the crosses mentioned above for positive *sca* effects showed negative *gca* effects, thereby confirming the presence of non-additive gene action in the form of over dominance and epistasis for hybrids with high *sca* effects.

Highest positive relative heterosis was noted for hybrids IR 67684A/Safri-17 followed by IR 62829A/Pusa Basmati. IR 68899A/Pusa Basmati and IR 62829A/Shyamala. Highest positive heterobeltiosis and standard heterosis were shown by IR 67684A/Safri-17 followed by IR 67684A/R-827-287, IR 62829A/Pusa Basmati and IR 62829A/Indira. These hybrids with high *per se* performances need not be the one with high *sca* effects and vice versa. Similar results were reported by Rao *et al.* (1980), Tseng and Huang (1987), Sharma and Mani (1990) and Mishra and Pandey (1999).

### 5.2.5 Total number of filled spikelets per panicle:

High sca variance in comparison to gca variance was registered for this trait, indicating the pre-dominance of non-additive gene action. Similar results have been observed by Kalaimani and Sundaram (1987), Dwivedi *et al.* (1999) and Satyanarayana *et al.* (2000).

Among the lines, IR 67684A showed highest positive gca effect. Highest positive gca effect, among testers, was shown by Swarna, followed by Shyamala, Kranti and R-827-287. Among the hybrids, high positive sca effects were shown by IR 67684A/Indira followed by 22A/BG-380, IR 62829A/R-574-11 and 22A/IR-64. These hybrids also showed high *per se* performance. At least both the parents of hybrids IR 67684A/Indira, 22A/BG-380 and IR 62829A/R-574-11 with high positive sca effects recorded negative gca effects. Such behaviour has been attributed to over dominance and epistasis.

Highest positive relative heterosis was shown by the hybrid IR 68899A/Pusa Basmati followed by IR 62829A/Shyamala, IR 68899A/Shyamala and IR 67684A/Pusa Basmati. Highest positive heterobeltiosis was shown by the hybrid IR 68899A/Pusa Basmati followed by IR 62829A/Shyamala, IR 67684A/Swarna and IR 62829A/Swarna. Highest positive standard heterosis was shown by IR 68899A/Pusa Basmati. Most of the hybrids showed positive relative heterosis but maximum showed negative heterobeltiosis and standard heterosis. Similar results was observed by Kalaimani and Kadambavanasundaram (1987), Sharma and Mani (1990) Panwar *et al.* (1998) and Singh and Haque (1999).

### 5.2.6 Total number of chaffy spikelets per panicle:

The sca variance noticed for this trait was greater than that of gca variance, indicating the preponderance of non-additive gene action. The results were in accordance with the results observed by Sharma and Koranne (1995) and Dwivedi *et al.* (1999).

Among the lines IR 68899A showed highest negative gca effect. Indira, among testers, showed highest positive gca effect, followed by Annada, BG-380, and Pusa Basmati. Seven testers, Kranti, Swarna, R-827-287, Shyamala, IR-64, R-15 and Abhaya showed negative significant gca effects.

Among the hybrids highest negative sca effect was shown by IR 67684A/Indira, followed by IR 62829A/BG-380, IR 67684A/Pusa Basmati and 22A/BG-380. Male parent Indira, Pusa Basmati, BG-380 showed high positive gca effect, while female parent IR 67684A showed negative gca effect, indicating the predominance of non-additive gene actions in the sca effects of the hybrids.

Highest negative relative heterosis was shown by hybrids IR 67684A/Indira followed by IR 68899A/Kranti. Highest negative heterobeltiosis was shown by hybrids IR 67684A/Indira and IR 68899A/Pusa Basmati while, highest negative standard heterosis was shown by IR 67684A/Indira and IR 68899A/ Pusa Basmati. Similar findings were reported by Das (2000) and Gannamani (2001).

### 5.2.7 Spikelets fertility percentage:

The gene action for this trait was predominantly non-additive as the estimated variance of sca was higher than the gca variance. Similar results were obtained by Haque *et al.* (1981), Banumathy and Prasad (1991), Sharma and Koranne (1995), Dwivedi *et al.* (1999), Lavanya (2000), Satyanarayana *et al.* (2000) and Sreeramachandra Babu *et al.* (2000).

Among the parental lines, IR 67684A registered high positive gca effect. Among the testers, Swarna showed high positive gca effect followed by Shyamala, IR-64, Kranti and R-827-287.

Among the hybrids, IR 67684A/Indira showed high positive gca effect, followed by IR 62829A/R-574-11, 22A/BG-380, IR 68899A/PusaBasmati and IR 62829A\BG-380. All these hybrids showed sca effects proportional to their high *per se* performance. Both the parents of some of the crosses with positive sca effects showed negative gca effects. While, all the crosses with negative sca effects had one or both the parents with positive gca effects, confirming the importance of non-additive gene action for this trait.

The highest positive relative heterosis was shown by IR 68899A/Pusa Basmati. Only three hybrids IR 67684A/Indira, IR 67684A/Pusa Basmati and IR 68899A/Pusa Basmati showed positive significant heterobeltiosis. The highest positive standard heterosis was shown by IR 68899A/Pusa Basmati. In all only nine hybrids showed positive significant standard

heterosis whereas, remaining thirty-nine of the forty-eight significant heterotic hybrids showed negative standard heterosis. Negative heterosis has also been reported by Rao *et al.* (1980), Tseng and Huang (1987) and Singh and Maurya (1999) whereas, positive heterosis for this trait has been reported by Zhang and Xu (1986), Uma (1994) and Reddy and Nerkar (1992).

#### **5.2.8 Pollen sterility percentage:**

The gene action for this trait is predominantly non-additive as the estimated variance of sca was higher than the gca variance. The results are similar to the findings of Haque *et al.* (1981), Manuel and Palanisami (1989), Banumathy and Prasad (1991) and Sharma and Koranne (1995).

Among the parents, line IR 67684A showed negative significant gca effect. Among the testers, highest negative gca effect was shown by Swarna followed by Kranti, IR-64 and Abhaya. Among the hybrids, highest negative sca effects were shown by IR 67684A/Indira. IR 62829A/BG-380, IR 62829A/R-574-11, IR 67684A/Pusa Basmati. These hybrids also showed high *per se* performance. The presence of one or both the parents with positive gca effects in the parentage of hybrids with high negative sca effects indicates the existence of non-additive gene action.

High negative relative heterosis was shown by IR 67684A/Swarna followed by 22A/R-827-287, IR 62829A/BG-380 and 22A/Abhaya. Highest negative heterobeltiosis was shown by IR 67684A/Swarna. All the remaining fifty-one

hybrids showed positive significant heterobeltiosis. Highest negative standard heterosis was shown by hybrid IR 67684A/Swarna whereas, all the remaining fifty-one hybrids showed positive significant standard heterosis. Similar results were reported by Zhang and Xu (1986).

### **5.2.9 100-grain weight:**

The *sca* variance for this trait was greater than the variance due to *gca*, which indicates the predominance of non-additive gene action for this character. Similar results have been reported by Manuel and Palanisamy (1989), Uma (1994), Manonmani and Ranganathan (1998), Satyanaranyana *et al.* (1998) Kalitha and Upadhaya (2000), Satyanaranyana *et al.* (2000) and Sreeramachandra Babu *et al.* (2000).

Among the female parents, none showed significant positive *gca* effects. Among the testers, Shyamala showed highest positive *gca* effects, followed by R-827-287, BG-380 and Pusa Basmati. Parents with high *gca* effects are good general combiner for this trait. Among the hybrids, 22A/ R-15 showed the highest positive *sca* effect. followed by IR 68899A/Shyamala, IR 68899A/Pusa Basmati and IR 67684A/R-15. The positive *sca* effects were also reflected in their *per se* mean performances.

High positive relative heterosis for this trait was shown by hybrid 22A/R-15, followed by IR 67684A/Annada, IR 68899A/Swarna and 22A/Shyamala. All the hybrids showed significant negative heterobeltiosis. Highest

positive standard heterosis was shown by hybrid 22A/R-15. Similar to these results positive relative heterosis was also observed by Zhang and Xu (1986), Tseng and Huang (1987), Sharma and Mani (1989), Bobby and Nadarajan (1994), Mishra and Pandey (1998) and Panwar *et al.* (1998).

#### 5.2.10 Grain yield per plant:

The variance due to sca for grain yield per plant was greater than variance due to gca, indicating the predominance of non-additive gene action. Similar results were also reported by Manuel and Palanisamy (1989), Banumathy and Prasad (1991), Uma (1994), Ramalingam *et al.* (1997), Satyanarayana *et al.* (1998), Dwivedi *et al.* (1999), Kalitha and Upadhaya (2000), Lavanya (2000) and Satyanarayana *et al.* (2000).

Among the lines IR 62829 A showed high positive gca effect. Among the testers, Swarna, BG-380, IR-64 and Kranti showed high positive gca effects. Among the hybrids IR 62829A/BG-380, IR 67684A/Swarna, IR 68899A/Safri-17, IR 67684A/Annada showed high positive sca effects. The hybrids IR 68899A/Safri-17, IR 67684A/Annada have one or both the parents with negative gca effects. Negative sca effects with high *per se* performance were also shown by IR 67684A/BG-380, IR 67684A/Kranti, IR 67684A/Safri-17, IR 62829A/Swarna. These hybrids had one or both the parents with positive gca effects. This reflects the presence of non-additive gene action for this trait. The best general and specific combiners for yield and yield related traits have been depicted in Table-12.

**Table-12: Best general combiners and specific combiners for different characters.**

Characters	Best general combiners		Best specific combiners
	Lines	Testers	
Plant height (cm)	IR 68899A, 22A	Shyamla, R-827-287	IR 62829A/PusaBasmati, IR 62829A/Annada, 22A/R-15, IR 62829A/R-574-11, IR 68899A/Annada, IR 68899A/R-827-287
Panicle length (cm)	22A, IR 67684A	Safri-17, BG-380, Pusa Basmati	22A/Annada, IR 68899A/Safri-17, IR 62829A/R-15, IR 62829A/Pusa Basmati
Total no. of productive tillers/plant	IR 67684A	BG-380, Annada, Kranti	IR 62829A/Annada, IR 62829A/BG-380, IR 68899A/Safri-17, IR 62829A/R-15
Total no. of filled spikelets/panicle	IR 67684A	Swarna, Shyamala, Kranti, R-827-287	IR 62829A/Indira, 22A/BG-380, IR 62829A/R-574-11, 22A/IR-64
Total no. of chaffy spikelets/panicle	IR 68899A	Swarna, Shyamala, IR-64, Kranti	IR 62829A/Indira, IR 62829A/BG-380, IR 62829A/PusaBasmati
Total no. of spikelets/panicle	IR 62829A	Pusa Basmati, Safri-17, Indira	22A/Kranti, IR 62829A/R-15, 22A/Abhaya, IR 68899A/Indira
Spikelet fertility %	IR 67684A	Swarna, Shyamala, IR-64, Kranti, R-827-287	IR 62829A/Indira, IR 62829A/R-574-11, 22A/BG-380, IR 68899A/Pusa Basmati, IR 62829A/BG-380
Pollen sterility %	IR 67684A	Swarna, Kranti, IR-64, Abhaya	IR 62829A/Indira, IR 62829A/BG-380, IR 62829A/R-574-11, IR 62829A/Pusa Basmati
100-grain weight (g)	IR 67684A	R-827-287, Shymala, BG-380, Pusa Basmati	22A/R-15, IR 68899A/Shyamala, IR 68899A/Pusa Basmati, IR 62829A/R-15
Grain yield/plant (g)	IR 62829A	Swarna, BG-380, IR-64, Kranti	IR 62829A/BG-380, IR 62829A/Swarna, IR 68899A/Safri-17, IR 62829A/Annada

**Table-13 : sca effects of hybrid combinations and gca effects of the parents for grain yield per plant.**

Cross combination	sca effects	gca effects of females	gca effect of males
IR 62829A/BG-380	15.78*	4.13*(H)	4.26*(H)
IR 67684A/Swarna	15.68*	1.89*(H)	13.07*(H)
IR 68899A/Safri-17	11.74*	-3.85*(L)	1.27(H)
IR 67684A/Annada	7.58*	1.89*(H)	-3.75*(L)
22A/BG-380	6.18*	-2.17*(L)	4.26*(H)
IR 68899A/Indira	5.45*	-3.85*(L)	-4.90*(L)
IR 62829A/Kranti	5.24*	4.13*(H)	1.60*(H)
22A/R-574-11	4.13*	-2.17*(L)	-6.20*(L)
IR 62829A/R-827-287	3.95	4.13*(H)	-0.84(L)

\* = Significant at P= 0.05 level.

H = High combining ability.

L = Low combining ability.

: Significant positive relative heterosis heterobeltiosis and standard heterosis were shown by hybrids IR 62829A/BG-380 (Plate-1), IR 67684A/Swarna (Plate-2). Most of the hybrids showed negative relative heterosis, heterobeltiosis and standard heterosis. The present findings are in agreement with the results of Shrivastava and Seshu (1982), Sasmal (1988), Sharma and Mani (1989), Young and Virmani (1990), Panwar *et al.* (1998), Singh and Haque (1999), Singh and Maurya (1999) and Lavanya (2000).

### **5.3 STUDIES ON VARIABILITY, HERITABILITY AND GENETIC ADVANCE:**

#### **5.3.1 Variability:**

Low genotypic and phenotypic coefficients of variation were observed for plant height. Moderate genotypic and phenotypic coefficient of variations were shown by pollen sterility percentage and grain yield per plant whereas, high genotypic and phenotypic coefficient of variations were expressed by panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelets fertility percentage and 100-grain weight.

High phenotypic variations observed were composed of high genotypic variations and low environmental variations which indicated the presence of high genetic variability for different traits and less influence of environment. Similar results were observed by Li *et al.* (1991), Singh and Choudhary (1996), Choudhary and Das (1998), Kaw *et al.* (1999), Sadhukhan and Chattopadhaya (2000), Shivani and Sree Rama Reddy (2000), Iftekharuddaula *et al.* (2001).



IR 62829A



IR 62829A BG-380



BG-380

PLATE-1: HETEROTIC HYBRID FOR GRAIN YIELD PER PLANT



IR 67684A



IR 67684A/SWARNA



SWARNA

PLATE-2: HETEROTIC HYBRID FOR GRAIN YIELD PER PLANT

**Table-14: *Per se* performance, sca effects, heterosis of F<sub>1</sub> hybrids and gca effects of the parents for grain yield per plant**

Cross combination	<i>Per se</i> performance yield/plant (g)	sca effect	gca effect of female	gca effect of male	heterosis	
					BP	Check
IR 67684A/Swarna	41.61	15.68*	1.89*(H)	13.07*(H)	31.84*	31.84*
IR 62829A/BG-380	35.11	15.75*	4.13*(H)	4.26*(H)	11.25*	76.52*

\* Significant at P =0.05 level. H = High combining ability

**Table-15: Restorers and maintainers for four CMS lines.**

CMS lines	Effective maintainers	Effective restorers
22A	Indira, R-574-11	R-827-287
IR 62829A	-	BG-380
IR 67684A	BG-380	Indira, Swarna, R-827-287, Pusa Basmati, Shyamata
IR 68899A	Indira, Annada, BG-380	-

### **5.3.2 Heritability :**

High heritability estimates were observed for all the characters studied, *viz.*, plant height, panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelets fertility percentage, pollen sterility percentage, 100-grain weight and grain yield per plant. High heritability indicates the scope of genetic improvement of these characters through selection. Similar results have been reported by Alias (1985), Babu (1996), Choudhary and Das (1998), Kaw *et al.* (1999), Shivani and Sree Rama Reddy (2000) and Iftekharuddaula *et al.* (2001).

### **5.3.3 Genetic Advance:**

High genetic advance was exhibited by total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelets fertility percentage, 100-grain weight and grain yield per plant. Moderate genetic advance was observed for panicle length whereas, low genetic advance was noted for plant height and pollen sterility percentage. Similar findings were reported by Maurya *et al.* (1986), Babu (1996) and Shivani and Sree Rama Reddy (2000).

### **5.4 ISOLATION OF MAINTAINERS AND RESTORERS :**

Isolation of maintainers and restorers was carried out by taking out observations *viz.*, pollen sterility percentage and spikelets fertility percentage. The findings of the present investigation are discussed here under:

#### **5.4.1 Isolation of Maintainers :**

The studies on pollen sterility and spikelets fertility percentage indicated that none of the hybrids possess 100 per cent pollen sterility and spikelets fertility. However, a very high magnitude of pollen sterility (>90 per cent) was observed for hybrids 22A/Indira (Plate-3), 22A/R-574-11 (Plate-4), IR 67684A/BG-380 (Plate-5), IR 68899A/Indira (Plate-6), IR 68899A/Annada (Plate-7) and IR 68899A/BG-380 (Plate-8). The pollen sterility and spikelets fertility percentage of these hybrids were in the order of 91.00 and 3.71 per cent, 97.37 and 2.88 per cent, 97.81 and 1.30 per cent, 90.60 and 3.52 per cent, 96.93 and 2.82 per cent, 95.97 and 1.98 per cent, respectively. The pollen parent of these hybrids namely, Indira, R-574-11, BG-380, Indira, Annada and BG-380 can be regarded as effective maintainers for the lines 22A, IR 67684A and IR 68899A, respectively.

#### **5.4.2 Isolation of Restorers:**

Based on spikelets fertility and pollen sterility percentage, Swarna (Plate-2), R-827-287 and Pusa Basmati (Plate-9) can be regarded as effective restorers for the CMS line IR 67684A as their respective hybrids had shown more than 85 per cent spikelets fertility and less than 5 per cent pollen sterility. Tester R-827-287 for CMS line 22A; tester Shyamala for CMS line IR 67684A and tester BG-380 (Plate-1) for CMS line IR 62829A can also be regarded as restorers as they showed less than five per cent pollen sterility and high spikelet fertility percentage (>70 per cent). Similar findings have been reported by Virmani (1985), Sharma and Mani(1989), Mandal *et al.*(1990). Prasad *et al.*(1992), Leenakumari *et al.*(1996), Padmavathi *et al.*(1997), Hemareddy *et al.*(2000) and Ushakumari *et al.*(2002).



22A



22A/INDIRA



INDIRA

**PLATE-3: EFFECTIVE MAINTAINER**



22A



22A/R-574-11



R-574-11

**PLATE-4: EFFECTIVE MAINTAINER**



IR 67684A



IR 67684A/BG-380



BG-380

**PLATE-5: EFFECTIVE MAINTAINER**



IR 68899A



IR 68899A/INDIRA



INDIRA

**PLATE-6: EFFECTIVE MAINTAINER**



IR 68899A



IR 68899A/ANNADA



ANNADA

**PLATE-7: EFFECTIVE MAINTAINER**



IR 68899A



IR 68899A/BG-380



BG-380

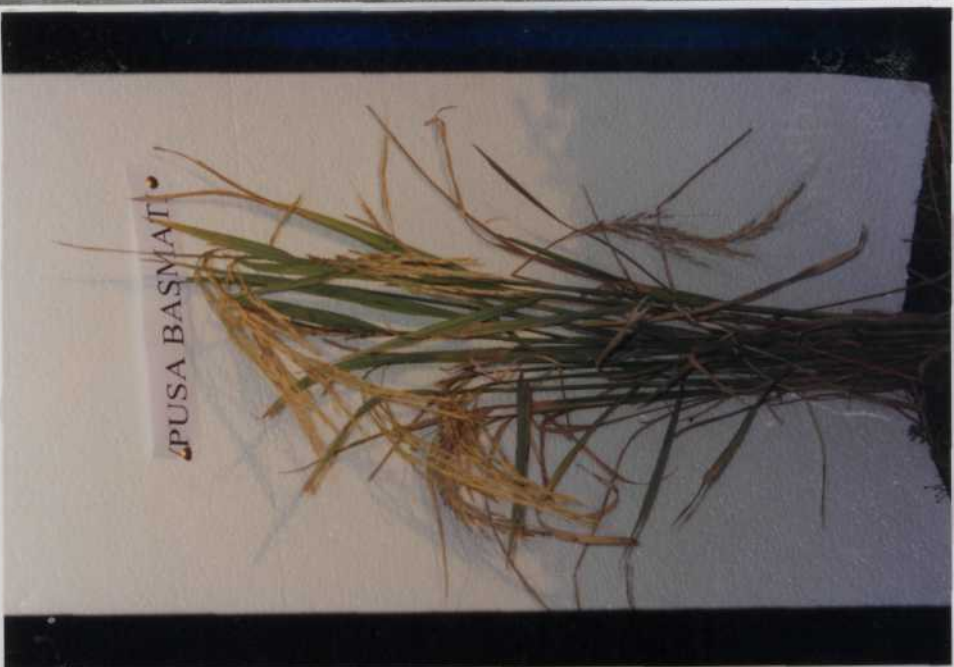
**PLATE-8: EFFECTIVE MAINTAINER**



IR 67684A



IR 67684A/PUSA BASMATI



PUSA BASMATI

**PLATE-9: EFFECTIVE RESTORER**

**SUMMARY, CONCLUSIONS AND  
SUGGESTIONS FOR FUTURE WORK**

## CHAPTER VI

# SUMMARY, CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

### SUMMARY AND CONCLUSION:

The present investigation "studies on combining ability and heterosis in  $F_1$  rice hybrids using cytoplasmic male sterile lines" was undertaken to ascertain in our condition the magnitude of exploitable heterosis; to assess the gca effects of parents and sca effects of crosses; to identify potential parents and crosses; to study type of gene action involved for yield and yield components; to identify the maintainers and restorers and to evaluate the variability, heritability and genetic advance of the various characters under study.

The experimental material consisted of four CMS lines, viz., 22A, IR 62829A, IR 67684A and IR 68899A; thirteen testers, viz., Kranti, Indira, Swarna, Annada, Shyamala, R-827-287, IR-64, Pusa Basmati, R-574-11, R-15, BG-380, Abhaya and Safri-17 and resulting fifty-two cross combinations. These four CMS lines, thirteen testers and fifty-two hybrids were used in line x testers analysis for the estimation of various genetic parameters. The parents and hybrids were raised in a Randomized Complete Block Design with two replications during *kharif*,2001 at the research farm, Department of Plant Breeding and Genetics, IGAU, Raipur (Chhattisgarh), India.

Observations were recorded for ten characters, viz., plant height, panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelet fertility percentage, pollen sterility percentage, 100-grain weight and grain yield per plant on five plant basis in each replication. Line x tester analysis was carried out adopting the method suggested by Kempthorne (1957). Relative heterosis, heterobeltiosis and standard heterosis (over Swarna) were also worked out.

Analysis of variance revealed that variance due to lines was significant for all the characters. Similarly variance due to line x tester was also significant for all the characters.

High **genotypic** and phenotypic coefficients of variations were observed for panicle length,, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelet fertility percentage, and 100-grain weight. Moderate genotypic and phenotypic coefficients of variations were observed for pollen sterility percentage and grain yield per plant whereas, low genotypic and phenotypic coefficient of variation was shown by plant height.

All the characters except plant height showed high broad sense heritability. A moderate heritability was observed for plant height. High genetic advance was observed for all the characters except plant height, panicle length and pollen sterility percentage. Moderate genetic advance was noted for panicle length whereas, plant height and pollen sterility percentage showed low genetic advance.

Combining ability analysis revealed the preponderance of non-additive gene action for all the characters. Line 22A was good general combiner for plant height, line IR62829A was best general combiner for total number of spikelets per panicle and grain yield per plant, line IR 67684A was good general combiner for total number of productive tillers per plant, total number of filled spikelets per panicle, spikelet fertility percentage and pollen sterility percentage whereas, IR 68899A was good general combiner for total number of chaffy spikelets per panicle. Among the testers, R-827-287 was the best general combiner for plant height, Safri-17 was the best general combiner for panicle length, tester BG-380 was best general combiner for total number of productive tillers per plant, tester Pusa Basmati was best general combiner for total number spikelets per panicle whereas, tester **Swarna** was best general combiner for total number of filled spikelets per panicle, spikelet fertility percentage, total number of chaffy spikelets per panicle, pollen sterility percentage and grain yield per plant.

On the basis of sca effects and *per se* performances, the following hybrids have been found superior for different characters. Hybrids IR 62829A/Shyamala for plant height, 22A/Annada for panicle length, IR 67684A/Indira and IR67684A/BG-380 for total number of productive tillers per plant, 22A/Kranti for total number of spikelets per panicle, IR 67684A/Indira for total number of filled spikelets per panicle, total number of chaffy spikelets per panicle spikelet fertility percentage and pollen sterility percentage, 22A/R-15 for 100-grainweight whereas, IR 62829A/BG-380 for grain yield per plant.

The estimates of relative heterosis, heterobeltiosis and standard heterosis were also obtained for ten different characters. A high degree of relative heterosis, heterobeltiosis and standard heterosis was observed for all the traits. Few hybrids, viz., IR 62829A/BG-380 and IR 67684A/Swarna showed high positive standard heterosis for grain yield per plant. However, a high degree of relative heterosis, heterobeltiosis and standard heterosis (over Swarna) for other traits in desired direction was also observed.

On the basis of high pollen sterility (>90 per cent) and low spikelet fertility percentage (<10 per cent) it may be concluded that Indira and R-574-11 for CMS line 22A, BG-380 for CMS line IR 67684A and Indira, Annada, BG-380 for CMS line IR 68899A can be regarded as effective maintainers.

Based on high spikelet fertility percentage and low pollen sterility percentage, testers Indira, Swarna. R-827-287, Shyamala and Pusa Basmati for CMS line IR 67684A; BG-380 for CMS line IR 62829A and R-827-287 for CMS line 22A were found as effective restorers.

#### **SUGGESTIONS FOR FUTURE WORK :**

Based on findings of the present investigations, the following suggestions are being made for future work:

1. The CMS line IR 62829A was identified as best general combiner for grain yield per plant and should further be utilized in developing superior hybrids with other source material also.

2. Testers Swarna, Shyamala, BG-380 and Kranti were identified as good general combiners for most of the characters and should be utilized in recombination breeding programme to bring in further improvement in respective traits.
3. The hybrids IR 62829A/BG-380, and IR 67684A/Swarna, showed superior *per se* performances and high standard heterosis for grain yield per plant and are therefore, recommended for commercial exploitation of heterosis.
4. Test varieties Indira, Swarna, R-827-287 and Pusa Basmati were identified as effective restorer for the CMS line IR 67684A. As the number of restorers is very low, more number of genotypes should be screened for identifying large number of restorers.
5. Future research work should be aimed at back crossing the testers identified in this investigation as effective **maintainers** with their respective F<sub>1</sub>'s to go for completely sterile back cross progenies in order to develop them as CMS lines.

**ABSTRACT**

# **STUDIES ON COMBINING ABILITY AND HETEROSIS IN F<sub>1</sub> RICE HYBRIDS USING CYTOPLASMIC MALE STERILE LINES**

by

**ABHINAV SAO**

## **ABSTRACT**

A study was conducted at Research farm, Department of Plant Breeding and Genetics, IGAU, Raipur (Chhattisgarh), to assess the gca of the parents and sca of hybrids for yield and related characters; to evaluate the magnitude of heterosis for various traits studied; to identify the maintainers and restorers for the CMS lines under study. Biological material for the present study consisted of four CMS lines, viz., 22A, IR 62829A, IR 67684A and IR 68899A and thirteen testers viz., Kranti, Indira, Swarna, Armada, Shyamala, R-827-287, IR-64, Pusa Basmati, R-574-11, R-15, BG-380, Abhaya and Safri-17 and resulting fifty-two hybrids.

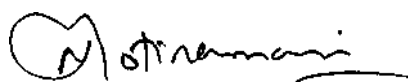
Combining ability analysis was carried out following the line x tester analysis for plant height, panicle length, total number of productive tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, total number of chaffy spikelets per panicle, spikelet fertility percentage, pollen sterility percentage, 100-grain weight and grain yield per plant. The analysis revealed the predominance of non-additive gene action for all the characters under study. This suggests the possibility of exploiting heterosis in the present material.

Among the CMS lines studied, 22A was good general combiner for plant height, CMS line IR 62829A was best general combiner for total number of spikelets per panicle and grain yield per plant, CMS line IR 67684A was good

general combiner for total number of productive tillers per plant, total number of filled spikelets per panicle, spikelet fertility percentage and pollen sterility percentage. CMS line IR 68899A was good general combiner for total number of chaffy spikelets per panicle. Tester, Shyamala was the best general combiner for plant height, Safri-17 was good general combiner for panicle length, BG-380 was good general combiner for total number of productive tiller per plant, Pusa Basmati was best general combiner for total number of spikelets per panicle whereas, Swarna was best general combiner for total number of filled spikelets per panicle, spikelet fertility percentage, total number of chaffy spikelets per panicle, pollen sterility percentage and grain yield per plant.

. The magnitude of relative heterosis, heterobeltiosis and standard heterosis were estimated for all the fifty-two hybrids. Two hybrids *viz.*, IR 62829A/BG-380 and IR 67684A/Swarna showed high positive standard heterosis (over Swarna), high positive sca effects and high *per se* performance. These two hybrids could be used for direct exploitation at commercial level.

Based on high pollen sterility and low spikelet fertility percentages, testers Indira, R-574-11 for CMS line 22A; BG-380 for CMS line IR 67684A; Indira, Annada, BG-380 for CMS line IR 68899A were found as effective maintainers. Similarly, based on high spikelet fertility percentage and low pollen sterility percentages the testers Indira, Swarna, R-827-287, Shyamala and Pusa Basmati for CMS line IR 67684A; tester BG-380 for CMS line IR 62829A and tester R-827-287 for CMS line 22A were found as effective restorers.



**(Dr. Narendra Kumar Motiramani)**  
**Major Advisor**

## BIBLIOGRAPHY

## BIBLIOGRAPHY

- Ahmad, M.I. 1997. Development and use of hybrid rice technology-Lesson learned from the Indian experience. *Int. Rice Comm. Newsl.*, 46:75-83.
- Alias, I. 1985. Relationship between main tiller and single plant yield performance of rice. *MARDI Res. Bull.*, 13 (2) : 186-189.
- Anand, G.; Amirthadevarathinam, A. and Edwin Rogbell, J. 1999. Combining ability and heterosis for tolerance in rice. *Oryza*, 36 (2): 114-117.
- Anonymous. 1996. Vision 2020. Perspective plan, DRR. Rajendra Nagar, Hyderabad.
- Babu, V.R. 1996. Study of genetic parameters, correlation and path coefficient analysis of rice (*Oryza Sativa* L.) under saline conditions. *Ann. Agric. Res.*, 17(4) : 370-374.
- Bai, D.L. and Luo, X. 1996. Liangyou Peite, a new two-lines hybrid rice released in China. *Int. Rice Res. Notes*. 21(1): 42-43.
- Bai, N.R.; Regina, A.; Devika, R. and Joseph, C.A. 1992. Genetic variability and association of characters in medium duration rice genotypes. *Oryza*, 29(1): 19-22.
- Banumathy, S. and Prasad. M.N. 1991. Studies on combining ability for development of new hybrid in rice. *Oryza*, 28: 439-442.
- Bobby, T.P.M. and Nadarajan, N. 1994. Heterosis and combining ability studies in rice hybrids involving CMS lines. *Oryza*, 31(1): 5-8.

- Borbora, T.K. and Hazarika, G.M. 1998. Study of genetic variability, heritability and genetic advance for panicle character in rice. *Oryza*, 35(4) : 419-421.
- Cheema, A.A.; Awan, M.A.; Tahir, G.R. and Aslam, M. 1988. Heterosis and combining ability studies in rice. *Pakistan J. Agric. Res.*, 9(1) : 41-45.
- Choubey, P.K. and Singh, R.P. 1994. Genetic variability, correlation and path analysis of yield components of rice. *Madras Agric. J.*, 81(9) : 468-470.
- Choudhary, D.; Rao, M.J.B.K.; Prasad, A.B. and Suriya Rao, A.V. 1980. Heritability and correlation in rice. *Oryza*, 17(3): 194-199.
- Choudhary, P.K.D. and Das, P.K. 1998. Genetic variability, correlation and path coefficient analysis in deep-water rice. *Ann. Agric. Res.*, 14(2) : 120-124.
- Das, B. 2000. Heterosis and combining ability studies in rice hybrids involving cyto-sterile lines. **M.Sc. (Ag.) Thesis**, IGAU, Raipur.
- Davis, R.L. 1927. Report of plant breeding. Annual Report. Puerto Rico Agr. Expt. Sta., pp. 14-45.
- De, R.N. and Rao, A.V.S. 1988. Genetic variability and correlation studies in rice under semi-deep water logged situation. *Oryza*, 25(4) : 360-364.
- Dwivedi, D.K.; Pandey, M.P.; Pandey, S.K. and Rongbai, L.T. 1999. Combining ability over environments in rice involving *indica* and tropical *japonica* lines. *Oryza*, 36(2): 101- 107.
- Fisher, R.A. 1918. The correlation between relatives on the supposition of Mendelian inheritance. *Tran. Royal. Sci. Edn.*, 52: 399-433.
- Ganeshan, K.N.; Thiagarajan, K.; Amaral, M.K. and Rangaswami, M. 1998. Restorers and maintainers for cytoplasmic genetic male sterile (CGMS) lines of rice. *Oryza*, 35(2): 163-164.

- Gannamani, N. 2001. Study of heterosis and combining ability by utilizing cytoplasmic genetic male sterility and fertility restoration system in rice (*Oryza sativa* L.). M.Sc. (Ag) Thesis, IGAU, Raipur.
- Gravois, K.A. and Mc New, R.W. 1993. Combining ability and heterosis in U.S. southern long grain rice. *Crop Sci.*, 33: 83-88.
- Haque, M.M.; Fardi, M.N.I.; Razzaque, C.A. and Nawaz, M.A. 1981. Combining ability for yield and component characters in rice. *Int. J. Agric. Sci.*, 51(10): 711-714.
- Hayman, B.I. and Mather, K. 1955. The description of gene interaction in continuous variation. *Biometrics*, 11:69-82.
- Hemareddy, H.B.; Lohithasva, H.C.; Patil, R.S.; Manjunath, A.; Mahadevappa, M. and Kulkarni, R.S. 2000. Differential fertility restoration behaviour of genotypes of WA, *Oryza perennis* and MS 577A cytosterile system of rice. *Oryza*, 37(1): 26-28.
- Iftekharuddaula. K.M.; Hassan, M.S.; Islam, M.J.; Badshah, M.A.; Islam, M.R. and Akhter, K. 2001. Genetic evaluation and selection criteria of hybrids rice in irrigated ecosystem of Bangladesh. *Pakistan J. Biological Sciences*, 4(7) : 790-792.
- Johnson, H.W.; Robinson, H.F. and Comstock, R.E. 1955. Estimate of genetic and environmental variability in Soybean. *Agron. J.*, 47 : 314-318.
- Jones, H.A. and Emsweler, S.L. 1937. A male sterile Onion. *Proc. Ann. Hort. Sci.*, 34: 582-585.
- Jones, J.W. 1926. Hybrid vigour in rice. *J. Am. Soc. Agron.*, 18 : 423-428.

- Kalaimani, S. and Kadambavanasundaram, M. 1987. Heterosis in rice (*Oryza sativa* L.). *Madras Agric. J.*, 24(10-11) : 450-454.
- Kalitha, U.C. and Upadhaya, L.P. 2000. Line x tester analysis of combining ability in rice under irrigated lowland condition. *Oryza*, 37(1) : 15-19.
- Kaul, M.L.H. and Kumar, V. 1982. Genetic variability in rice. *Genetic Agraria*, 36 (3/4): 257-268.
- Kaw, R.N.; Aquino, R.C.; Moon, H.P.; Yae, J.D. and Haq, N. 1999. Variability and Interrelations in rice under cold stress environment. *Oryza*, 36(1) : 1-4.
- Kempthorne, O. 1957. An introduction to Genetic Statistics. John Wiley and Sons Inc., New York.
- Kumar, B.M.D. and Chanrappa, H.M. 1994. Combining ability studies for yield and its components in rice. *Mysore J. Agric. Sci.*, 28(3) : 193-198.
- Kumar, C.R.A. and Rangaswami, S.R.S. 1984. Combining ability of dwarf lines of *Indica* rice. *Oryza*, 21(4) : 218-224.
- Lavanya, C. 2000. Combining ability for yield and its components in hybrid rice. *Oryza*, 37(1) : 11-14.
- Leenakumari, S.; Mahadevappa, M. and Kulkarni, S. 1996. Fertility restoration studies in four WA-CMS lines of rice (*Oryza sativa* L.). In: "Abstracts, Proc. 3<sup>rd</sup> Int. Symp. On Hybrid Rice". DRR, Hyderabad, India. pp. 73.
- Li, Q.L.; Li, G.T.; Guo, G.Z.; Jiang, G. and Zhu, Y. 1991. Study on high yield breeding and genetic analysis of yield components of main rice cultivars in Jilin, China. *Hereditas*. 13(5) : 3-6.

- Lin, S.C. and Yuan, L.P. 1980. Hybrid rice breeding in China. *In: Innovative approaches to rice breeding*. IRRI, Philippine. pp. 33-51.
- Mandal, R.K.; Saran, S. and Sahai, V.N. 1990. Fertility restoration in a male sterile line of rice. *Oryza*, 27: 319-321.
- Mani, S.C.; Verma, S.K. and Sharma, R.K. 1997. Genetic variability and character association for panicle traits in Basmati rice. *Agric. Sci. Digest*, 13(3) : 155-157.
- Manonmani, S. and Ranganathan, R.B. 1998. Genetic analysis in early lines of *Indica* rice. *Oryza*, 35(4) : 358-360.
- Manuel, W.W. and Palanisamy, S. 1989. Line x tester analysis of combining ability in rice. *Oryza*, 26(1) : 27-32.
- Manuel, W.W. and Prasad, M.N. 1993. Genetic variability in medium duration rice. *Oryza*, 30 : 355-356.
- Maurya, D.M.; Singh, S.K. and Singh, R.S. 1986. Genetic variability in 48 lowland rice cultivars of Uttar Pradesh, India. *Int. Rice Res. Newsl.*, 11(4) : 13.
- Meenakshi, T. and Amirthadevarathinam, A. 1999. Combining ability for yield and physiological characters in semi-dwarf rice. *Oryza*, 36(2) : 111-113.
- Mishra, M. and Pandey, M.P. 1998. Heterosis breeding in rice for irrigated subhumid tropics in north India. *Oryza*, 35(1) : 8-14.
- Munhot, M.K.; Sarawgi, A.K. and Rastogi, N.K. 2000. Gene action and combining ability for yield, grain quality and other related characters in rice. *Oryza*, 37 (1) : 1-6.

- Nguyen, Thi. Lang. and Bui, Chi. Buu. 1993. Combining ability and heterosis for some physiological traits in rice. *Int. Rice Res. Notes*, 18(1): 7-8.
- Padmavathi, M.; Mahadevappa, M. and Reddy, O.U.K. 1997. Restorers and Maintainers for WA and 577A cytoosteriles. *Oryza*, 34(3): 264-266.
- Panase, D.V.S. and Sukhatme, P.V. 1961. Statistical Methods for Agricultural workers, 2<sup>nd</sup> Ed., ICAR, New Delhi. pp. 318.
- Panwar, D.V.S.; Kumar, R.; Singh, A. and Mehta, B.S. 1998. Studying heterosis for grain yield and its components in hybrid rice. *Int. Rice Res. Notes*, 23 : 15.
- Peng, J.Y. and Virmani, S.S. 1990. Combining ability for yield and four related traits in relation to hybrid breeding in rice. *Oryza*, 27 : 1-10.
- Peng, J.Y. and Virmani, S.S. 1991. Heterosis in some inter-varietal crosses of rice. *Oryza*, 28 : 31-36.
- Prasad, M.N.; Thiyagarajan, K.; Jayamani, P. and Rangaswami, M. 1992. Isolation of maintainers and restorers for CMS lines in Rice. *Int. Rice Res. Notes*, 18:10.
- Ramaiah, K. 1933. Inheritance of flowering duration in rice. *Indian J. Agric. Sci.*, 3:341 -377.
- Ramalingam, J.; Nadanajan,N.; Vanniarajan, C. and Rangaswami, P. 1994. Heterosis in rice hybrids. *Indian J. Genet.*, 54(4) : 371-375.
- Ramalingam, J.; Nadarajan,N.; Vanniarajan, C. and Rangaswami, P. 1997. Combining ability studies involving CMS lines in Rice. *Oryza*, 34(1) : 4-7.
- Ramesha, M.S.; Viraktamath, B.C.; Ilyas Ahmad, M.; Vijaya Kumar, C.H.M. and Singh, S. 1996. Yield system analysis in rice hybrids. 3<sup>rd</sup> Int. Symp. on Hybrid Rice. Directorate of Rice Research, Hyderabad, India. pp. 46.

- Rao, A.V.; Krishna, S.T. and Prasad, A.S.R. 1980. Combining ability in rice. *Indian J. Agric. Sci.*, 50(3) : 193-197.
- Rao, S.A.; Khan, M.A.; Me Meilly, T. and Khan, A.A. 1997. Cause and affect relation of yield and yield components in rice (*Oryza sativa* L.). *Genetics Breeding*, 51(1): 1-5.
- Reddy, C.D.R. and Nerkar, Y.S. 1992. Heterosis and inbreeding depression for grain characters in rice under upland conditions. *J. Maharashtra Agric. Univ.*, 17(1) : 146-147.
- \*Sampath, S. and Mohanthy, H.K. 1954. Cytology of semisterile rice hybrids. *Curr. Sci*, 182-183.
- Sadhukhan, R.N. and Chattopadhyay, P. 2000. Variability and character association between yield attributes and grain quality in aromatic rice. *J. Intercad.* 4(4): 494-497.
- Sarawgi, A.K.; Shrivastava, M.N. and Choudhary, B.P. 1991. Partial diallel cross analysis of yield and its related characters in rice (*Oryza sativa* L.) under irrigated conditions and rainfed situations. *Indian J. Genet.* 51(10) : 30-36.
- Sarawgi, A.K. and Soni, D.K. 1994. Variability analysis in rice under irrigated and rainfed situations. *Current Research*, 23(3/4) : 33-35.
- Sasmal, B. 1988. Hybrid vigour in diverse crosses of rice. *Environment ecology*, 6(3) : 611-614.
- Satyanarayana. P.V.; Kumar, Ish. and Reddy, M.S.S. 1988. Studies on combining ability and heterosis in rice. *Int. Rice Res Notes*, 23(3): 10.

- Satyanarayana, P.V.; Reddy, M.S.S.; Kumar, Ish. and Madhuri, J. 2000. Combining ability studies on yield and yield components in rice. *Oryza*, 37(1) : 22-25.
- Sharma, D.K.; Shrivastava, M.N. and Tiwari, D.K. 1987. Line x tester analysis for harvest index and related characters in rice (*Oryzasativa* L.). *Indian J. Genet.*, 47(2): 211-218.
- Sharma, J.P. and Mani, S.C. 1989. A medium duration high yielding scented hybrid rice. *Int. Rice Res. Newsl.*, 14 : 7.
- Sharma, J.P. and Mani, S.C. 1990. A study of heterosis by utilizing male sterility, fertility restoration system in rice (*Oryza sativa* L.). *Oryza*, 27 : 202 - 204.
- Sharma, R.K. and Koranne, K.D. 1995. Line x tester analysis for yield and yield components in *indica* x *japonica* crosses of rice. *Oryza*, 32 : 234-238.
- Shivani, D. and Sree Rama Reddy, N. 2000. Variability, heritability and genetic advance for morphological and physiological traits in certain rice hybrids. *Oryza*, 37(3) : 231-233.
- Shrivastava, M.N. and Seshu, D.V. 1982. Heterosis in rice involving parents with resistance to various stresses. *Oryza*, 19 : 172-177.
- Shukla, T.C; Khandekar, M.P. and Sahu, R.K. 1972. Phenotypic variation and inheritable component in quantitative yield contributing characters in rice (*Oryza sativa* L.). *Indian J. Agric. Sci.*, 42 : 660-663.
- Siddiq, E.A. 2000. Rice : Yawning productivity gaps. The Hindu Survey of Indian Agriculture. M/S Kasturi and sons Ltd., Chennai. pp. 40-43.
- Singh, B.N.; Ratho, S.N. and Rao, R.N. 2001. Hybrid Rice Staple food to fight hunger to reduce poverty. *Indian Farming*. 51(8) : 20-22.

- Singh, M. and Maurya, D.M. 1999. Heterosis and inbreeding depression in rice for yield and yield components using CMS system. *Oryza*, 36(1) : 24-27.
- Singh, R.K. and Choudhary, B.D. 1985. Biometrical methods in quantitative analysis. Kalyani Publishers, New Delhi. pp. 318.
- Singh, S. and Choudhary, B.S. 1996. Variability, heritability and genetic advance in cultivars of rice (*Oryzasativa* L.). *Crop Research*, 12(2) : 165-167.
- Singh, S.K. and Haque, M.F. 1999. Heterosis for yield and yield components in rice. *Indian J. Genet.*, 59(2) : 237-238
- Sinha, T.S. and Bhattacharya, R.K. 1980. Note on genetic variability in Sundarban rice - varieties under saline soil. *Indian J. Agric. Sci.*, 50(9) : 719-721.
- Sivasubramanian, J. and Madhavamenon, P. 1973. Genotypic and phenotypic variability in rice. *Madras Agric. J.*, 12 : 15-16.
- Sprague, G.F. and Tatum, L.A. 1942. General versus specific combining ability in single crosses of Corn. *J. Am.Soc. Agron.*, 34 : 923-932.
- Sreeramachandra Babu. M.; Satyanarayana, P.V.; Madhuri, J. and Kumar, R.V. 2000. Combining ability analysis for identifying elite parents for heterotis rice hybrids. *Oryza*, 37(1) : 19-22.
- Tseng, T.H. and Huang. C.S. 1987. Yield and combining ability of hybrid rice. *Chinese J. Agric. Res.*, 36 : 151-164.
- Uma. R. 1994. Study of *indica-japonica* hybrids with reference for yield and male sterility in rice (*Oryza sativa* L.). M.Sc. (Ag.) thesis. TNAU, Coimbatore. India.
- Ushakumari, R.; Rangasami, P. and Deepthy Antony, P. 2002. Pollen fertility studies in *Indica-Japonica* wide compatible rice hybrids. *Indian J. Genet.*, 62(1): 71-72.

- Virmani, S.S. 1985. Cytoplasmic genetic male sterility and fertility restoration in rice. GEU training programme. Feb. 4 to May 24, 1985. IRRI, Philippines.
- Watanesk, O. 1993. Heterosis and combining ability evaluation of cytoplasmic male sterile and restorer lines. *Int. Rice Res. Notes*. 18 : 7-8.
- Wynne, J.C.; Emery, D.A. and Rice, P.W. 1970. Combining ability in *Arachis hypogea* L. II. Field performance of F<sub>1</sub> hybrids. *Crop Sci.*, 10: 713-715.
- \*Yang, C. and Song, Q. 1994. Genetic analysis of some agronomic traits in wide compatibility rice lines 02428. *Acta Agriculture*, Shanghai, 10(30) : 90-93.
- Young, J.B. and Virmani, S.S. 1990. Effects of cytoplasm on heterosis and combining ability for agronomic traits in rice (*Oryza sativa* L.). *Euphytica*, 48 : 177-188.
- \*Yuan, L.P. 1980. Hybrid rice in China. *Chinese J. Sci.*, 8:18.
- \*Zhang, S.Q. and Xu, C. 1986. Utilization of segregating glutinosity in hybrid rice breeding. *Zhejiang Agricultural Science*, 4 : 174-175.
- \*Zhou, K.D.; Lim, H.Y.; Li, R.D. and Luo, G.J. 1982. Preliminary study on combining ability and heritability of the main characters of hybrid rice. *Acta Agronomica Sinicas*, 8 : 145-152.

\* Original paper not seen.