


GENETIC ANALYSIS OF YIELD, YIELD COMPONENTS AND  
RESISTANCE TO BACTERIAL LEAF BLIGHT DISEASE  
IN RICE (ORYZA SATIVA L.)

THESIS SUBMITTED TO THE  
ANDHRA PRADESH AGRICULTURAL UNIVERSITY  
IN PART FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE OF  
DOCTOR OF PHILOSOPHY

BY

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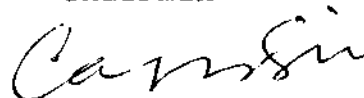
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Shri B. Ragaiah has satisfactorily prosecuted the course of research and that the thesis entitled "Genetic analysis of yield, yield components and resistance to bacterial leaf blight disease in rice (Oryza sativa L.)" submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

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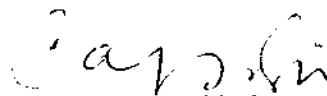
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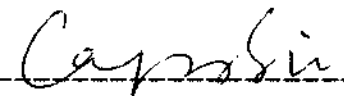

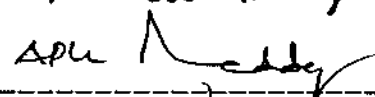
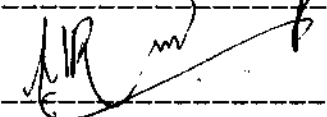
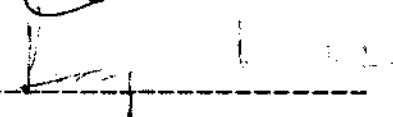
This is to certify that the thesis entitled "Genetic analysis of yield, yield components and resistance to bacterial leaf blight disease in rice (*Oryza sativa* L.)" submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agriculture, in the major subject of Genetics and Plant Breeding of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Sri B. Ragaiah, under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma.

All assistance and help received during the course of the investigation have been duly acknowledged by him.

  
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## ACKNOWLEDGEMENT

I have immense pleasure in expressing my sincere and profound sense of gratitude and etiquette to Dr. C.A. Jagdish, Professor and Head, Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar, Hyderabad and Chairman of the Advisory Committee for his encouragement and meticulous guidance during the course of this investigation and preparation of the manuscript.

I am highly thankful to Dr. V.V.S. Murthy, Senior Rice Breeder, Directorate of Rice Research, Rajendranagar, Hyderabad who acted as Chairman of my Advisory Committee till his retirement from service, for suggesting the problem and for his valuable suggestions and help rendered during the course of investigation.

I am grateful to Dr. A.P.K. Reddy, Senior Plant Pathologist and Head, Division of Plant Pathology, Directorate of Rice Research, Rajendranagar, Hyderabad for providing the material and laboratory facilities for the studies on bacterial leaf blight resistance and I also express my fidelity for his encouragement and suggestions during the course of this investigation as member of the Advisory Committee.

I am thankful to Dr. K.A. Sayana, Associate Professor, Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar for his constant encouragement,

valuable suggestions, critically going through the manuscript and acting as member of the Advisory Committee.

I wish to express my sincere thanks to Shri A.V. Rao, Senior Statistician, DRR, Rajendranagar and member of Advisory Committee for his valuable suggestions in processing the data and preparation of the thesis.

My thanks are also due to Dr. B. Gopal Singh, Associate Professor, Department of Plant Physiology, College of Agriculture, Rajendranagar, Hyderabad and member of Advisory Committee for his suggestions and timely help in bringing out this thesis.

I am thankful to Sri A. Satyanarayana, Research Officer I/C computer unit, Andhra Pradesh Agricultural University for his timely help in analysing the data by computer and offering suggestions.

I am extremely thankful to Dr. R. Seetharaman Project Director (retired) and Dr. J.E. Shinde I/C project Director, Directorate of Rice Research, Rajendranagar for providing land and necessary facilities.

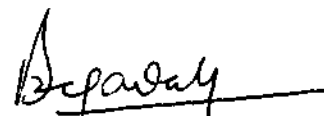
I am thankful to the staff of Directorate of Rice Research, Rajendranagar and staff members of Department of Genetics and Plant Breeding, College of Agriculture, Rajendranagar for their kind cooperation and help extended to me during the course of this investigation.

The Senior fellowship provided by ICAR during the course of this investigation and the privilege extended to me as inservice candidate by the Andhra Pradesh Agricultural University are gratefully acknowledged.

I wish to take this privilege to express my deep sense of affection and gratitude to my family members especially to my wife Vijaya Lakshmi who inspite of her illness, inspired and encouraged me to bring out this thesis. I thank my son Mr. Murali Dhar, daughters Smt. Manjulata, Miss Sailaja, son-in-law Chandra Sekhara Rao and my nephew Mr. V. Sambasiva Rao for their encouragement and help rendered during the course of preparation of the thesis.

My appreciation goes to Computer Information and Training Centre, Rajendranagar for their accomplishment and precision in typing the thesis.

10th December, 1987.



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Author : B. Ragaiah

Title of the thesis : Genetic analysis of yield, yield components and resistance to bacterial leaf blight disease in rice (Oryza sativa L.).

Degree : Ph.D.

Faculty : Agriculture (Plant breeding and Genetics)

Guide : Dr. C.A. Jagadish

University : Andhra Pradesh Agricultural University.

Year of submission : 1987

#### ABSTRACT

The investigations were carried out at the Directorate of Rice Research, Rajendranagar, Hyderabad, to evaluate genetically seven rice varieties and breeding lines consisting of one susceptible (IR 8) and six resistant types (IET 8320, IR 19660-274-3-3-1-3, IR 54, Cisadane, Kuntlan and Nigeria 5) to bacterial leaf blight and for quantitative characters contributing to yield as also to study their reaction and allelic relationships in conferring resistance to the wide spread bacterial leaf blight disease of rice.

Combining ability studies brought out the importance of both additive and non - additive variances in the

inheritance of almost all characters. Non-additive factors were important for total tillers per plant, earbearing tillers per plant, fertile spikelets per panicle, sterile spikelets per panicle, sterility percent, BLB score and single plant grain yield. For all these characters narrow sense heritability was low as expected. Improvement for these characters is possible only through heterosis breeding. Large amount of heterosis and heterobeltiosis was found to be associated with not only these characters but also with all other characters. It was suggested from the results that this line of approach be followed for improving rather stagnant yield levels in rice.

IET 8320 and Nigeria 5 were identified to possess desirable gca effects for single plant grain yield as a result of possessing desirable gca effects for more than two component characters. There was an agreement between mean performance and gca effects of parents for characters which are rather simply inherited, than for characters whose inheritance is complex. No parent possessed desirable gca effects for all the characters. Several crosses were identified to possess significant sca effects, but no cross was found to possess desirable sca effects for all the characters. The results obtained do not suggest the possibility of predicting the performance of hybrid on the basis of the performance of parents.

Heritability in narrow sense was lower for characters governed by non-additive factors and higher for characters governed by additive factors, a fact not clearly brought out by estimation of heritability in broad sense alone. There were large differences between these two estimates. The relationship between heritability estimates and gene action became apparent by such analysis.

Correlation studies in parents,  $F_1$ 's and  $F_2$  generations made clear the importance of total tillers per plant, earbearing tillers per plant, fertile spikelets per panicle and panicle length which could profitably be used while making selections in different generations. These characters also possess positive direct contribution to single plant grain yield, but the relative amount of contribution varied with different generations and hence the need for shifting the emphasis to changes in these relationships as the material advances.

Evaluation of  $F_2$  generation (dwarfs) in two experiments revealed the superiority of some  $F_2$  progenies over the parents and the retention of correlations. The results suggest the possibility of pedigree selection in further improvement of yield levels in association with bacterial leaf blight resistance.

Study on the inheritance of bacterial leaf blight resistance in two sets of crosses revealed the presence of different genes governing the inheritance in different crosses. The highest number of genes identified were three dominant duplicate genes. Evidence was also presented to show that certain genes conferring resistance function at specific stage during the life cycle of rice plant.

## LIST OF ABBREVIATIONS

ALCRIP	All India Coordinated Rice Improvement Project
ASI	Agricultural Situation in India
BLB	Bacterial Leaf Blight
CV	Coefficient of Variation
DRR	Directorate of Rice Research
df	Degrees of Freedom
Ebt	Earbearing Tillers
F <sub>1</sub>	Filial Generation 1
F <sub>2</sub>	Filial Generation 2
gca	General Combining Ability
IMD	Indian Meteorological Department
IRBBN	International Rice Bacterial Blight Nursery
IRRI	International Rice Research Institute
L/B	Length/Breadth
MSS	Mean Sums of Squares
'P'	Probability Value
R	Resistant
r	Regression Coefficient
RBD	Randomized Block Design
S	Susceptible
sca	Specific Combining Ability
Xa	Dominant Gene for Bacterial Leaf Blight Resistance
xa	Recessive Gene for Bacterial Leaf Blight Resistance

# INTRODUCTION

## CHAPTER I

### INTRODUCTION

Rice is the staple food of over half the world's population. It is the foremost food of the developing world. About 90 percent of the rice is produced and consumed in Asia. More than 95 percent of the world's rice area is in the developing countries, mostly in Asia-pacific region. Rice occupies one-third of the area planted to cereals in the developing countries which is about 50 percent more than the area under wheat, the second most important crop. During 1984 it was cultivated on 146.87 million hectares in world with annual production of 464.5 million tonnes of paddy (Singh, 1985). In India rice covered an area of 40.9 million hectares with a total production of 64.15 million tonnes of paddy with a mean productivity of 1568 kg/ha during 1985-86. Andhra Pradesh occupied seventh place in productivity (2209 kg/ha) having 6th place in area (3.47 million hectares and third place in production (7.66 million tonnes of paddy, A.S.I. 1986). Being staple food, it occupies a predominant place in the agriculture of Andhra Pradesh state.

Prior to 1960's most varieties were selected from land races and production increase was due mainly to an increase of rice acreage. Beginning in the 1960's, rice breeders began transferring semi-dwarf gene to adapted indica types with phenomenal success. The major impetus was to promote lodging resistance and fertilizer responsiveness

of traditional tall varieties. Thus, the architecture of rice plant was changed from traditional photosensitive, tall, leafy with weak culms, panicle weight types to short stature, fertilizer responsive, high tillering, erect leaved, photo period insensitive with stiff culms panicle number types. As a result several high yielding varieties like IR 8, Jaya etc. were developed which doubled the yield potential of tropical Asia. These modern semidwarfs are more efficient at harvesting solar radiation. The configuration of new technology revolutionized rice production by mid 1960's in the tropical Asian Countries, especially under irrigated and favourable rainfed low land conditions.

At the second stage in India and elsewhere quality was given greater attention and several varieties with fine grain type like Prakash, Ratna etc., contemporaries of IR 20 were released. Several of these, although high yielding were susceptible for pests and diseases. The green revolution produced several second generation problems. The lush growth of uniform stands of plants with narrower genetic base encouraged by the use of large quantities of nitrogenous fertilizers with high yielding varieties constituted a favourable environment for pests and diseases. Soil nutritional imbalance such as zinc and sulphur deficiency and other unfavourable environmental stresses like cold, drought etc. became constraints for high yielding semidwarf varieties which did not affect so much the traditional tall varieties. Coarse grain quality of most of the high yielding

varieties particularly in India posed additional problem as there is always an incentive in the rice trade to improve rice quality.

In the following decade rice scientists developed varieties which besides being high yielding were also resistant/tolerant to common diseases and several other stress conditions. Modern IRRI varieties like IR 36 and certain multiple resistant varieties developed under national breeding programmes with genetic capacity to resist some of the pests and diseases that had plagued the earlier varieties were produced which stabilized rice yields. More recently varieties with shorter growth periods to suit multiple cropping were also developed.

In spite of all these renewed efforts the upsurge in population will create a growing demand for food with progressive decrease in land/person ratio. To keep pace as far as possible with this rapidly rising demand, it is but necessary to find out new technologies to boost further the existing static yield levels. A number of research and breeding programmes have now been initiated with such aims in mind and some promising varieties are already available.

One of the most significant recent breakthroughs in plant breeding is with  $F_1$  hybrid rice. Chinese scientists successfully developed and used  $F_1$  rice hybrids which from 1976 to 1984 covered a total of 42.6 million hectares resulting in an increase of 32 million tonnes of rice

production for China (Kang, 1985). In the farmer's fields these hybrids yield 15 to 20 percent more than the best available pure line varieties (Khush, 1985). Currently China grows about 8 million hectares under  $F_1$  rice hybrids which increased rice production in the country by about 6 million tonnes during 1984 (Virmani, 1985). With this prelude a number of national rice improvement programmes have initiated hybrid rice research during recent years.

Modern rice breeding programmes are directed towards the exploitation of indigenous and exotic varieties for improving grain yield which by itself is a complex entity. So, information on genetic nature based on combining ability for yield contributing traits is helpful in sorting out outstanding varieties with favourable alleles (Singh and Richharia, 1978). A knowledge of combining ability of parents possessing resistance to pests and diseases would help breeders in choosing parents in a resistant breeding programme. The best parent is not always the best general combiner (Rao et al., 1980 b). Potential crosses could be identified from good and poor general combiners due to interaction between dominant and recessive alleles for utilization in heterosis breeding (Shamsuddin et al., 1980). The choice of parents and prediction of their performance at the earlier stages itself assumes great importance by saving time and labour. Finlay (1963) also pointed out that the general combining ability is correlated with wide adaptability.

Bacterial leaf blight of rice (BLB) caused by Xanthomonas campestris is of major importance in rice growing countries of tropical Asia with modern rice varieties under improved agronomic practices. In the absence of effective chemical control measures for this disease, breeding resistant varieties with broad genetic base serves as a component of integrated approach to control this disease. The resistance breeding programme has to be cyclic with respect to pathogens like Xanthomonas campestris which have races of variable virulence. Resistance in a variety may break down with the evolution of more virulent pathogen. This is where the importance of allelic relationships is realised (Singh and Nanda, 1977). However, majority of the studies carried out in this regard mainly dealt with inheritance and allelic relationships of very few genes for resistance to bacterial leaf blight.

A knowledge of associations between various quantitative characters and their contribution to grain yield by direct and indirect effects through other characters would be of great utility to the breeders to evaluate and fix selection indices in different generations for crop improvement.

When more number of donors for resistance are available, it is but logical, for the breeder to enquire, as to which one or more among them would prove to be superior, in respect of transmission of desirable agronomic attributes in order to be able to combine resistance with good yield

potential. It is precisely with these following objectives, the present research work was undertaken.

- 1 Evaluation of breeding lines, released varieties and selected germplasm possessing resistance to bacterial leaf blight in terms of their mean performance, combining ability and heterosis. Character association to understand genetics of ever increasing test lines which gets incorporated in the development of varieties with high yield potential with added features like resistance to bacterial leaf blight.
- 2 To study the type of reaction of parents, hybrids and  $F_2$  generation at different stages of growth namely seedling and adult plant to the infection by causal organism of bacterial leaf blight.
- 3 To understand genetics of resistance to bacterial leaf blight and to identify number and nature of genes involved in conferring resistance.
- 4 To evaluate  $F_2$  generation of dwarf combinations for their yield potential as well as character association to seek the possibility of improving yield by pedigree selection and to realise the correlated responses.

## REVIEW OF LITERATURE

## CHAPTER II

### REVIEW OF LITERATURE

#### 2.1 Combing ability and gene action:

Majority of the economic traits which must be dealt in breeding programmes are of quantitative nature and are especially important in breeding pest and disease resistant high yielding varieties. Application of biometrical techniques in recent years, has led to greater understanding of genetics of quantitative characters and proved to be extremely valuable for systematic planning of breeding programmes and procedures. The shift of plant-type from long culm native varieties of panicle weight type to lodging resistant short culm varieties of the panicle number type resulted in a dramatic yield improvement in rice and several high yielding dwarf and semi-dwarf varieties are available at present for different conditions. Further efforts are under way to stabilize the yields against different stresses including pests, diseases and adverse climatic conditions.

The rice plant offers a wealth of variability for different quantitative characters because of its wide ecological distribution and enormous number of variations encountered in its makeup. Large range of phenotypic variability does not necessarily help in effective selection, because phenotypic variation is a combination of genetic as well as environmental variability. It is the extent of

genetic variability or more precisely the variability due to additive gene effects that can be fixed by appropriate selection procedures for effective crop improvement. The best parent is not always the best combiner (Rao et al., 1980 a). So information on genetic nature based on combining ability for yield contributing traits may be helpful in sorting out outstanding varieties with favourable alleles (Singh and Richharia, 1978).

In breeding of disease and pest resistant high yielding varieties, the breeder often faces with the problem of selecting the parents. Elimination of poor yielding crosses on the basis of their performance has been more often suggested. Nevertheless, a knowledge of genetic architecture of yield and yield components and information on combining ability of parents in general and specific combinations to predict their performance in earlier stages and heritability and genetic advance of the characters will be of immense value to breeder for producing desirable recombinations. Yamada (1984) suggested application of biometrical genetics for analysis of resistance to bacterial leaf blight also.

Grain size and shape (width and thickness) are closely related to yields of head rice recovery. It is futile to spend years developing high yielding, pest and disease resistant lines only to find that farmers, millers or consumers discriminate against them because of unacceptable grain measurements (Jennings et al., 1979). According to

them grain length and shape are quantitatively inherited. The  $F_1$  is typically intermediate between its parents in size; transgressive segregation for longer or shorter grain is common in  $F_2$ . Grain size is highly heritable in most environments. Despite the apparent complexity of their inheritance, grain length and shape appear to be fixed exceptionally early in the segregating generations. A thorough understanding of parental performance and nature of gene actions is of great use for breeding quality rices.

In self-fertilized crops like rice, diallel analysis proposed by Griffing (1956) has widely been used for testing the performance of genotypes in hybrid combinations and also for characterizing the nature and magnitude of gene effects and other genetic parameters involved in controlling a quantitative trait by several workers (Mohanty and Mohapatra, 1973; Nancharaiah et al., 1974; Maurya and Singh, 1977; Khaleque et al., 1978; Srivastava and Seshu, 1983; Singh and Singh, 1985; Panwar et al., 1985; Murai and Kinoshita, 1986; Sarathe and Singh, 1986; and Sardana and Borthakur 1987).

General combining ability is the average performance of a line in a hybrid combination and specific combining ability is to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance involved (Sprague and Tatum, 1942).

Highly significant genetic variations among four parents studied, were observed in complete diallel experiment (IRRI, 1967). No maternal effects were registered. Earliness showed dominance over lateness and tallness over short height. High panicle number was dominant over low. In conjunction with the dominant genes, other genes of additive nature appeared to control a major portion of genetic variance. Roychoudhary (1967) observed high heritability values which he attributed to low influence of environmental variation with replicated plots. The high heritability indicates the usefulness and effectiveness of selection based on phenotypic expression, but fails to indicate the genetic progress (Johnson et al., 1955). Therefore high heritability does not always mean greater genetic gain.

Li and Chang (1970) observed additive and dominant effects for six characters. However, incomplete dominance was indicated for all the traits studied except panicle weight. Overdominance predominated for panicle weight. Earliness, tall stature, long, heavy and higher number of panicles and many spikelets per panicle resulted due to dominance effect.

High heritability values were reported by Seetharaman et al. (1971) for panicle number per plant and spikelet number per panicle. Tsai (1971) reported higher heritability values for heading date and height than for other characters. He also estimated number of genes

controlling each trait. Heading date was controlled by two to four pairs of genes with epistasis, plant height by two pairs, panicle length by one to four pairs and grain number per panicle by one to eight pairs of genes.

In a study of 4 x 4 diallel analysis, Mohanty and Mohapatra (1973) observed highly significant gca and sca variances indicating that yield and its components are governed by both additive and non-additive gene effects. The additive genetic effects were more important for number of grains per panicle and 1000-grain weight. For yield and the remaining three components namely panicles per plant, panicle length and panicle weight non-additive genetic effects were of greater importance than additive effects. They identified based on sca effects, a cross Adt 27/IR 8 to be more promising which also exhibited high degree of heterosis for all the characters except 1000-grain weight.

Sivasubramaniam and Madhavamenon (1973 a, b) reported predominance of additive gene action for expression of grain yield and tiller number. Since gca variances were found to be greater than that of sca, they suggested phenotypic selection for these characters. Non-additive gene action which is mostly non-fixable was indicated for the rest of the characters and however, suggested appropriate manipulations of interactions for enhancing the variability and heterosis. High heritability values were recorded for tiller number, yield, grain number and plant height. They

observed high gca effects for most of the characters in the most widely adapted parents indicating additive gene action. Finlay (1963) has also pointed out that there is relationship between wide adaptation and high gca. The combination of high x low was found to be the best for grain yield and other characters studied. The combination of high x high failed to register significant sca. Varieties having semidwarf genes had maximum sca in their combinations. Semidwarf x semidwarf crosses showed marked overdominance.

Ranganathan et al. (1973) observed additive and dominance effects for number of productive tillers and 1000-grain weight. Overdominance was recorded for plant height and partial dominance for days to flowering, panicle length, grains per panicle and grain yield. For plant height, dominance or overdominance for tillering and overdominance for panicle length and grain number per panicle were reported by Sukanya-subrahmanian and Madhavamenon (1973) in a study involving tall and dwarf parents.

In a diallel set of crosses involving five resistant and one susceptible varieties for bacterial leaf blight, Singh and Nanda (1976 a) detected highly significant differences among the varieties for all the characters except 100-grain weight. Predominant role of additive gene action in the expression of these characters and non-additive gene action for other characters namely single plant grain yield, 100-grain weight, grains / panicle, and panicle length were

reported. The narrow sense heritability was of higher magnitude for panicle number than for other characters.. In another study Singh and Nanda (1976 b) reported overdominance for yield per plant and panicle length and partial dominance for panicle number. Estimates of genetic components of variance indicated that additive and dominant gene actions were important for yield per plant and additive gene action for panicle length and panicles per plant.

Maurya and Singh (1977) in a study of 13 characters in diallel set of crosses involving seven parents found that the variances of both gca and sca were significant for all the characters indicating the importance of both additive and non-additive gene actions. In general, the best parent was observed to be the best combiner for particular trait (except Jaya for grain yield). However, none of the parents or specific combinations was good combiner for all the characters.

Reddy and Rao (1978) in a study of 8 x 8 diallel analysis of resistance to bacterial leaf blight in rice reported highly significant additive gene system for disease reaction to BLB . Complete dominance was evident in the direction of susceptibility to BLB among the rice varieties. No maternal influence on bacterial leaf blight reaction was evident.

Singh and Richharia (1978) found that the gca and sca variances were significant for days to heading, plant height,

and productive tillers showing high gca / sca ratios. The per se performance was an indication of their gca effects for all the traits studied. Superior cross combinations were recorded between high x high, high x low and low x low combinations but the ones having highest sca effects were from high x low combinations. No reciprocal differences were recorded in any of the traits studied.

Singh et al. (1979) studied five yield contributing characters in a diallel set (6 x 6) of crosses excluding reciprocals and observed highly significant combining ability for all the characters except 100-grain weight, indicating the importance of both additive and non-additive gene actions. The sca variances were higher than those due to gca which revealed the predominance of non-additive gene action for all the characters. All the parents exhibited significant gca effects for panicle length but no specific cross combination was found desirable for panicle length as indicated by sca effects.

Rao et al. (1979) working with short statured rice cultivars from North East India, found that the short-statured parents were the best general combiners for plant height and spikelet sterility, while the tall parents were good for grains per panicle, earbearing tillers and grain yield.

Chaudhary et al. (1980) found high estimates of heritability and genetic advances for number of spikelets

panicle and 100-grain weight both in  $F_1$  and  $F_2$  generations, which formed a good basis for selection. According to Johnson et al. (1955) heritability estimates along with genetic advance are more useful than heritability alone.

Singh et al. (1980 a) studied combining ability and observed predominance of non-additive gene actions (dominance or epistasis). The crosses involving the parents with good general combining ability had high sca effects and were more promising.

Rao et al. (1980 a) reported that variances for general and specific combining ability were highly significant for all the characters they studied in a 7 x 7 diallel set. They found that the best parent was not always the best combiner.

Haque et al. (1981) in the  $F_2$  of 5 x 5 diallel crosses of rice recorded non-additive genetic effects for days to flowering, plant height and sterility and additive genetic effects for grain yield. They concluded that the  $F_2$  generation could be employed for combining ability studies but with some reservation and for some specific characters only. Paramasivan (1981) reported low heritability and genetic advance for number of effective tillers and grain yield per plant.

Rahman et al. (1981) observed both additive and non additive effects for all the characters except panicle length

for which the sca effect was not significant. Further, gca variances were higher than sca variances for all the characters indicating the predominance of additive gene effects. No single parent was found to be a good general combiner for more than two characters.

High estimates of heritability and genetic advance for 1000-grain weight indicating additive gene action have been reported by Kaul and Kumar (1982) and Zhou (1983).

Panwar and Paroda (1983) in a study of 10 x 10 diallel crosses involving parents with fine quality rice broughtout the importance of both additive and non-additive gene effects for the expression of 1000-grain weight, kernel length, kernel breadth and kernel shape (L/B ratio) although additive gene effects had a predominant role in the  $F_1$  and  $F_2$ . According to them, the per se performance of the parents appeared to be highly correlated with gca effects.

Srivastava and Seshu (1983) in a study of combining ability in rice involving semidwarf and tall parents reported significant gca variances for 16 characters and sca variances for 12 characters. Specific combining ability was not important for number of spikelets per panicle and width of grains. Ratios of components of gca and sca variances indicated that sca was more important than gca for three of the characters including grain yield per plant. Semidwarfing gene did not seem to limit the expression of the panicle

traits that are important for further improvements over present yield levels of semidwarfs.

Anandakumar and Sreerangasamy (1984 a) observed predominance of non-additive gene action (dominance or epistasis) by recording higher sca variances for plant height, panicle length and per plant yield, in a line x tester analysis.

In a study of advanced generations of hybrid derivatives, Misal et al. (1985) reported high heritability coupled with high expected genetic advance for plant height, 1000-grain weight, low heritability and expected genetic advance for days to 50% flowering, tillers per plant, number of effective tillers and grain yield per plant. Low heritability and higher expected genetic advance were recorded for number of grains per panicle.

$F_1$  and two sets of  $F_2$ 's of a 10 x 10 diallel set of rice were studied by Panwar et al. (1985). The variance for gca and sca were highly significant for all, yield and related characters studied. Certain specific crosses having both the parents as good general combiners (high x high) and some combinations that had one good general combiner (high x low) were identified as good crosses that might throw out desirable transgressive segregants which might be used for inter-se crossing to accelerate genetic recombinations and help breaking linkage blocks.

Murai and Kinoshita (1986) observed predominance of additive gene action over the dominance gene action for number of panicles per plant, number of spikelets per panicle and culm length. On the other hand mean sums of squares for dominance were large for panicle weight per plant, 100-kernel weight and grain length.

Sarathe and Singh (1986) reported in an examination of 8 x 8 diallel crosses the importance of both additive and non-additive interactions for all the traits studied. They also observed that the specific crosses between parents with high gca effects resulted in promising recombinations with high sca effects for yield and yield components.

Maurya et al. (1986) observed wide range of phenotypic variation for grains per panicle, plant height and days to flowering in a study of 48 low land rice cultivars. They have reported high heritability (H) and high genetic advance for kernel length, kernel L/B ratio, plant height grains per panicle, test weight and panicle length which are regarded a useful selection criteria in low land rice.

Sharma et al. (1986) reported predominance of dominance effects over additive in grain yield. For yield components additive x additive effects were reported to be usually the most important.

In a study of 5 x 5 diallel crosses (excluding reciprocals) for genetic variability, gca and sca Sardana and

Borthakaur (1987) observed significant differences for grain yield per plant, days to flowering, plant height, effective tillers per plant, panicle length, filled grains per panicle and 100-grain weight. Both additive and non-additive gene effects were important for all these characters. A preponderance of non-additive gene effect over additive effect was observed for grain yield per plant and filled grains per panicle, whereas it was the reverse for 100-grain weight, panicle length and days to flowering.

## 2.2 Heterosis:

Heterosis is a complex biological phenomenon manifested in the superiority of hybrids over the parent forms. Heterosis manifest for grain yield is expressed in the form of increased grain yield which in itself is dependent on the contribution of its components.

Hybrid vigour or heterosis is defined as the increase in size or vigour of a hybrid over its parents or over the average of its parents (Poehlman and Borthakaur 1972). A hybrid between any two unrelated homozygous parents is certain to show at least some increase in vigour over its parents. In genetical sense, heterosis refers to the increase or decrease of  $F_1$  value over the mean parental value (Viramani et al. (1981). From the view point of plant breeding, increase of  $F_1$  value over the better parent and / or the best commercial variety is most relevant. The

manifest of heterosis over better parent is designated as heterobeltiosis (Fanseco and Peterson, 1968) and that of over the best commercial variety as the standard heterosis. Mohapatra and Mohanty (1986) coined another term the "overall heterosis" as the percentage increase of  $F_1$  mean over the mean of all the parents. Virmani and Edwards (1983) reviewed the current status and future prospects of hybrid rice and wheat analysing the existing methodologies and formulated clear-cut strategies to exploit heterosis for improving productivity, particularly in potential high yield areas and where conventional breeding has apparently reached yield plateau.

The tendency for the offspring of crossed varieties to have more culms and greater productivity than the parental varieties in rice was first observed by Jones (1926). Since then, rice breeders have shown increasing interest in heterosis and several workers (Shinjyo and Omura, 1966; Watanabe, 1971; Athwal and Viramani, 1972; Carnahan et al., 1972 and Swaminathan et al., 1972) suggested exploiting heterosis commercially by developing hybrid rice varieties. However, difficulties in hybrid seed production discouraged the attempts. The Chinese were the first to exploit heterosis in rice by developing commercial  $F_1$  hybrids recording 20-30 percent higher yield and possess wider adaptability than the best semidwarf commercial varieties (Lin and Yuan, 1980).

**Heterosis for yield and yield components:**

Reports in the literature have provided ample evidence of significant positive heterosis and heterobeltiosis for yield ranging from 1.0% (Mallick et al., 1978) to 368.9% (Rao, 1965) in rice.

Some of the early works on heterosis in rice have been reviewed by Ramiah and Ramaswamy (1941), Sen and Mitra (1958), Purohit (1972), Yap and Chang (1976), Nayak et al. (1978) and Virmani et al. (1981).

The major yield components in rice are number of panicles, spikelet number per panicle, spikelet fertility percentage and 1000-grain weight (Virmani and Edwards 1983). Grafius (1959) suggested that there would be no separate gene system for yield per se and that the yield is an end product of the multiplicative interaction between yield components. This would indicate that heterosis for yield should be through heterosis for individual yield components or alternatively due to the multiplicative effects of dominance of component effects.

Namboodri (1963) reported marked heterosis for panicle number per plant (9.1 to 122.8), plant height (14.9 to 42.7%), grains per pancile (3.4 to 20.2%) and grain weight (0.6 to 3.8%) in a study involving four crosses. Mean  $F_1$  hybrid values did not, however, exceed those of better

parents for panicle weight, number of grains per panicle 1000-grain weight and length of grain.

Chang et al. (1971) observed 192  $F_1$  hybrids manifesting heterosis than mid-parent and 145  $F_1$  hybrids than better parent in a study of 265  $F_1$  hybrids of rice. Number of panicles per plant and grains per panicle were the most important components associated with heterosis for grain yield. They also noted heterosis for earliness of heading, plant height, panicle length and panicle weight. Negative heterosis for yield was observed in some crosses which was attributed to high level of sterility in the hybrids.

High level of heteroses for grain yield in rice over better parent (210%) and best parent (122%) were reported by Carnahan et al. (1972). The increased grain yield in hybrids was attributed to simultaneous heterosis for a number of yield components. Negative values for grain yield due to high level of sterility in  $F_1$  hybrids of certain crosses were also reported by them. Purohit (1972) observed positive heterosis in the  $F_1$  hybrids for plant height, earbearing tillers, panicle length, number of grains per panicle and grain yield. Negative heterosis however, was recorded for number of days to flowering and maturity. Swaminathan et al. (1972) suggested that heterosis of 20-50 percent over better parent could offset the cost of hybrid seed.

Sivasubramaniam and Madhavamenon, (1973 e) observed heteroses over mid parent ranging from -16.6 to 48.5% for grain yield, -35.5 to 43.2% for grains per panicle, -14.7 to 84.8% for panicle number and 0.9 to 58.9 for plant height. Heterobeltioses ranged from -69.0 to 28.7% for yield and -14.5 to 51.2% for plant height.

In a study of diallel set of crosses, Mohanty and Mohapatra (1973) found significant heterosis for all the traits studied except number of grains per panicle. Heterosis for yield and its components appeared to differ very much from cross to cross. Heterosis in one cross for yield was observed to be due, primarily to heterosis for panicle weight and 1000-grain weight.

Murayama (1973) showed that the degree of heterosis was high for grain yield and number of spikelets per panicle. In grain yield, eight out of 33 combinations exceeded their higher parent. One cross having the highest combining ability exceeded higher parent by 50%.

Rajagopalan et al. (1973) noted heterosis for plant height, ear number per plant, spikelet sterility and yield of grain and straw in crosses between tall and dwarf indica rice varieties.

Pronounced hybrid vigour for number of panicles per plant and grain yield involving blast resistant and susceptible indica varieties has been reported by Palaniswamy

and Palaniswamy (1973). Saini and IshKumar (1973) observed high mid-parent heterosis for grain yield (112.45%) in rice because of simultaneous heterosis for other yield components like earbearing tillers (71.67%), spikelets per panicle (77.77%) and 1000-grain weight (24.24%). Saini et al. (1974) also observed positive standard heterosis when the  $F_1$  hybrids were derived from selected parents with improved plant-type. However, Khaleque et al. (1977) found no association between parental and hybrid yield performance.

In an experiment involving crosses between a tall photosensitive long duration variety and five semi-dwarf photoinsensitive short to medium duration high yielding varieties, Bardhan Roy et al. (1975) reported negative heterosis in respect of duration in all the five crosses and positive heterosis in respect of plant height, number of effective tillers, ear length and grain weight.

Davis and Rutger (1976) studied yield and yield components of  $F_1$  hybrids in three experiments in 30 cm x 30 cm and one experiment in 15 cm x 15 cm spacings. In the 30 cm x 30 cm experiments ten out of 14 hybrids significantly outyielded their higher parents. However, only two hybrids outyielded the best cultivars (23 and 16%). Four hybrids in 15 cm x 15 cm spacing experiment yielded 59% to 92% as much as their parents. These findings indicate the influence of plant spacing on heterosis in contrast to the findings of Murayama et al. (1974).

Maurya and Singh (1978) reported significant heterosis for yield, earbearing tillers, number of grains per panicle, panicle length, days to heading, plant height and grain width. The magnitude of heterosis varied from 36.1% to 124.5% over better parent. The mechanism of heterosis in different crosses was different. Obviously, the heterosis for grain yield in the crosses was due to increase in one, two or all the three basic complements of yield and / or fertility percentage. Absence of heterosis in six crosses studied by them was attributed to absence of heterosis for component characters mainly for earbearing tillers and test weight. In some crosses they noted that the advantageous effect was found cancelled by negative heterosis for other component characters. Increased sterility in hybrids was found to be responsible for such negative heterosis. Complex traits like yield and test weight registered high magnitude of heterosis when compared to their component traits. In general, crosses involving one good and the other poor combiners exhibited high heterosis.

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Mallick et al. (1978) studied heterosis in  $F_1$  and  $F_2$  generations of 6 crosses excluding reciprocals for six quantitative characters in indica rice varieties. They observed positive heterosis for plant height (25.1%), panicles per plant (64.2%) and grain yield (21.1%) and negative heterosis for days to heading (-19.8%), panicle length (-15.1%) and number of fertile grains for panicle

(- 37.7%) over the better parent. The extent of vigour was reduced in  $F_2$ . Vigour in panicles per plant influenced the heterosis for yield.

Singh and Singh (1978) observed heterosis and heterobeltiosis in two crosses in the desirable direction for plant height (-37.1 to 54.1% and -40.0 to 59.1%) number of productive tillers (12.0 to 78.9% and 7.7 to 41.7%) and for grain yield per plant (33.3 to 64.3% and 1.9 to 22.0%) respectively. They also observed negative heterosis for panicle length and 100-grain weight.

Paramasivan (1979) in a study of four rice varieties crossed with IR 8 reported positive heterosis for yield and spikelet sterility over superior parent in all the four crosses. Maximum heterobeltiosis for plant height was reported in crosses between tall and dwarf varieties.

Mid-parent and better parent heteroses for grain yield in 15 hybrids of rice were studied by Singh et al. (1980 b). They observed a range of 32.80% to 69.76% and -37.59% to 69.61% of heteroses over mid-parent and better parent respectively. In all, hybrids showed significant heterosis over the corresponding better parents for other eight component characters also indicating their contribution to heterosis for grain yield.

The most comprehensive commercial utilization of heterosis in rice has been that reported from China. More

than 12 hybrids were officially released prior to 1980 (Lin and Yuan, 1980). Yields under large scale production have exceeded the best commercial conventionally bred varieties by 20% to 30%. The hybrids, though manifest fewer effective panicles per square meter have significantly more filled grains per panicle and larger seeds. The speed and ease with which favourable dominant genes for disease and pest resistance were could be incorporated was also indicated for development of resistant commercial rice hybrids.

Work on heterosis at IRRI during 1980-81 has shown that levels of as much as 73%, 59% and 34% for mid-parent, higher parent and standard heteroses respectively have been recorded in yield (Virmani and Edwards 1983). Of a total of 202  $F_1$  hybrids evaluated for yield during 1980-82, 63% showed positive high parent heterosis (4% to 64.3%) and 50% showed positive standard heterosis (0.1% to 46.4%). Yields of the  $F_1$  were found to be positively correlated with the parental mean ( $r = 0.45^{**}$ ). The parents were selected for high per se yield performance, diverse genetic back ground and resistance to diseases and insects incorporated through conventional breeding.

Srivastava and Seshu (1982) reported high mean heterosis in crosses of parents with resistance to various stresses, for grain yield per plant (26.1%) grain yield per panicle (20.0%), spikelet number per panicle (18.48%) and plant height (15.48%). Heterosis was moderate (less than 7%)

for test weight, panicle length, number of primary branches per panicle and width of grains. The highest yielding hybrid (IR 36 / CR 1002) yielded 62.5% higher than the better parent and 28.9% higher than the highest yielding parent (IR 46). Degree of genetic divergence was correlated with the resulting hybrid vigour. Ghorai and Pande (1982) also observed high degree of positive heterosis for earbearing tillers per plant (25%) and yield per plant (35%). Heterobeltiosis was negative for spikelets per panicle (-161.5%) and test weight (-309.63%). They attributed high heterosis on either direction to dominance and / or epistasis or any other kind of gene action. Mandal (1982) reported that the estimates for overall degree and direction of heterosis were significantly high and positive for plant height (17.4%) and yield per plant (18.3%). Earbearing tillers showed positive heterosis (33.8% to 92.0%) in 8 crosses out of which three showed 48.3% to 60.4% heterosis.

Amirthadevarathinam (1983) in a line x tester analysis found that the amount and degree of heterosis varied with the different cross combinations or the major yield components. Two crosses showed very high heterosis for three important yield components namely, productive tillers, grains per panicle and plant yield.

Nijaguna and Mahadevappa (1983) reported highly significant heterosis and heterobeltiosis for plant height, spikelet weight, grain number per plant, 1000-grain weight,

straw yield and spikelet sterility in all the three crosses. They also observed that all the attributes except days to heading (heterosis and heterobeltiosis), 1000-grain weight (heterosis), manifested highly significant negative values indicating that no improvement for grain yield could be made by selection for any of those components. This indicates the possibility of obtaining more heterotic hybrids in specific crosses.

Shanmugasundaram and Sivasubramanian (1983) studied heterosis and heterobeltiosis in eight crosses for five quantitative characters. High heterosis for grain yield in one cross was attributed to simultaneous heterosis for number of effective tillers and grain number. They also stressed the need to identify the hybrids showing simultaneous heterosis for more than one yield component.

Anandakumar and Sreeragasamy (1984 b) analysed the performance of  $F_1$  hybrids of 14 dwarf parents crossed with one tall parent used as male. All the crosses showed heterosis over mid, better and superior parent with regard to plant height. Five crosses showed positive heterosis for productive tillers over mid-parent. Nine crosses showed positive heterosis for yield. Only one cross recorded highest positive heterosis, heterobeltiosis and standard heterosis which was also heterotic for effective tillers and panicle length. They also reported the better expression of component characters like plant height, tiller number and

panicle length resulting in heterotic vigour in  $F_1$  and inbreeding depression in  $F_2$ , in all the 21 cross combinations studied, for atleast one of the characters. The inbreeding depression was expressed as percent decrease in the mean values of  $F_2$ 's over  $F_1$ 's.

A diallel analysis with eight varieties of rice revealed very poor manifestation of heterosis for kernel length, breadth and L/B ratio (Singh and Singh, 1985). For L/B ratio the extent of heterosis over mid-parent was 26.13%. Three crosses showed significant positive heterosis for L/B ratio over mid-parent. The mean in most of the crosses was close to the mid-parent indicating the absence of dominance or over-dominance.

Dwivedi (1985) reported heteroses over mid-parent better parent and also over standard check for yield per plant, panicle length, 1000-grain weight, days to maturity, tillers per plant and plant height to varying degrees in different combinations. In grain yield, mid-parent heterosis upto 69.3%, heterobeltiosis upto 62.02% and standard heterosis upto 28.32% were reported. Seven of the eight  $F_1$  hybrids showed high positive heterosis (34.62% to 66.98%) for tillers per plant. High magnitude of mid-parent heterosis upto 17.16% and standard heterosis upto 20.21% was recorded for 100-grain weight.

Grain quality characters of hybrids were generally intermediate between their parents (Lin and Yuan 1980).

However, shashi et al. (1986) reported positive heterosis, heterobeltiosis and standard heterosis for kernel breadth, while L/B ratio exhibited negative heterosis, heterobeltiosis and standard heterosis in all the three hybrids examined. They concluded that rice hybrids with desirable grain quality could be produced by complementation of quality traits present in the parents.

Mohapatra and Mohanty (1986) reported heterosis over mid-parent in grain yield to varying degrees. Parents with high gca also exhibited high variety heterosis, indicating the importance of genes with additive action in heterosis. Non-additive gene action was also reported to be important as evidenced by significant sca in some heterotic hybrids. They opined that the genetic diversity of parents in gca effects for realising heterosis is important, as heterotic hybrids appeared more frequently in crosses involving parents with high x low rather than H x H or L x L for gca.

Jun et al. (1986) in a study of 36  $F_1$ 's and  $F_2$ 's derived from a diallel mating observed over dominance effects for late heading in  $F_1$ 's and incomplete dominance in  $F_2$ . Heterosis relative to the later parent was 1% to 20% in the  $F_1$  and 2% to 14% in the  $F_2$ .

Kaushik and Sharma (1986) studied the extent of heterosis in rice under cold stress conditions of Himachal Pradesh. The highest heterotic effects for grain yield were 60.4% over mid-parent, 38.8% over better parent and 32.3%

over the best variety (Himdhan). Heterosis for grain yield was due to increase in tiller number, panicle length, spikelets per panicle and 1000-grain weight. Many crosses showed heterosis for late flowering taking more than 120 days to flower and suffered yield losses due to cold stress at the reproductive stage.

Prakash and Mahadevappa (1987) in an evaluation studies of 15 rice hybrids found two hybrids expressing significant positive heterosis over the male parent for grain yield. Because of high spikelet sterility (ranging from 3.00% to 61.7%) many hybrids did not express significant standard heterosis for grain yield and some of its components. They stressed the need to improve spikelet fertility for realising heterosis in grain yield.

In most of the studies on heterosis, significant positive heteroses have been observed for yield or one or more of the main yield components like panicle number, spikelet number for panicle, spikelet fertility percentage and 1000-grain weight. Negative heterosis for yield is usually compensated by positive heterosis in other characters indicating that yield in hybrids was the result of increased sink size.

### 2.3 Correlations and path-coefficient studies

A knowledge of the correlation of various quantitative characters among themselves and their

association with yield and the direct and indirect contribution to grain yield would be of immense utility to the plant breeders for crop improvement. However, it should be recognized that improvement in one character as a result of selection for another depends not only on the correlations, but also genotypic and phenotypic variances associated with them (Johnson et al., 1955). Several workers reported correlations between different quantitative characters that have bearing on grain yield directly or indirectly in rice.

Chaudhary and Sen (1953) found negative associations between plant height and tiller number and between panicle length and tiller number.

Positive correlation between plant height and panicle length were reported by Chandraratna (1964). Wang (1965) in a study of indica japonica crosses reported significant positive correlation between grain yield and plant height. Chaudhary et al. (1976) observed positive correlation between plant height and number of tillers. Yadav and Singh (1979) also observed that grain yield was positively correlated with plant height. However, Khaleque et al. (1978) reported a positive correlation between grain yield and shortness in plant stature. Significant positive correlations were observed between earbearing tillers and grain number per panicle with single plant grain yield by Sastry et al. (1967).

Ahmed and Rao (1967) obtained a positive significant correlation to varying levels between yield and yield components. Earbearing tillers, number of grains per panicle and length of panicle were found to be correlated with grain yield. Roychoudhury (1967) reported that grain yield was genotypically and phenotypically correlated with plant height, number of panicles and 1000-grain weight.

Sivasubramaniam et al., (1968) reported that the differences in the yield components were varietal and they differed significantly among and within the groups of different duration groups. The panicle length showed highly significant positive correlation with the number of grains and chaff per panicle.

In the studies of Mohanty and Singh (1969), single plant grain yield showed positive correlation with panicle number, number of grains per panicle and test weight. They reported that grain yield panicle number and spikelet sterility were highly variable with low heritability values. High heritability values were reported for plant height, flowering duration and number of grains per panicle.

Chang and Tagumpay (1970) observed that largest positive contribution to yield was obtained by high panicle number and early maturity next to erect flag leaf angle in a sample of  $F_7$  lines of peta / I-Geo-Tze cross. Low grain yield was observed to be closely associated with tall

stature, drooping leaves and low panicle number in the tall lines.

Shiro Okabe (1972) observed that high grain number and high tiller number were negatively correlated with high yield. Longer panicles accompanied by few tillers were likely to produce higher yield since, that correlation gave a large number of grains with better filling.

Sukanya Subramanian and Madhavamenon (1973) reported that plant height, panicle length, grain number per primary panicle and 1000-grain weight had significant positive correlation with grain yield in tall x tall crosses, while plant height, number of earbearing tillers and panicle length showed positive correlation with yield in dwarf x dwarf crosses. Estimates of correlation coefficients indicated that panicle length and grain number per primary panicle were consistently correlated with grain yield.

Rao et al. (1973) noted highly significant correlation between yield and number of earbearing tillers and panicle weight. Chaudhury et al. (1973) observed significant positive association between panicle weight and grain number per panicle as also between 1000-grain weight and single plant grain yield. 1000-grain weight and panicle weight were negatively correlated with number of panicles per plant and number of grains per panicle with panicle number per plant. They suggested selection based on grain number per panicle and 1000-grain weight would be effective.

Lenka and Misra (1973) showed that the number of panicles per plant and grains per panicle were important determinants of yield which can be relied upon while selection for grain yield. Panicle length had a positive and direct effect on grain yield and 1000-grain weight.

Correlation studies by Mukherji and Mandal (1973) revealed earbearing tillers per hill as one of the major characters that influenced the yield. Intermediate plant height and not too long panicles were suggested to be desirable.

Ishankumar and Saini (1973) reported that tiller number, spikelet number and days to maturity had appreciable direct effect on grain yield.

Sidhu (1973) reported that total number of tillers, number of spike - bearing tillers, length of panicle, number of grains per panicle and 1000-grain weight were positively and significantly correlated with yield. While Sreerangasami and Murugesan (1973) reported highly significant correlation for plant height with leaf length and panicle length in diploids. They also found through path analysis that leaf length, productive tillers and plant height had significant direct effect on grain yield in diploids. Positive correlation between panicle length and yield was reported by Palaniswami (1974), Dora and Venkateswarlu (1976) and Mahajan et al. (1981).

Siva<sup>a</sup> subramaniam and Madhavamenon (1973 b) emphasised the importance of panicle length and number of grains in the primary ear in the selection of desirable recombinants with high grain yield, through correlation studies. Rao (1970) also noted positive significant correlation between panicle length and number of grains per panicle.

Number of days to flowering has been found to be positively correlated with grain yields (Ranganathan *et al.*, 1973; Reddy and Prasad, 1977; Yadav and Singh, 1979). However, Talwar and Goud (1974) reported a negative association between number of days to flowering and grain yield.

Panicle length was found to be negatively correlated with earbearing tillers and plant height (Singh and Nanda, 1975).

Maurya (1976) reported that an improvement in grain yield could be best effected by selection for high grain number per panicle, high test weight and long grains. Similar results were also reported by Saini and Gagneja (1975) and Benerjee and Sinha (1977).

Rao *et al.* (1976) observed that the direct effect of earbearing tillers, grain number per panicle and 1000-grain weight on grain yield was positive. The direct effect of sterility percentage strengthened by grain number per panicle

was negative. The indirect effect of panicle length was negative through earbearing tillers and positive through grain number per panicle.

Eunus et al. (1976) reported that grain yield was correlated positively with number of panicles per unit area, number of filled grains per panicle and also per unit area and negatively with plant height. Nakayama and Saito (1976) however, observed that number of productive tillers were having negative correlation with most of the other characters.

Agrawal et al. (1978) reported that panicle number and plant height<sup>e</sup> followed by 100-grain weight and number of spikelets had high correlations with grain yield.

In general, a negative correlation between the number of earbearing tillers and other characters is well known (Nakayama and Saito, 1976). Number of earbearing tillers showing negative correlation with grain number and test weight of grain was also observed by Mishra et al. (1973) and with days to heading by Saini and Gagneja (1975). However, there are reports of positive correlations also between earbearing tillers with panicle length, spikelet density and number of grains per panicle (Rao et al., (1977) and with plant height and yield (Agrawal et al., 1978 ; Paramasivan, 1979).

Aly (1979) observed highly significant differences and positive correlations between plant height and total

tillers, earbearing tillers, number of grains and plant dry weight. Number of earbearing tillers and number of grains per plant had direct influence on plant yield.

Significant positive correlation between grain number per panicle and grain yield to form reliable index of yielding ability was reported by Kaul and Bhan (1974). Vinaya Rai and Murthy (1979) reported that grains per panicle and total dry weight at flowering showed significant positive association with yield at both low and high fertility levels. Grain number per panicle recorded the largest direct effect on yield.

Singh (1980) detected grain yield to be positively correlated with panicle bearing tillers, grain weight and fertile grains per panicle in  $F_1$  and  $F_2$ . Conversely, panicle length in  $F_1$  and  $F_2$  and grains per panicle in  $F_1$  showed strong negative correlations with grain yields. Path-coefficient analysis revealed that panicle bearing tillers, grain weight and fertile grains per panicle in  $F_1$  and  $F_2$  had high positive direct effects on grain yield.

Chaudhary et al. (1980) found that the number of spikelets per panicle and earbearing tillers showed positive association with grain yield and negative association with 100-grain weight. Significant positive environmental association showing greater role of environment was observed between earbearing tillers and grain yield per plant. Plant height showed positive association with panicle length.

Spikelets per panicle had negative association with 100-grain weight. Negative association was also noted between 100-grain weight and grain yield.

Rao et al. (1980 b) observed that earbearing tillers, grain number per panicle and 100-grain weight to be the principal contributing traits to grain yield in late varieties. They also recorded significant influence of earbearing tillers and grain number per panicle on single plant grain yield. Principal component analysis (Mahajan et al., 1981) showed significant negative correlation between earbearing tillers and grain number per panicle.

Grain yield was reported to be positively correlated with earbearing tillers and negatively with spikelets per panicle and test weight. Negative correlation was also recorded between earbearing tillers and test weight. (Ghorai and Pande, 1982).

According to Lal et al. (1983), the desirable traits in individual plant or line selections were comparatively tall, early flowering plants with average number of panicle bearing tillers, medium to long panicles of greater density and high grain yield per plant.

Ghosh et al. (1983) reported that spikelet sterility was negatively correlated with temperature, days to flower and plant height uniformly. Flowering duration showed

positive correlation with plant height. Correlation between yield and sterility was negative and correlation between yield and temperature was mostly positive.

Chauhan and Tandon (1984) reported that plant height, number of grains per panicle and 1000-grain weight had positive and significant correlation with grain yield under upland environment while the earbearing tillers showed positive and significant correlation under irrigated environment. Path analysis supported the results of correlations observed.

Correlation studies on upland rices by Singh et al. (1984) revealed that panicle number per square metre and number of grains per panicle had significant positive association with grain yield while spikelet sterility had significant negative association with grain yield. Plant height had significant positive correlation with panicle length and days to maturity whereas spikelet sterility percentage and 100-grain weight showed negative association with grain yield. Path analysis brought out the direct impact of panicle number per square metre, panicle length, number of grains per panicle and 100-grain weight on ultimate grain yield. They concluded that tall plants with more number of panicles per square metre, longer panicle length, maximum number of grains per panicle and higher seed size would be a better plant-type for upland rice.

Anandakumar and Sreerangasamy (1986 b) reported that number of productive tillers per plant showed the greatest positive correlation with grain yield per plant. Plant height did not have direct effect on yield.

Moeljopawiro (1986) in a study of grain characters in  $F_1$  and  $F_2$  generation observed that grain width and 100-grain weight were correlated positively with each other but negatively with the other traits. Grain length was negatively correlated with grain width and suggested selection based on several traits simultaneously.

Singh and Nanda (1976 c) found that there was no considerable loss in 1000-grain weight in certain varieties infected by X.campestris p.v. oryzae. However, yield per plant was considerably reduced.

The disease intensity score of BLB was negatively correlated with yield in parents as well as in segregating populations. Length of panicle and plant height were positively correlated with yield in hybrids, while 100-seed weight showed no correlation with yield (Reddy, 1978).

#### 2.4 Studies on $F_2$ generation:

Since  $F_2$  is the earliest segregating generation subjected to selection in pedigree method of breeding several studies on  $F_2$  generation have been reported. Following is the review on  $F_2$  studies.

Maurya and Singh (1978) reported that inbreeding depression was high in crosses having high heterosis. Inbreeding depression in  $F_2$  was less in crosses where heterosis for yield was due to heterosis in several characters. The depression was however, higher where only one or very few components showed heterosis. Mallick et al. (1978) also observed that the extent of vigour was reduced in the  $F_2$ .

Khaleque et al. (1978) noted more significant  $F_2$  reduction than  $F_1$  in majority of the crosses and characters. In three crosses (of nine), the  $F_2$  yield was lower than  $F_1$ .

Srivastava et al. (1978) studied the  $F_2$  generation of diallel set of 8 varieties of rice. Both additive and non additive components in the inheritance of L/B ratio was observed to be important. Complete dominance was observed for L/B ratio and estimates of heritability were high. High correlation was observed between parental means and gca effects and between per se performance and the sca effects.

Dwivedi et al. (1978) observed that earlier generation selection was ineffective for grain number per panicle and grain yield in a study of  $F_2$  and  $F_3$  generation of four crosses.

Haque et al. (1981) carried out combining ability studies using  $F_2$  data of a diallel set of crosses.  $F_2$  showed a marked decline in the proportion of specific combining

variances for different characters. However, the two generations were grown in different seasons and as such the results could not be generalized. Such a decline was attributed to the reduction of dominance from the  $F_1$  to  $F_2$  generation (Paroda and Joshi, 1970). Haque et al (1981) also observed lack of association between gca effects obtained from  $F_1$  and  $F_2$  generations for some of the characters, particularly grain yield questioned the reliability of  $F_2$  data in such studies. However, the coefficient of correlation between the sca effects of  $F_1$  and  $F_2$  generation was consistent for 3 characters namely number of grains per panicle, sterility and 1000-grain weight out of seven characters studied.

Chaudhary et al. (1980) recorded moderately high to high (67.8% to 97.9%) heritability in  $F_2$  for all the characters studied. High genetic advance was recorded for earbearing tillers, spikelets per panicle, 100-grain weight, grain length and grain yield per plant (54.9 to 81.3%). It was also observed that for grain breadth, the estimates of heritability were higher in  $F_2$  than in  $F_1$ . The change in values over generations, was attributed to change in genetic components of population, as in  $F_2$ , the dominant components decrease due to homozygosity (Maurya, 1976).

Singh (1980) reported that the grain yield was positively correlated with panicle bearing tillers, grain weight and fertile grains in  $F_2$ . Conversely, panicle length

in  $F_2$  showed strong negative correlations with grain yield. It was also observed by him that panicle bearing tillers, grain weight and fertile grains per panicle in  $F_2$  had high positive direct effects on yield.

Singh and Richharia (1980) observed unequal distribution of positive and negative alleles in the  $F_1$  and  $F_2$  for all the traits. They also reported epistasis for grain yield per plant and overdominance for days to heading as also for 100-grain weight in  $F_1$  and  $F_2$ .

Yoneza and Yamagata (1981) in a comparison of early selection ( $F_2$ ) and delayed selection ( $F_4$  or  $F_5$ ) demonstrated that a larger chance of success with a given breeding cost (including time and labour) could be achieved by a breeding system incorporating early selection.

Pham Van Ro (1982) reported that number of grains per panicle was correlated significantly and positively with grain yield in advanced generation ( $F_4$ ).

Estimation of genetic parameters in the investigation of Chauhan and Nanda (1983) was confined to  $F_2$  population, the earliest segregating generation to predict the effectiveness of early generation selection. Substantial range among  $F_2$  populations was observed in estimates of range, mean and genotypic coefficients of variability for each character. High heritability estimates with high genetic advance were reported for kernel length, kernel

breadth and L/B ratio of kernel which are relatively less influenced by the environmental factors. They opined that these characters are either simply inherited traits and are governed by few major genes or additive effects play an important role in the inheritance of these traits even if they are under polygenic control. Selection in  $F_2$  for these characters, they suggested, would be quite effective. The differences observed in the estimates of various genetic parameters among  $F_2$  populations were due to differences in the genetic structure of the populations.

Panwar and Paroda (1983) recorded significant gca and sca effects for 1000-grain weight, kernel length, breadth and L/B ratio in the  $F_1$  as well as  $F_2$ 's indicating the importance of additive and non-additive gene effects and also predominance of additive gene effects in their inheritance.

Yamada (1984) reported that the heritabilities of quantitative resistance to BLB were fairly high in  $F_2$  generation and the level of those estimates was equal to that of heading date and culm length of rice plant. Heading date and culm length have so far positively been selected at an early generation of hybrid and their genetic gains by this type of selection proved to be large enough so that positive selection at an early generation of hybrid is effective also for quantitative resistance for BLB. In the  $F_2$  generation, the quantitative resistance to bacterial groups II, III and IV was highly correlated with each other genotypically and

phenotypically. These high correlations make it feasible to select the plants non-specifically resistant to all the bacterial groups by means of inoculation of only one of them.

Misal et al. (1985) in correlation study of advanced generations ( $F_3$ ,  $F_4$  and  $F_5$ ) of breeding material observed that plant height, days to 50% flowering, days to maturity, number of grains per panicle and 1000-grain weight were the most important yield contributing characters having significant genotypic correlations with yield. Path analysis revealed that plant height, panicle length days to 50% flowering and number of grains per panicle had maximum direct effect on grain yield. Direct effect of 1000-grain weight on grain yield was negative, but indirect effect through days to 50% flowering and days to maturity was high and positive. Similar trend was also exhibited by days to maturity which had positive direct effects through panicle length, days to 50% flowering, number <sup>of</sup> grains per panicle and 1000-grain weight.

In another study Panwar et al. (1985) reported significant gca and sca effects for 8 characters including grain yield in both  $F_1$  and  $F_2$ 's. Over-dominance or preponderance of non-additive gene action for grains per panicle and grain yield was reported in  $F_1$  and  $F_2$ . Partial dominance was observed for plant height and 1000-grain weight in  $F_1$  and  $F_2$  and for days to heading, panicles per plant, panicle length and spikelets per panicle in  $F_2$  indicating a predominant role of additive gene action.

Anandakumar and Sreerangasami (1986 a) estimated inbreeding depression in  $F_2$  expressed as percent decrease in the mean values of  $F_2$ 's over  $F_1$ 's. Inbreeding depression in  $F_2$  was noticed in all the cross combinations for at least one of the characters studied by them.

Jun et al. (1986) in a comparative study of  $F_1$  and  $F_2$ , observed over dominance effects for late heading in the  $F_1$  and incomplete dominance in  $F_2$ . Additive effects were significant in  $F_1$  while non-additive effects were predominant in the  $F_2$ . Heterosis relative to the later parent was 1% to 20% in  $F_1$  and 2% to 14% in the  $F_2$ .

According to Perera et al. (1986) the properties of the recombinant inbred lines that can be extracted from  $F_2$  of a cross between two inbred lines could be predicted with a high degree of accuracy. In a triple test cross experiment in rice they found that all the four characters were controlled by genes with additive, dominance and epistatic effects of duplicate type and atleast some of these genes are linked in repulsion phase. The predictions indicated that it was fairly easy to obtain superior lines for three of the four characters studied.

## 2.5 Bacterial leaf blight resistance:

Bacterial leaf blight disease caused by Xanthomonas campestris pv. oryzae (Uyeda and Ishiyama, Dowson) Dye is one of the most important diseases of rice in most of the rice

growing regions of the world. It was first reported in 1890 from Japan (Tagami and Mizukami, 1962; Mizukami and Wakimoto, 1969). The devastation caused by this disease was not properly realised until the occurrence of the 'Kresek' phase of the disease on rice seedlings in Indonesia (Reitsuma and Schure, 1950). The disease has since been reported from almost all the important rice growing regions of South and South east Asia.

In India bacterial leaf blight was first noticed in Maharashtra state in 1951 in a severe form causing crop losses (Bhapkar et al., 1960). The disease became wide spread and severe with introduction of dwarf high yielding susceptible varieties of rice by mid 1960's causing severe losses in farmer's fields (AICRIP, 1969 and Srivastava, 1972). Several workers attempted to estimate the reduction in grain yield to be ranging from 2% to 74% depending on location, variety, stage of the crop, dose of nitrogen applied, season and weather conditions and inherent susceptibility of the varieties (Wakimoto and Yoshii, 1954; Srivastava and Rao, 1963; Srivastava, 1972; Have and Kauffman, 1972 ; Reddy et al., 1978).

#### 2.5.1 Symptoms on the host plant:

The disease develops as water soaked spots at the leaf margins, enlarging gradually to yellowish blotches or stripes developing parallel to the veins under flooded conditions. When Plants are infected in the seedling stage,

the entire crown is affected and the whole seedling wilts in susceptible varieties. The infected leaf crinkles and usually folds along the midrib. In India, it occurs as a vascular wilt in early stages of crop growth and leaf blight in later stages (Reddy *et al.*, 1980). In the infected plants the root system is poorly developed, tillering is reduced, growth is stunted and they have incompletely filled spikelets reducing the weight, or empty spikelets (Ou, 1973).

#### 2.5.2 Methods of testing:

Several methods of testing for critical evaluation of resistance of *Xanthomonas campestris* pv. *oryzae*, like spraying inoculum, dip inoculation, needle prick inoculation, bacterial exudation method, bunch method, disease garden and clip inoculation method have been reported (Devadath, 1985). Clip inoculation is widely used in India and IRRI. In this method bacterial suspension is prepared to contain  $10^9$  cells/ml. Each plant is inoculated by dipping the scissors in the bacterial inoculum and clipping the tips of the top leaves. Inoculum prepared from pure culture or from infected leaves can be used (Kauffman *et al.*, 1973). A screening system subsequently developed (IRRI, 1973) and being followed in many countries is as follows.

#### Standard evaluation system for rice:

0 = No incidence

1 = Less than 1%



- 3 = 1.5%  
 5 = 6.25%  
 7 = 26 - 50%  
 9 = 51 - 100%

#### 2.5.4 Inheritance of resistance to bacterial leaf blight:

Studies on the inheritance of resistance to bacterial leaf blight were first initiated in Japan. Several genetic studies on the resistance in some rice cultivars to *Xanthomonas campestris* pv. *oryzae*, Japanese isolates, have been reported from Japan (Sakaguchi, 1967; Sakaguchi *et al.*, 1968; Toriyama, 1972; Ezuka *et al.*, 1975; Ogawa *et al.*, 1978; Horino and Yamada, 1980; Yamada and Horino, 1981; Wasano and Dhanapala, 1982). Collectively, these studies indicate that resistance to the leaf blight pathogen may be dominant or recessive and monogenic or polygenic. Four dominant genes for resistance to Japanese isolates Xa 1, Xa 2, Xa 3 and Xa 4 were identified in Japan. Sakaguchi (1967) identified two dominant genes for resistance in Ranta-Emas group and reported that at least two genes Xa 1 and Xa 2 govern resistance. Xa 1 and Xa 2 are closely linked and are located in chromosome 11. Kogyoku group cultivars possess dominant gene Xa 1 for resistance against group I bacteria isolates. Irrespective of their aggressiveness, Kogyoku group cultivars showed symptomless type of resistance reaction to group I isolates (Kaku and Kinmura 1987). The gene, Xa 1 is linked with the liguleless gene (lg) with 6 - 14 percent recombination value (Nishimura 1961). Resistance of Wase

Aikoku group to all the three groups of bacterial isolates (I, II and III) is controlled by a single dominant gene, Xa-w (redesignated as Xa-3 by Petpisit et al., 1977) and was independent of Xa 1 and Xa 2 (Ezuka et al., 1975). Ogawa et al. (1978) reported another resistance dominant gene, Xa kg in the varieties Kogyoku and Java 14 to group V isolates to be independent of the known gene Xa w, but linked closely with Xa 1 with a recombination value of about 2 percent. Thus, four dominant genes (Xa 1, Xa 2, Xa 3 and Xa kg) for resistance to Japanese isolates of *X. campestris* pv. *oryzae* were identified in Japan, Yamada and Horino (1981) reported two major genes, Xa 1<sup>h</sup> (allelic to Xa 1), and Xa kg<sup>h</sup> (allelic to Xa kg) conferring resistance to bacterial groups I and V (Multiple alleles).

Investigations at IRRI to Philippines isolates resulted in identification of eight genes - Xa 4, xa 5, Xa 6, Xa 7, xa 8, xa 9, Xa 10 and Xa 11 conferring resistance (Olufowote et al., 1977; Petpisit et al., 1977; Sidhu and Khush, 1978; Sidhu et al., 1978; Singh et al., 1983; Yoshimura et al., 1983 and Ogawa and Yamamoto, 1986).

## MATERIALS AND METHODS

## CHAPTER III

### 3. MATERIAL AND METHODS

The present studies were carried out at the Directorate of Rice Research (formerly All India Coordinated Rice Improvement Project), Rajendranagar, Hyderabad, Andhra Pradesh, India during the years 1985 and 1986 in both the rabi and kharif seasons. The Directorate of Rice Research is located at 17° 19' N latitude and 78° 23' longitude and 542.6 m. above mean sea level with tropical dry and semi-arid climate. The south-west monsoons usually set in during first week of June and withdraw towards middle of October every year with an annual rain fall of 764.4 mm normally spread over 40 to 50 rainy days every year (IMD, 1978). The soils are clayey with a pH value of 8.1

Parental material for the present studies was made available by the Directorate of Rice Research, Rajendranagar, Hyderabad, India drawn from the list of IRBBN'84. The material included six cultivars known to be resistant to bacterial leaf blight caused by Xanthomonas campestris pv. oryzae (Uyeda and Ishiyama, Dowson) Dye and one susceptible variety, IR 8.

The present studies include broadly four aspects.

- (I) Hybridization programme among 7 diverse parents in all possible combinations without reciprocals to

form a 7 x 7 diallel set during rabi and kharif seasons 1985.

- (II) Testing of parents and F1 hybrids in randomized block design for resistance to bacterial leaf blight and other quantitative traits contributing to yield during rabi season 1986.
- (III) Testing of parents, F1's and F2 populations for resistance to bacterial leaf blight at seedling and booting stages during kharif 1986 to study inheritance of resistance and allelic relationships of resistance genes in parents.
- (IV) Evaluation of segregating F<sub>2</sub> populations of the crosses along with parents for resistance to bacterial leaf blight and other quantitative characters ( in dwarfs) under field conditions during kharif 1986 for confirmation of F<sub>1</sub> results.

### 3.1 Parental material:

The varietal characters of seven parents involved in the study are furnished below:

#### 1. IET 8320 (RP 2151-40-1):

It is a dwarf indica strain bred from a cross between IET 4141/CR 98-72-1-6 at All India Coordinated Rice Improvement Project, Rajendranagar, Hyderabad. It has been identified as resistant to bacterial leaf blight. It is a

photoinsensitive line, maturing in about 135 days. It has a good planttype with erect, thick dark green leaves, good tillering, stiff straw and compact panicles. It responds well to added fertilizers and has a good yield potential with grain yields ranging from 4.5 to 6.5 t/ha. and was significantly superior to the check, IR 36 (DRR, 1986). The grains are medium bold with translucent kernels.

2. IR 19660-274-3-3-1-3:

It is a dwarf breeding line derived from the cross PTB 33/4 // IR 3403-267-1 at International Rice Research Institute, Los Baños, Philippines. It<sup>a</sup> is photoinsensitive line maturing in about 145 days. The leaves are erect and dark green. The culm is stiff and tillers moderately. It has been identified as resistant to bacterial leaf blight among entries of IRBBN, 1984 at Directorate of Rice Research, Rajendranagar. The grains are long slender with translucent kernels.

3. IR 54:

It is dwarf indica variety bred from a cross between Namsagui 19/IR 2071-88// IR 2061-214-3-6-20 at IRRI, Los Baños Philippines. It is a medium duration dwarf variety maturing in 135 days with profuse compact tillering, dark green erect leaves and weak straw. All the plant parts are green. It is moderately susceptible for lodging at maturity at higher doses of nitrogen. It is resistant to bacterial

leaf blight. The grain is super fine (long slender) with translucent kernels.

#### 4. IR 8:

It is a dwarf indica variety bred from a cross between Peta and Deo-Geo-Woo-Gen at the IRRI, Los Banos, Philippines. It is essentially photoinsensitive (Chang and Vergara, 1971), maturing in 140 to 145 days. All the plant parts are green. It has a good plant-type with sharp, erect thick dark green leaves, good tillering, stiff straw and compact short panicles. It has wide range of adaptability, responsive to heavy fertilization and possesses good yield potential with grain yields ranging from 5 to 8 t/ha. The grains are long bold and possess abdominal white. Studies at All India Coordinated Rice Improvement Project (AICRIP, 1969) Rajendranagar and International Rice Research Institute (IRRI, 1970) Phillipines, indicate that it is highly susceptible to bacterial leaf blight.

#### 5 Cisadane:

It is a semidwarf cultivar derived from a multiple cross Pelita 1-1/IR 789-98-2-3/IR 2157-3. It is a rainfed low land rice variety extensively grown in Indonesia. It is photoinsensitive and matures in about 140 days. It manifests dark green, broad, erect leaves and strong culms. All the plant parts are green. The grains are straw glume in colour and medium to long slender with translucent kernels. The

variety has a good yield potential with fair level of resistance to bacterial leaf blight.

6. Kuntlan:

It is a tall variety drawn from germplasm collection of Indonesia. It is a photosensitive, late duration variety maturing in about 145 days. The culms are strong and stiff with long droopy and pubescent leaves. Leaf sheath, stigma and tip of spikelet are purple pigmented. The spikelets are short bold with purple awns of 4 cm to 5 cm long. The kernels are translucent and manifest light scent. The seeds exhibit dormancy for about 2 weeks. It is sensitive to fluctuating temperatures resulting in spikelet sterility. However, it offers fair level of resistance to bacterial leaf blight disease.

7. Nigeria5:

It is a tall variety collected from Sri Lanka germplasm pool. It is a photoinsensitive early variety maturing in about 115 days. The leaves are long droopy and glabrous. The culm is weak with long internodes and moderate tillering. It lodges at maturity. The panicles are long and well exerted with close setting of spikelets. The plant parts like leaf sheath, ligule, auricle, stigma and tip of spikelet are purple pigmented. The grains are medium slender with red kernels. It is sensitive to high and low temperatures and adverse climatic conditions resulting in

different degrees of spikelet sterility. It offers fair level of resistance to bacterial leaf blight.

### 3.2 Bacterial culture :

Xanthomonas campestris pv. oryzae isolate used in the present studies was made available from stock culture collection of Department of Plant Pathology, Directorate of Rice Research, Rajendranagar. The isolate was maintained either in lyophilized condition or over calcium chloride at 5° c. Pathotype I (H. 561) was activated and increased in the laboratory for inoculation.

#### 3.2.1 Medium used for bacterial culture :

Modified Hayward's medium (Hayward, 1960) was used for the isolation and multiplication of Xanthomonas campestris pv. oryzae throughout the studies.

#### Composition of modified Hayward's medium

Peptone	10.00 g
Sucrose	20.00 g
Di-ammonium orthophosphate <sup>h</sup>	0.30 g
Magnesium sulphate	0.25 g
Agar-agar	20.00 g
Distilled water (6.8 - 7.0 P <sup>H</sup> )	1000.00 ml

The ingredients were dissolved in distilled water by thorough stirring and boiling. The medium so prepared was poured into conical flasks and autoclaved for 20 minutes at

20 lb/sq inch pressure. The medium was cooled to room temperature and poured into Petridishes under aseptic conditions.

### 3.2.2 Preparation of Inoculum:

The bacterium ( pathotype I ) from healthy colony of purified isolate was streaked on modified Hayward's medium in Petridishes with the help of sterilized glass rod under spirit lamp in a specially designed chamber with laminated floor sterilized with UV light. The Petridishes were incubated at  $26^{\circ}\text{C} \pm 1^{\circ}\text{C}$  for 72 hours until clear yellow stripes of bacterial colonies were seen. The yellow bacterial growth was scraped and washed by suspending in distilled water. 7 to 8 petridishes with well grown bacterium were used to prepare one litre of inoculum. The bacterial suspension contained approximately  $10^9$  viable cells per ml.

### 3.2.3. Inoculation technique:

The inoculum was taken into clean plastic buckets and the plants were inoculated at bootleaf stage by clipping the tips (top 4 to 5cm) of top 3 to 4 leaves with sterilized tailor's scissors dipped in bacterial suspension during cool hours of the day (Reddy and Kauffman, 1972 ; Kauffman et al., 1973).

### 3.3 Hybridization programme:

A diallel crossing programme (7 x 7) without reciprocals among the selected parents was carried out during rabi 1984-85 & kharif 1985 by clipping method (Jennings et al., 1979). Three plantings of parents with an interval of 15 days were taken to assure simultaneous flowering to produce adequate crossed seed. Parents were grown from the bulk seed supplied, during rabi 84-85 in the screen house. Few panicles were selected from each variety true to its characters, hand threshed and dried for sowing to serve as parents for crossing programme.

Twenty five day old seedlings were transplanted in pots having solid bottoms at 3 per each pot and labelled. Each parent was planted in 4 such pots. The pots were kept in the screen house to avoid possible rodent damage. The pots were periodically top dressed with urea and watered regularly. The plants were protected from insect pests by periodical application of carbofuron granules. The same procedure was repeated for all the three sets of staggered plantings.

#### 3.3.1 Emasculation:

Emasculation by clipping and removal of anthers (Jennings et al., 1979) was followed. Tillers from healthy potted plants with 50% to 60% emerged panicles were selected and leaf sheaths were carefully removed. The florets that completed anthesis from top and the young florets from

bottom of the panicle were cut off. The remaining florets of the panicle with anthers extended more than half of the height of floret were cut away obliquely with a fine pair of scissors a third to half of the length of the floret to expose the anthers. All the six anthers of floret were carefully and gently lifted out with forceps. The emasculated panicles were covered with butter paper bags neatly labelled. The entire process of emasculation was carried out during cool hours in the afternoons (after 4 pm) to avoid possible selfing.

### 3.3.2. Pollination:

On the following morning panicles having large number of blooming florets were selected from healthy representative male parents. The culms were cut to convenient length below the panicle and kept in pots containing water after removal of the flag leaves. The panicles were observed closely for anther extrusion. Butter paper covers were removed from the emasculated panicles and checked up for any left over anthers for removal. The blooming panicles were gently shaken over the female parent until adequate pollen is deposited on the stigmas of the emasculated panicle. The pollinated panicles were covered again with butter paper bags duly labelled and fixed to peduncle with clips against the support of thin bamboo stake. Since, the stigmas of emasculated spikelets remain receptive for at least 5 days (Jennings et al., 1979), the pollination

was repeated on the successive morning also. The process of pollination was continued up to 11:30 am. The crossed seeds were collected after 27 to 30 days of crossing from the panicles, counted and placed in small envelopes. The covers with crossed seed were dried in a dry-air oven for 7 days at from 50° to 55° C, to break dormancy (Jennings et al., 1979) and stored in refrigerator until sown.

#### 3.4 Study of F<sub>1</sub> generation:

Crossed seeds of 21 crosses and seeds of seven parents were pre-treated with 0.2% solution of captaf (50 wp) and soaked in 0.1% solution of bavistin for 24 to 30 hours. The seeds were kept on filter papers in Petridishes at the room temperature just moistened. Thus, the naked crossed seeds were protected from external and internal infection by spores of disease organisms, during germination. Satisfactory visible germination was observed on the 4th day after soaking.

Small earthen pots filled with fine moist soil enriched with compost and superphosphate were sterilized. One week old seedlings were transplanted in the small pots at 5 seedlings per pot and were labelled. 'Tracel' solution (1 g in 1 litre of water) was prepared and added to the pots along with light topdress of nitrogen. The pots were periodically topdressed with urea and protected from insect pests by application of furadon granules. The seedlings were

healthy and ready for transplanting by 34 days of age (Fig.1).

Long uniform bed extending from South to North with assured water supply in the net-house was chosen for  $F_1$  studies. The bed was well puddled after incorporation of well rotten compost. A basal dress to supply 50 kg  $P_2O_5$ , 40 kg  $K_2O$  and 50 kg zinc sulphate per hectare was given. Furadon granules at 40 kg/ha were applied and the bed was puddled again thoroughly and levelled. Healthy  $F_1$  seedlings of all the 21 crosses and seven parents were transplanted. The particulars of experimental design are given in Table 1.

Table 1 Particulars of experimental design of  $F_1$  hybrids and parents.

Design	RBD
Replications	2
Entries (7 parents and 21 crosses)	28
Spacing	20 x 30 cm
Number of seedlings per hill	1
Number of hills per row	8

Urea super-granules (spic) were placed 1" deep at the rate of one briquet for every four plants. Nuvacron at 2.5 ml/litre was sprayed followed by application of furadon granules. Urea to supply 30 kg N/ha was applied as top dress.



Fig. 1: Healthy  $F_1$  seedlings raised in small pots ready for transplanting.

All the entries were inoculated at booting stage with bacterial inoculum of pathotype I. Top 3 to 4 leaves of each tiller, of all the plants were inoculated by scissors method. Disease reaction was recorded after 3 weeks of inoculation on all the plants as per the standard evaluation system for rice, (IRRI, 1980).

### 3.5. Characters studied and collection of data:

The following important characters were studied in respect of parents and  $F_1$  hybrids in both the replications on six single plants of each entry excluding border plants.

- (1) **Days to Flowering:** The number of days from the date of seed soaking to 50% flowering of tillers of single plant were counted and the means were computed.
- (2) **Plant height:** The height of the plant was measured in centimeters from the ground level to the tip of the tallest panicle of the plant.
- (3) **Total tillers:** The number of vegetative tillers on each plant were counted at maximum tillering phase usually after 45 to 50 days after transplanting.
- (4) **Earbearing tillers (Ebt) per plant:** The number of productive tillers bearing ears at maturity were counted on each plant usually 20 days after 50% flowering date.

- (5) **Panicle length:** The length from base of the panicle to the tip was measured in centimeters. Mean length of three panicles per plant was taken. The length of awn was not taken into consideration.
- (6) **Number of Fertile spikelets per panicle:** Number of filled spikelets in each panicle were counted. The same sample of three panicles used for recording panicle length were utilized for recording the number of fertile and sterile spikelets also and the mean values were computed.
- (7) **Number of sterile spikelets per panicle:** Number of sterile spikelets were counted on the same basis on the above samples and mean values were computed.
- (8) **Percentage of sterility:** Sterility percentage was calculated as the percent of sterile spikelets to the total number of spikelets (fertile and sterile) per panicle.
- (9) **Length Breadth (L/B) ratio of kernel:** Five grains from each plant (from the sample used to record 1000-grain weight) were taken at random and dehusked by hand. Length and breadth measurements were recorded with the help of a dial thickness gauge, code No.7305 (Fig. 2). The mean values for L/B ratio of the kernel were computed.

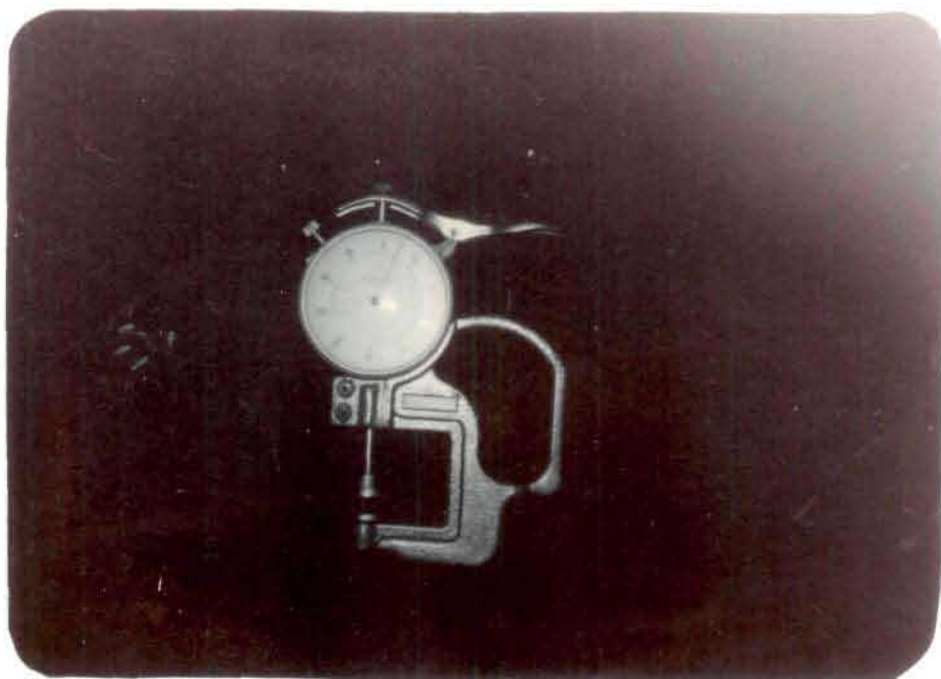


Fig. 2: Dial thickness gauge code No. 7305 used to measure length and breadth of kernel.

- (10) 1000-grain weight : 250 filled grains were counted at random from the produce of each plant, weighed and expressed in grams computed for 1000-grains.
- (11) Bacterial Leaf Blight (BLB) score : Reaction of rice varieties,  $F_1$  hybrids and  $F_2$  populations to pathotype I of bacterial leaf blight was recorded 3 weeks after inoculation. Disease evaluation was done based on 0 - 9 scale (kauffman et al., 1973; IRRI, 1980) on individual plant basis. The index value and the corresponding levels of stress severity of disease are presented in Table 2.

Table 2 : Index value and corresponding levels of stress severity for bacterial leaf blight on rice

Disease Index	Description of disease severity
0	No visible lesion
1	Lesions restricted to 0.5 to 1.0 cm
3	Lesions elongated, less than 1/4th of the leaf blade length.
5	Lesions coalesce and upper portion of leaves dead; lesions extended to 1/2 of the leaf blade.
7	Lesions extended from 3/4th to base of the leaf blade. Less than 1/2 of the leaf sheath is also affected.
9	Lesions completely destroy the leaf blade and leaf sheath.

Resistant (R) : 0,1,3      Susceptible (S) : 5,7 and 9

(12) Single plant grain yield: The panicles at maturity were harvested, threshed, cleaned and dried in covers to 12 - 14 % moisture content. The weights of produce were recorded plantwise and expressed in grams.

### 3.6 Study of $F_2$ generation:

Seeds from all the  $F_1$  plants were mixed crosswise. Seed samples (150 g) were drawn from all the 21 crosses and seven parents and soaked for 24 hours in water in soaking cloth bags. The soaked seed was incubated for 48 hours, buried in a pit, wrapped in moist straw until visible sprouting was observed. Available crossed seeds (atleast 15 seeds in each cross) of all the 21 crosses were also soaked in Petridishes on the same day and  $F_1$  seedlings raised crosswise in pots by taking all the precautions explained earlier (item 3.3). The sprouted seeds for  $F_2$  of 21 crosses and also seven parents were sown in the nursery beds under wet conditions. The bed and pots received 100 kg N , 60 kg  $P_2O_5$  and 40 kg  $K_2O$  per hectare and were protected from insect pests by application of carbofuron granules. Study of  $F_2$  along with parents and  $F_1$ 's was carried out in two stages. (1) Net house studies at seedling stage and (2) Field studies at flowering stage.

#### 3.6.1 Net house studies on parents, $F_1$ and $F_2$ generation:

About half of each nursery bed of parents and  $F_2$  populations and about 10 to 12  $F_1$  seedlings in pots of each cross were inoculated with freshly prepared bacterial leaf

blight inoculum (Pathotype I), 25 days after sowing. Data on disease reaction in 0 - 9 scale were recorded 21 to 25 days after inoculation on the inoculated seedlings of parents (200 each),  $F_1$ 's (10 to 12) and  $F_2$  populations (400 - 550) on single seedling basis.

### 3.6.2. Field studies on parents, $F_1$ and $F_2$ generations:

The main field received 45 kg N, 90 kg  $P_2O_5$ , 60 kg  $K_2O$  and 50 kg zinc sulphate per hectare as basal dose.  $F_2$  populations along with parents were transplanted in a trial in the main field. The layout particulars are furnished in Table 3 (Fig.3).

Table 3 Field Experimental design for  $F_2$  populations and parents

Item	Particulars
Lay out	RBD
Number of replications	Two
Number of entries	28
Number of rows per each entry	4
Spacing	15 x 20 cm
Number of seedlings/hill	Single
Season and year	<u>kharif</u> 1986

$F_1$ 's were not planted in the replicated trial due to paucity of seedlings. The available  $F_1$  seedlings were



Fig. 3: Testing of parents and  $F_1$ 's in the net house. Vigour and resistant reaction of  $F_1$ 's may be noticed.

planted separately crosswise in single lines and utilized only for scoring disease reaction at flowering stage.

The crop was protected against insect pests by periodical application of insecticide granules and spraying of insecticides. The entries were inoculated at booting stage with freshly prepared inoculum of pathotype I of bacterial leaf blight by scissors method in evenings.

The following data were recorded:

- (1) Disease reaction for parents,  $F_1$  and  $F_2$  populations to pathotype I in 0 - 9 scale, 21 days after inoculation.
- (2) Data on other quantitative characters viz., plant height, earbearing tillers, panicle length and single plant grain yields on 40 random  $F_2$  plants in 4 crosses in which IR 8, the susceptible parent was involved.
- (3) Plot yields of five dwarf parents and their ten  $F_2$  populations in both the replications.

### 3.7. Statistical Procedures followed:

#### 3.7.1. Analysis of variance:

The mean values of data on each character collected replication wise were analysed using the DCM computer in the

randomised block design. The analysis was based on the following additive model.

$$y_{ijp} = \mu + \alpha_i + \beta_j + E_{ijp}$$

where,  $Y_{ijp}$  = observation value on the p-th genotype of the j-th block in which i-th treatment occurs.

$$i = 1, 2, \dots, t,$$

$$j = 1, 2, \dots, r,$$

$$p = 1, 2, \dots, k,$$

$\mu$  = General mean,

$\alpha_i$  = i-th treatment effect,

$\beta_j$  = j-th block effect.

$E_{ijp}$ 's are the experimental errors which are independently and normally distributed with zero mean and common variance  $\sigma^2$  ( Rao, 1983 ).

Analysis of variance of the randomized block design for  $F_1$ 's and  $F_2$ 's along with parents was carried out separately and the break up of components of variance is presented in the following Table.

## A N O V A

Source	d.f	Mss	'F' calculated
Replecations	(r-1)	M r	$\frac{M r}{E}$
Treatments	(t-1)	M t	$\frac{M t}{E}$
Parents (p)	(p-1)	M p	$\frac{M p}{E}$
Crosses (c)	(c-1)	M c	$\frac{M c}{E}$
Parents Vs. Crosses 1			
Error	(r-1) (t-1)	E	
Total	(rt-1)		

Where, r = number of replications.

t = number of treatments

p = number of parents

c = number of crosses

The sum of squares due to treatments were partitioned as due to parents,  $F_1$ 's and parents Vs. Crosses. Similar partitioning of variances in  $F_2$  generations for parents and  $F_2$  populations was also done. The sum of squares of each character was tested against the corresponding error degrees of freedom using 'F' test.

Coefficient of variation (CV) as percentage was calculated for all the characters studied using the formula:

$$CV(\%) = \frac{\text{Standard deviation}}{\text{Mean}} \times 100$$

### 3.7.2 Estimation of heterosis and heterobeltiosis:

#### 3.7.2.1 Heterosis:

Heterosis, expressed as percentage increase or decrease of  $F_1$  in its effect over mid parental (MP) value was estimated for 12 characters in accordance with the following formula:

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

Where,

$\bar{F}_1$  = Mean value of  $F_1$  hybrid for the character.

$\bar{MP}$  = Mean value of both the parents of that particular cross combination.

#### 3.7.2.2. Heterobeltiosis:

Heterobeltiosis expressed as percentage increase or decrease of  $F_1$  over better parent (BP) in that particular

cross combination was estimated according to the methods suggested by Hays, et al. (1955) and Briggie (1963).

$$\text{Heterobeltiosis} = \frac{\bar{F}_1 - \bar{BP}}{\bar{BP}} \times 100$$

where,

$\bar{BP}$  = mean value of the superior parent of a particular cross combination, in the desired direction.

$\bar{F}_1$  = mean value of  $F_1$  for the character under study.

### 3.7.2.3 Test of significance:

The heterosis and heterobeltiosis values were tested for statistical significance by 't' test formulae.

$$'t'_{(28-1)} \text{ (for heterosis)} = \frac{H\bar{M}\bar{P}}{SE(H\bar{M}\bar{P})}$$

$$'t'_{(28-1)} \text{ (for heterobeltiosis)} = \frac{H\bar{B}\bar{P}}{SE(H\bar{B}\bar{P})}$$

where ,

$$H\bar{M}\bar{P} = \bar{F}_1 - \bar{M}\bar{P}$$

$$H\bar{B}\bar{P} = \bar{F}_1 - \bar{B}\bar{P}$$

$$SE = \sqrt{\text{Var. of } F_1 \text{'s} + \text{parents}}$$

### 3.7.3 Combining ability analysis:

Estimates of combining ability variances and effects from diallel crosses were calculated following method 2, model I of Griffing (1956). This model was considered more appropriate since, the study was restricted to the parents and single crosses. It was assumed that the effect of reciprocal differences was negligible in rice (Reddy and Rao, 1978 ; Singh and Richharia, 1978) and hence, the single crosses without reciprocals were made and studied. The mathematical model used for this purpose was as follows.

$$x_{ij} = \mu + g_i + g_j + s_{ij} + eijkl$$

where,

$x_{ij}$  = yield of the cross between  
i-th and j-th parents.

$\mu$  = population mean common to  
all parents.

$g_i$  and  $g_j$  = general combining ability (gca) effects  
of i-th and j-th parents respectively,  
in each cross.

$s_{ij}$  = specific combining ability (sca)  
effects of the cross between i-th  
and j-th parents.

$eijkl$  = environmental effect (error) associated  
with individual observation.

## 3.7.3.1 ANOVA:

Analysis of variance (ANOVA) for combining ability was further partitioned into gca and sca as furnished below.

## ANOVA for combining ability by method 2 and model I

Source of variation	d.f	Mss	Estimated mean squares
gca	$P - 1$	$Mg$	$\sigma^2_e + \frac{(p+2)}{(p-1)} \sum g_i^2$
sca	$p(p-1)/2$	$Ms$	$\sigma^2_e + \frac{2}{p(p-1)} \sum_{i < j} s_{ij}^2$
Error	$m$	$M'e$	$\sigma^2_e$

where,

$$M'e = \frac{\text{Error mean sum of squares}}{\text{No. of replications.}}$$

$$m = \text{Degrees of freedom for error}$$

The above partitioning was made as per the following formulae:

$$\text{Correction factor} = 2X^2 \dots / p(p+1) = \frac{(\text{Grand total})^2}{\text{Total No. of plots}}$$

Sum of squares for combining ability

$$S_g = \frac{1}{p+2} \left[ \sum_i (X_i + X_{ij})^2 - 4/p X^2 \dots \right]$$

$$S_s = \sum_{i \leq j} X_{ij}^2 - \frac{1}{p+2} \left[ \sum_i (X_i + X_{ij})^2 + \frac{2}{(p+1)(p+2)} X^2 \dots \right]$$

$$= \text{Genotype s.s.} - \text{gca s.s.}$$

$$= \sum \sum X_{ij}^2 - \text{c.f.} - S_g$$

### 3.7.3.2 Estimation of genetic components:

Keeping in view the expectations of the mean squares the estimates of genetic components were calculated (Singh and Chaudhary 1985) as follows.

$$i) \quad \text{Components due to gca} = \frac{1}{(p-1)} \sum_i g_i^2 = \frac{(Mg - M'e)}{(p+2)}$$

$$ii) \quad \text{Components due to sca} = \frac{2}{p(p-1)} \sum_i \sum_{i < j} s_{ij}^2$$

$$= Ms - M'e$$

iii) Ratio of gca variance to sca variance

$$= \frac{1}{p-1} \sum_i g_i^2 / \frac{2}{p(p-1)} \sum_i \sum_{i < j} s_{ij}^2$$

$$= \frac{\text{Components due to gca}}{\text{Components due to sca}}$$

### 3.7.3.3 Estimation of gca and sca effects:

General combining ability effects ( $\hat{g}_i$ ) of the parents and the specific combining ability effects ( $\hat{s}_{ij}$ ) of the crosses were calculated as per the following formulae

$$i) \quad \hat{g}_i = \frac{1}{p+2} \left[ \sum (X_i + X_{ii}) - \frac{2}{p} X. \right]$$

with restriction  $\sum g_i = 0$

$$ii) s_{ij} = X_{ij} - \frac{1}{p+2} [X_i + X_{ii} + X_j + X_{jj}] + \frac{2}{(p+1)(p+2)} X..$$

$$\text{with restriction } \sum s_{ij} + s_{ii} = 0$$

where,

- $p$  = Number of parents
- $X_i$  = Total of the array involving  $i$ -th parent
- $X_j$  = Total of the array involving  $j$ -th parent.
- $X_{ii}$  = Mean value of the  $i$ -th parent.
- $X_{ij}$  = Mean value of the  $j$ -th parent.
- $X$  = Total of the  $\frac{p(p+1)}{2}$  items in the daillel table.

Standard error (SE) difference between the effects of two crosses having one parent in common was estimated as follows :

$$SE(a) = (s_{ij}^{\wedge} - s_{ik}^{\wedge}) = \frac{2(p+1)}{(p+2)} \sigma^2_e \quad (i \neq j, k; j \neq k).$$

SE of difference between effects of two crosses having no parent in common was calculated as per the following formulae

$$SE(b) = (s_{ij}^{\wedge} - s_{kl}^{\wedge}) = \frac{2p}{(p+2)} \sigma^2_e \quad (i \neq j, k, l; J \neq k, l; k \neq l)$$

$$\text{Var } (g_i^{\wedge}) = \frac{(p-1)}{p(p+2)} \sigma^2_e$$

$$\text{Var } (\hat{s}_{ij}) = \frac{p+2}{(p+1)(p+2)} \sigma^2_e \quad (i \neq j)$$

$$\text{Var } (\hat{g}_i - \hat{g}_j) = \frac{2 \sigma^2_e}{(p+2)}$$

$$\text{Var } (x_{ij} - x_{kl}) = 2 \sigma^2_e$$

The combining ability (gca or sca) effects so calculated were tested for their significance using 't' test formula.

$$'t' = \frac{\text{effect}}{\sqrt{\text{variance of concerned effect}}}$$

### 3.7.3.2 Heritability (H):

Heritability in broad sense (H) is the ratio of genetic variance to the total variance (phenotypic variance) and was calculated by utilizing the formula suggested by Allard (1960) and expressed as percentage. Heritability in narrow sense (h) was estimated by using the formula given by Gardner (1963) and expressed as percentage.

$$i) \text{ Heritability in broad sense (H)} = \frac{\sigma^2_G}{\sigma^2_G + \sigma^2_E}$$

where,

H = Heritability in broad sense.

$$\sigma^2_G = \text{Genetic variance} = \frac{\sigma^2_P - \sigma^2_E}{r}$$

$$\sigma^2_P = \text{Phenotypic variance} = (\sigma^2_G + \sigma^2_E)$$

r = number of replications

$$\sigma^2_E = \text{Environmental variance}$$

ii) Heritability in narrow sense (h)

$$= \frac{\sigma^2_{gca}}{\sigma^2_{gca} + \sigma^2_{sca} + \sigma^2_e}$$

where,

$\sigma^2_{gca}$  = Additive variance (component due to gca variance)

$$= \frac{M_{gi} - M'e}{(P + 2)}$$

$\sigma^2_{sca}$  = Non-additive variance (component due to sca)  
 $= (M s_{ij} - M'e)$

$\sigma^2_e$  = Error component of variance

### 3.7.5 Estimation of expected genetic advance under selection (G.S):

$$G.S = (K) (\sigma_P) (H) = \text{unit/plot}$$

Where,

G.S = Expected genetic advance under selection

K = Selection differential at 5% selection pressure  
 i.e., 2.06

$\sigma_P$  = Phenotypic standard deviation of the mean

H = Heritability coefficient  $\sigma^2_G / \sigma^2_P$

Genetic advance expressed in percent of the population mean

$$= \frac{G.S}{\bar{x}} \times 100$$

( $\bar{x}$  = population mean)

### 3.7.6 Phenotypic and Genotypic correlations:

Variance and covariance for the individual character and for the character pairs were worked out on the basis of mean values of each plot (panse and Sukhatme, 1961). Parents,  $F_1$ 's and  $F_2$ 's were analysed seperately.

All the possible correlation coefficients were calculated at the phenotypic ( $r_p$ ) and genotypic ( $r_g$ ) levels using the formulae suggested by Al-jibouri *et al.* (1958).

$$r_{P_{12}} = \frac{\text{Co V. } P_{12}}{\sqrt{\text{var } P_{11} \times \text{var } P_{22}}}$$

Where,

Cov.  $p_{12}$  = Phenotypic covariance of characters  $x_1$  and  $x_2$

Var.  $p_{11}$  = Phenotypic variance of character  $x_1$

Var.  $P_{22}$  = phenotypic variance of character  $x_2$

$$r_{g_{12}} = \frac{\text{Cov. } g_{12}}{\sqrt{\text{Var. } g_{11} \times \text{Var } g_{22}}}$$

where,

Cov.  $g_{12}$  = Genotypic variance of  $x_1$  and  $x_2$

Var.  $g_{11}$  = Genotypic variance of character  $x_1$

Var. $G_{22}$  = Genotypic variance of character  $x_2$

The values of genotypic correlation exceeding unity should be considered as unity only (of same sign).

### 3.7.6.1 Test of significance:

The estimated values of correlation coefficients at phenotypic and genotypic levels were compared with table values (Fisher and Yates, 1967), at  $n-2$  degrees of freedom to test the significance at 5% and 1% level, where 'n' denotes the number of entries tested.

### 3.7.7 Path coefficient analysis:

Taking single plant yield as dependent variable the direct and indirect effects at phenotypic and genotypic levels for parents,  $F_1$ 's and parents and  $F_1$ 's together were estimated using path coefficient analysis suggested by Wright (1921) and elaborated by Dewey and Lu (1959) to find out the path in which the dependent variable (single plant grain yield) was influenced by the set of characters studied. The following equations were formed and solved simultaneously for estimating the various direct and indirect effects.

$$r_{1y} = P_{1y}r_{11} + P_{2y}r_{12} + P_{3y}r_{13} \dots + P_{10y}r_{110}$$

$$r_{2y} = P_{1y}r_{21} + P_{2y}r_{22} + P_{3y}r_{23} \dots + P_{10y}r_{210}$$

..

..

$$r_{10y} = P_{1y}r_{101} + P_{2y}r_{102} + P_{3y}r_{103} \dots + P_{10y}r_{1010}$$

where.

1,2, .... 10 = independent variables

y = dependent variable (single plant grain yield)

$r_{1y} r_{2y} \dots r_{10y}$  = Coefficients of correlations between independent characters and dependent character Y.

$p_{1y}$  to  $p_{10y}$  = direct effects of characters 1 to 10 on character Y.

### 3.7.8 Residual effects :

The residual effect ( $PR_y$ ) which measures the contributions of the rest of the characters which were not included in the scheme was estimated by using the following formula.

$$\text{Residual effect } (PR_y) = \sqrt{1 - (p_{1y}r_{1y} + p_{2y}r_{2y} + \dots + p_{10y}r_{10y})}$$

where,

$PR_y$  = Residual effect or coefficient.

...

## RESULTS

## CHAPTER IV

### RESULTS

The data recorded on twelve quantitative characters of seven rice varieties and their 21 hybrids used in the present study were statistically analysed and presented under the following heads.

#### 4.1 Testing of parents and $F_1$ hybrids for yield, yield components and resistance to bacterial leaf blight by

- 1 Mean performance and variability.
- 2 Analysis of variance for parents and  $F_1$ 's.
- 3 Estimation of heterosis and heterobeltiosis.
- 4 Combining ability and gene actions.
- 5 Heritability and genetic advance.
- 6 Correlations and character associations.
- 7 Path-coefficient analysis.

#### 4.2 Testing of parents and $F_2$ populations for yield, yield components and resistance to bacterial leaf blight.

- 1 Mean performance of parents and  $F_2$  populations.
- 2 Analysis of variance in parents and  $F_2$  populations.
- 3 Heritability and genetic advance in  $F_2$  populations.
- 4 Correlations and character association in dwarf parents and  $F_2$  populations.
- 5 Path coefficient analysis in dwarf parents and  $F_2$  populations.

- 6 Grain yield performance of five dwarf parents and ten  $F_2$  populations.
  - 7 Analysis of variance of parents and  $F_2$  populations for grain yield.
- 4.3 Testing of parents,  $F_1$ 's and  $F_2$  populations for disease reaction at the seedling and adult plant stages to study inheritance of bacterial leaf blight and allelic relationships among parents for resistance.

4.1 Testing of parents and  $F_1$  hybrids.

4.1.1 Mean performance of parents and hybrids:

Mean performance of parents and their hybrids (Fig.3) used in the present study in relation to 12 quantitative characters are presented in Table 4.

4.1.1.1 Days to 50% flowering:

The mean values of parents and hybrids were 110.05 days and 107.92 days respectively and the general mean was 108.45 days. The parental mean values were greater than the progeny mean values indicating the dominance for early flowering. Among the parents, Nigeria 5 was the earliest to flower with a mean number of 85.09 days to flowering while IR 8, was late to flower with a mean of 121.50 days to flowering followed by IR 19660-274-3-3-1-3 with 120.50 days. Among the  $F_1$  hybrids, the earliest to flower was the hybrid of the cross IET 8320/Nigeria 5 (1/7) with a mean of 82.92

Table 4. Mean performance of 7 parents and 21 F1 hybrids of diallel crosses (without reciprocals) in rice

Sl. No. Parents / Crosses	Days to 50% flowering (No.)	Plant height (cm)	Total tillers/plant (No.)	Earbering tillers/plant (No.)	Paniclen-gth (cm)	Fertile spikelets/panicle (No.) (cm)	Sterile spikelets/panicle (No.)	Sterility percentage	L/B ratio of kernel	1000-grain weight (g)	BLB score (0-9 scale)	Single plant grain yield (g)
===== Parents =====												
1 IET 8320	108.75	83.84	20.42	18.34	22.29	160.67	43.42	23.49	2.37	22.10	2.25	41.71
2 IR 19660	120.50	83.25	15.92	13.00	27.14	128.09	12.50	8.88	3.17	25.85	2.50	29.94
3 IR 54	105.84	75.59	22.59	20.17	21.47	116.00	32.67	21.89	3.14	20.21	3.42	35.36
4 IR 8	121.50	76.92	20.39	17.42	23.21	108.42	11.33	9.44	2.51	24.95	6.85	29.28
5 Cisadane	111.17	87.08	16.34	13.75	23.63	151.25	39.67	20.18	2.98	21.53	3.59	29.98
6 Kuntlan	117.50	139.50	21.25	18.92	27.03	67.17	60.67	47.41	2.29	24.05	2.25	21.63
7 Nigeria 5	85.09	118.17	17.59	16.33	28.40	159.34	72.09	31.08	2.50	18.14	3.42	34.80
Mean	110.05	94.90	19.21	16.84	24.74	127.27	38.91	23.20	2.71	22.40	3.47	31.81
===== Crosses =====												
1 1 / 2	107.59	79.92	23.00	18.10	24.75	140.67	20.50	12.55	2.59	23.46	3.25	41.64
2 1 / 3	105.25	83.40	27.17	24.17	23.16	175.78	47.49	21.58	2.53	19.80	4.65	63.85
3 1 / 4	110.92	87.92	30.75	23.42	23.85	133.17	28.50	17.66	2.39	22.57	5.09	55.45
4 1 / 5	110.25	95.09	31.92	26.50	23.77	157.42	28.49	15.33	2.53	21.08	4.25	63.63
5 1 / 6	115.67	127.67	34.25	29.17	26.74	69.84	117.33	62.07	2.22	25.65	2.25	43.34
6 1 / 7	82.92	104.42	28.67	26.59	25.62	137.84	104.00	42.96	2.44	21.16	3.09	52.39
7 2 / 3	109.00	79.17	31.50	24.25	24.40	113.42	46.58	29.03	2.99	23.84	3.17	47.55
8 2 / 4	121.34	85.17	27.09	23.34	25.64	132.17	12.83	9.07	3.00	26.71	2.09	62.57
9 2 / 5	109.34	84.92	22.50	19.67	25.42	137.17	27.42	16.37	3.01	25.50	2.50	39.38

Contd..

Table 4 Mean performance of 7 parents and 21 F1 hybrids of diallel crosses (without reciprocals) in rice

Sl. No. of Parents/Crosses	Days to flowering (No.)	Plant height (cm)	Total tillers/plant (No.)	Ear-bearing tillers/plant (No.)	Panicle length (cm)	Fertile spikelets/panicle (No.)	Sterility percentage	1000-grain weight (g)	BLB score (0-9)	Single plant grain yield (g)			
10	2 / 6	121.25	133.83	29.50	25.17	28.01	46.84	131.83	73.78	2.50	27.83	4.75	22.35
11	2 / 7	108.34	121.09	22.50	20.09	27.17	152.59	52.50	25.30	2.66	20.01	2.00	59.13
12	3 / 4	107.42	84.34	28.34	24.59	23.55	119.50	53.50	30.79	2.85	22.37	5.58	41.83
13	3 / 5	108.00	86.67	30.84	26.34	24.08	125.42	61.84	33.03	3.01	21.83	2.84	51.55
14	3 / 6	108.67	116.42	28.08	26.17	24.69	64.25	105.00	61.99	2.37	24.00	2.09	25.70
15	3 / 7	95.92	111.83	22.17	20.59	25.89	146.25	46.84	24.30	2.59	19.48	2.59	40.05
16	4 / 5	118.09	80.67	20.59	18.00	23.10	127.33	10.50	7.82	2.72	23.76	3.59	36.42
17	4 / 6	120.34	126.92	31.50	25.17	27.95	89.50	84.00	47.85	2.18	25.47	6.34	46.80
18	4 / 7	95.25	106.50	24.00	22.34	26.05	148.09	96.75	39.46	2.33	21.23	1.92	50.29
19	5 / 6	115.42	113.17	33.25	28.42	26.26	127.34	73.75	36.77	2.50	23.61	4.67	56.54
20	5 / 7	102.09	121.34	29.00	27.17	27.11	170.25	83.50	33.00	2.64	19.55	2.17	58.23
21	6 / 7	93.25	150.34	32.09	30.83	29.20	173.58	54.50	23.90	2.28	21.09	2.00	72.40
Mean		107.45	103.85	28.03	24.29	25.54	128.02	61.32	31.65	2.59	22.90	3.37	49.10
Gen. Mean		108.45	101.61	25.83	22.43	25.34	127.83	55.71	29.53	2.62	22.78	3.40	44.78
SE. (+/-)		0.55	3.31	2.57	1.99	1.02	14.78	13.67	5.52	0.04	0.55	0.43	6.84
CD. (0.05)		1.12	6.78	5.28	4.09	2.10	30.33	28.05	11.22	0.09	1.12	0.88	14.03
CV. (%)		0.50	3.25	9.96	8.88	4.03	11.56	24.53	18.68	1.66	2.40	12.59	15.27

days to flowering.  $F_1$  progeny of the cross IR 19660-274-3-3-1-3/IR 8 (2/4) recorded the maximum number of 121.34 days to flowering in which both the parents involved were of long duration. The range was 36.41 days in parents and 38.42 days in the  $F_1$  hybrids indicating a wide magnitude of variability for this character. Nigeria 5, the parent with shortest duration to flower resulted in  $F_1$  hybrids with shorter duration and the one that recorded the lesser mean number of days to flowering (1/7) also had Nigeria 5 as one of its parents.

#### 4.1.1.2 Plant height:

Plant height among the parents ranged from a minimum of 75.59 cm recorded by IR 54 to a maximum of 139.50 cm recorded by Kuntlan with a general mean of 94.90cm. Among the  $F_1$  hybrids of different crosses also, the variability in plant height was high which ranged from a minimum of 79.17cm in the cross IR 19660-274-3-3-1-3/IR 54 (2/3) to a maximum of 150.34 cm in Kuntlan/Nigeria 5 (6/7) with a  $F_1$  mean of 103.85 cm. The  $F_1$ 's in general, excelled the parents both in range as well as general mean in plant height indicating heterotic effect. The shortest (2 / 3) and the tallest (6/7) among the  $F_1$  hybrids were the progenies of two dwarf and two tall parents respectively.

#### 4.1.1.3 Total tillers per plant:

Data on number of total tillers at maximum tillering phase revealed that the hybrids with a mean of 28.03 tillers

per plant were superior to the parents that recorded a mean number of 19.21 tillers per plant. The tiller number ranged from a minimum of 15.92 (IR 19660-274-3-3-1-3) to a maximum of 22.59 among parents, while in  $F_1$  hybrids, the range was from 20.59 recorded by the cross IR 8/Cisadane (4/5) to 34.25 recorded by the cross IET 8320/Kuntlan (1/6).

#### 4.1.1.4 Earbearing tillers (EBT) per plant:

As expected the number of earbearing tillers per plant were less than the number of total tillers in both parents and crosses. The percentage of effective tillers in parents (87.68) was slightly more than that of the crosses (86.64), indicating that the ineffective tillers were slightly more in hybrids. Earbearing tiller number per plant ranged from a minimum of 13.00 (IR 19660-274-3-3-1-3) to a maximum of 20.17 (IR 54) with a mean of 16.84 in parents and the range in  $F_1$  hybrids was from 18.10 to 30.83 with a mean of 24.29. The  $F_1$  hybrids of the cross Kuntlan/Nigeria 5 (6/7) recorded the maximum number of vegetative tillers as well as the earbearing tillers per plant.

#### 4.1.1.5 Panicle length:

The mean values in panicle length in parents and hybrids were 24.74 cm and 25.54 cm respectively. The highest panicle length among the parents was registered by Nigeria 5 (28.40) while the lowest panicle length was recorded by IR 54 (21.47cm). The range was comparatively narrow in hybrids (23.10 to 29.20) than in parents (21.47 to 28.40cm). It is

interesting to note that mean values of panicle length of tall lines were more than that of the dwarfs both in parents as well as hybrids.

#### 4.1.1.6 Fertile spikelets per panicle:

Number of fertile spikelets per panicle ranged from a minimum of 67.17 (Kuntlan) to a maximum of 160.67 (IET 8320) in parents with a mean of 127.27. The mean values of hybrids ranged from 46.84 (IR 19660-274-3-3-1-3/Kuntlan) to 175.78 (IET 8320/IR 54) extending widely on either side of the parental mean of 128.02 fertile spikelets per panicle. It was evident from the results that Kuntlan, a parent that recorded the least number of fertile spikelets, also contributed poor performance to its hybrids.

#### 4.1.1.7 Sterile spikelets per panicle:

Among the parents, the highest number of sterile spikelets per panicle was recorded by Nigeria 5 (72.09) followed by Kuntlan with 60.67. However, the number of sterile spikelets was not so spectacular in its hybrids in combination with other parents. The number of sterile spikelets was the least in IR 8 with 11.33 closely followed by IR 19660-274-3-3-1-3 with 12.5 per panicle. Among the  $F_1$  hybrids, highest number of sterile spikelets per panicle (131.83) was found in the cross IR 19660-274-3-3-1-3/Kuntlan (2/6), while it was least (10.50) in the cross IR 8/ Cisadane (4/5). The means of parents and crosses were 38.91 and 61.32

indicating the intensity and magnitude of sterile spikelets manifested by the  $F_1$  hybrids.

#### 4.1.1.8 Sterility percentage:

Sterility percentage in parents ranged from a minimum of 8.88 (IR 19660-274-3-3-1-3) to a maximum of 47.41 (Kuntlan) and in  $F_1$  hybrids the range was from 7.82 (IR 8/Cisadane) to 73.78 (IR 19660-274-3-3-1-3/Kuntlan).  $F_1$  hybrids, in general, registered spectacular increase in sterility over the parents. In Nigeria 5 and its  $F_1$  derivatives in combination with other parents, the percentage of sterility however was comparatively low.

#### 4.1.1.9 L/B ratio of the kernel:

The mean values of L/B ratios of kernel were high in IR 19660-274-3-3-1-3 and IR 54 since, both the varieties manifested long slender grain type. The mean L/B ratio values ranged from a minimum of 2.29 recorded in Kuntlan, a variety with short bold grain type, to a maximum of 3.17 in IR 19660-274-3-3-1-3, a long slender line. The mean of parents was 2.71. In  $F_1$  hybrids the trend was more towards coarse grain type. The L/B ratios ranged from a minimum of 2.18 in the cross IR 8/Kuntlan (4/6) to a maximum of 3.01 recorded in two crosses, IR 19660-274-3-3-1-3/Cisadane (2/5) and IR 54/Cisadane (3/5), with a general mean of 2.59. Cisadane, a medium slender variety recorded higher mean values of L/B ratio in combination with IR 19660-274-3-3-1-3

and IR 54 having long bold and long slender grain types respectively.

#### 4.1.1.10 1000-grain weight:

As expected, the varieties with coarse grain type recorded higher 1000-grain weight. IR 19660-274-3-3-1-3, a long slender variety recorded the maximum 1000-grain weight of 25.85 g closely followed by IR 8 with 24.95 g. Nigeria 5, a medium fine variety recorded the lowest 1000-grain weight of 18.14g. The mean value of the parents was 22.40 g. The mean 1000-grain weight of hybrids (22.90g) was slightly more than the mean value of parents. The highest 1000-grain weight among the hybrids was 27.85g recorded by the cross IR 19660-274-3-3-1-3/Kuntlan (2/6) and the lowest was 19.48g recorded in IR 54/Nigeria 5 (3/7) with a general mean of 22.78 g indicating wide variability on either side of parental mean.

#### 4.1.1.11 BLB Score ( 0 - 9):

The virulent isolate of Xanthomonas campestris pv. oryzae (pathotype I) was inoculated on all the seven cultivars and their 21 F<sub>1</sub> hybrids and the reaction for disease resistance was scored in 0-9 scale. The cultivars as well as hybrids showed clear cut differences and wide variability in their reaction for disease resistance.

Among the parents, IR 8 showed susceptible reaction for the disease. IET 8320, Kuntlan and IR 19660-274-3-3-1-3

were resistant while the rest i.e., IR 54, Cisadane and Nigeria 5 were moderately resistant. The mean disease score among the parents ranged from a minimum of 2.25 to a maximum of 6.85 (IR 8) with an overall mean of 3.47. Disease reaction among the hybrids ranged from a highly resistant reaction (1.92) recorded in IR 8/Nigeria 5 to a susceptible reaction (6.34) recorded in IR 8/Kuntlan with an overall mean of 3.37. It is interesting to note that IR 8, the susceptible parent, resulted in  $F_1$  hybrids of different grades of resistance in combination with different resistant parents and on the contrary, resistant parents produced resistant as well as moderately resistant  $F_1$  hybrids. Nigeria 5, a moderately resistant variety with red rice could produce all resistant hybrids in combination with resistant as well as susceptible varieties.

#### 4.1.1.12 Single plant grain yield:

Single plant grain yield in parents ranged from 21.63 g (Kuntlan) to 41.71g (IET 8320) with a mean of 31.81g. IET 8320 ranked first followed by IR 54 and Nigeria 5. The mean single plant grain yield of hybrids was 49.10 g. The range in single plant grain yields among the hybrids was very wide and conspicuous starting from a minimum of 22.35 g recorded by the cross IR 19660-274-3-3-1-3/Kuntlan (2/6) to a maximum of 72.40 g recorded by Kuntlan/Nigeria 5 (6/7). The performance of hybrids of the crosses in which Cisadane was involved as one of the parents was comparatively superior to

others. The mean of hybrids (49.10 g) was higher than that of either parents or parents and hybrids combined (44.78 g) indicating the role of heterosis for single plant grain yield in  $F_1$ .

#### 4.1.2 Analysis of variance for parents and $F_1$ hybrids:

The ANOVA for 12 characters of seven parents and 21  $F_1$  hybrids is presented in Table 5.

It could be seen from the data that no significant differences exist between the replications for any of the characters studied. Treatments which included both parents and their hybrids registered highly significant differences among themselves for all the characters. This source was further partitioned as, due to parents and crosses and analysed statistically. Significant differences were registered for all the characters except two i.e., total tillers and single plant grain yield among parents. The differences among the hybrids were significant for all the characters studied. By comparing the parents Vs. crosses considering them as separate groups, significant differences were observed for ten characters. However, the differences were not significant for two characters viz. fertile spikelets per panicle and BLB score. Differences in panicle length for parents Vs. crosses, were significant at 5% level only, probably due to the fact that the range and mean among parents and hybrids are more or less similar.

Table 5 ANOVA for 12 characters of 7 parents and 21 hybrids in a diallel set of crosses (without reciprocals) in rice

Source	df	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
Reps.	1	0.42	8.48	0.25	1.38	0.23	74.36	6.92	0.35	0.0001	0.019	0.005	106.29
Treats.	27	214.79	955.21	58.02	43.02	7.94	2323.19	2273.45	587.72	0.1689	11.832	3.833	370.79
Parents	6	226.37	1182.09	13.38	14.16	14.90	2271.35	1030.61	351.22	0.2800	14.983	5.120	78.85
Crosses	20	216.01	892.95	33.46	24.74	5.92	2454.61	2496.29	650.59	0.1363	11.347	3.633	320.06
P.Vs.C.	1	120.97	839.33	817.13	581.58	6.82	5.80	5273.63	749.46	0.1534	2.623	0.093	3137.10
Error	27	0.30	10.92	6.62	3.97	1.05	208.48	186.86	30.43	0.0019	0.298	0.183	46.75
SED.(+/-)		0.55	3.31	2.57	1.99	1.02	14.78	13.67	5.56	0.0440	0.546	0.427	6.84
CD.(0.05)		1.12	6.78	5.28	4.09	2.10	30.33	28.05	11.32	0.0903	1.121	0.877	14.03

\* significant at 5% \*\* significant at 1%

#### 4.1.3 Heterosis and heterobeltiosis:

Heterosis and heterobeltiosis were calculated for 12 characters in 21 hybrids as percentage increase or decrease ( $\pm$ ) over the mid parental value and that over the better parental value respectively. The values were tested for their significance and presented in the tables 6 and 7 for heterosis and heterobeltiosis respectively.

##### 4.1.3.1 Days to flowering:

Lesser number of days to 50% flowering leads to early maturity. Negative values of heterosis or heterobeltiosis over parent with shorter duration are considered desirable. Heterosis percentage for days to flowering ranged from  $-14.45^{**}$  (1/7) to  $5.39^{**}$  (2/7). Ten crosses out of 21 studied, had significant percentage of negative values for heterosis resulting in hybrids with shorter duration to flowering. Percentage of heterobeltiosis ranged from  $-2.55^{**}$  (1/7) to  $27.33^{**}$  (2/7). Only three crosses expressed significant level of heterobeltiosis<sup>†</sup> for days to flowering in the desired direction. Crosses, in which parents like Nigeria 5, IR 54 and IET 8320 were involved as parents appeared to have heterosis and heterobeltiosis for early flowering, a desirable trait, in rice for crop improvement.

Table 6 Heterosis (%) for 12 characters in 21 F1 hybrids of 7 x 7 diallel set of crosses in rice.

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicles length	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
1 / 2	** -6.14	-4.34	26.62	15.53	0.15	-2.57	-26.67	-22.46	-6.67	-2.15	36.84	16.22
1 / 3	** -1.90	4.63	26.35	25.53	5.86	27.07	24.82	-4.90	-8.33	-6.39	64.17	65.70
1 / 4	** -3.66	9.39	50.74	30.99	4.86	-1.02	4.12	7.25	-1.84	-4.08	11.76	56.22
1 / 5	** 0.26	11.27	73.69	65.19	3.52	0.94	-31.43	-29.78	-5.37	-3.38	45.67	79.26
1 / 6	** 2.25	14.33	64.41	56.59	8.46	-38.70	125.46	75.08	-4.86	11.16	0.00	36.84
1 / 7	** -14.45	3.38	50.87	53.38	1.08	-13.85	80.09	57.45	0.16	5.14	8.91	36.93
2 / 3	** -3.68	-0.39	63.63	46.24	0.39	-7.07	106.24	88.65	-5.18	3.53	7.02	45.65
2 / 4	** 0.28	6.41	49.23	55.44	1.86	11.77	7.68	-0.93	5.64	5.16	-55.40	111.32
2 / 5	** -5.61	-0.29	39.54	47.07	0.12	-1.79	5.12	12.18	-2.13	7.65	-17.83	31.44
2 / 6	** 1.89	20.16	58.75	57.73	3.43	-52.03	260.36	162.15	-8.29	11.52	100.00	-13.31
2 / 7	** 5.39	20.23	34.33	36.96	-2.18	6.18	24.14	26.64	-6.14	-4.48	-32.54	82.65

contd..

Table 6 contd..

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Paniccle length	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
3 / 4	-5.50**	10.60*	31.88*	30.89**	5.43	6.50	143.18*	96.49*	0.84	-0.94	8.72	29.43**
3 / 5	-0.46	6.56	58.45**	55.30**	6.76	-6.14	70.96	57.04*	-1.63	4.63	-19.00	57.81
3 / 6	-2.69**	8.25*	28.12*	33.91*	1.83	-29.85	125.00**	78.87**	-12.79**	8.44**	-26.39	-9.81*
3 / 7	0.48**	15.44**	10.36	12.81	3.83	6.23	-10.58	-8.25	-12.81**	1.58	-24.31	14.18
4 / 5	1.50**	-1.62**	12.12**	15.51**	-1.36*	-1.93	-58.82**	-47.21**	-0.95**	2.25	-31.29**	22.92**
4 / 6	0.70**	17.29**	51.32**	38.54**	11.29*	1.95	133.35**	68.33**	-9.06**	3.96	39.23**	83.89**
4 / 7	-7.79**	9.19*	26.42*	32.38*	0.96	10.61	131.97**	94.78**	-6.72**	-1.49	-62.59**	56.96*
5 / 6	0.95**	-0.11**	76.93**	73.98**	3.68	16.60	47.01	8.79	5.21**	3.59	59.90**	119.15**
5 / 7	4.03**	18.23**	70.99**	80.62**	4.21	9.63	49.43	28.77*	-3.40*	-1.42	38.14**	79.78**
6 / 7	-7.94**	16.69**	65.24**	74.95**	5.37	53.27**	-17.89	-39.11**	-4.66*	-0.02	-29.39**	156.62**
Min	-14.45	-4.34	10.36	12.81	-2.18	-52.03	-31.43	-47.21	-12.81	-6.39	-62.59	-13.31
Maxi	5.39	20.23	76.93	80.62	11.29	53.27	260.36	162.15	5.64	11.52	100.00	156.62

\* Significant at 5% level. \*\* Significant at 1% level.

Table 7 Heterobeltiosis (%) for 12 characters in 21 F1 hybrids of 7 x 7 diallel set of Crosses in rice.

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
1 / 2	* -1.07	-4.00	12.66	-1.28	* -8.81	-12.45	61.60	** -18.40	** -9.25	* 44.44	-0.18
1 / 3	-0.55	10.34	20.28	19.84	3.93	9.41	45.35	** -19.51	** -10.41	** 106.67	53.08
1 / 4	** 1.99	** 14.31	** 50.63	* 27.71	2.78	-17.12	151.55	* -6.26	** -9.56	** 126.00	32.93
1 / 5	* 1.38	** 13.42	** 56.33	** 44.53	0.57	-2.02	-28.20	** -14.98	** -4.64	** 88.89	52.54
1 / 6	** 6.36	** 52.29	** 61.18	** 54.19	-1.06	** -56.53	170.25	** -6.53	** 6.65	0.00	3.90
1 / 7	** -2.55	** 24.55	** 40.41	** 45.00	* -9.81	-14.21	139.55	-2.36	-4.28	37.11	25.59
2 / 3	** 2.99	4.74	** 39.47	* 20.26	* -10.10	-11.45	* 272.64	** -5.65	** -7.78	26.60	34.49
2 / 4	0.69	** 10.73	* 32.87	33.99	-5.53	3.19	13.24	** -5.40	3.33	-16.60	108.97
2 / 5	** -1.65	2.00	* 37.74	** 43.06	-6.36	-9.31	119.36	** -5.08	-1.35	0.00	31.36
2 / 6	** 3.20	** 60.76	** 38.82	** 33.07	3.21	-63.43	954.64	** -21.02	** 7.64	111.11	-25.35
2 / 7	** 27.33	** 45.45	27.95	22.99	-4.35	-4.24	320.00	** -16.09	** -18.72	-20.20	69.90

contd..

Table 7 contd..

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Paniclen-gth	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility tage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
3 / 4	1.50**	11.58*	25.46*	21.92*	1.49	3.08	372.20**	226.06**	-9.28**	-10.36**	63.40**	18.30
3 / 5	2.05**	14.67**	36.53**	30.60**	1.88	-17.08	89.27*	63.72*	-4.14**	1.42	-16.98	45.88*
3 / 6	2.67**	54.02**	24.33*	29.76**	-8.64*	-44.61**	221.40**	183.12**	-24.55**	-0.23	-7.33	-27.32
3 / 7	12.73**	47.95**	-1.86	2.08	-8.84*	-8.21	43.36	10.99	-17.53**	-3.61	-24.31	13.28
4 / 5	6.22**	4.88	0.98	3.36	-2.24	-15.82	-7.33	-17.20	-8.77**	-4.77*	0.00	21.49
4 / 6	2.41**	65.01**	48.24**	33.04**	3.42	-17.45**	641.40**	406.81**	-12.96**	2.08	181.56**	59.86*
4 / 7	11.95**	38.47**	17.73**	28.25*	-8.28*	-7.06	753.93**	317.96**	-16.13**	-14.93**	-43.78**	44.49*
5 / 6	3.82**	29.96**	56.47**	50.23**	-2.83	-15.81	86.67*	82.21**	-16.12**	-1.85	107.33**	88.62**
5 / 7	19.98**	39.41**	64.91**	66.35**	-4.54	6.85	110.49**	63.56*	-11.19**	-9.18**	36.60**	67.31**
6 / 7	9.60**	27.23**	50.99**	62.99**	2.82	8.94	-10.16	-23.12	-8.61**	-12.31**	-11.11	108.05**
Min.	-2.55	-4.00	-1.86	-1.28	-10.10	-63.43	-28.20	-24.01	-24.55	-18.72	-43.78	-27.32
Max.	27.33	65.01	64.91	66.35	3.93	9.41	954.64	731.01	-2.36	7.64	181.56	108.97

\* Significant at 5% level.

\*\* Significant at 1% level.

#### 4.1.3.2 Plant height:

Dwarf to semidwarf plant stature in rice is usually considered to be a better plant type that resists lodging. The percentage of heterosis and heterobeltiosis ranged from -4.34 (1/2) to 20.23<sup>\*\*</sup> (2/7) and -4.00 (1/2) to 65.01<sup>\*\*</sup> (4/6) respectively. Since the percentage of negative heterosis or heterobeltiosis is considered desirable, it is interesting to note that none of the hybrids studied showed any significant heterosis or heterobeltiosis in the desired direction. In other words most of the hybrids were significantly taller than the mid parent or the better parent (dwarf) and the positive values of plant height were highly significant in crosses where a tall parent was involved.

#### 4.1.3.3 Total tillers:

Number of total tillers per plant at maximum tillering phase is the index of vigour and productivity of the crop. The heterosis (%) for this character ranged from 10.36 (3/7) to 76.93<sup>\*\*</sup> (5/6), while the percentage of heterobeltiosis ranged from -1.86 (3/7) to 64.91<sup>\*\*</sup> (5/7). However, none of the hybrids registered a significant percent of negative value of heterobeltiosis for this character. It could be seen from the data that crosses in which IET 8320, IR 54 and Cisadane were involved as parents, produced hybrids with significant percent of positive values of high magnitude of heterosis and also heterobeltiosis. Only one cross (3/7) recorded feeble negative heterobeltiosis.

#### 4.1.3.4 Ear bearing tillers per plant:

The percentage increase of earbearing tillers per plant over mid parent varied widely with a range of 12.81 (3/7) to 80.62\*\* (5/7). Hybrids of 18 crosses registered statistically significant levels of heterosis for this character. Since, the contribution of this character for grain yield is considered to be obvious, it is desirable to have crosses with high level of heterosis or heterobeltiosis for number ear bearing tillers per plant.

Except in the cross IET 8320 / IR 19660-274-3-3-1-3 (1/2), all the crosses expressed positive heterobeltiosis. There is a wide range among the crosses starting from negative heterobeltiosis of -1.28 (1/2) to a highly significant positive value of 66.35\*\* (5/7). Of the 21 crosses studied, 15 crosses registered significant percentage of increased number of earbearing tillers over the better parent. It is evident from the data that  $F_1$  hybrids produced maximum tillers at maximum tillering phase, also produced maximum number of ear bearing tillers per plant.

#### 4.1.3.5 Panicle length:

The heterobeltiosis for this character ranged from -2.18 (2/7) to 11.29\* percent (4/6). Negative heterosis was observed in two crosses. Though positive heterosis for panicle length was recorded by many of the crosses studied,

except in the cross IR 8 / Kuntlan (4/6), in none of the other crosses it was statistically significant.

Heterobeltiosis in negative direction for panicle length was significant at 5% level in six crosses. Heterobeltiosis ranged from  $-10.10^*$  (2/3) to  $3.93$  (1/3). 13 crosses recorded negative values of heterobeltiosis. Kuntlan/IR 54 appears to contribute more for heterosis and heterobeltiosis for this character. However, none of the  $F_1$  hybrids exhibited desired positive heterobeltiosis.

#### 4.1.3.6 Fertile spikelets per panicle:

The heterosis for this character ranged between  $-52.03^{**}$  (2/6) and  $53.27^{**}$  (6/7). Out of ten crosses that registered negative heterosis, two were highly significant. All the remaining crosses, though possessed positive values, only two (1/3 and 6/7) exhibited significant heterosis. Heterobeltiosis for fertile spikelets was highly significant in the negative direction in four crosses. Of the 5 crosses that recorded positive heterosis, none registered any significant increase over the better parent.

#### 4.1.3.7 Sterile spikelets per panicle:

In this character the negative values are important as reduced percentage of spikelet sterility would mean higher productivity and hence, the parent with lesser number of sterile spikelets was considered as better parent. Heterosis

for this character ranged from -31.43 (1/5) to 260.36\*\* percent (2/6), while the range for heterobeltiosis was -28.20 (1/5) to 954.64\*\* percent (2/6). However, in both the cases no significant values in the desired direction (negative) were registered. On the contrary, seven crosses had significant percentage of increase over mid parent and 12 crosses over better parent for number of sterile grains per panicle.

#### 4.1.3.8 Sterility percentage:

Seven crosses recorded negative heterosis for percentage of sterility ranging from -47.21 (4/5) to -0.93 (2/4) of which, only in one cross, Kuntlan/Nigeria 5 (6/7) it was significant (-39.11\*\*). Among the 14 crosses with positive heterosis ranging from 7.25 (1/4) to a maximum of 162.15\*\* (2/6), six crosses were significant at 1% level and an additional 3 at 5% level.

Negative heterobeltiosis was observed in four crosses ranging from -24.01 (1/5) to -1.43 (1/3) percent and in none of the crosses it was significant. These four crosses also showed negative heterosis for sterility. Among the 17 crosses with positive heterobeltiosis, 10 crosses were highly significant and two were significant at 5% level. On critical examination of data, it appears that Kuntlan having maximum percentage of sterility among parents (47.41) also contributed more for positive heterosis and / or heterobeltiosis in combination with most of the parents for percentage of sterility, an undesirable character. However,

the contribution of Kuntlan in specific combination with Nigeria 5 exhibited significant heterosis in the desired direction.

#### 4.1.3.9 L/B Ratio of the kernel:

Narrower the L/B ratio of the kernel, Coarser would be rice in quality. So the parent with wider L/B ratio was considered as better parent and hence the positive values of heterosis and/or heterobeltiosis were considered desirable. Only four, crosses registered positive heterosis for L/B ratio, of which two crosses (2/4 and 5/6) were significant. Among the 17 crosses that exhibited negative heterosis, 13 crosses were significant. The heterosis for this character ranged from  $-12.81^{**}$  (3/7) to  $5.64^{**}$  (2/4). All the crosses registered significant negative heterobeltiosis except IET 8320/Nigeria 5 (1/7). In other words it is clear that none of the cross combinations could produce hybrids with fine rice than the better parent with finer rice quality.

#### 4.1.3.10 1000-grain weight:

Among 21 crosses studied, 12 crosses registered positive heterosis for 1000-grain weight of which five crosses were significant with values ranging from  $5.16^*$  (2/4) to  $11.52^{**}$  (2/6). Among the crosses that recorded negative heterosis, only one cross, IET 8320/IR 54 showed significant negative heterosis ( $-6.39^*$ ).

Parent with higher 1000-grain weight was taken as better parent for this character and significant percentages of positive increase over better parent were established only in two crosses namely IR 19660-274-3-3-1-3/Kuntlan ( $7.64^{**}$ ) and IET 8320 / Kuntlan ( $6.65^{**}$ ). Negative heterobeltiosis registered in 16 crosses ranged from  $-18.72^{**}$  (2/7) to  $-0.23$  (3/6). Only in one cross, IR 19660-274-3-3-1-3/IR 8 (2/4), the  $F_1$  hybrids were heterotic simultaneously both for L/B ratio and 1000-grain weight in the desired direction i.e., with fine grain quality and high 1000-grain weight.

#### 4.1.3.11 BLB Score:

Parent with high level of resistance having low BLB score was considered as better parent and hybrids having lesser BLB score than the mid parent or the better parent are desirable showing negative values of heterosis or heterobeltiosis. Out of nine crosses that scored negative heterosis for BLB score, only four were significant and the values ranged from  $-62.59^{**}$  (4/7) to  $-17.83$  (2/5). In most of the crosses that scored negative heterosis, Nigeria 5 and Cisadane were involved as one of the two parents. Percentage of positive heterosis ranged from nil (1/6) to  $100.00^*$  (2/6).

Heterobeltiosis in the negative direction was highly significant only in two crosses IR 8/Nigeria 5 ( $-43.78^{**}$ ) and Cisadane /Nigeria 5 ( $-36.60^{**}$ ). The range varied from  $-43.78^{**}$  to  $-7.33$  percent. The involvement of Nigeria 5 and Cisadane in crosses appears to have contributed more for

negative values of heterobeltiosis giving scope to predict heterotic, highly resistant genotypes.

#### 4.1.3.12 Single plant yield

Heterosis for single plant grain yield ranged from -13.31 (2/6) to 156.62<sup>\*\*</sup> (6/7) percent. Except two crosses, all the 19 crosses registered positive heterosis of which, 13 were significant. Three crosses recorded feeble negative heterobeltiosis ranging from -27.32 (3/6) to -0.18 (1/2). Of the 18 crosses that registered positive heterobeltiosis for yield, seven crosses recorded significant values. Heterobeltiosis for single plant grain yield among promising crosses ranged from 44.49<sup>\*</sup> (4 x 7) to 108.97<sup>\*\*</sup> (2/4) percent. From the data it can be seen that Nigeria 5, Cisadane and IR8 contributed more for significant positive heterobeltiosis for grain yield.

#### 4.1.4 Combining ability and gene actions:

##### 4.1.4.1 Analysis of variance for combining ability:

Analysis of variance and genetic components for combining ability were done for all the twelve characters and the results presented in Table 8.

Variance due to gca for all the characters were highly significant indicating that all the seven parents studied, differed significantly in their general combining ability for the characters studied. Sca variances were

Table 8 ANOVA for combining ability in 7 parents and 21 F1 hybrids of 7 x 7 diallel set of crosses in rice

df	Days to flowering	Plant height	Total tillers/plant	Earbearing tillers/plant	Panicleness	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
6	408.918	1916.618	24.308	22.866	15.748	3453.931	2216.686	696.280	0.336	23.020	3.469	135.693
21	21.248	66.461	30.355	21.120	0.608	506.642	828.162	178.886	0.013	1.029	1.473	199.592
27	0.149	5.462	3.312	1.984	0.524	109.239	93.431	15.213	0.001	0.149	0.091	23.377

Genetic components.

Due to gca	45.419	212.351	2.333	2.320	1.692	371.633	235.917	75.674	0.037	2.541	0.375	12.480
Due to sca	21.099	60.999	27.043	19.136	0.084	397.404	734.731	163.673	0.012	0.880	1.381	176.222
gca/sca Var.	2.153	3.481	0.086	0.121	20.162	0.935	0.321	0.462	0.180	2.888	0.272	0.071
Narrow sense heritability as % (n)	68.130	76.160	7.140	9.900	73.570	42.310	22.170	29.730	74.550	71.180	20.310	5.880

\* Significant at 5% level. \*\* Significant at 1% level.

significant for eleven characters and was not significant for panicle length which implies that the specific combining ability is also equally important except in the case of panicle length.

Estimates of components of variance due to gca were higher than that of sca and consequently the ratio of gca variance to sca variance was higher than unity for flowering duration, plant height, panicle length, L/B ratio, and 1000-grain weight. The components of variance due to sca were higher than the components of variance due to gca for rest of the characters i.e., total tillers, earbearing tillers, number of fertile spikelets per panicle, number of sterile spikelets per panicle, percentage of sterility, BLB score and single plant grain yield and consequently the ratio of sca variance to gca variance was lesser or closer to unity. This indicates that the influence of non-additive gene action is predominant in the former five characters with high percent of heritability values in narrow sense, while in the case of later seven characters the presence of both additive and the non-additive gene action is indicated. Heritability in narrow sense ranged from 76.16 percent for plant height to 5.88 percent for single plant grain yield.

#### 4.1.4.2 Genral combining ability effects:

The gca effects for all the 12 characters of seven parents were estimated and presented in table 9. The merits of parents were evaluated on the basis of gca effects.

Table 9 General combining ability effects of 7 parents crossed in 7 x 7 diallel set (without reciprocals) in rice.

Sl. No.	Parents	Days to flowering	Plant height	Total tillers/plant	Earbering tillers/plant	Paniclen-gth	Fertile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
1	IET 8320	-1.947	-7.422	1.107	0.577	-0.142	12.597	-1.397	-0.166	-0.480	-0.011	5.055
2	IR 19660-274-3-3-1-3	5.582	-6.922	-2.077	-2.533	0.770	-4.849	-14.338	0.239	1.980	-0.491	-2.858
3	IR 54	-2.408	-11.099	0.738	0.778	-1.558	-5.116	-2.126	0.185	-1.167	0.063	-1.886
4	IR 8	5.416	-9.727	-0.398	-0.860	-0.686	-6.229	-15.218	-0.050	1.086	1.236	-0.702
5	Cisadane	1.990	-6.320	-0.651	-0.647	-0.638	13.862	-8.986	0.158	-0.428	0.0003	0.831
6	Kuntlan	4.664	26.050	2.728	2.592	1.575	-35.221	26.893	-0.256	1.502	-0.065	-5.315
7	Nigeria 5	-13.297	15.439	-1.447	0.093	1.678	24.956	15.172	-0.110	-2.493	-0.732	4.874
	SE.(gi)	0.119	0.721	0.562	0.435	0.223	3.225	2.983	1.204	0.0096	0.119	0.093
	SE.(gi-gj)	0.182	1.102	0.858	0.664	0.341	4.927	4.557	1.839	0.0147	0.182	0.142

\* Significant at 5% level. \*\* Significant at 1% level.

## 4.1.4.2.1 Days to flowering:

Gca effects for days to flowering in all the seven parents were highly significant. Short duration varieties Nigeria 5, IR 54 and IET 8320 recorded negative effects while long duration varieties IR 19660-274-3-3-1-3, IR 8, Kuntlan and Cisadane recorded positive effects. Highest significant negative gca effect of  $-13.297^{**}$  and highest significant positive gca effect of  $5.582^{**}$  were recorded in Nigeria 5 and IR 19660-274-3-3-1-3 respectively.

## 4.1.4.2.2 Plant height:

All the seven parents were highly significant in their gca effects for plant height. Except the tall indicas, Kuntlan and Nigeria 5, the remaining five dwarf to semidwarf indica parents recorded negative gca effects ranging from  $-11.099^{**}$  (IR 54) to  $-6.320^{**}$  (Cisadane). Kuntlan, the tallest parent recorded maximum positive effect of  $26.050^{**}$  followed by Nigeria 5 with  $15.439^{**}$ .

## 4.1.4.2.3 Total tillers:

Only three parents recorded significant gca effects for this character of which, two registered negative gca effects significant at 5% level and one, positive gca effect highly significant. Kuntlan recorded the highest positive significant gca effect of  $2.728^{**}$ .

#### 4.1.4.2.4 Earbearing tillers:

Four parents recorded positive gca effects and three parents negative gca effects. Among those that recorded significant gca effects, Kuntlan with (2.592<sup>\*\*</sup>) positive and IR 19660-274-3-3-1-3 with (-2.533<sup>\*\*</sup>) negative gca effects were highly significant indicating that the former was a good general combiner for earbearing tillers per plant.

#### 4.1.4.2.5 Panicle length:

All the parents recorded significant values of gca effects for panicle length. Parents with comparatively shorter panicles recorded negative gca effects. Among them, IET 8320 and IR 54 were highly significant (1% level), while IR 8 and Cisadane were significant at 5% level. Varieties with longer panicles recorded positive gca effects. It is interesting to note that both Kuntlan and Nigeria 5, the tall indicas recorded highly significant positive gca effects of 1.575<sup>\*\*</sup> and 1.678<sup>\*\*</sup> respectively for panicle length.

#### 4.1.4.2.6 Number of fertile spikelets per panicle:

The gca effects of parents for this character varied widely from -35.221<sup>\*\*</sup> (Kuntlan) to 24.956<sup>\*\*</sup> (Nigeria 5). Among the seven parents studied, four parents recorded highly significant gca effects of which three parents IET 8320, Cisadane and Nigeria 5 had positive effects, while

Kuntlan had significant negative effect. The two tall indica parents Kuntlan and Nigeria 5, differed widely for this character in that they exerted significant negative and positive gca effects respectively.

#### 4.1.4.2.7 Number of sterile spikelets per panicle:

Except the two tall indica parents Kuntlan and Nigeria 5, the rest of five dwarf and semidwarf indica parents recorded negative gca effects. IR 19660-274-3-3-1-3 and IR 8 were significant at 1% level, while Cisadane at 5% level. Kuntlan and Nigeria 5 recorded positive gca effects of 26.893<sup>\*\*</sup> and 15.172<sup>\*\*</sup> respectively. It is important to note that Nigeria 5 which recorded highly significant positive gca effect for number of fertile spikelets also recorded highly significant positive gca effect for number of sterile spikelets per panicle and strikingly all the three IRRI parents namely IR 19660-274-3-3-1-3, IR 54 and IR 8 recorded negative gca effects for both the above mentioned characters. However, the negative gca effects were significant only in IR 19660-274-3-3-1-3 and IR 8 for sterile spikelets per panicle.

#### 4.1.4.2.8 Sterility percentage:

IR 19660-274-3-3-1-3, Cisadane and IR 8 showed highly significant negative gca effects. Kuntlan, showed highly significant positive gca effect for sterility

percentage (18.324\*\*), as expected. Kuntlan recorded the highest percentage of sterility among the parents studied.

#### 4.1.4.2.9 L/B ratio of kernel:

The gca effects in all the seven parents were highly significant. Long slender varieties with higher L/B ratios (IR 19660-274-3-3-1-3, IR 54 and Cisadane) recorded highly significant positive gca effects (0.239\*\*, 0.185\*\* and 0.158\*\* respectively), while the medium slender and medium bold varieties namely Nigeria 5, IET 8320, IR 8 and Kuntlan recorded highly significant negative gca effects.

#### 4.1.4.2.10 1000-grain weight:

All the seven varieties showed significant gca effects. The effects were positive in IR 19660-274-3-3-1-3, IR 8 and Kuntlan, the highest being 1.980\*\* in IR 19660-274-3-3-1-3. Among the four parents that recorded negative gca effects, the highest (-2.493\*\*) was observed in Nigeria 5.

#### 4.1.4.2.11 BLB score:

IR 8, the susceptible variety for bacterial leaf blight disease recorded highly significant positive gca effect of 1.236\*\*. Among the four parents that recorded negative gca effects, only Nigeria 5 (-0.732\*\*) and IR 19660-274-3-3-1-3 (-0.491\*\*) were observed to have highly significant values of gca effects indicating their high level of resistance.

#### 4.1.4.2.12 Single plant grain yield:

All the three IRRI parents (IR 19660-274-3-3-1-3, IR 54 and IR 8) and one tall indica, Kuntlan recorded negative gca effects for grain yield, of which, it was significant only in Kuntlan ( $-5.320^*$ ). Two parents (IET 8320 and Nigeria 5), Out of three with positive gca effects were significant. IET 8320 ( $5.055^*$ ) and Nigeria 5 ( $4.874^*$ ) were the best combiners for grain yield. Nigeria 5 has red coloured rice which is not accepted by many consumers.

#### 4.1.4.3 Specific combining ability (sca) effects:

Specific combining ability (sca) effects for all the 12 characters in 21 cross combinations were estimated and presented in table 10. The data revealed that the crosses varied widely in their specific combining ability for different characters. For days to 50% flowering 11 crosses out 21 registered positive sca effects, of which nine were highly significant (1%) and one was significant at 5% level. Among the crosses with positive sca effects, IR 19660- 274-3-3-1-3 / Nigeria 5 (2/7) recorded the maximum sca effect of  $7.600^{**}$  followed by Cisadane/ Nigeria 5 (5/7) with  $4.942^{**}$  and IET 8320 /Kuntlan (1/6) with  $4.497^{**}$ . The cross IET 8320/ Nigeria 5 (1/7) that recorded the highly significant negative sca effect of  $- 10.291^{**}$  had both the short duration parents.

Table 10 Specific combining ability effects for 12 characters in 21 F1 hybrids in rice.

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
1 / 2	-4.501**	-7.346**	-1.856	-2.370	-0.219	5.090	-19.478*	-9.250*	-0.104	-0.818	0.356	-5.330
1 / 3	1.155*	0.312	-0.506	0.384	0.519	40.462**	-4.705	-6.966**	-0.110**	-1.331**	1.202**	15.906**
1 / 4	-1.004*	3.459*	4.215*	1.273	0.337	-1.034	-1.598	-2.779**	-6.032**	-0.819*	0.464	6.317
1 / 5	1.757**	7.217**	5.632**	4.144**	0.204	3.125	-16.845**	-6.335**	-0.078*	-0.795*	0.865**	12.964**
1 / 6	4.497**	7.432**	4.588*	3.570*	0.966	-35.373**	36.121**	16.116**	0.023	1.850**	-1.070**	-1.180
1 / 7	-10.291**	-5.212*	3.179	3.489*	-0.262	-27.549**	34.512**	13.685**	0.098**	1.350**	0.431	-2.319
2 / 3	-2.624**	-4.423*	7.013**	3.579**	-0.153	-4.447	7.330	4.408*	-0.051	0.249	0.198	7.518
2 / 4	1.887**	0.204	3.734*	4.303**	0.215	15.416	-13.323	-7.437*	0.193**	0.866*	-2.055**	21.350**
2 / 5	-6.687**	-3.453**	-0.598	0.424	-0.058	0.320	-4.969	-1.443	-6.021**	1.170**	-0.405	-3.373
2 / 6	2.553**	13.092**	3.023	2.685*	0.324	-40.927**	63.562**	31.759**	-0.096**	1.565**	1.910**	-14.253**
2 / 7	7.600**	10.958**	0.198	0.099	-0.624	4.646	-4.048	-0.048	-0.086**	-1.255**	0.178	12.333**
3 / 7	-4.037**	3.557	2.169	2.241	0.453	3.013	15.130	7.530*	0.094**	-0.331**	0.886**	-0.363

\* Significant at 5% level.

\*\* Significant at 1% level.

contd..

Table 10 contd...

Cross	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
3 / 5	-0.032	2.497	4.926	3.778	0.930	-11.163	17.234	8.548	0.048	0.648	-0.624	7.830
3 / 6	-2.041	-0.146	-1.212	0.368	-0.668	-23.245	24.520	13.214	-0.179	0.883	-1.309	-11.880
3 / 7	3.176	5.880	-2.952	-2.713	0.429	-1.422	-21.925	-7.795	-0.104	0.358	-0.142	-7.714
4 / 5	2.229	-4.893	-4.192	-2.919	-0.917	-8.134	-21.009	-8.562	-9.010	0.324	-1.047	-8.489
4 / 6	1.805	8.986	3.344	1.007	1.721	3.118	16.612	7.187	-0.129	0.105	1.768	8.041
4 / 7	-5.318	-0.822	0.019	0.676	-0.283	1.527	41.083	15.476	-0.122	-0.146	-1.980	1.337
5 / 6	0.311	-8.176	5.346	4.044	-0.018	20.862	0.130	-5.129	-0.022	-0.246	1.333	16.248
5 / 7	4.942	10.606	5.272	5.293	0.729	3.601	21.601	7.784	-0.020	-0.307	-0.499	7.745
6 / 7	-6.567	7.235	4.978	5.719	0.606	56.013	-43.279	-25.609	0.032	-0.696	-0.599	28.065
SE. (sij)	0.347	2.097	1.633	1.264	0.650	9.381	8.675	3.501	0.028	0.347	0.271	4.339
SE. (sij-sik)	0.515	3.116	2.427	1.878	0.965	13.936	12.888	5.201	0.041	0.515	0.403	6.447
SE. (sij-ski)	0.482	2.915	2.270	1.757	0.903	13.036	12.056	4.865	0.039	0.482	0.377	6.030

\* Significant at 5% level.

\*\* Significant at 1% level.

Maximum negative sca effect of  $-8.176^{**}$  for plant height was recorded by the cross Cisadane/Kuntlan (5/6) followed by IET 8320 /IR 19660-274-3-3-1-3 (1/2) with  $-7.346^{**}$ . The maximum positive sca effect ( $13.092^{**}$ ) was recorded in the cross IR 19660-274-3-3-1-3/Kuntlan (2/6). Of the 21 crosses, 5 crosses registered significant negative sca effects and 8 crosses significant positive sca effects for plant height.

Nine crosses exhibited positive significant sca effects for total tillers. Maximum positive sca effect of  $7.013^{**}$  was recorded in the cross IR 19660- 274-3-3-1-3 / IR 54 (2/3). Among the six crosses that recorded the negative sca effects, only one cross ie., IR 8/Cisadane (4/5) recorded significant negative sca effect ( $-4.192^*$ ) for number of total tillers per plant.

Among the 18 crosses showing positive sca effects for earbearing tillers, 10 crosses recorded significant sca effects. The cross Kuntlan/ Nigeria 5 (6/7) recorded the highest positive significant sca effect of  $5.719^{**}$ . Only two crosses (3/7 and 4/5) recorded negative sca effects significant at 5% level.

For panicle length nine crosses out of 21, recorded negative effects and none of them were significant. Of all the remaining 12 crosses that recorded positive sca effects, only one cross IR 8/Kuntlan (4/6) recorded significant (at 5% level) positive sca effect.

Among the 12 crosses showing positive sca effects only three crosses recorded significant positive sca effects for number of fertile spikelets. They were IET 8320/IR 54 (1/3: 40.462<sup>\*\*</sup>), Cisadane/Kuntlan (5/6: 20.862<sup>\*</sup>) and Kuntlan/Nigeria 5 (6/7) (56.013<sup>\*\*</sup>). Four crosses, IET 8320 / Kuntlan (1/6, -35.373<sup>\*\*</sup>), IET 8320/Nigeria 5 (1/7, -27.549<sup>\*\*</sup>), IR 19660-274-3-3-1-3/Kuntlan (2/6, -40.927<sup>\*\*</sup>) and IR 54 /Kuntlan (3/6, -23.245<sup>\*</sup>) showed significant negative sca effects.

For number of sterile spikelets per panicle, the cross Nigeria 5/Kuntlan (6/7) showed highly significant negative sca effect and three other crosses were also significant with negative values at 5% level. Four crosses, IET 8320/Kuntlan (1/6; 36.121<sup>\*\*</sup>) IET 8320/Nigeria 5 (1/7; 34.512<sup>\*\*</sup>), IR 19660-274-3-3-1-3/Kuntlan (2/6; 63.562<sup>\*\*</sup>) and IR 8/Nigeria 5 (4/7; 41.083<sup>\*\*</sup>) exhibited highly significant positive sca effects while one cross, Cisadane/Nigeria 5 (5/7: 21.61<sup>\*</sup>) was significant at 5% level. It is obvious, on critical comparison that none of the crosses that recorded significant either positive or negative sca effects could also record the significant same effect for both the characters i.e., number fertile and sterile spikelets per panicle. On the contrary most of the crosses that showed significant sca effects in one direction for one of the two characters resulted in showing significant sca effects in other direction for the second character.

Negative sca effects for percentage of sterility, a derived character was significantly higher at 1% level in one cross, Kuntlan/Nigeria 5 (6/7:  $-25.609^{**}$ ) and significant at 5% level in four crosses namely IET 8320/IR 19660-274-3-3-1-3 (1/2 :  $-9.250^*$ ), IR 19660-274-3-3-1-3 / IR 8 (2/4:  $-7.437^*$ ), IR 54/Nigeria 5 (3/7:  $-7.795^*$ ) and IR 8 / Cisadane (4/5:  $-8.562^*$ ). Highly significant positive sca effects were recorded in five crosses. Maximum positive sca effect of  $31.759^{**}$  for sterility percentage was recorded in the cross IR 19660-274-3-3-1-3/Kuntlan (2/6). However, positive sca effect was significant at 5% in three crosses.

Sca effects were positive and highly significant for L/B ratio in three hybrids of the crosses, IET 8320/Nigeria 5 (1/7:  $0.098^{**}$ ), IR 19660-274-3-3-1-3/IR 8 (2/4:  $0.193^{**}$ ) and IR 54/IR 8 (3/4:  $0.094^{**}$ ). However, majority of the crosses recorded negative sca effects of which 11 crosses were highly significant at 5% level. Maximum negative sca effect of  $-9.010^{**}$  was displayed by the cross IR 8/Cisadane (4/5) followed by IET 8320/IR 8 (1/4) with  $-6.032^{**}$ . In both the cases IR 8, a long bold variety with narrow L/B ratio having substantially higher negative sca effect for the character was involved.

Significant positive sca effects for 1000-grain weight in hybrids of six crosses and significant negative sca effects in hybrids of five crosses were registered. It is

important to note that the combination of long slender and long bold varieties with broad L/B ratios and higher positive gca effects like IR 19660-274-3-3-1-3, IR 8 and short bold varieties with narrow L/B ratios like Kuntlan resulted in hybrids with significantly higher positive sca effects for 1000-grain weight.

Highly significant negative sca effects for BLB score were registered in five crosses. In two crosses, the negative sca effects were significant at 5% level. Highest negative effect ( $-2.055^{**}$ ) was recorded in the hybrid of the cross IR 19660-274-3-3-1-3/IR 8 (2/4) and the highest positive effect ( $1.910^{**}$ ) in the cross IR 19660-274-3-3-1-3/Kuntlan (2/6). Six crosses recorded significant positive sca effects with due relevance to their parental gca effects and magnitude of their susceptibility for bacterial leaf blight disease.

Six hybrids were observed to be highly heterotic for single plant grain yield with highly significant positive sca effects of high magnitude ranging from  $28.065^{**}$  in Kuntlan/Nigeria 5 (6/7) to  $12.333^{**}$  in IR 19660-274-3-3-1-3/Nigeria 5 (2/7). Significant negative sca effects for grain yield were recorded in two crosses i.e., IR 19660-274-3-3-1-3/Kuntlan (2/6) and IR 54/Kuntlan (3/6) with  $-14.253^{**}$  and  $-11.888^{**}$  respectively.

#### 4.1.5 Heritability and genetic advance :

Estimates of heritability as a ratio of the genotypic variance to the total phenotypic variance expressed as percentage, genetic advance and genetic advance in relation to mean as percent are presented in Table 11.

##### 4.1.5.1 Heritability :

It can be observed from the results that the heritability (H) values in broad sense are greater than the narrow sense heritability (n) values for all the characters. High estimates of heritability in narrow sense (more than 50%) were obtained for days to 50% flowering (68.13), plant height (76.16), panicle length (73.57), L/B ratio of Kernel (74.55) and 1000-grain weight (71.18). Narrow sense heritability estimates ranged from 20 to 50 percent (medium) for four characters i.e., BLB score (20.31), number of sterile spikelets per panicle (22.17), sterility percentage (29.73) and number of fertile spikelets per panicle (42.31). Low heritability values (less than 20%) were observed for the remaining three characters namely, number of earbearing tillers per plant (9.90%), total tillers per plant (7.14%) and single plant grain yield (5.88%). It can be deduced from the results that the proportion of variability due to genetic causes which can be exploited by a judicious breeding programme is very low for characters like grain yield, total tillers and earbearing tillers per plant, moderate for BLB score, sterile spikelets per panicle, sterility percentage

Table 11 Estimation of heritability and genetic advance for 12 quantitative characters in rice.

Source	Days to flowering	Plant height	Total tillers/plant	Ear-bearing tillers/plant	Paniclen-gth	Fertile spikelets/panicle	Sterile spikelets/panicle	Sterility percentage	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
Genotypic var.	107.25	472.15	25.7	19.520	3.450	1057.360	1043.300	278.650	0.084	5.770	1.830	162.020
Phenotypic var.	107.55	483.07	32.32	23.490	4.500	1265.830	1230.150	309.080	0.086	6.070	2.010	208.770
Broad sense heritability	99.72	97.74	79.51	83.110	76.700	83.530	84.810	90.160	97.780	95.090	90.900	77.610
Narrow sense heritability (n) as %	68.13	76.16	7.14	9.900	73.570	42.310	22.170	29.730	74.550	71.180	20.310	5.880
Genetic advance under selection (G.S)	21.3	44.25	9.31	8.300	3.350	61.220	61.280	32.650	0.590	4.820	2.650	23.100
Genetic advance as % of mean	19.64	43.55	36.04	37.000	13.220	47.890	110.000	110.570	22.480	21.180	77.940	51.590
Reduction in heritability as % of H	31.68	22.08	91.02	88.090	4.080	49.340	73.860	67.030	23.760	25.140	77.660	92.420

and number of fertile spikelets per panicle and very high for characters like days to 50% flowering, plant height, panicle length, L/B ratio of kernel and 1000-grain weight.

#### 4.1.5.2 Genetic advance (G.S) :

Genetic advance under selection (G.S) ranged from 0.59 (L/B ratio of kernel) to 61.28 (number of sterile spikelets per panicle). Genetic advance under selection was high (above 50) only in the case of number of sterile (61.28) and fertile spikelets (61.22) per panicle, moderate (20-50) in the case of plant height (44.25), sterility percentage (32.65), single plant grain yield (23.10) and days to 50% flowering (21.30) and was low (below 10) in the case of total tillers (9.31), number of earbearing tillers per plant (8.30), 1000-grain weight (4.82), panicle length (3.35), BLB score (2.65) and L/B ratio of kernel (0.59).

#### 4.1.5.3 Genetic advance in relation to mean :

Estimates of genetic advance in relation to mean expressed as percentage ranged from 13.22 (panicle length) to 110.57 (sterility percentage). A genetic advance ( $\pm$ ) of 19.64 days for days to 50% flowering, 43.55cm for plant height, 77.94 in resistance to BLB and 51.59 g for single plant grain yield of the mean of selected plants in the next generation can be expected. It is clear from the data that the order of relative ranking of characters in relation to genetic advance and genetic advance as percentage of mean could be seen altered.

#### 4.1.6 Correlations and character associations :

Phenotypic and genotypic correlations have been separately worked out for parents, for hybrids and also for parents and hybrids together and presented in tables 12,13 and 14 respectively. In general, the genotypic correlation coefficients (given in parenthesis) are higher than phenotypic correlation coefficients as expected.

##### 4.1.6.1 Days to 50% Flowering :

It can be seen from the results that in parents days to 50% flowering had a highly significant positive correlation both phenotypically ( $0.915^{**}$ ) and genotypically ( $0.961^{**}$ ) with 1000-grain weight, while it was found to be negatively correlated phenotypically ( $-0.679^{**}$ ) and genotypically ( $-0.781^{**}$ ) with number of sterile spikelets per panicle. Also it had negative significant correlation with number of fertile spikelets per panicle phenotypically ( $-0.540^*$ ) and genotypically ( $-0.590^*$ ). Days to 50% Flowering showed a significant negative genotypic correlation ( $-0.595^*$ ) with single plant grain yield in parents.

In  $F_1$  hybrids, it is evident that days to 50% flowering was negatively correlated with number of fertile spikelets both phenotypically ( $-0.513^{**}$ ) and genotypically ( $-0.560^{**}$ ) but not with number of sterile spikelets per panicle as was noticed in parents. A negative genotypic correlation of  $-0.315^*$  was also observed between days to 50%

Table 12 Phenotypic and Genotypic correlation coefficients for 11 characters in 7 parents of rice.

Character	Plant height	Total tillers /plant	Ear bearing tillers /plant	Panicle length	Fertile spikelets / panicle	Sterile spikelets / panicle	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
Days to flowering	-0.266 (-0.270)	0.080 (0.084)	-0.116 (-0.134)	-0.244 (-0.255)	-0.540 (-0.590)	-0.679 (-0.781)	0.127 (0.128)	0.915 (0.961)	0.191 (0.189)	-0.422 (-0.595)
plant height	0.051 (0.022)	0.155 (0.147)	0.155 (0.147)	0.718 (0.718)	-0.363 (-0.433)	0.766 (0.816)	-0.586 (-0.585)	-0.134 (-0.162)	-0.389 (-0.395)	-0.427 (-0.686)
Total tillers /plant	0.950 (1.016)	0.950 (1.016)	0.950 (1.016)	-0.403 (-0.666)	-0.405 (-0.658)	0.144 (0.026)	-0.308 (-0.394)	-0.061 (-0.103)	0.119 (0.105)	0.194 (-0.157)
Earbearing tillers /plant	-0.342 (-0.516)	-0.342 (-0.505)	-0.342 (-0.505)	-0.323 (-0.505)	0.241 (0.305)	0.241 (0.305)	-0.401 (-0.459)	-0.209 (-0.315)	0.022 (0.031)	0.259 (0.020)
Panicle length	-0.081 (-0.144)	-0.081 (-0.144)	-0.081 (-0.144)	0.424 (0.430)	0.424 (0.430)	0.424 (0.430)	-0.195 (-0.192)	0.046 (0.016)	-0.278 (-0.291)	-0.325 (-0.662)
Fertile spikelets /panicle	0.094 (0.124)	0.094 (0.124)	0.094 (0.124)	0.094 (0.124)	0.094 (0.124)	0.094 (0.124)	0.148 (0.197)	-0.441 (-0.609)	-0.082 (-0.107)	0.780 (0.818)
Sterile spikelets /panicle	-0.499 (-0.553)	-0.499 (-0.553)	-0.499 (-0.553)	-0.499 (-0.553)	-0.499 (-0.553)	-0.499 (-0.553)	-0.434 (-0.499)	-0.621 (-0.748)	-0.434 (-0.499)	0.013 (0.035)
L/B ratio of kernel	0.027 (0.041)	0.027 (0.041)	0.027 (0.041)	0.027 (0.041)	0.027 (0.041)	0.027 (0.041)	-0.053 (-0.052)	0.042 (0.111)	-0.053 (-0.111)	0.042 (0.111)
1000-grain weight	0.139 (0.157)	0.139 (0.157)	0.139 (0.157)	0.139 (0.157)	0.139 (0.157)	0.139 (0.157)	-0.359 (-0.727)	0.139 (0.157)	-0.359 (-0.727)	-0.359 (-0.727)
BLB score	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)	-0.087 (-0.162)

Genotypic correlation coefficients are given in parenthesis

\* significant at 5%

\*\* significant at 1%

Table 13 Phenotypic and Genotypic correlation coefficients for 11 characters in 21 F1 hybrids of rice

Characters	Plant height	Total tillers/plant	Ear bearing/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	L/B ratio of kernel	1000-grain weight	BLB score	Single plant yield
Days to flowering	-0.122 (-0.122)	0.133 (0.164)	0.115 (-0.144)	-0.084 (-0.083)	-0.513 (-0.560)	-0.131 (-0.142)	0.163 (0.165)	0.723 (0.744)	0.379 (0.398)	-0.266 (-0.315)
plant height		0.325 (0.369)	0.535 (0.592)	0.803 (0.999)	-0.200 (-0.251)	0.627 (0.698)	-0.657 (-0.665)	0.024 (0.018)	-0.160 (-0.161)	0.051 (-0.002)
Total tillers/plant			0.889 (.894)	0.270 (0.143)	-0.189 (-0.408)	0.357 (0.475)	-0.276 (-0.364)	0.127 (0.193)	0.308 (0.304)	0.339 (0.183)
Earbearing tillers/plant				0.402 (-0.349)	-0.055 (-0.260)	0.481 (0.635)	-0.364 (-0.425)	-0.040 (-0.042)	0.066 (0.017)	0.409 (0.219)
Panicle length					-0.090 (-0.202)	0.451 (0.568)	-0.386 (-0.500)	0.168 (0.187)	-0.163 (-0.301)	0.136 (0.031)
Fertile spikelets/panicle						-0.559 (-0.563)	0.161 (0.197)	-0.722 (-0.814)	-0.201 (-0.241)	0.769 (0.764)
Sterile spikelets/panicle							-0.506 (-0.566)	0.146 (0.153)	-0.042 (-0.013)	-0.339 (-0.359)
L/B ratio of kernel								0.076 (0.092)	-0.150 (-0.175)	-0.032 (-0.010)
1000-grain weight									0.154 (0.210)	-0.459 (-0.570)
BLB score										-0.088 (-0.122)

Genotypic correlation coefficients are given in parenthesis

\* Significant at 5%

\*\* Significant at 1%

Table 14 Phenotypic and Genotypic correlation coefficients for 11 characters in diallel set of 7 parents and 21 F1 hybrids of rice.

Characters	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
Days to flowering	-0.178 (-0.181)	0.024 (0.021)	-0.144 (-0.160)	-0.141 (-0.164)	-0.515 (-0.562)	-0.247 (-0.270)	0.164 (0.165)	0.767 (0.794)	0.322 (0.333)	-0.281 (-0.319)
Plant height		0.316 (0.327)	0.448 (0.458)	0.777 (0.878)	-0.234 (-0.289)	0.652 (0.712)	-0.642 (-0.647)	-0.004 (-0.016)	-0.226 (-0.233)	0.077 (0.039)
Total tillers/plant			0.943 (0.961)	0.199 (0.112)	-0.154 (-0.275)	0.424 (0.495)	-0.317 (-0.362)	0.127 (0.158)	0.175 (0.142)	0.562 (0.540)
Earbearing tillers/plant				0.266 (0.201)	-0.068 (-0.197)	0.508 (0.605)	-0.383 (-0.413)	0.006 (0.002)	0.024 (-0.011)	0.603 (0.546)
Panicle length					-0.083 (-0.170)	0.452 (0.510)	-0.334 (-0.387)	0.139 (0.135)	-0.202 (-0.293)	0.126 (0.047)
Fertile spikelets/panicle						-0.430 (-0.427)	0.150 (0.188)	-0.646 (-0.752)	-0.170 (-0.206)	0.645 (0.605)
Sterile spikelets/panicle							-0.502 (-0.554)	0.027 (0.022)	-0.115 (-0.105)	-0.100 (-0.067)
L/B ratio of kernel								0.042 (0.057)	-0.110 (-0.124)	-0.111 (-0.103)
1000-grain weight									0.147 (0.190)	-0.311 (-0.394)
BLB score										-0.085 (-0.117)

Genotypic correlation coefficients are given in parenthesis

\* significant at 5% level

\*\* Significant at 1% level.

flowering and single plant grain yield. Days to 50% flowering was positively and significantly correlated both phenotypically ( $0.723^{**}$ ) and genotypically ( $0.744^{**}$ ) with 1000-grain weight as in the case of parents. But, unlike in parents the  $F_1$  hybrids showed significant positive correlations for days to 50% flowering with BLB score both phenotypically ( $0.379^*$ ) and genotypically ( $0.398^{**}$ ). When parents and  $F_1$  hybrids were considered together, flowering duration showed negative phenotypic ( $-0.515^{**}$ ) and genotypic ( $-0.562^{**}$ ) correlations with number of fertile spikelets per panicle and also phenotypic ( $-0.281^*$ ) and genotypic ( $-0.319^*$ ) negative correlations with single plant grain yield. However, it was positively correlated with 1000 grain weight phenotypically ( $0.767^{**}$ ) and genotypically ( $0.794^{**}$ ). Flowering duration also showed positive phenotypic ( $0.322^*$ ) and genotypic ( $0.333^*$ ) correlations with BLB score.

#### 4.1.6.2 Plant height :

Highly significant positive correlations were registered between plant height and panicle length phenotypically ( $0.718^{**}$ ) and genotypically ( $0.718^{**}$ ). Plant height also had highly significant positive phenotypic ( $0.766^{**}$ ) and genotypic ( $0.816^{**}$ ) correlation with number of sterile spikelets per panicle in parents. It was negatively correlated with L/B ratio of kernel both phenotypically ( $-0.586^*$ ) and genotypically ( $-0.585^*$ ) and genotypically ( $-0.686^*$ ) alone with single plant grain yield. The  $F_1$

hybrids showed a positive significant correlations both at phenotypic and genotypic levels between plant height and total tillers ( $0.325^*$ / $0.369^*$ ), earbearing tillers per plant ( $0.535^{**}$ / $0.592^{**}$ ), panicle length ( $0.803^{**}$ / $0.999^{**}$ ) and number of sterile spikelets per panicle ( $0.627^{**}$ / $0.698^{**}$ ). Significant negative correlations were, however, recorded for L/B ratio of kernel both phenotypically ( $-0.657^{**}$ ) and genotypically ( $-0.665^{**}$ ). Parents and hybrids together as a group, also behaved same as hybrids except that a negative genotypic correlation ( $-0.289^*$ ) was recorded in addition, for number of fertile spikelets per panicle with plant height.

#### 4.1.6.3 Total number of tillers per plant:

Strong positive correlation at both phenotypic and genotypic levels was observed between total tillers per plant and ear bearing tillers in parents ( $0.950^{**}$ / $1.016^{**}$ ), hybrids ( $0.889^{**}$ / $0.894^{**}$ ), and also in parents and hybrids ( $0.943^{**}$ / $0.961^{**}$ ). This character was observed to be negatively correlated with panicle length ( $-0.666^{**}$ ) and number of fertile spikelets ( $-0.658^*$ ) genotypically in parents probably due to the fact that in general, shy tillering varieties have longer panicles and higher number of fertile grains per panicle. In  $F_1$  hybrids, this character also registered positive significant phenotypic and genotypic correlations with number of sterile spikelets per panicle ( $0.357^*$ / $0.475^{**}$ ) and BLB score ( $0.308^{**}$ / $0.304^*$ ).

tillers per plant however, had positive phenotypic correlation ( $0.339^*$ ) with single plant grain yield and negative genotypic correlation ( $-0.364^*$ ) with L/B ratio of kernel in hybrids.

When parents and hybrids were considered together, this character was also observed to be positively associated phenotypically and genotypically with number of sterile spikelets ( $0.424^{**}/0.495^{**}$ ) and single plant grain yield ( $0.562^{**}/0.540^{**}$ ) and exhibited a negative genotypic association with number of fertile spikelets per panicle ( $0.275^*$ ). It was also observed to have negative phenotypic ( $-0.317^*$ ) and genotypic ( $-0.362^{**}$ ) correlation for L/B ratio of kernel.

#### 4.1.6.4 Earbearing tillers per plant:

In parents, none of the characters studied, seem to have any significant association with earbearing tillers per plant. In  $F_1$  hybrids significant correlations were established with panicle length ( $0.402^{**}/0.349^*$ ), number of sterile spikelets per panicle ( $0.481^{**}/0.635^{**}$ ) both phenotypically and genotypically and only phenotypically with single plant grain yield ( $0.409^{**}$ ) in positive direction. Earbearing tillers showed negative phenotypic ( $-0.364^*$ ) and genotypic ( $-0.425^{**}$ ) correlation with L/B ratio of kernel. In parents and hybrids together, earbearing tillers per plant registered highly significant phenotypic ( $0.508^{**}$ ) and

genotypic (0.605\*\*) positive correlation with number of sterile spikelets per panicle as also with single plant grain yields at phenotypic (0.603\*\*) and genotypic (0.546\*\*) levels. Earbearing tillers per plant established highly significant negative phenotypic correlation (-0.383\*\*) and genotypic correlation (-0.413\*\*) with L/B ratio of kernel.

#### 4.1.6.5 Panicle length:

Panicle length in parents showed a highly significant negative genotypic (-0.662\*\*) correlation with single plant grain yield which was not present in hybrids as well as parents and hybrids together. In  $F_1$  hybrids panicle length was positively correlated with number of sterile spikelets (0.461\*\*/0.568\*\*) and negatively with L/B ratio of kernel -0.386\*\* / -0.500\*\*). A negative genotypic correlation (-0.293\*) was observed with BLB score when parents and hybrids were considered together.

#### 4.1.6.6 Number of fertile spikelets per panicle:

Number of fertile spikelets per panicle was observed to have highly significant positive correlations both phenotypically and genotypically with single plant grain yields in parents (0.780\*\*/0.818\*\*), in hybrids (0.769\*\* / 0.764\*\*) and in parents and hybrids together (0.645\*\* / 0.605\*\*). This character seemed to have a direct bearing on the grain yield, the ultimate product from the crop. It was

negatively correlated with 1000-grain weight genotypically ( $-0.609^*$ ) in parents, both phenotypically ( $-0.722^{**}$ ) and genotypically ( $-0.814^{**}$ ) in hybrids and also in parents and hybrids ( $-0.646^{**}/-0.758^{**}$ ). It also had negative correlation with number of sterile spikelets per panicle at both phenotypic ( $-0.559^{**}$ ) and genotypic ( $-0.563^{**}$ ) level in hybrids as well as in parents and hybrids ( $-0.430^{**}/-0.427^{**}$ ) together.

#### 4.1.6.7 Number of sterile spikelets per panicle:

Phenotypic ( $-0.631^*$ ) and genotypic ( $-0.748^{**}$ ) correlations were observed to be negative in parents between number of sterile spikelets per panicle and 1000-grain weight and only genotypically ( $-0.553^*$ ) with L/B ratio of kernel. Significant phenotypic and genotypic negative correlations were also recorded in hybrids between this character and L/B ratio of kernel ( $-0.506^{**}/-0.566^{**}$ ) and single plant grain yield ( $-0.339^*/-0.359^*$ ). When parents and hybrids were considered together, this character was negatively correlated with L/B ratio of kernel phenotypically ( $-0.503^*$ ) and genotypically ( $-0.554^{**}$ ). It is interesting to note that number of sterile spikelets per panicle was negatively correlated with L/B ratio of kernel in parents, hybrids and in parents and hybrids together, indicating that higher number of sterile spikelets is more prevalent in coarser grained genotypes.

#### 4.1.6.8 L/B ratio of kernel:

L/B ratio of kernel was not correlated either with 1000 grain weight, BLB score or with single plant grain yield in parents, hybrids and in parents and hybrids together.

#### 4.1.6.9 1000-grain weight:

Strong genotypic negative correlation ( $-0.727^{**}$ ) was observed in parents between 1000-grain weight and single plant grain yield. In the case of hybrids negative correlation was highly significant both phenotypically ( $-0.459^{**}$ ) and genotypically ( $-0.570^{**}$ ). Parents and hybrids together also exhibited same trend by recording significant negative phenotypic ( $-0.311^*$ ) and genotypic ( $-0.394^{**}$ ) correlations between 1000-grain weight and single plant grain yield.

#### 4.1.6.10 BLB score:

BLB score had no significant correlation with single plant grain yield in parents, hybrids as also in parents and hybrids.

#### 4.1.7 Path-coefficient analysis:

Phenotypic and genotypic path-coefficients for ten quantitative characters namely days to 50% flowering, plant height, total tillers per plant, earbearing tillers per plant, panicle length, fertile spikelets per panicle, sterile

spikelets per panicle, L/B ratio of kernel, 1000-grain weight and BLB score in relation to single plant grain yield were estimated for seven parents (Fig.11), 21  $F_1$  hybrids (Fig.12) and for seven parents and 21  $F_1$  hybrids together and presented in tables 15,16 and 17 respectively.

#### 4.1.7.1 Path-coefficient analysis in parents:

The highest positive direct effect on single plant grain yield both phenotypically and genotypically was exhibited by fertile spikelets per panicle (1.012/1.255) followed by earbearing tillers per plant (0.443/0.511), total tillers per plant (0.334/0.429), panicle length (0.221/0.314), and 1000-grain weight (0.109/0.237). Negative phenotypic and genotypic direct effects were recorded by days to 50% flowering (-0.056/-0.228), plant height (-0.251/-0.397), sterile spikelets per panicle (-0.197/-0.269), L/B ratio of kernel (-0.032/-0.049) and BLB score (-0.182/-0.285) on single plant grain yield.

Flowering duration exhibited a negative direct effect (-0.056/-0.228) and negative indirect effects through earbearing tillers per panicle (-0.052/-0.068), panicle length (-0.056/-0.080), fertile spikelets per panicle (-0.547/-0.740), L/B ratio of kernel (-0.004/-0.006) and BLB score (-0.035/-0.054). It showed positive indirect effects through plant height (0.067/0.107), total tillers per plant (0.027/0.036), sterile spikelets per panicle (0.134/0.210)

Table 15 Path coefficient analysis for 10 characters on single plant grain yield in 7 parents of rice.

Characters	Days to flower- ring	Plant height	Total tillers /plant	Ear bearing tillers /plant	Panicle length	Fertile spike- lets / panicle	Sterile spike- lets / panicle	L/B ratio of kernel	1000- grain weight	BLB score	Single plant grain yield
Days to flowering	<u>-0.056</u> (-0.228)	0.067 (0.107)	0.027 (0.036)	-0.052 (-0.068)	-0.056 (-0.080)	-0.547 (-0.740)	0.134 (0.210)	-0.004 (-0.006)	0.100 (0.228)	-0.035 (-0.054)	-0.422 (-0.595)*
Plant height	0.015 (0.062)	<u>-0.251</u> (-0.397)	0.017 (0.010)	0.069 (0.075)	0.166 (0.226)	-0.367 (-0.544)	-0.151 (-0.219)	0.019 (0.029)	-0.015 (-0.039)	0.071 (0.113)	-0.427 (-0.686)*
Total til- lers/plant	-0.004 (-0.019)	-0.013 (-0.009)	<u>0.334</u> (0.429)	0.421 (0.519)	-0.093 (-0.209)	-0.420 (-0.826)	-0.022 (-0.007)	0.010 (0.019)	-0.007 (-0.024)	-0.022 (-0.030)	0.194 (-0.157)
Earbearing tillers/plant	0.007 (0.030)	-0.039 (-0.058)	0.317 (0.436)	0.443 (0.511)	-0.079 (-0.162)	-0.326 (-0.634)	-0.047 (-0.082)	0.013 (0.022)	-0.023 (-0.075)	-0.006 (0.009)	0.259 (-0.020)
Panicle length	0.014 (0.058)	-0.180 (-0.285)	-0.135 (-0.286)	-0.151 (-0.264)	0.221 (0.314)	-0.082 (-0.180)	-0.084 (-0.116)	0.006 (0.009)	0.005 (0.004)	0.051 (0.083)	-0.325 (-0.662)**
Fertile spike- lets/panicle	0.030 (0.134)	0.091 (0.172)	-0.135 (-0.282)	-0.143 (-0.258)	-0.019 (-0.045)	1.012 (1.255)	-0.019 (-0.033)	-0.005 (-0.010)	-0.048 (-0.145)	0.015 (0.030)	0.780 ** (0.818)**
Sterile spike- lets/panicle	0.038 (0.178)	-0.192 (-0.324)	0.038 (0.011)	0.107 (0.156)	0.098 (0.135)	0.095 (0.156)	-0.197 (-0.269)	0.016 (0.027)	-0.069 (-0.178)	0.079 (0.142)	0.013 (0.035)
L/B ratio of kernel	-0.007 (-0.029)	0.147 (0.232)	-0.103 (-0.169)	-0.178 (-0.235)	-0.045 (-0.060)	0.150 (0.247)	0.098 (0.149)	<u>-0.032</u> (-0.049)	0.003 (0.010)	0.010 (0.015)	0.042 (0.111)
1000-grain weight	-0.051 (-0.219)	0.034 (0.064)	-0.020 (-0.044)	-0.093 (-0.161)	0.011 (0.005)	-0.447 (-0.764)	0.124 (0.201)	-0.001 (-0.002)	0.109 (0.237)	-0.025 (-0.045)	-0.359 (-0.727)**
BLB score	0.011 (-0.043)	0.098 (0.157)	0.040 (0.045)	0.014 (0.016)	0.064 (-0.092)	-0.083 (-0.134)	0.086 (0.134)	0.002 (0.003)	0.015 (0.037)	<u>-0.182</u> (-0.285)	-0.087 (-0.162)

Genotypic effects are given in parenthesis

\* significant at 5% level.

\*\* Significant at 1% level.

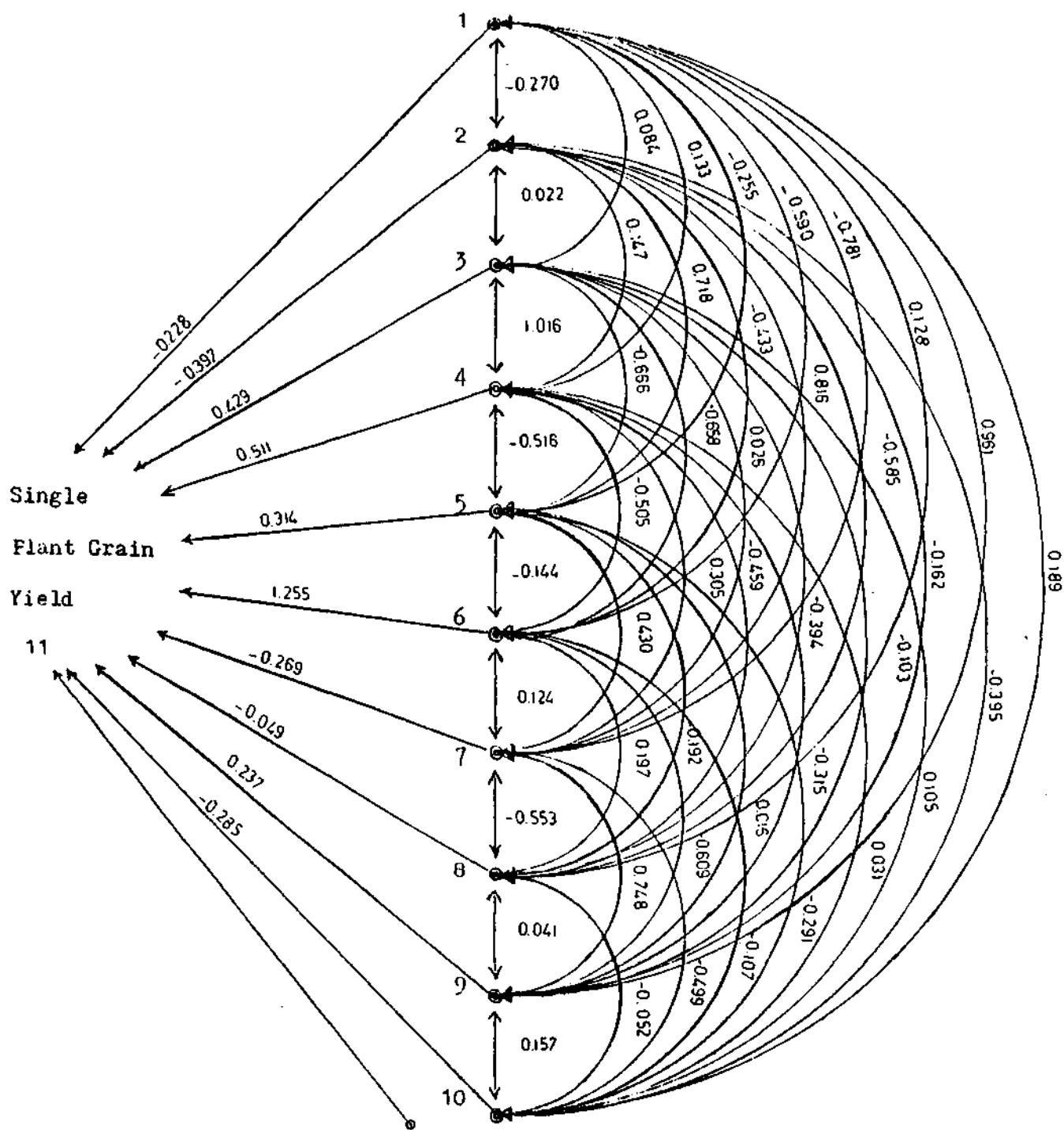


Fig. 11 Path analysis of 10 characters influencing on grain yield in 7 parents in rice.

( Double arrow indicates direct effect and Single arrow correlation coefficient )

and 1000-grain weight (0.100/0.228) which finally resulted in significant negative genotypic correlation with single plant grain yield (-0.422/-0.595<sup>\*</sup>). Plant height showed a significant negative genotypic correlation (-0.427/-0.686<sup>\*</sup>) with single plant grain yield by recording a negative direct effect (-0.251/ -0.397) and also negative indirect effects through fertile spikelets per panicle (-0.367/-0.544), sterile spikelets per panicle (-0.151/-0.219) and 1000-grain weight (-0.015/-0.039). Positive indirect effects of plant height were recorded through flowering duration (0.015/0.062), total tillers (0.017/0.010), earbearing tillers per plant (0.069/0.075), panicle length (0.166/0.226), L/B ratio of kernel (0.019/0.029) and BLB score (0.071/0.113).

Panicle length had positive direct effect (0.221/0.314). It had positive and negative indirect effects through which it could establish a substantial negative genotypic correlation (-0.325/-0.662<sup>\*\*</sup>) with single plant grain yield. The negative genotypic indirect effects that contributed for negative correlation were through plant height (-0.285), total tillers (-0.286), earbearing tillers per plant (-0.264), fertile spikelets per panicle (-0.180) and sterile spikelets per panicle (-0.116). Fertile spikelets per panicle having highest positive direct contribution phenotypically and genotypically (1.012/1.255) had also positive indirect effects through days to 50% flowering

(0.030/0.134), plant height (0.091/0.172) and BLB score (0.015/0.030) which resulted in higher positive correlations both phenotypically and genotypically ( $0.780^{**}/0.818^{**}$ ) with single plant grain yield than any other character in parents. It had negative indirect effects through total tillers (-0.135/-0.282), earbearing tillers (-0.143/-0.258), panicle length (-0.019/ -0.045), sterile spikelets per panicle (-0.019/-0.033), L/B ratio of kernel (-0.005/-0.010) and 1000-grain weight (-0.048 / -0.145). The direct contribution of 1000-grain weight to single plant grain yield was positive (0.109/0.237) and also had positive indirect effects through plant height (0.034/0.064), panicle length (0.011/0.005) and sterile spikelets per panicle (0.124/0.201). However, it could influence severally by negative genotypic indirect effects through days to 50% flowering (-0.219), total tillers per plant (-0.044) earbearing tillers per plant (-0.161), fertile spikelets per panicle (-0.764), L/B ratio of kernel (-0.002) and BLB score (-0.045) resulting in a substantial and highly significant negative genotypic correlation with single plant grain yield ( $-0.727^{**}$ ).

Total tillers per plant and earbearing tillers per plant, though had sizable positive direct effects (0.334/0.429 and 0.443/0.511 respectively), could not show any significant correlation with single plant grain yield because of negative indirect effects through other characters nullifying the direct effects. Sterile spikelets per

panicle, L/B ratio of kernel and BLB score, however could not manifest any significant impact on single plant grain yield in parents studied.

#### 4.1.7.2 Path-coefficient analysis in $F_1$ hybrids :

Path-coefficient analysis in  $F_1$  hybrids for component characters with single plant grain yield showed several significant correlations (Table 16 and Fig.12). Of the ten components, as in the case of parents, in  $F_1$  hybrids also fertile spikelets per panicle had the highest positive direct effect both phenotypically (1.001) and genotypically (1.570) on single plant grain yield followed by total tillers per plant (0.432/1.229). Highest negative genotypic direct effect was exhibited by earbearing tillers per plant (-0.682).

A significant negative genotypic correlation (-0.315\*) between flowering duration and single plant grain yield was registered in  $F_1$  hybrids. Days to 50% flowering had positive genotypic direct effect (0.186) and genotypic indirect effect through total tillers per plant (0.201), earbearing tillers per plant (0.098), panicle length (0.006) and 1000-grain weight (0.276). However, negative genotypic indirect effects through plant height (-0.278), fertile spikelets per panicle (-0.879), sterile spikelets per panicle (-0.028), L/B ratio of Kernel (-0.005) and BLB score (-0.088) were predominant nullifying the positive genotypic effects finally resulting in the negative correlation with grain

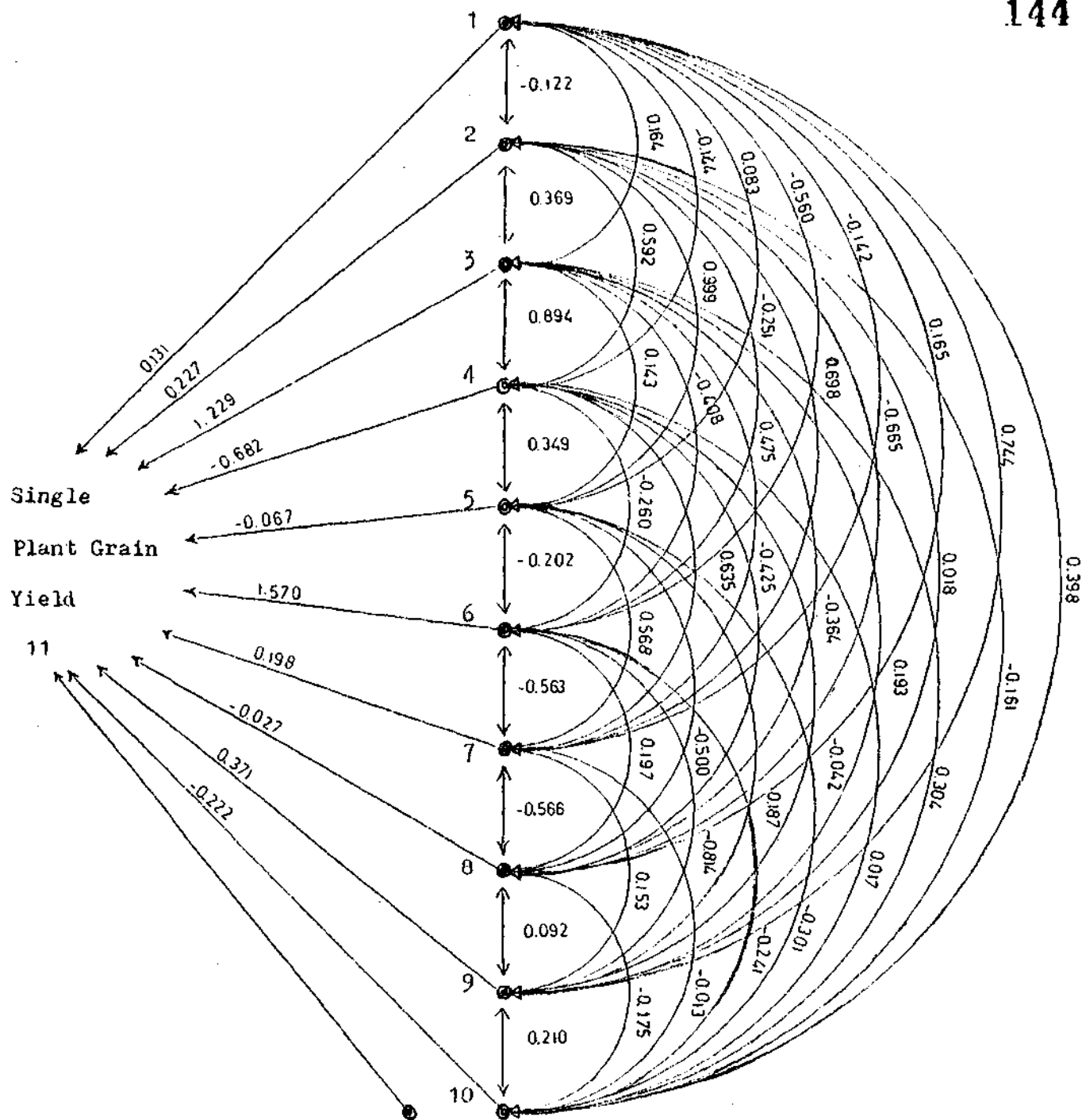


Fig. 12 Path analysis of 10 characters influencing on grain yield in 21 F<sub>1</sub> hybrids of rice.

( Double arrow indicates direct effect and Single arrow correlation coefficient )

yield. Genotypic and phenotypic indirect effects of days to 50% flowering through plant height (0.002/-0.278), earbearing tillers per plant (-0.010/0.098) and panicle length (-0.002/0.006) differed in their direction of contribution between genotypic and phenotypic levels.

Total tillers per plant had profound positive direct effect phenotypically (0.432) and genotypically (1.229). Though the direct positive phenotypic effect was comparatively less than that of positive genotypic effect, the phenotypic correlation with single plant grain yield was positive and significant (0.339<sup>\*</sup>), because of substantial cumulative phenotypic indirect effects through flowering duration (0.025 earbearing tillers per plant (0.074), panicle length (0.008), L/B ratio of Kernel (0.032) and 1000-grain weight (0.014) inspite of having indirect negative phenotypic effects through plant height (-0.004), fertile spikelets per panicle (-0.189), sterile spikelets per panicle (-0.012) and BLB score (-0.040). Earbearing tillers per plant had positive phenotypic direct effect (0.083) reinforced by indirect positive effects through flowering duration (0.021), total tillers per plant (0.384), panicle length (0.012), fertile spikelets per panicle (0.055) and L/B ratio of Kernel (0.042) resulting in a highly significant positive phenotypic correlation (0.409<sup>\*\*</sup>) with single plant grain yield. Earbearing tillers, though recorded the highest negative genotypic direct effect (-0.682), no significant

correlation with single plant grain yield could be established due to cumulative counteraction of positive indirect effects through other characters like total tillers per plant (1.099), plant height (0.134), sterile spikelets per panicle (0.126) and L/B ratio of the Kernel (0.012).

Highly significant positive correlations were recorded between fertile spikelets per panicle and single plant grain yield both genotypically ( $0.764^{**}$ ) and phenotypically ( $0.769^{**}$ ). This character registered the maximum positive genotypic direct effect (1.570) on grain yield. Indirectly it showed positive genotypic effect through earbearing tiller (0.177), panicle length (0.014) and BLB score (0.053) and negative genotypic indirect effects through days to 50% flowering (-0.073), plant height (-0.057), total tillers per plant (-0.501), sterile spikelets per panicle (-0.111), L/B ratio of Kernel (-0.005) and 1000-grain weight (-0.302). Phenotypically also fertile spikelets per panicle exhibited maximum positive direct effect (1.001) and positive indirect effect through plant height (0.002), earbearing tillers per plant (0.005), panicle length (0.003), sterile spikelets per panicle (0.019) and BLB score (0.026). However, it had negative phenotypic indirect effects through days to 50% flowering (-0.095), total tillers per plant (-0.081), L/B ratio of Kernel (-0.019) and 1000-grain weight (-0.077).

Sterile spikelets per panicle having a direct genotypic positive effect (0.198) and direct phenotypic

negative effect (-0.034) also manifested significant correlations with single plant grain yield but in a negative direction both genotypically (-0.359<sup>\*</sup>) and phenotypically (-0.339<sup>\*</sup>). It could also influence by genotypic indirect effects through days to 50% flowering (-0.019), earbearing tillers per plant (-0.433), panicle length (-0.038) and fertile spikelets per panicle (-0.884) negatively, and through plant height (0.159), total tillers per plant (0.583), L/B ratio of Kernel (0.015), 1000-grain weight (0.057) and BLB score (0.003) positively. Phenotypically it showed negative indirect effects through days to 50% flowering (-0.024), plant height (-0.008), fertile spikelets per panicle (-0.560) and positive indirect effects through total tillers (0.154), earbearing tillers per plant (0.040), panicle length (0.014), L/B ratio of Kernel (0.058), 1000-grain weight (0.016) and BLB score (0.005). It is interesting to note that the indirect negative effects through fertile spikelets both genotypically (-0.884) and phenotypically (-0.560) were higher than even direct effects of the character.

Highly significant negative correlation was observed between 1000-grain weight and single plant grain yield genotypically (-0.570<sup>\*\*</sup>) and also phenotypically (-0.459<sup>\*\*</sup>). 1000-grain weight had a direct positive genotypic effect (0.371) and also indirect positive genotypic effect through days to 50% flowering (0.097), plant height (0.004), total tillers per plant (0.238), ear bearing tillers per plant

(0.029) and number of sterile spikelets per panicle (0.030). The indirect negative genotypic effect through fertile spikelets was very high (-1.277) supported by genotypic negative indirect effects through other characters namely panicle length (-0.013), L/B ratio of kernel (-0.003) and BLB score (-0.047). It exhibited a similar trend phenotypically also. The phenotypic direct effect was positive (0.106) and indirect phenotypic effects through days to 50% flowering (0.135), total tillers per plant (0.055) and panicle length (0.005) were also positive. However, the cumulative negative phenotypic indirect effect through plant height (-0.001), earbearing tillers per plant (-0.003), fertile spikelets per panicle (-0.723), sterile spikelets per panicle (-0.005), L/B ratio of kernel (-0.009) and BLB score (-0.020) rendered 1000-grain weight to have a significant negative correlation with single plant grain yield phenotypically.

Other characters viz., plant height, panicle length, L/B ratio of kernel and BLB score could not manifest any significant correlations with single plant grain yield either genotypically or phenotypically, though they had positive or negative direct effects and also indirect effects of different magnitudes through other characters.

#### 4.1.7.3 Path-Coefficient analysis in 7 parents and 21 $F_1$ 's together:

Path-coefficient analysis for all the ten quantitative characters in relation to single plant grain

yield of parents and  $F_1$  hybrids are presented in table 17. The genotypic direct effect of total tillers per plant was positive and the highest (1.516), followed by number of fertile spikelets per panicle (1.098) which reflected in displaying significant genotypic positive correlations with single plant yield ( $0.540^{**}$  and  $0.605^{**}$  respectively). It is worth mentioning that the same type of positive genotypic correlations for the above two characters have been recorded in hybrids also when analysed separately in the same order of ranking. Parents however, differed in the above two characters (Table 15) by recording highest positive genotypic and phenotypic direct effects (1.012/1.255) resulting in highest genotypic and phenotypic correlations ( $0.780^{**}/0.818^{**}$ ) with single plant grain yields in respect of fertile spikelets per panicle. Total tillers did not show any significant effects in parents.

Days to 50% flowering had negative genotypic (-0.073) and positive phenotypic (0.143) direct effects resulting in significant negative correlations both genotypically ( $-0.319^*$ ) and phenotypically ( $-0.281^*$ ). High negative indirect effects (-0.617) through fertile spikelets per panicle followed by plant height (-0.107) resulted in significant negative genotypic correlation with single plant grain yield. Days to 50% flowering, though recorded a positive phenotypic direct effect, showed a significant negative phenotypic correlation with single plant grain yield

Table 17 Path coefficient analysis for 10 characters on single plant grain yield in a diallel set of 7 parents and 21 F1 hybrids of rice.

Characters	Days to flowering	Plant height	Total tillers/plant	Ear bearing tillers/plant	Panicle length	Fertile spikelets/panicle	Sterile spikelets/panicle	L/B ratio of kernel	1000-grain weight	BLB score	Single plant grain yield
Days to flowering	0.143 (-0.073)	0.013 (-0.107)	0.010 (0.032)	-0.049 (0.130)	-0.016 (0.046)	0.039 (0.033)	0.039 (0.033)	-0.014 (0.016)	-0.001 (0.253)	-0.035 (-0.032)	-0.281 (-0.319)
Plant height	-0.025 (0.013)	-0.070 (0.590)	0.129 (0.496)	0.152 (-0.371)	0.086 (-0.243)	-0.169 (-0.317)	-0.104 (-0.086)	0.053 (-0.061)	0.000 (-0.005)	0.025 (0.023)	0.077 (0.038)
Total tillers/plant	0.003 (-0.002)	-0.022 (0.193)	0.410 (1.516)	0.320 (-0.777)	0.022 (0.031)	-0.111 (-0.302)	-0.067 (-0.060)	0.026 (-0.034)	-0.001 (0.050)	-0.019 (-0.014)	0.562 (0.540)
Earbearing tillers/plant	-0.020 (0.012)	-0.031 (0.270)	0.387 (1.456)	0.339 (-0.809)	0.030 (-0.056)	-0.049 (-0.216)	-0.081 (-0.073)	0.032 (-0.039)	0.000 (0.001)	0.003 (0.001)	0.603 (0.546)
Panicle length	-0.020 (0.012)	-0.054 (0.518)	0.082 (0.170)	0.090 (-0.163)	0.111 (-0.277)	-0.060 (-0.187)	-0.072 (-0.062)	0.028 (-0.037)	-0.0001 (0.043)	0.022 (0.028)	0.126 (0.047)
Fertile spikelets/panicle	-0.073 (0.041)	0.016 (-0.170)	-0.063 (-0.417)	-0.023 (0.159)	-0.009 (0.047)	0.723 (1.098)	0.068 (0.052)	-0.012 (0.018)	0.0003 (-0.242)	0.018 (0.020)	0.645 (0.605)
Sterile spikelets/panicle	-0.035 (0.020)	-0.046 (0.420)	0.174 (0.750)	0.172 (-0.490)	0.050 (-0.141)	-0.311 (-0.470)	-0.159 (-0.121)	0.042 (-0.052)	0.0000 (0.007)	0.013 (0.010)	-0.100 (-0.067)
L/B ratio of kernel	-0.023 (-0.012)	0.045 (-0.382)	-0.130 (-0.549)	-0.130 (0.334)	-0.037 (0.177)	0.109 (0.207)	0.080 (0.067)	-0.083 (0.095)	0.0000 (0.018)	0.012 (0.012)	-0.111 (-0.103)
1000-grain weight	0.110 (-0.058)	0.001 (-0.009)	0.052 (0.240)	0.003 (-0.001)	0.016 (-0.037)	-0.467 (-0.832)	-0.004 (-0.003)	-0.004 (0.005)	-0.001 (0.319)	-0.016 (-0.018)	-0.311 (-0.394)
BLB score	0.046 (-0.024)	0.016 (-0.137)	0.072 (0.215)	0.008 (0.009)	-0.023 (0.081)	-0.230 (-0.226)	0.018 (0.013)	0.009 (-0.012)	-0.0001 (0.061)	-0.108 (-0.097)	-0.085 (-0.117)

Genotypic coefficients are given in parenthesis residual effect 0.310/(0.207)

\* significant at 5% \*\* significant at 1%

because of the counteraction of negative phenotypic indirect effects exhibited through fertile spikelets per panicle (-0.372), earbearing tillers per plant (-0.049), BLB score (-0.035), panicle length (-0.016), L/B ratio of kernel (-0.014) and 1000-grain weight (-0.001).

In the case of total tillers per plant, the contribution to single plant grain yield by positive genotypic direct effect (1.516) was the highest, reinforced by positive genotypic indirect effects through plant height (0.193), panicle length (0.031) and 1000-grain weight (0.050). It had some negative genotypic indirect effects also through other characters namely days to 50% flowering (-0.022), earbearing tillers per plant (-0.777), fertile spikelets per panicle (-0.302), sterile spikelets per panicle (-0.060) and L/B ratio of kernel (-0.034).

Highest negative genotypic direct effect on single plant grain yield was registered by earbearing tillers per plant (-0.809) followed by panicle length (-0.277). Earbearing tillers, though recorded the highest negative genotypic direct effect, resulted in a positive genotypic highly significant correlation ( $0.546^{**}$ ) with single plant grain yield having added positive indirect effects through total tillers per plant (1.456), plant height (0.270), days to 50% flowering (0.012), 1000 grain weight (0.001) and BLB score (0.001). However, the genotypic indirect effects through fertile spikelets per panicle (-0.216), sterile

spikelets per panicle (-0.073), panicle length (-0.056) and L/B ratio of kernel (-0.039) were negative. Phenotypically also this character showed a highly significant positive correlation ( $0.603^{**}$ ) with single plant grain yield by having positive phenotypic direct effect (0.339) and positive indirect effects through total tillers per plant (0.387), panicle length (0.030), L/B ratio of kernel (0.032) and BLB score (0.003).

Fertile spikelets per panicle had the highest positive genotypic correlation ( $0.605^{**}$ ) with single plant grain yield. The direct genotypic effect was positive (1.098). It had also positive genotypic indirect effects through days to 50% flowering (0.041), earbearing tillers per plant (0.159), panicle length (0.047), sterile spikelets per panicle (0.052), L/B ratio of kernel (0.018) and BLB score (0.020). However, the genotypic indirect effects of this character through total tillers per plant (-0.417), 1000-grain weight (-0.242) and plant height (-0.170) were negative. Phenotypically also this character registered a highly significant positive correlation ( $0.645^{**}$ ) with single plant grain yield by recording a positive phenotypic direct effect of 0.723.

1000-grain weight could negatively influence the single plant grain yield both genotypically and phenotypically. It recorded a positive genotypic direct effect (0.319) and also positive genotypic indirect effects

through, total tillers per plant (0.240) and L/B ratio of kernel (0.005). The genotypic correlation ( $-0.394^{**}$ ) with single plant grain yield was negative and highly significant as the negative genotypic indirect effects through fertile spikelets per panicle ( $-0.832$ ), days to 50% flowering (0.058), panicle length ( $-0.037$ ), BLB score ( $-0.018$ ), plant height ( $-0.009$ ), sterile spikelets per panicle ( $-0.003$ ) and earbearing tillers per plant ( $-0.001$ ) were operating. The phenotypic direct effect was negative and negligible, but resulted in a significant negative phenotypic correlation ( $-0.311^*$ ) with the single plant grain yield by the added negative phenotypic indirect effects through fertile spikelets per panicle ( $-0.467$ ), BLB score ( $-0.016$ ) sterile spikelets per panicle ( $-0.004$ ) and L/B ratio of kernel ( $-0.004$ ).

The rest of the characters studied, namely plant height, panicle length, number of sterile spikelets per panicle, L/B ratio of kernal and BLB score though had negative or positive direct effects and indirect effects through other characters of different magnitude could not establish any significant correlation with single plant grain yield either genotypically or phenotypically in the set of parents and  $F_1$  hybrids combined.

#### 4.1.7.4 Residual effects:

Genotypic and phenotypic residual effects of unknown characters or the rest of characters which were not included

in the present study were also estimated and presented in Table 18.

Table 18: Residual effects on single plant grain yield in 7 parents, 21  $F_1$  hybrids and 7 parents and 21  $F_1$  hybrids in rice

Source	Residual effect	
	Genotypic	Phenotypic
Parents	0.000	0.058
Crosses	0.156	0.345
Parents and Crosses	0.207	0.310

The genotypic residual effect was more (0.207) when parents and crosses were considered together, than either crosses or parents. In crosses, the genotypic contribution of unknown characters to single plant grain yield was 0.156 which worked out to 15.60 percent, while in the parents there was no genotypic residual effect indicating that the contribution of characters studied, explain adequately the dependence of single plant grain yield on the components taken into consideration.

It could be seen from the data presented, that the phenotypic residual effect was more (0.345) in hybrids than either in parents (0.058) or in parents and hybrids together. It was also apparent that the phenotypic residual effects

were more than that of genotypic residual effects in all the three groups namely parents, hybrids and parents and hybrids together, as the effects of environment get confounded into phenotype.

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#### 4.2 Testing of parents and $F_2$ populations:

Five dwarf parents including one susceptible (IR 8) and four resistant (IET 8320, IR 19660-274-3-3-1-3, IR 54 and Cisadane) to bacterial leaf blight and their resulting four  $F_2$  populations were grown in randomized block design with two replications (Fig.4). IR 8, the susceptible parent for BLB disease was commonly involved in all the four crosses. Data were collected on five selected quantitative characters namely plant height, earbearing tillers per plant, panicle length, BLB score and single plant grain yield and presented in Table 19.  $F_2$  populations of dwarf / tall parents were not considered for recording data on the above mentioned yield components as dwarf segregants could not express properly being shaded by tall plants. However, data on BLB score was recorded in  $F_2$  populations of all the crosses and parents to study inheritance of resistance to bacterial leaf blight and allelic relationships of genes governing resistance.



Fig. 4: Field view of parents and  $F_2$  populations showing tall and dwarf crosses planted separately.

4.2.1 Mean performance of five dwarf parents and four  $F_2$  populations (dwarf/dwarf) of crosses involving IR 8, as common parent:

The general mean values for parents and  $F_2$  populations were 85.13 cm for plant height, 11.56 for earbearing tillers, 24.01 cm for panicle length, 3.16 for ELB score and 20.45 g for single plant grain yield. The mean values of plant height in parents ranged from 74.40 cm in IR8 to a maximum of 100.25 cm in IET 8320 followed by Cisadane with 93.85 cm and IR 54 with 87.70 cm. The parental mean for plant height was 86.97 cm. IET 8320, though recorded the highest plant height among dwarf parents studied, did not lodge at any stage of the crop growth. IR 54, with a mean plant height of 87.70 cm was observed to have partial lodging at pre-harvest stage. Among the  $F_2$  populations the mean plant height was 82.84 cm which ranged from 77.54 cm (IR 19660-274-3-3-1-3 / IR 8) to a maximum of 88.54 cm (IET 8320/ IR 8). It is noteworthy to mention that the  $F_2$  populations involving a common parent (IR 8) differed widely in plant height within the same physical class of dwarfs (Fig.5).

IR 54, among the parents, recorded the highest mean number of earbearing tillers per plant (14.20) while the rest of the four parents did not differ much from each other in this character. The parental mean was 12.04 earbearing tillers per plant. The highest earbearing tillers per plant



Fig. 5:  $F_2$  populations showing differences in height within the same physical class of dwarfs.

among  $F_2$  populations was recorded by IR 54/IR 8 (12.67) followed by IET 8320/IR 8 (11.03) and the lowest (10.05) was in the  $F_2$  population of the cross IR 19660-274-3-3-1-3/ IR 8. The mean number of earbearing tillers per plant in  $F_2$  populations of four crosses (10.96) was less than that of the mean of five parents (12.04).

The mean panicle length ranged from a minimum of 21.93 cm in IR 8 to a maximum of 25.68 cm in IET 8320 among parents and from 22.93 cm in IR 8/Cisadane to a maximum of 24.75 cm in IET 8320/IR 8 among  $F_2$  populations. The mean panicle length of parents was 24.21 cm. Except IR 8, the remaining four parents recorded mean panicle length on par or higher than that of either parental mean or general mean of parents and  $F_2$  populations. The mean panicle length of parents (24.21 cm) was more than mean panicle length of  $F_2$  populations (23.76 cm).

Mean BLB score in parents (2.99) was less than that of  $F_2$  populations of four crosses. Among the parents it ranged from 1.60 in IR 54 indicating resistant reaction to 6.15 in IR 8. Among parents, only IR 8 is classified as susceptible.

Table 19: Mean performance of five dwarf parents and four  $F_2$  populations.

Parent/ $F_2$ population	Plant height (cm)	Ear bearing tillers per plant	Panicle length (cm)	BLB score (0-9 scale)	Single plant grain yield (g)
<b>Parents</b>					
IET 8320	100.25	11.90	25.68	1.95	28.50
IR 19660-274-3-3-1-3	78.65	11.90	24.65	2.60	15.37
IR 54	87.70	14.20	24.55	1.60	16.41
Cisadance	93.85	11.45	24.25	2.65	20.23
IR 8	74.40	10.75	21.93	6.15	19.16
Mean of parents	86.97	12.04	24.21	2.99	19.33
<b>Crosses</b>					
IET 8320/IR 8	88.54	10.03	24.75	2.93	29.81
IR 19660-274-3-3-1-3/ IR 8	77.54	10.05	23.74	3.62	20.12
IR 54/IR 8	80.98	12.67	23.61	3.22	17.34
IR 8/Cisadane	84.28	10.07	22.93	3.74	17.11
Mean of $F_2$ populations	82.84	10.96	23.76	3.38	21.10
S.E. dif(+)	1.97	0.63	0.81	0.28	2.00
C.D. (0.05)	4.55	1.46	1.88	0.65	4.61
General Mean	85.13	11.56	24.01	3.16	20.45

Next to IR 54, IET 8320 recorded a resistant reaction to bacterial leaf blight with a mean score of 1.95. Among the  $F_2$  populations of four crosses the mean BLB score ranged from 2.93 (IET 8320 / IR 8) to 3.74 (IR 8 / Cisadane). The  $F_2$  populations differed widely from the parents in BLB score and the trend was more towards susceptibility.

Mean single plant grain yields among parents ranged from a minimum of 15.37 g (IR 19660-274-3-3-1-3) to a maximum of 28.50 g (IET 8320) with a parental mean of 19.33 g. In  $F_2$  populations also, the combination of IET 8320 with the common parent, IR 8 recorded the maximum mean single plant grain yield of 29.81 g. The mean single plant grain yields among  $F_2$  populations ranged from 17.11 g (IR 8 / Cisadane) to 29.81 g (IET 8320/IR 8) with a  $F_2$  population mean of 21.10 g.

It is interesting to note that the parents recorded higher mean values than the  $F_2$  populations in respect of plant height, earbearing tillers per plant and panicle length and lesser mean values in respect of BLB score and single plant grain yields.

#### 4.2.2 Analysis of variance in parents and $F_2$ populations:

The analysis of variance for five parents and four  $F_2$  populations for five quantitative characters is presented in Table 20.

Table 20: ANOVA for five dwarf parents and four  $F_2$  populations for five quantitative characters in rice .

Source	df	Plant height (cm)	Ear bearing tillers per plant	Panicle length (cm)	BLB score (0-9 scale)	Single plant grain yield
Replications	1	0.01	2.07	1.16	0.29	3.09
Treatments	8	138.90 **	3.47 **	2.46 **	3.50 **	54.32 **
Parents	4	225.73 **	3.36 **	3.84 **	6.63 **	53.68 **
$F_2$ population	3	44.09 **	3.03 **	1.13	0.28	71.28 **
Parents Vs $F_2$ populations	1	76.04 **	5.26 **	0.92	0.66 *	6.01
Error	8	3.89	0.40	0.66	0.08	4.00
S.E. dif (+-)		1.97	0.63	0.82	0.28	2.00
C.D. (0.05)		4.55	1.46	1.88	0.65	4.62

When all the treatments including both parents and  $F_2$  populations were tested, significant differences among them were recorded for all the five characters. When partitioned, as parents and  $F_2$  populations, the parents showed significant differences among themselves for all the characters studied. Significant differences were also observed among  $F_2$  populations for plant height and single plant grain yield (1% level) and earbearing tillers per plant (5% level).  $F_2$  populations, (crosses) however, did not differ in respect of panicle length and BLB score. By comparing the parents versus  $F_2$  populations, significant differences were noticed

for three characters namely plant height, earbearing tillers per plant and BLB score. However, the  $F_2$  populations did not differ significantly from the parents for panicle length and single plant grain yield.

#### 4.2.3 Heritability and genetic advance in $F_2$ generation:

Estimates of heritability in broad sense as percent and genetic advance under selection and also as percent of mean were estimated for five characters in  $F_2$  generation and presented in Table - 21.

Table 21 : Estimation of Heritability (H) and genetic advance for 5 characters in  $F_2$  populations

Parameters	Plant height (cm)	Ear bearing tillers per plant	Panicle length (cm)	BLB score (0-9 scale)	Single plant grain yield
Genotypic variance	67.51	1.54	0.90	1.71	25.16
Phenotypic variance	71.40	1.94	1.56	1.79	29.16
Broad sense heritability as% (H)	94.55	79.33	57.69	95.53	86.28
Genetic advance under selection(GS)	16.46	2.27	1.48	2.63	9.60
Genetic advance as % of mean	19.33	19.66	6.18	83.29	46.93

Heritabilities in broad sense were generally high for all the characters studied in  $F_2$  generation. BLB score (95.53%) followed by plant height (94.55%) recorded the highest heritability in broad sense. It is interesting to note that single plant grain yield had an impressive heritability (86.28%) with 46.93% of genetic advance as percent of mean. A comparison of heritabilities in broad sense in  $F_1$  generation and  $F_2$  generation revealed that the values were higher in  $F_2$  than in  $F_1$  generation for single plant grain yield and BLB score. However, genetic advance for single plant grain yield in  $F_2$  (46.93) was comparatively less than in  $F_1$  (51.59%). BLB score alone recorded higher broad sense heritability with highest genetic advance as percent of mean in  $F_2$  generation compared to  $F_1$  generation.

#### 4.2.4 Correlation and character associations in $F_2$ populations:

Phenotypic and genotypic correlations were computed for parents and  $F_2$  populations and presented in Tables 22 and 23 respectively. In general, the genotypic correlation coefficients were higher than the phenotypic correlation coefficients, as expected.

##### 4.2.4.1 Correlations in parents grown along with $F_2$ populations:

It is evident from the results (Table 22) that the plant height had significant genotypic ( $0.829^{**}$ ) and

phenotypic ( $0.728^*$ ) positive correlations with panicle length and also with single plant grain yield genotypically ( $0.749^*$ ) and phenotypically ( $0.718^*$ ). Interestingly it had significant negative correlation genotypically ( $-0.704^*$ ) and phenotypically ( $-0.682^*$ ) with BLB score. Earbearing tillers per plant was negatively correlated with BLB score both genotypically ( $-1.097^{**}$ ) and phenotypically ( $-0.820^{**}$ ). BLB score was observed to have consistently negative significant association with all the characters studied. However, the negative correlation with single plant grain yield was not significant. The positive correlations of plant height with panicle length and single plant grain yield were also observed in the same pattern as in parents grown along with  $F_1$ 's. Significant negative correlation between plant height and BLB score might be due to the fact that the semidwarfs recorded lesser BLB score than the dwarfs within the set of dwarf parents.

#### 4.2.4.2 Correlations in $F_2$ populations:

It can be seen from the results (Table - 23) that earbearing tillers per plant in  $F_2$  populations exhibited a negative significant genotypic correlation ( $-0.722^*$ ) with BLB score. Panicle length had highly significant negative correlation with BLB score both genotypically ( $-0.870^{**}$ ) and phenotypically ( $0.865^{**}$ ) and positive correlation with single plant grain yield genotypically ( $1.000^{**}$ ) and phenotypically ( $0.885^{**}$ ). BLB score registered a significant negative

Table - 22 : Phenotypic and genotypic correlation coefficients between 5 characters in 5 dwarf parents.

Character	Earbearing tillers per plant	Panicle length	BLB score	Single plant grain yield
Plant height	0.249 (0.224)	0.728 <sup>*</sup> (0.829 <sup>**</sup> )	-0.682 <sup>*</sup> (-0.704 <sup>*</sup> )	0.718 <sup>*</sup> (0.749 <sup>*</sup> )
Earbearing tillers/plant		0.519 (0.398)	-0.675 <sup>*</sup> (-0.755 <sup>*</sup> )	-0.159 (-0.431)
Panicle length			-0.820 <sup>**</sup> (-1.097 <sup>**</sup> )	0.432 (0.326)
BLB score				-0.133 (-0.120)

genotypic coefficients are given in parenthesis

\*\* significant at 1%      \* significant at 5%

Table 23: Phenotypic and genotypic correlation coefficients between 5 characters in 4 dwarf F<sub>2</sub> populations

Character	Earbearing tillers per plant	Panicle length	BLB score	Single plant grain yield
Plant height	0.050 (0.061)	0.455 (0.488)	-0.578 (-0.565)	0.658 (-0.047)
Earbearing tillers/plant		0.134 (0.295)	-0.531 <sup>*</sup> (-0.722 <sup>*</sup> )	-0.071 (-0.047)
Panicle length			-0.865 <sup>**</sup> (-0.870 <sup>**</sup> )	0.885 <sup>**</sup> (1.000 <sup>**</sup> )
BLB score				-0.741 <sup>*</sup> (-0.761 <sup>*</sup> )

genotypic coefficients are given in parenthesis

\*\* significant at 1%      \* significant at 5%

correlation with single plant grain yield genotypically ( $-0.761^*$ ) and phenotypically ( $-0.741^*$ ). It is interesting to note that the correlations among various characters in  $F_1$  and  $F_2$  generations showed several differences in their direction.

#### 4.2.5 Path-coefficient analysis in dwarf parents and $F_2$ populations:

Phenotypic and genotypic path-coefficients for five characters namely plant height, earbearing tillers per plant, panicle length and BLB score in relation to single plant grain yield were estimated for five dwarf parents and four  $F_2$  populations (dwarf/dwarf) and presented in Tables 24 and 25 respectively.

##### 4.2.5.1 Path-coefficient analysis in dwarf parents grown along with $F_2$ populations:

Plant height among the dwarf group of parents exhibited the highest positive direct effect genotypically (1.095) and phenotypically (1.016) followed by BLB score genotypically (0.476) and phenotypically (0.915). Earbearing tillers per plant recorded negative direct effects at both genotypic ( $-0.349$ ) and phenotypic ( $-0.032$ ) levels. Among the characters studied, only plant height could establish a significant positive correlation with single plant grain yield at both genotypic ( $r = 0.749^*$ ) and phenotypic ( $r = 0.718^*$ ) levels. Plant height also had indirect positive genotypic (0.067) and phenotypic (0.334)

Table - 24 Path-coefficient analysis for 4 characters on grain yield in 5 parents.

Characters	Plant height	Earbearing tillers per plant	Panicle length	BLB score	Single plant grain yield (r value)
Plant height	1.016 (1.095)	-0.008 (-0.078)	0.334 (0.067)	-0.624 (-0.335)	0.718* (0.749*)
Earbearing tillers/plant	0.253 (0.245)	-0.032 (-0.349)	0.238 (0.032)	-0.618 (-0.359)	-0.159 (-0.431)
Panicle length	0.740 (0.907)	-0.017 (-0.139)	0.458 (0.081)	-0.750 (-0.523)	0.432 (0.326)
BLB score	-0.693 (-0.771)	0.022 (0.263)	-0.376 (-0.089)	0.915 (0.476)	-0.133 (-0.120)

Genotypic effects are given in parenthesis

\* significant at 5%.

effects through panicle length. However, plant height had indirect negative effects through BLB score genotypically (-0.335) and phenotypically (-0.624) and also through earbearing tillers it had negative genotypic (-0.078) and negative phenotypic (-0.008) indirect effects.

#### 4.2.5.2 Path-coefficient analysis in four $F_2$ populations (dwarf/dwarf):

In dwarf  $F_2$  populations, panicle length by recording the highest positive genotypic direct effect (1.236) and positive genotypic indirect effect through plant height (0.160) showed a significant positive genotypic correlation ( $r = 1.000^{**}$ ) with single plant grain yield, though it had some counteracting negative indirect genotypic effects through earbearing tillers per plant (-0.040) and BLB score (-0.355). Phenotypically also panicle length had the same trend of direct and indirect effects on single plant grain yield.

BLB score had positive direct genotypic (0.408) and phenotypic (0.142) effects and also indirect positive effects through earbearing tillers both genotypically and phenotypically. Despite these positive direct and indirect effects, BLB score resulted in a significant negative genotypic correlation ( $r = -0.760^*$ ) and negative phenotypic correlation ( $r = -0.741^*$ ) with single plant grain yield because of the high genotypic negative indirect effects it

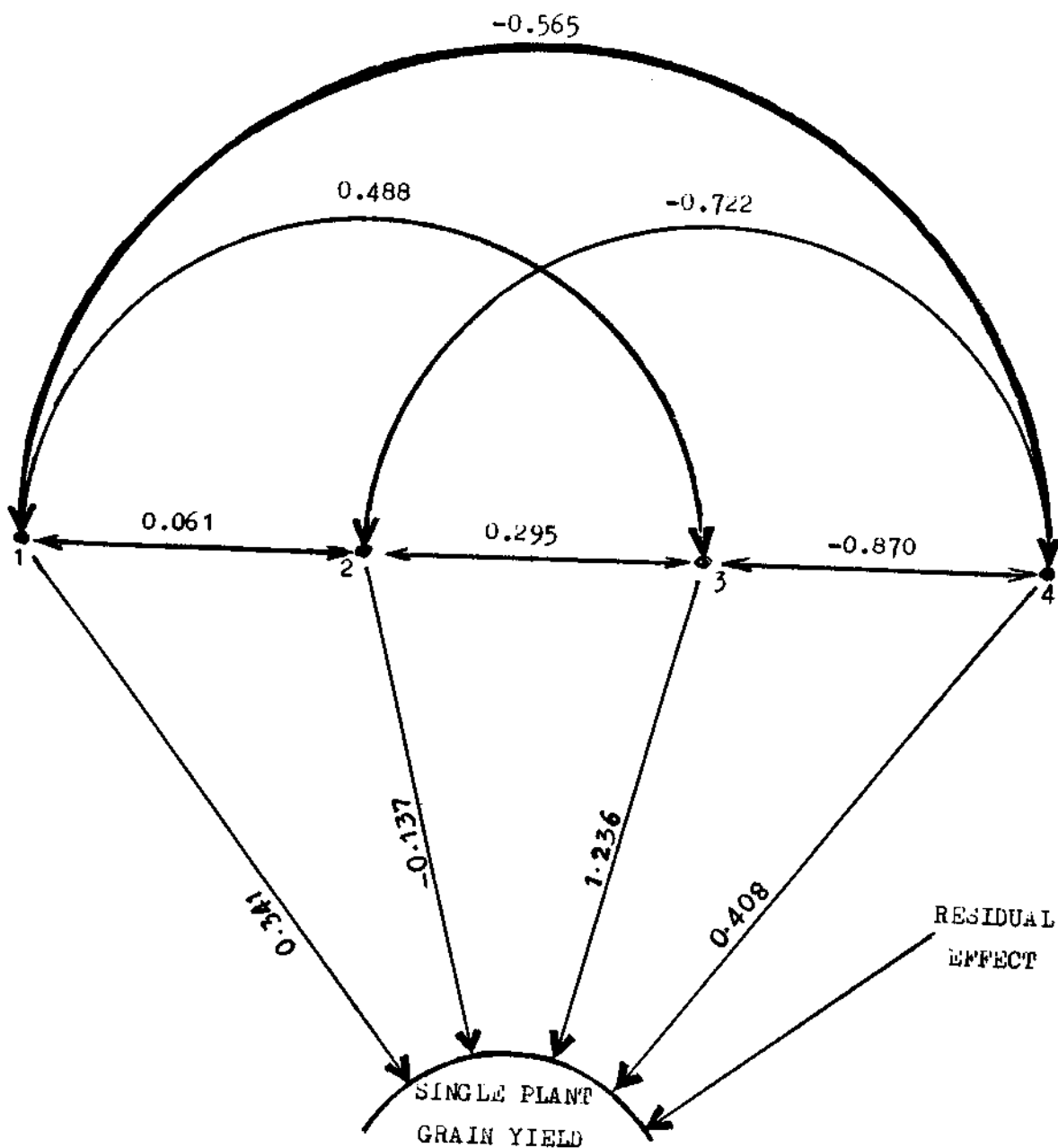


Fig. 13 Path analysis of 4 characters influencing single plant grain yield in  $F_2$  populations of rice.

( Double arrow indicates direct effect and single arrow correlation coefficient )

Table 25 Path-coefficient analysis for 4 characters on grain yield in 4  $F_2$  populations

Characters	Plant height	Earbearing tillers per plant	Panicle length	BLB score	Single plant grain yield (r value)
Plant height	0.353 (0.341)	-0.006 (-0.008)	0.394 (0.578)	-0.082 (-0.231)	0.658 (0.680)
Earbearing tillers/plant	0.018 (0.021)	-0.128 (-0.137)	0.116 (0.364)	-0.076 (-0.295)	-0.071 (-0.047)
Panicle length	0.161 (0.160)	-0.017 (-0.040)	0.864 (1.236)	-0.123 (-0.355)	0.885 <sup>**</sup> (1.000 <sup>**</sup> )
BLB score	-0.204 (-0.193)	0.068 (0.099)	-0.747 (-1.075)	0.142 (0.408)	-0.741 <sup>*</sup> (-0.760 <sup>*</sup> )

Genotypic effects are given in parenthesis

\* significant at 5%.

\*\* significant at 1%

had through panicle length (-1.075) and plant height (-0.193). Neither plant height nor earbearing tillers could show any significant association in  $F_2$  populations. (Table 25 and Fig 13)

#### 4.2.6 Grain yield performance of five dwarf parents and ten dwarf $F_2$ populations:

Grain yields of five dwarf parents and ten  $F_2$  populations of the crosses were recorded in plots of three square metres in both the replications. The mean grain yields were computed per hectare and presented in Table 26.

Among the five dwarf parents studied, IR 54 recorded the maximum grain yield of 6.53 t/ha closely followed by IET 8320 with 6.30 t/ha and both were on par with each other statistically. IR 19660-274-3-3-1-3 recorded minimum grain yield of 4.38 t/ha. The mean grain yield of parents was 5.71 t/ha. Three parents, IR 54, IET 8320 and Cisadane recorded higher grain yields per hectare than the parental mean.

The  $F_2$  population of the cross IET 8320 / IR 8 had the maximum grain yield of 8.95 t/ha closely followed by  $F_2$  population of the cross IET 8320 / IR 19660-274-3-3-1-3 with 8.67 t/ha. It is interesting to note that IET 8320 in combination with IR 19660-274-3-3-1-3 and with IR 8 could produce  $F_2$  populations having very high grain yield. The combination of both the high yielding dwarf parents IR 54 and IET 8320 could also produce  $F_2$  populations of high potential

Table 26 Grain yield performance of five dwarf parents and ten F<sub>2</sub> populations of dwarf x dwarf crosses.

S.No.	Parent/ F <sub>2</sub> population	Mean grain yield/ plot (kg)	Mean grain yield (t/ha)	Rank among parents/ F2 populations	Total entries
<b>Parents</b>					
1	IET 8320	1.890	6.30	2	8
2	IR 19660-274-3-3-1-3	1.315	4.38	5	15
3	IR 54	1.960	6.53	1	6
4	Cisadane	1.725	5.75	3	11
5	IR 8	1.675	5.58	4	12
	Mean of parents	1.713	5.71		
<b>F<sub>2</sub> Populations</b>					
6	IET 8320/IR 19660-274-3-3-1-3	2.600	8.67	2	2
7	IET 8320 / IR 54	2.410	8.03	3	3
8	IET 8320 / IR 8	2.685	8.95	1	1
9	IET 8320 / Cisadane	1.910	6.37	6	7
10	IR 19660-274-3-3-1-3/IR 54	2.060	6.87	5	5
11	IR 19660-274-3-3-1-3/IR 8	1.780	5.93	8	10
12	IR 19660-274-3-3-1-3/Cisadane	1.385	4.62	10	14
13	IR 54 / IR 8	1.630	5.43	9	13
14	IR 54/ Cisadane	2.095	6.98	4	4
15	IR 8 / Cisadane	1.815	6.05	7	9
	Mean of F2 populations	2.037	6.79		
	General mean	1.929	6.43		
	S.E. dif.(+/-)	0.081	0.27		
	C.D. (0.05)	0.174	0.58		

of the order 8.03 t/ha. The grain yields per hectare in  $F_2$  populations in general were higher than the parents. The grain yields in  $F_2$  populations ranged from a minimum of 4.62 t/ha (IR 19660-274-3-3-1-3 / Cisadane ) to a maximum of 8.95 t/ha (IET 8320 / IR 8) with a mean of 6.79 t/ha. The general mean of experiment (parents and crosses combined) was 6.43 t/ha which was significantly higher than the parental mean.

#### 4.2.7 Analysis of variance for parents and $F_2$ populations for grain yields:

The analysis of variance for grain yields per plot of five dwarf parents and ten  $F_2$  populations is presented in Table 27.

It can be seen from the ANOVA that unlike in earlier experiments involving parents and  $F_1$ 's, significant differences between replications occurred. This may be due to segregation in  $F_2$  populations. When all the entries including both parents and  $F_2$  populations were tested, significant differences for grain yield among them were noticed. When partitioned as parents and  $F_2$  populations significant differences also were exhibited among the parents as well as  $F_2$  populations. The parents also differed significantly from  $F_2$  populations for grain yield when tested against each other and as the mean of the  $F_2$  population is higher than parental mean, it confirms the superior performance of  $F_2$  population over parents for grain yield per plot.

Table 27 : ANOVA for grain yield of five dwarf parents and ten  $F_2$  populations of dwarf x dwarf crosses.

Source	df	M.s.s
Replications	1	1.1347**
Treatments	14	0.3149**
Parents	4	0.1262**
$F_2$ populations	9	0.3560**
Parents vs $F_2$ populations	1	0.6998**
Error	14	0.0066
S.E. dif.(+-)		0.0813
C.D. (0.05)		0.1743

#### 4.3 Inheritance of resistance to bacterial leaf blight disease:

Inheritance of resistance to bacterial leaf blight of rice was studied in two sets of crosses. The first set consisted of crosses between susceptible and resistant parents. IR 8, which showed susceptible reaction to the disease (Fig.6) has been used as common parent in the first set of crosses with the rest of six resistant parents. The second set of crosses was among resistant parents. The parents,  $F_1$ 's and  $F_2$  populations were screened for resistance to pathotype I of bacterial leaf blight. The screening for resistance was done at two stages namely seedling stage and adult plant stage. The results obtained along with the test for goodness of fit are presented in the Tables 28 and 29.

In all the crosses the  $F_1$  showed resistant reaction.

##### 4.3.1 Resistant/susceptible crosses (first set):

###### 4.3.1.1 IET 8320/IR 8 :

The segregation ratio of  $F_2$  population of IET 8320/IR 8 gave a good fit for the ratio of 13 resistant : 3 susceptible, at both seedling and adult plant stages. This indicates that there is one dominant and one recessive gene governing resistance, independent of each other in IET 8320 at both seedling and adult plant stages.



Fig. 6: IR 8 showing susceptibility and  $F_2$  of IR 8/Cisadane showing segregation to BLB reaction at adult plant stage.

## 4.3.1.2 IR 19660-274-3-3-1-3 / IR 8 :

The  $F_2$  segregation gave a good fit for 3 resistant : 1 susceptible ratio indicating the presence of one dominant gene governing resistance in IR 19660-274-3-3-1-3 in seedling as well as adult plant stages.

## 4.3.1.3 IR 54 / IR 8:

The  $F_2$  population of this cross showed a segregation ratio of 15 resistant : 1 susceptible suggesting that resistance in IR 54 is controlled by two dominant duplicate genes at both seedling as well as adult plant stages (flag leaf stage).

## 4.3.1.4 IR 8 / Cisadane :

As indicated in Table 28 the observed segregations for the resistance to pathotype I showed a good fit to the ratio 13 resistant : 3 susceptible at both seedling as well as adult plant stages. This suggests a digenic control of resistance having one dominant and one recessive gene for resistance, independent of each other in Cisadane (Fig.7).

## 4.3.1.5 IR 8 / Kuntlan :

The  $F_2$  segregation pattern at seedling stage gave a good fit for 3 resistant : 1 susceptible ratio indicating that resistance to bacterial leaf blight at seedling stage in Kuntlan is governed by single dominant gene. However, at adult plant stage the segregation gave a good fit for



Fig. 7:  $F_2$  populations of IR 8/Cisadane showing segregation for BLB reaction at adult plant stage.

Table 28 Segregation for bacterial leaf blight resistance in F2 populations of six crosses involving resistant/susceptible parents (set I)

S.no	Cross	Plant stage	F1 reaction		F2 population size	Classification				'P' value between		
			mean score	reaction		observed res.	observed sus.	expected res.	expected sus.		segregation ratio	chi square
1	IET 8320/IR8 (1/4)	S A	3.00 4.05	R R	520 600	419 497	101 103	422.5 487.5	97.5 112.5	13:3 13:3	0.15 0.99	0.70-0.50 0.50-0.30
2	IR19660-274-3- 3-1-3/IR8 (2/4)	S A	2.30 2.20	R R	512 596	387 456	125 140	384.0 447.0	128.0 149.0	3:1 3:1	0.66 0.72	0.50-0.30 0.50-0.30
3	IR 54/IR 8 (3/4)	S A	2.80 4.00	R R	456 592	430 550	26 42	427.5 555.0	28.5 37.0	15:1 15:1	0.23 0.72	0.70-0.50 0.50-0.30
4	IR 8/Cisadane (4/5)	S A	2.67 3.40	R R	528 616	436 492	92 124	429.0 500.5	99.0 115.5	13:3 13:3	0.61 0.77	0.50-0.30 0.50-0.30
5	IR 8/Kuntlan (4/6)	S A	3.20 4.40	R R	520 596	399 494	121 102	390.0 484.3	130.0 111.7	3:1 13:3	0.83 1.05	0.50-0.30 0.50-0.30
6	IR 8/Nigeria 5 (4/7)	S A	1.75 1.90	R R	452 592	418 549	34 43	423.8 555.0	28.2 37.0	15:1 15:1	1.25 1.04	0.30-0.20 0.50-0.30

S:Seedling stage

A:Adult plant stage

a digenic ratio of 13 resistant : 3 susceptible indicating the presence of one recessive gene in addition to 1 dominant gene governing resistance to bacterial leaf blight.

It is not clear from the data whether the same gene is functioning for resistance at seedling and adult plant stages. It appears that they could be the same or different, besides, there are indications to show, as in the case of IR 8 / Kuntlan, that additional gene or genes may come into operation at adult plant stage. This also would open up possibility that genes may come into operation at different stages during the life history of plant.

#### 4.3.1.6 IR 8 / Nigeria 5 :

The F<sub>2</sub> data of this cross both at seedling and adult plant stages showed a segregation ratio of 15 resistant : 1 susceptible, thereby showing that the resistance in Nigeria 5 is governed by a pair of duplicate dominant genes.

#### 4.3.2 Resistant/Resistant cross (second set):

The second set of crosses was among the six resistant parents. There were 15 crosses under this group where both the parents were resistant for pathotype I of bacterial leaf blight. The F<sub>1</sub>'s in all the 15 crosses showed resistant reaction to bacterial leaf blight in seedling as well as adult plant stages. In most of the crosses, like the ones between IET 8320 with IR 19660-274-3-3-1-3 (Fig. 8), IR 54 and Cisadane; between IR 19660-274-3-3-1-3 with IR 54,



Fig. 8:  $F_2$  population of IET 8320/IR 19660-274-3-3-1-3 showing no segregation for BLB reaction.

Table 29 Segregation for bacterial leaf blight resistance in F2 populations of 15 crosses between resistant parents (set II)

S.no	Cross	F1 reaction		Plant stage	HLB score	Rea-ction	F2 popu-lation size	Classification			segre-gation ratio	chi <sup>2</sup>	'P' value between
		S	R					observed	expected	res. sus.			
1	IET 8320/IR 19660-274-3-3-1-3 (1/2)	S	R	S	2.36	R	518	518	-	-	-	-	-
		A	R	A	2.75	R	600	600	-	-	-	-	-
2	IET 8320/IR 54 3-1-3/IR8 (1/3)	S	R	S	2.80	R	515	515	-	-	-	-	-
		A	R	A	3.50	R	593	593	-	-	-	-	-
3	IET 8320/Cisadane (1/5)	S	R	S	2.50	R	518	518	-	-	-	-	-
		A	R	A	3.25	R	604	604	-	-	-	-	-
4	IET 8320/Kuntlan (1/6)	S	R	S	2.20	R	372	284	88	279.0	93.0	3:1	0.36 0.70-0.50
		A	R	A	2.25	R	587	574	13	577.8	9.7	63:1	1.62 0.30-0.20
5	IET 8320/Nigeria 5 (1/7)	S	R	S	2.17	R	476	467	9	468.6	7.4	63:1	0.33 0.70-0.50
		A	R	A	2.15	R	580	569	11	570.9	9.1	63:1	0.42 0.70-0.50
6	IR 19660-274-3-3-1-3/IR 54 (2/3)	S	R	S	2.80	R	510	510	-	510.0	-	-	-
		A	R	A	2.95	R	600	600	-	600.0	-	-	-
7	IR 19660-274-3-3-1-3/Cisadane (2/5)	S	R	S	2.67	R	396	288	108	297.0	99.0	3:1	1.09 0.30-0.20
		A	R	A	2.45	R	602	602	-	602.0	-	-	-
8	IR 19660-274-3-3-1-3/Kuntlan (2/6)	S	R	S	2.75	R	450	450	-	450.0	-	-	-
		A	R	A	3.50	R	608	608	-	608.0	-	-	-

S:Seedling stage A:Adult plant stage

contd..

Table 29 contd..

S.no	Cross	Plant stage	F1 reaction		F2 population size	Classification		segregation ratio	chi <sup>2</sup>	'P' value between			
			mean score	Reaction		observed res. sus.	expected res. sus.						
9	IR 19660-274-3-3-1-3/Nigeria 5 (2/7)	S A	1.90 2.00	R R	312 592	307 580	5 12	307.1 582.8	4.9 9.2	63:1 63:1	0.003 0.83	0.95-0.98 0.50-0.30	
10	IR 54/Cisadane (3/5)	S A	2.67 2.80	R R	500 590	500 590	- -	500.0 590.0	- -	- -	- -	- -	- -
11	IR 54/Kuntlan (3/6)	S A	2.00 2.35	R R	340 610	340 564	- 46	340.0 571.9	- 38.1	- 15:1	- 1.74	- 0.20-0.10	- -
12	IR 54/Nigeria 5 (3/7)	S A	2.70 2.60	R R	449 590	449 590	- -	449.0 590.0	- -	- -	- -	- -	- -
13	Cisadane/Kuntlan (5/6)	S A	2.92 3.75	R R	330 590	257 555	73 35	247.5 553.1	82.5 36.9	3:1 15:1	1.46 0.10	0.30-0.20 0.80-0.70	- -
14	Cisadane/Nigeria 5 (5/7)	S A	1.91 2.10	R R	440 578	431 538	9 40	433.1 541.9	6.9 36.1	63:1 15:1	0.67 0.42	0.50-0.30 0.7-0.50	- -
15	Kuntlan/Nigeria 5 (6/7)	S A	1.70 1.65	R R	514 570	504 528	10 42	506.0 534.4	8.0 35.6	63:1 15:1	0.49 0.22	0.50-0.30 0.70-0.50	- -

S:Seedling stage                      A:Adult plant stage

Cisadane (at adult plant stage Fig.9) and Kuntlan: between IR 54 with Cisadane, Kuntalan (at the seedling stage) and Nigeria 5 did not exhibit any segregation in the  $F_2$  generation (Table 29) indicating that the gene or genes governing resistance are allelic or that the number of genes involved in the inheritance is very large resulting in lack of segregation in a population of about 600 plants taken into consideration in the present study. The results of crosses where segregation was observed are presented below.

#### 4.3.2.1 IET 8320 / Kuntlan (Fig. 10):

The  $F_2$  segregation at seedling and adult plant stages gave a good fit for the ratio 3 resistant: 1 susceptible and 63 resistant: 1 susceptible respectively indicating the operation of one dominant gene at seedling stage and 3 dominant duplicate genes at adult plant stage in the inheritance of bacterial leaf blight disease (Fig.10).

#### 4.3.2.2 IET 8320 / Nigeria 5:

At the seedling stage as well as at the adult plant stage, the  $F_2$  segregation gave a good fit for 63 resistant: 1 susceptible ratio indicating the operation of 3 dominant duplicate genes.

#### 4.3.2.3 IR 19660-274-3-3-1-3 / Cisadane:

The  $F_2$  segregation gave a good fit for 3 resistant : 1 susceptible at seedling stage indicating operation of one



Fig. 9:  $F_2$  population of IR 19660-274-3-3-1-3 / Cisadane showing no segregation for BLB reaction. IR 19660-274-3-3-1-3 (Resistant parent) can also be seen.



Fig. 10:  $F_2$  population of IET 8320 / Kuntlan showing segregation for different characters (Plant height, Panicle characters and BLB reaction).

dominant gene governing resistance. However, at adult plant stage there was no segregation.

#### 4.3.2.4 IR 19660-274-3-3-1-3 / Nigeria 5 :

The  $F_2$  segregation gave a good fit for 63 resistant: 1 susceptible ratio both at seedling stage and adult plant stage indicating the presence of 3 dominant duplicate genes.

#### 4.3.2.5 IR 54 / Kuntlan:

There was no segregation at seedling stage. But the segregation at adult plant stage gave a good fit for 15 resistant: 1 susceptible ratio indicating the operation of 2 dominant duplicate genes.

#### 4.3.2.6 Cisadane / Kuntlan :

The  $F_2$  segregation at seedling stage showed a monogenic ratio of 3 resistant: 1 susceptible where as at adult plant stage it gave a good fit for 15 resistant : 1 susceptible indicating the presence of one dominant gene at seedling stage and two dominant duplicate genes at adult plant stage.

#### 4.3.2.7 Cisadane / Nigeria 5 and (8) Kuntlan / Nigeria 5 :

The  $F_2$  segregation in these two crosses were similar. At seedling stage the segregation gave a good fit for 63 resistant: 1 susceptible indicating the operation of 3 dominant duplicate genes. At adult plant stage the

segregation gave a good fit for 15 resistant : 1 susceptible ratio indicating the presence of only two dominant duplicate genes.

From the above results it appears that the dominant and recessive genes conferring resistance at seedling stage may or may not confer resistance at adult plant stage. Additional gene or genes may start functioning at adult plant stage. Similarly genes functioning at seedling stage may stop functioning at adult plant stage.

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## **DISCUSSION AND CONCLUSION**

## CHAPTER V

### DISCUSSION AND CONCLUSION

#### 5.1 Discussion:

With the advent of dwarf and semi-dwarf rice varieties during 1960's varietal improvement through hybridization became the most important method of breeding replacing the earlier simpler methods. With such a change in the strategy of breeding, germplasm hitherto neglected or unused is being introduced into the background of elite breeding lines, enlarging their diversity. Most of the germplasm that is being incorporated possesses desirable genes not only for yield but also for other characters like resistance to pests and diseases, superior grain quality etc. The new breeding lines and varieties thus produced form a part of newer breeding cycle where these lines or varieties become base upon which further improvement is sought. Genetic analysis of these lines must precede utilizing them in <sup>the</sup> next cycle of breeding. The present work was taken up with the objectives of not only genetically evaluating the lines and varieties thus produced, but also to study their reaction to the widespread bacterial leaf blight disease. The results obtained are discussed below.

##### 5.1.1 Combining ability and gene actions:

In the present study mean sums of squares for general combining ability (gca) and specific combining

ability (sca) are highly significant for all the characters except for panicle length which was not significant for sca (Table 8). Similar results were also reported by Rahman et al. (1981). The magnitude of variance was in general higher for gca than for sca except in cases of total tillers per plant and single plant grain yield. Sivasubramaniam and Madhavamenon (1973), Singh and Richharia (1978), Panwar and Paroda (1983), Anandakumar and Sreerangasamy (1984 a), Panwar et al. (1985), Sarathe and Singh (1986) and Sardana and Borthakur (1987) observed significant mean sums of squares for gca and sca for all the characters studied and reported that the mean sums of squares for gca were higher than that of sca for all the characters.

However, in some instances the sca variances were observed to be higher than that of gca eventhough both gca and sca were significant. Except in case of single plant grain yield and number of tillers per plant, the mean sums of squares of sca were greater than that of gca for the rest of the characters studied, namely panicle length, panicle weight, number of grains per panicle and plant height. Singh et al. (1979) noted higher values for sca mean sums of squares than gca for all the characters studied i.e. panicle length, number of bold grains per panicle, number of chaff grains per panicle, days to maturity and 1000-grain weight. Rao et al. (1979) and Rao et al. (1980a) also obtained higher significant sca mean sums of squares for certain quantitative characters like earbearing tillers and single plant grain yield respectively than that of gca.

Mean sums of squares due to gca were reported to be significant for all the characters studied except for few characters like number of panicles (Mohanty and Mohapatra, 1973), plant height (Rao et al., 1980 a), flag leaf width (Singh et al., 1980 a), panicle weight per plant and total weight per plant (Murai and Kinoshita, 1986), for which the sca mean sums of squares were invariably higher than that of gca. The mean sums of squares in certain studies were significant for gca for all the characters studied and not significant for sca for characters like panicle length (Rahman et al., 1981), kernel length (Singh and Singh, 1985) and for effective length of primary branch of panicle, number of spikelets per secondary branch, number of spikelets per panicle and width of grains (Srivastava and Seshu, 1983) and obviously the mean sums of squares for gca were higher than sca.

In some other cases the mean sums of squares of both gca and sca were not significant for some characters like earbearing tillers, number of grains per panicle, sterility percentage, 1000-grain weight and grain yield (Haque et al., 1981). Mean sums of squares of gca for kernel characters like thickness and that of sca for grain breadth and kernel breadth were not significant (Mohapatra and Mohanty, 1986). Sardana and Borthakur (1987) also observed that the mean sums of squares of gca for 100-grain weight and that of sca for effective tillers and 100-grain weight were not significant. Thus, the parents and hybrids studied in different

investigations manifested combining ability to various degrees of magnitude as has been also found in the present study.

Genetic component analysis reduced the difference in magnitude of mean sums of squares between gca and sca. While there was no great reduction in the magnitude of sca component, the component due to gca registered great reduction in almost all the cases. The component due to gca was about 10% of mean sums of squares due to gca (Table 8). These changes in the magnitude had a bearing on the degree of dominance which ranged from 20.162 for panicle length to 0.071 for single plant grain yield. For a number of important characters like total tillers per plant, earbearing tillers per plant, fertile spikelets per panicle, sterile spikelets per panicle, sterility percentage, BLB score and single plant grain yield, non-additive variance was far more important than additive variance. For all these characters in general, the narrow sense heritability was also very low. Additive variance was found to be important for days to flowering, plant height, panicle length, L/B ratio of kernel and 1000-grain weight. These characters had very high narrow sense heritability values.

Variation is the plant breeders material for selection of parents to make crosses. Variance is additive if a hybrid is mid-way between its homozygous parents. Departures from mid point indicate non-additive effects (Vander plank, 1984). In most of the combining ability

analyses degree and extent of the genetic variability present in the test material and the type of gene action in the expression of different quantitative characters have been reported earlier based on mean sums of squares of gca and sca by several researchers (Mohanty and Mohapatra, 1973; Sivasubramaniam and Madhavamenon, 1973 b; Singh and Nanda, 1976 a; Singh and Richharia, 1978; Rao et al., 1979; Rao et al., 1980 a; Rahman et al., 1981; Singh and Singh, 1985; Mohapatra and Mohanty, 1986 ; Sardana and Borthakur, 1987).

Mohanty and Mohapatra (1973) reported predominant additive gene action for 1000-grain weight and number of spikelets per panicle while non-additive gene action was important for grain yield, panicles per plant, panicle length and panicle weight. Singh and Nanda (1976 a) observed additive gene action for grains per panicle, panicle length, panicle number and grain yield and non-additive gene action for 100- grain weight. However, Singh et al. (1979) observed predominance of non-additive gene actions for all the characters (dominance and epistasis) studied namely panicle length, number of bold grains, number of chaff grains, days to maturity and 100-grain weight by recording higher sca variances than gca variances.

Rao et al. (1980 a) recorded both additive and non additive gene actions in diallel set of crosses in rice. Additive gene action was predominant for almost all the characters (except for single plant grain yield), i.e., for

days to 50% flowering, plant height, earbearing tillers, panicle length, spikelets per panicle, 100-grain weight, panicle weight, grains per panicle and sterility (%). Haque *et al.* (1981) reported that the gene action was predominantly additive for grain yield, earbearing tillers, number of grains per panicle and 1000-grain weight and non-additive for days to flowering, plant height and sterility of spikelets. Similar to the results obtained in the present study, Rahman *et al.* (1981) reported higher mean sums of squares of *gca* for heading time, plant height, panicle number, grains per panicle and yield per plant indicating the predominance of additive gene effect. The mean sums of squares of *sca* per panicle length however, were higher than *gca* showing the importance of non-additive gene action for this character. However, Sardana and Borthakur (1987) noted the importance of additive and non-additive gene actions in their study; additive gene action being predominant for all the characters studied.

For quantitative characters of grain quality which determine the market price of produce, Singh and Singh (1985) recorded the importance of additive gene action for kernel length and both additive and non-additive gene action for kernel breadth and kernel L/B ratio.

Determination of combining ability and gene action for different traits present in the parents and specific crosses, by mean sums of squares of *gca* and *sca* alone may not

reveal the degree and magnitude in its true dimension. It is but, logical to determine these by genetic component analysis. Very few workers (Panwar and Paroda, 1983; Anandakumar and Sreerangasamy, 1984; Panwar *et al.*, 1985; Sarathe and Singh, 1986; and Kaw and Khush, 1987) have reported combining ability and gene actions through genetic component analysis. However, some workers like Takeda and Saito (1983) reported the predominance of additive genetic variance for kernel weight and non-additive genetic variance for white belly frequency based on the trend of heritability estimates in advanced generations.

Comparison of broad sense and narrow sense heritabilities (Table 11) reveals that there was a great reduction in the values of heritability estimations for days to flowering, total tillers per plant, earbearing tillers per plant, fertile and sterile spikelets per panicle, sterility percentage, BLB score and single plant grain yield. As expected, these reductions were great for those characters which are predominantly governed by non-additive gene action.

High estimates of narrow sense heritability were obtained (Table 11) for days to 50% flowering, plant height, panicle length, L/B ratio of kernel and 1000-grain weight. The narrow sense heritability values for important characters like total tillers, earbearing tillers and yield were low.

Singh and Nanda (1976 a) reported high heritability for earbearing tillers and low values for yield/plant,

panicle length, grains/panicle and 100-grain weight. However, Maurya (1976) obtained high heritability for plant height, grain length and test weight but low for earbearing tillers, panicle length, grain breadth and yield per plant.

Chaudhary et al. (1980) reported different heritability values for  $F_1$  in kharif and rabi and attributed the variation partly due to parents used and partly due to environmental variation. They also observed that spikelets per panicle and 100-grain weight recorded high heritability as well as high genetic advance. Chauhan and Nanda (1983) reported high heritability and genetic advance for traits like kernel length and kernel L/B ratio and suggested that these characters are either simply inherited traits governed by a few major genes or additive gene effects play an important role in the inheritance of these traits even if they are under polygenic control.

According to Johnson et al. (1955) high heritability estimate coupled with high genetic advance is more advantageous than heritability alone in predicting the resultant effect for the selection of best individual from segregating population. From this point of view among the characters having high narrow sense heritability, plant height, L/B ratio and 1000-grain weight have sufficiently large narrow sense heritability and genetic advance.

High heritability values for component characters like plant height, grain length, test weight and earbearing

tillers etc. and low heritability for single plant grain yield as in the present study, have been reported by several other workers (Maurya, 1976; Singh and Nanda, 1976 a; Chaudhary et al., 1980). The present study has brought out clearly not only very low heritability value for yield (5.88% in narrow sense), but also highlights the futility of attempting genetic manipulations by way of pedigree selection for yield, as the improvement would be marginal. On the other hand multiple crosses among parents with desirable gca effects and ultimate utilization of heterosis breeding may hold an answer for overcoming yield plateaus experienced at present by the rice breeders.

Maurya and Singh (1977) reported that the best parent was the best general combiner for that character. Singh (1977) and Singh and Richharia (1978) also reported that per se performance of parents was an indication for their general combining abilities. However, Singh and Richharia (1978) presented evidences to show that a parent having a good general combining ability effects need not necessarily produce better hybrids. They further observed that a parent with poor general combining ability might produce better hybrids. Sivasubramaniam and Madhavamenon (1973 a) also could not identify a parent other than IR 8 as a good general combiner for all the characters studied. Mohanty and Mohapatra (1973), Singh and Nanda (1976 a) Rao et al. (1979), Rao et al. (1980 a) and Singh et al. (1980 a) also reported similar results.

Srivastava and Seshu (1983) found CR 1002, LMN 111 and IR 42 to be good general combiners for grain yield per plant. However, they attribute the desirability of these parents as due to different component characters. They also reported that none of the parents were good general combiners for all the characters studied. They could identify the fact that semidwarfing gene does not limit the expression of most of the yield related traits. They could discern a good relationship between performance of parent per se and gca effects. Gilbert (1958) has devised a statistical test termed as heterogeneity of potence to determine parents which are most potent than the others. Judged from this test, however, the results of Srivastava and Seshu (1983) failed to predict the hybrid performance from the parental performance for several characters including grain yield.

Panwar and Paroda (1983) found good correlation between gca effects and per se performance for all the characters studied by them. They suggest that yield be used as a selection criterion of parent as it would save time.

Anandakumar and Sreerangasamy (1984 a) also reported that no single parent was a good general combiner for all the characters. Panwar et al. (1985) reported sona, IR 8, Jhona 349, BJ 1 and IR 2055-43-2-5-4 to be good general combiners for grain yield and some other traits. They also found that no parent was good for all the characters. They suggest multiple crosses and selection in advance generations

to bring together different desirable traits. They also opined that diallel selective mating may be followed in rice as it might break linkage blocks and foster genetic recombination (Jensen, 1970).

Sarathe and Singh (1986) reported that four varieties namely Laloo 14, Madhuri, IR 43 and Kalimoochh 64 were good combiners for yield per plant. Better performance of Laloo 14 than the late maturing varieties was reported to be due to its earliness which escaped the detrimental effect of low temperatures. They also reported that high yielding cultivars Sabarmati and Madhuri exhibited negative gca effects for yield per plant and were poor combiners. The reason for this was ascribed to high sterility caused by low temperatures at the time of flowering resulting in higher panicle sterility. None of the parents were good combiners for all the characters studied.

Sardana and Borthakur (1987) observed Jaya as the best general combiner for grain yield per plant which also had significant gca effect for 100-grain weight. Similarly, the second best combiner Pizum (local tall) for grain yield was also a good combiner for number of grains per panicle and panicle length. However, no single parent was good general combiner for all the traits in their study.

The results obtained in the present study are in general agreement to the earlier reports to the extent that no single parent was desirable for all the characters

studied. In such cases an overall assessment based on general combining ability effects of several characters need to be taken into consideration with due emphasis on the final character i.e., single plant yield. IET 8320 appears to be a desirable parent in the present study from the points of days to flowering, plant height and single plant grain yield, while Nigeria 5 appears to be desirable from the points of days to flowering, panicle length, BLB score and single plant grain yield. Kuntlan appears to be undesirable from the points of days to flowering, plant height, sterile spikelets per panicle, sterility percentage, L/B ratio of kernel and single plant grain yield. The other parents are not desirable from the point of single plant grain yield as they recorded no significant gca effects for this character. They have different combinations of gca effects for other characters.

A comparison of mean yield (Table 4) and gca effects (Table 9) of parents revealed that, for single plant grain yield, the best and the poorest<sup>e</sup> parents were the same on both the considerations. However, the remaining five parents had differential rankings when viewed jointly. A similar joint viewing of per se performance and gca effects for days to 50% flowering reveals higher number of agreements in the ranking than could be seen for the single plant grain yield.

For plant height the agreement in ranking was far higher than that could be seen for days to 50% flowering and

single plant grain yield. It is obvious, that there would be higher agreement for relative ranking for per se performance and gca effects, if the number of genes governing the character is smaller with very high heritability values. The narrow sense heritability (Table 8) was highest for plant height (76.16%) followed by days to flowering (68.13%) and the least was for single plant grain yield (5.88%). As the earlier workers have not viewed the results in the manner done in the present study, conflicting reports have been presented in the literature regarding the agreement of relative ranking due to per se performance and gca effects.

The mean performance of 21 crosses is presented in Table 4 and the sca effects are presented in Table 10. The highest significant sca effects for single plant grain yield was obtained for the cross Kuntlan / Nigeria 5 followed by IR 19660-274-3-3-1-3 / IR 8. Several other crosses also exhibited significant positive sca effects for single plant grain yield like Cisadane / Kuntalan, IET 8320 / IR 54, IR 19660-274-3-3-1-3 / Nigeria 5 and IET 8320 / Cisadane. However, none of the crosses are desirable from the point of view of all the characters. Some of them were desirable for more number of characters like the case of Kuntlan/Nigeria 5, which was desirable for days to 50% flowering, total tillers per plant, earbearing tillers per plant fertile and sterile spikelets per panicle, sterility percentage and BLB score besides grain yield. However, this cross represents a tall/tall cross with very highly undersirable plant-type.

There is no possibility of getting a dwarf or semidwarf plant-type in subsequent generations. The  $F_1$  had red kernels and this character would segregate in future generations. Similarly each of the crosses was desirable or otherwise for different combination of characters. No single cross among those mentioned, was desirable on the basis of all the characters.

Mohanty and Mohapatra (1973) reported that the best heterotic hybrids obtained by them did not register significant sca effects for yield. Similarly the hybrids possessing high sca effects for yield did not exhibit positive significant sca effects for any of the components. Sivasubramaniam and Madhavamenon (1973 a) reported that the product of two general combiners did not register high specific combining ability effects in the hybrid. The parental performance alone or even their hybrids may not always indicate their ability to produce transgressive segregants (Jinks and Jones 1958). Singh and Richharia (1978) however, observed that high x high crosses might involve dominant x dominant interactions and therefore, they have a high probability of deriving good homozygous lines in the progeny. Rao et al. (1979) observed that parents possessing good gca for single plant grain yield and low or high gca for other component characters are more desirable. Rao et al. (1980 a) observed that desirable significant sca effects are registered by crosses which are either low x high or high x high general combiners.

Rahman et al. (1981) reported that the best specific combiners for each of the character studied were the result of low x low general combiners and they attribute their superiority to over dominance and epistasis.

Srivastava and Seshu (1983) explained their results on the basis that sca effects reflect deviation of performance of a cross combination from its expected performance (based on the gca effects). Because of the dominance of genes for certain characters, the  $F_1$ 's would be nearer to the dominant parent and thereby would show high sca effects. If both parents belonged to the same group, the  $F_1$ 's would be nearer to mid-parental value resulting in low sca effects depending on the nature of modifying genes. They further observed that crosses between good general combiners may not always result in good  $F_1$  combinations.

In the present study six hybrids had positive sca effects for single plant grain yield while two had negative significant sca effects. In both the crosses where negative significant sca effects were encountered, i.e., IR 19660-274-3-3-1-3/Kuntlan and IR 54/Kuntlan, Kuntlan was the common male parent which also had negative gca effect for single plant grain yield. The six crosses which had positive sca effects are IET 8320/Kuntlan, IR 19660-274-3-3-1-3 / IR 8, IR 19660-274-3-3-1-3/Nigeria 5, Cisadane/Kuntalan and Kuntlan/Nigeria 5. Among those crosses, Kuntlan/Nigeria 5 had the highest positive sca effect (28.065<sup>\*\*</sup>). One parent, Kuntlan

had negative significant gca effect (-5.315\*\*) and the other parent, Nigeria 5 had positive significant gca effect (4.874\*). The hybrid between Kuntlan/Nigeria 5 was also desirable for days to 50% flowering, total tillers per plant, earbearing tillers per plant, fertile and sterile spikelets per panicle, sterility percentage and BLB score. Incidentally it suffers from having red kernels which is not preferred outside Kerala state. Similarly, the rest of five crosses with positive sca effects for single plant grain yield were undesirable for one or more characters.

The other crosses which recorded highly significant sca effects were between parents having either negative or positive significant gca effects. On the other hand the combination of IET 8320/Kuntlan was between high x low and the  $F_1$  did not register significant sca effect. For other characters also the results are somewhat similar. The two crosses that have recorded negative significant sca effects i.e., IR 19660-274-3-3-1-3/Kuntalan and IR 54/Kuntlan also recorded very low single plant grain yields of 22.35 g and 25.70 g respectively. In fact, these two crosses were the lowest yielding combinations. Hence, it appears that it would be difficult to generalise the performance of  $F_1$  hybrids in terms of sca effects based on parental general combining ability effects.

### 5.1.2 Heterosis and heterobeltiosis:

In general sense heterosis refers to the increase or decrease of  $F_1$  value over the mean parental value. From the view point of plant breeding, increase of  $F_1$  value over better parent or the best commercial variety is more relevant (Virmani et al., 1981). The former is designated as heterobeltiosis (Fanseco and Peterson, 1968) and the latter as standard heterosis.

Ramiah (1935) was <sup>the</sup> first to recognise the presence of heterosis in rice though Jones (1926) earlier, observed higher number of culms and greater productivity of  $F_1$ 's over parents in rice. Several workers later notably Capinpin and Punyasingh (1938), Ramiah and Ramaswamy (1941), Brown (1953), Sen and Mitra (1958), Shinjyo and Omura (1966), Chang et al. (1971), Watanabe (1971), Purohit (1972), Athwal and Virmani (1972), Cornahan et al. (1972), Swaminathan et al. (1972), Palaniswamy and Palaniswamy (1973), Murayama (1973), Baldi and Malagoni (1975), Yap and Chang (1976), Nayak et al. (1978), Singh and Singh (1978), Mallick et al. (1978), Paramasivan (1979), Lin and Yuan (1980), Virmani et al. (1981), Srivastava and Seshu (1982), Amirthadevarathinam (1983), Viramani and Edwards (1983), Shanmugasundaram and Sivasubramanian (1983), Anandakumar and Sreerangasamy (1984b), Dwivedi (1985), Singh and Singh (1985), Shashi et al. (1986), Mohapatra and Mohanty (1986), Jun et al. (1986), Kaushik and Sharma (1986) and Prakash and Mahadevappa (1987) reported heterosis in rice.

Successful development of hybrid maize in 1930's created enormous impetus among breeders of other crops including self pollinated crops like rice and wheat. By far the greatest development of commercial hybrids has been in maize. In 1950's usable male sterility was found in Sorghum in the progeny of crosses having milo as the female parent and kafir as the pollen parent (Stephens et al., 1954). Production of hybrid pearl millet also became practical since finding of cytoplasmic male sterility (Tift 23 A) and fertility restoring genes (Burton, 1965 ; Athwal, 1965). In other commercial crops like cotton and in some vegetable crops heteroses have since been successfully exploited by manual emasculation and hybridization which produces sizable quantity of hybrid seed.

Identification of male sterile lines in other self-pollinated crops was visualised as an essential tool for commercial production of  $F_1$  hybrid seed. Chinese were the first to use cytoplasmic male sterility to develop commercial  $F_1$  rice hybrids in 1973 (Lin and Yaun 1980), which contributed significantly for increasing rice production in China.

Rice scientists in 1977 became aware of the Chinese hybrid rice which was released for general cultivation in China. They were successful in transferring male sterile gene from related wild species to cultivated background and utilized the sterile lines for production of commercial

hybrid seed. In general, the hybrid rice has an yield improvement of 20 to 30% over the best traditional varieties (Virmani et al.,1981). Besides grain yield, quality characters of rice like L/B ratio, that decide market price as also resistance for major diseases and insect pests for stable yields are important aspects on which detailed information is lacking.

The results obtained in the present studies pertaining to heterotic behaviour for yield, yield components, certain related characters, L/B ratio of kernel and resistance to bacterial leaf blight disease are discussed.

The extent of heterosis for single plant grain yield which is of prime concern to the breeders ranged from -13.31 to 156.62<sup>\*\*</sup> percent in different crosses studied. Out of 21 crosses, 19 recorded positive heterosis of which, 13 crosses expressed significant positive heterosis. Ten out of 21 crosses exhibited heterosis over better parent. The magnitude of positive heterobeltiosis varied from 44.49<sup>\*</sup> to 108.05<sup>\*\*</sup> percent among the ten crosses. Carnahan et al. (1972), Saini and Ishkumar (1974) and Maurya and Singh (1978) also observed heteroses varying from 122 to 156 percent over better parent. A detailed examination of individual crosses showing high magnitude of heterosis for single plant grain yield indicated that the mechanism of expression of heterosis was different in different crosses. Kuntalan/Nigeria 5 which

had the highest per se performance, manifested high positive heterosis over better parent for total tillers, earbearing tillers, fertile spikelets per panicle and reduced sterility percentage.

High heterosis over better parent and high performance over mid-parent in IR 19660-274-3-3-1-3/IR 8 with high per se performance was due to simultaneous heterosis for total tillers, earbearing tillers, fertile spikelets per panicle and negative heterosis for L/B ratio and BLB score compared with better and mid-parent values. Though certain extent of negative heterosis has been expressed for certain yield components like 1000-grain weight and fertile spikelet number per panicle, however, it was compensated by increase in other major yield components like earbearing tillers and negative sterility percentage resulting in high positive heterotic effect for grain yield. Obviously, the heterosis for single plant grain yield in these crosses are due to increase in one, two or all the basic components of yield and/or reduced percentage of sterility. It is now widely accepted that heterosis for grain yield is due to simultaneous heterosis in number of yield components which bears with the present observations. Carnahan et al. (1972), Mohanty and Mohapatra (1973), Saini and Ishkumar (1974), Maurya and Singh (1978), IRRI (1980), Shanmugasundaram and Sivasubramaniam (1983), Anandakumar and Sreerangasamy (1984 b) and Kaushik and Sharama (1986) also observed heterosis for

yield because of simultaneous heterosis in a number of yield components.

Absence of significant heterosis in yield as observed in rest of the seven crosses studied, seemed to be due to absence of heterosis in component characters namely earbearing tillers, 1000-grain weight or number of fertile spikelets as also due to high per se performance of their parents or high sterility associated with  $F_1$  hybrids in some instances. A comparison between heterotic and non-heterotic crosses also revealed that the former showed heterosis for more than two component characters whereas the latter showed heterosis mostly for a single component character or at best two. Besides, in some crosses the advantageous effect was found cancelled by negative heterosis for other component characters as observed in the cross IR 19660-274-3-3-1-3/Kuntlan<sup>in</sup> which the heterotic advantage for total tillers and earbearing tillers has been nullified by high negative heterosis in fertile spikelets and positive heterosis for sterility percentage and BLB score which finally resulted in negative heterosis in grain yield. Such negative values for grain yield were also observed by Carnahan et al. (1972) due to increased sterility in hybrids.

It has been proposed that the more diverse the parents greater are the chances of heterotic expression in  $F_1$  (Anand and Murthy, 1968; Maurya and Singh, 1978). A critical appraisal of data has substantiated this fact in the present

study also as was observed in crosses like Kuntlan / Nigeria 5, IR 19660-274-3-3-1-3 / IR 8 and Cisadane / Kuntlan. However, IET 8320 recorded higher heterosis for grain yield only with parents with high per se performance.

Hybrid breeding enables expeditious incorporation of disease resistance governed by dominant genes. In China, by utilizing IR 26 as restorer parent, resistance to bacterial leaf blight and brown planthopper could easily be incorporated in to the hybrids (Lin and Yaun, 1980).

Heterosis for BLB score in the hybrids in the present studies ranged from  $-62.59^{**}\%$  to  $100^{\%}$ . Five crosses exhibited significant positive heterosis over mid-parent and eight crosses over better parent for BLB score. Hybrids showing negative heterosis for BLB score over mid or better-parent are desirable since the higher score implies susceptibility. Four crosses recorded significant negative heterosis over mid-parent and two crosses significant negative heterobeltiosis for BLB score. In the heterotic crosses for resistance, any one or two of the following three resistant parents namely Nigeria 5, Cisadane and IR 19660-274-3-3-1-3 were involved. The hybrids of the two crosses that expressed significant heterobeltiosis for disease resistance were the  $F_1$  of IR 8 / Nigeria 5 ( $-43.78^{**}$ ) and Cisadane / Nigeria 5 ( $-36.60^{**}$ ). In addition five crosses over mid-parent and six crosses over better-parent showed a trend of having resistance to bacterial leaf blight by recording negative heterois for BLB score.

The results obtained clearly indicate that the commercial rice hybrids with fair level of resistance to bacterial leaf blight can successfully be developed by incorporating the favourable dominant genes for resistance. Studies on quantitative inheritance and heterosis breeding for disease resistance are very few in rice. Reddy and Rao (1978) reported dominant gene relationship and additive genic system for reaction to bacterial leaf blight and allelic relationship of recessive genes for resistance in certain resistant varieties.

#### 5.1.3 Correlations and character associations:

Correlation coefficients among quantitative characters like plant height, total tillers per plant, earbearing tillers per plant, panicle length, fertile and sterile spikelets per panicle, L/B ratio of kernel, 1000-grain weight, BLB score and single plant grain yields have been calculated for parents,  $F_1$ 's and for parents and  $F_1$ 's together. A perusal of Table 12, 13 and 14 reveals that number of fertile spikelets alone is common among the three populations which showed positive correlation with single plant grain yield. In the analysis involving parents and  $F_1$ 's together, two more characters have been identified exhibiting positive significant correlation with single plant grain yield namely total tillers per plant and earbearing tillers per plant. There was positive correlation between total tillers per plant and earbearing tillers per plant as

expected. But surprisingly number of total tillers per plant was negatively correlated with fertile spikelets. This could mean that an increase in either total tillers per plant or fertile spikelets would adversely affect the other character. Since, single plant grain yield is positively correlated with these characters, a proper balance needs to be arrived at to realise increased grain yield. Number of earbearing tillers per plant, though positively correlated with single plant grain yield, was found to be not correlated with fertile spikelets per panicle.

Days to 50% flowering and 1000-grain weight were consistently negatively correlated with single plant grain yield. Besides these two characters, plant height and panicle length in parents and sterile spikelets per panicle in  $F_1$  hybrids were also negatively correlated with single plant grain yield. These characters were either positively correlated or not correlated among themselves. Any selection for higher values of these characters would not only depress yield directly, but also increase the value of the characters which are negatively correlated with yield, which would also result in increasing the depression in single plant grain yield. In other words, selection for shorter duration, short plant height and short panicle length, lower number of sterile spikelets per panicle and lesser 1000-grain weight will improve the grain yield directly and indirectly.

Length breadth ratio (L/B ratio) and BLB score were consistently not correlated with single plant grain yield in all the three instances. Besides these two characters, total tillers per plant, earbearing tillers per plant and sterile spikelets per panicle in parents, plant height, earbearing tillers per plant and panicle length in  $F_1$  hybrids and plant height, panicle length and sterile spikelets per panicle in parents and  $F_1$ 's together also did not show any correlation with single plant grain yield. These characters among themselves were some times positively correlated as in the case of total tillers per plant with earbearing tillers per plant in parents, plant height with earbearing tillers per plant and panicle length and earbearing tillers with panicle length in  $F_1$  hybrids and plant height with panicle length, sterile spikelets per panicle and panicle length with sterile spikelets in parents and  $F_1$ 's together. There were instances of negative correlation among these characters which are not correlated with yield as in the case of sterile spikelets with L/B ratio in parents, plant height with L/B ratio, earbearing tillers with L/B ratio and panicle length with L/B ratio in  $F_1$  hybrids and plant height with L/B ratio, panicle length with L/B ratio and BLB score and sterile spikelets with L/B ratio in combined analysis of parents and  $F_1$ 's. The rest of the character pairs have shown no significant correlations among themselves. However, it must be remembered that the presence or absence of correlation among these characters would have very little bearing on the

single plant grain yield, as these characters showed no correlation with ultimate grain yield.

There are several interesting associations between groups of characters which are positively correlated with yield, and not correlated with yield. It is only logical to expect that the characters which are positively correlated with yield and the characters which are negatively correlated with yield should be either negatively correlated or if independent, not correlated with each other. In parents, fertile spikelets per panicle alone being positively correlated with yield, showed as expected, negative correlation with days to 50% flowering and 1000-grain weight, besides establishing no correlation with plant height and panicle length. Similarly in  $F_1$  hybrids fertile spikelets per panicle alone being positively correlated with yield exhibited significant negative correlation with days to 50% flowering sterile spikelets per panicle and 1000-grain weight all of them which have negative correlation with single plant grain yield. In the analysis involving parents and  $F_1$ 's together fertile spikelets per panicle established negative correlation with days to 50% flowering and 1000-grain weight. All other associations were not significant.

It is evident from the above presentation that in general, the results are as expected, in establishing associations among themselves. Chaudhury *et al.* (1973) identified negative correlation between panicle number with

number of grains per panicle and 1000-grain weight. Panicle length was positively correlated with number of grains per panicle. 1000-grain weight was positively correlated with single plant grain yield, whereas panicle length and 1000-grain weight were negatively correlated with single plant grain yield and fertile spikelets per panicle and positively correlated with single plant grain yield in the present study.

Negative correlation between earbearing tillers per plant and single plant grain yield was reported by Mishra et al. (1973), which could not be detected in the present study. They have also observed positive and significant association between number of grains per panicle and grain yield as in the present study. However, the present study bears with the results of Vinaya Rai and Murthy (1979), in which significant positive correlation was observed between grain yield and grains per panicle at two fertilizer rates and water regimes tested. Chaudhary et al. (1980), observed significant correlation of spikelets per panicle and grains per panicle with single plant grain yield. The results are similar to the present study as their grains per panicle could be equated with fertile spikelets in the present study. They observed positive correlation between plant height and panicle length as has been also observed in the present study. They further observed negative correlation between grains per panicle with 1000-grain weight as was seen between fertile spikelets and 1000-grain weight in the present study.

Rao et al. (1980 b) observed positive association between earbearing tillers with grain yield as has been observed in the analysis involving parents and  $F_1$ 's together in the present study. They also observed positive association between grains per panicle and grain yield per plant as seen between fertile spikelets per panicle with single plant grain yield in all the analyses in the present study. Surprisingly in five out of seven cases studied by them, they found significant positive association between 100-grain weight and grain yield, contrary to consistent negative association between 1000-grain weight and single plant grain yield in the present study. They have also reported negative association between earbearing tillers and grains per panicle both of which were positively correlated with yield. A similar situation was met with in the present study in the combined analysis of parents and  $F_1$ 's together where total tillers and fertile spikelets have registered negative association while both of them were positively correlated with single plant grain yield.

Singh (1980) observed that panicle bearing tillers, fertile grains per panicle and grain weight were positively associated with grain yield per plant, while no association between panicle length and single plant grain yield as seen in  $F_1$  hybrids and in combined analysis of parents and  $F_1$ 's in the present study. In parents a negative association could be detected between these two characters in the present study. Similarly the association between 1000-grain weight

and single plant grain yield was consistently negative in the present study. Ghorai and Pande (1982) could identify the negative association between test weight and yield as observed in the present study.

Singh et al. (1984) have also observed a negative association between number of grains per panicle and grain yield. However, they could not detect any association between 1000-grain weight and grain yield. Misal et al. (1985) found significant positive association between plant height, days to 50% flowering, number of grains per panicle and 1000-grain weight with grain yield per plant. They could detect negative association between length of panicle and grain yield per plant as observed among parents in the present study.

As could be seen from foregoing discussion there are more often similarities between the published work and present study. The differences are mostly due to the nature of the material as even in the present study differences could be noticed when analysis was done on parents, hybrids and in combination of parents and hybrids. Hence, genetic nature in terms of homozygosity, heterozygosity, segregation resulting from recombination and selective mating leading to breakage of linkage blocks appear to determine the magnitude and type of association between characters in a population.

#### 5.1.4 Path-coefficient analysis:

As in the case of correlations, path-coefficient analysis was also performed in parents, hybrids and combination of parents and hybrids. From path-coefficient analysis several interesting features could be deduced.

The number of fertile spikelets has direct positive contribution in all the three instances and successfully could establish positive correlation with yield. Number of total tillers per plant, which also had positive direct contribution to grain yield could establish significant contribution to yield only in analysis involving parents and  $F_1$ 's together. In other two cases no correlation could be discerned. 1000-grain weight, which also had positive direct contribution to grain yield could only establish significant negative correlation with single plant grain yield in all the cases. On the other hand, BLB score has negative direct contribution to grain yield in all the three cases but could not establish any significant correlation with grain yield.

The changes in magnitude and direction of direct contributions in final terms of correlation are due to their indirect contribution through other yield components to grain yield per plant. When the sum total of indirect contributions are in the opposite direction or of low magnitude, the correlations established assume either opposite directions or result in no association being established. Viewed from this point, number of fertile

spikelets and 1000-grain weight are very important characters as the first one retained its direction and association with yield, while the second one was able to retain the association but in the opposite direction. BLB score which had negative direct contribution due to its indirect contribution through other characters failed to establish any association with grain yield. There are other instances which merit mention as the ones having positive direct contribution but negative association, like 1000-grain weight, eg. panicle length in parents and days to 50% flowering and sterile spikelets in  $F_1$ 's. On the other hand, there is an instance where the direct contribution was negative but with positive correlation, Eg., L/B ratio in combined analysis of parents and  $F_1$ 's. There are several instances where there was direct positive contribution with establishment of no correlation, like total tillers per plant and earbearing tillers per plant in parents, plant height and total tillers in  $F_1$ 's and plant height in combination of parents and  $F_1$ 's together. As opposed to this, besides BLB score, there are instances where the direct contribution is negative with no correlation like sterile spikelets in parents, earbearing tillers per plant, panicle length and L/B ratio in  $F_1$ 's and panicle length and sterile spikelets in combined parents and  $F_1$ 's.

Mishra et al. (1973) identified positive direct effects on yield by number of earbearing tillers, number of

grains per panicle and 1000-grain weight as also observed in the present study.

Lenka and Mishra (1973) studied path-analysis in four cultivars of rice and found that pure line selected variety Ptb 10, differed from IR 8, T(N)<sub>1</sub> and Bala which were all resultant of hybridization and selection. The direct effect of number of fertile grains was negative and that of panicle length was positive in ptb 10, whereas the direct effects of number of tillers, number of fertile grains per panicle and 1000-grain weight were positive. The direct effect of panicle length was negative in the high yielding varieties studied. Both fertile spikelets and panicle length recorded positive contribution in the present study.

Vinaya Rai and Murthy (1979) reported positive direct contribution and significant positive correlation under low and high nitrogen (N) rates between grains per panicle and yield. Yadav and Singh (1979) observed positive direct contribution to yield by days to flowering, number of panicle bearing tillers, plant height, number of grains per panicle and 1000-grain weight. However, in the present study, days to flowering had negative direct contribution. The differences in the results could be due to the material taken into consideration in these two studies. Yadav and Singh (1979) reported results based on 18 pure breeding homozygous semi-dwarf strains of different eco-geographical regions, whereas the present study is based on highly

improved semi-dwarf varieties, tall varieties with desirable bacterial leaf blight resistance and their hybrids which has brought to surface the negative contribution made by days to flowering which could not be detected in their study. Singh (1980) observed positive contribution by panicle length, grains per panicle, number of fertile grains per panicle and negative direct contribution by plant height and sterile grains per panicle, to grain yield per plant in the  $F_1$  generation. Panicle bearing tillers, fertile grains per panicle and 1000-grain weight could establish significant positive correlation with grain yield, while panicle length and grains per panicle could establish significant negative correlation with grain yield per plant.

Singh et al. (1984) identified negative direct contribution by spikelet sterility percent and days to maturity and positive direct contribution by plant height, panicle length, number of grains per panicle and 100-seed weight. Of these, number of grains per panicle exhibited significant positive correlation with yield and spikelet sterility established a significant negative correlation with yield.

Misal et al. (1985) identified positive direct contribution by plant height, length of panicle, days to 50% flowering and number of grains per panicle, while days to maturity and 1000-grain weight had negative direct contributions. All these characters were significantly

correlated with grain yield except panicle length registering correlation in negative direction. As far as 1000-grain weight is concerned the present result is directly opposite of what they have realised.

From the foregoing discussion it could be seen that the magnitude and direction of direct contribution is not a permanent feature in as much as the fact that indirect contributions through other characters profoundly influenced the final outcome in terms of establishing a valid character association which could be used as a criterion for selection. In spite of several characters having direct positive contribution to yield, very few could establish significant correlation like number of fertile spikelets. In this aspect the indirect contributions through other characters and their direction assume immense importance, like in the case of combined analysis of parents and hybrids where earbearing tillers per plant was found to have a direct contribution of -0.809 but a positive contribution of 1.456 through total tillers per plant, ultimately resulting in establishment of highly significant positive correlation ( $0.546^{**}$ ) with single plant grain yield. The results obtained in the present study clearly indicate the need for such analysis afresh every time in plant breeding devoted to evolve a selection criterion based on component analysis to gain correlated responses.

### 5.1.5 Studies in $F_2$ generation:

It is very well established that  $F_2$  populations involving segregation for different height classes result in shading of the dwarf plants by the tall plants. Consequently the dwarf plants fail to express their potential for many quantitative characters including yield (AICRIP, 1968; Ragaiah, 1971). A strategy was evolved to overcome this phenomenon by identifying the dwarf segregants in such crosses in the nursery beds itself. Depending on the objectives of breeding, these were separately planted and selection exercised (AICRIP, 1968 ; Ragaiah, 1971).

In the present study four crosses alone were chosen representing  $F_2$  generation of crosses involving IR 8 as common parent with IET 8320, IR 19660-274-3-3-1-3, IR 54 and Cisadane. Since all parents are dwarf having common gene for height, no significant difference was expected for this character. The genotypes could express themselves to their full potential. The mean values for plant height, earbearing tillers and panicle length were lesser in  $F_2$  populations than in parents, while the mean values for BLB score and single plant grain yield were higher in  $F_2$  populations than in parents. For all the characters there were significant differences in parents, while in  $F_2$  significant differences did not exist for panicle length and BLB score. Comparison of parents and  $F_2$  populations revealed the existence of significant differences between these two groups except for

panicle length. Heritabilities in broad sense were generally higher ranging between 57.92% for panicle length to 94.55% for plant height. Single plant grain yield had an impressive 86.28% heritability with 46.93% genetic advance as percent of mean. Latif and Zaman (1965) observed in  $F_2$  generation high heritability for characters like earbearing tillers, panicle length, number of fertile grains per panicle. Interestingly they observed low heritability for plant height. Tsai (1971) observed high heritabilities for days to flower and plant height. Sivasubramaniam and Madhavamenon (1973) observed in  $F_2$  generation of crosses involving both tall and dwarf varieties, high heritability associated with grain yield, number of tillers, number of grains per panicle. Genetic advance was however, found to be high for grain yield and number of grains per panicle only. Wisudharamn and Weerapat, (1974) realised low heritability estimates for grain yield per plant and number of panicles per plant. For 1000-grain weight moderate heritability and for plant height, high heritability were observed by them. Nancharaiah et al. (1976) observed high heritability for days to flowering in  $F_2$  generation, while Chang (1977) observed high heritability for number of panicles per plant under high nitrogen level. It is apparent that heritability values in broad sense for quantitative characters like plant height, earbearing tillers, panicle length, BLB score and single plant grain yield in general were high. Wherever genetic advance under selection was reported, it was also high in  $F_2$  generation.

In the present study also, all these five characters, have shown very high heritability (broad sense) values as also genetic advances. The  $F_2$  being first segregating generation, it is expected that highest variance would be associated with all the quantitative characters. Under pedigree method of selection, initial selection is made in this generation. The superior or otherwise of selected genotypes in this generation depend greatly on the amount of heterozygosity besides the nature of genotype. Through progressive reduction in the heterozygosity in the subsequent generations, individuals of truly desirable genotypic combinations would retain their superiority. Hence, the presence of high heritability coupled with high genetic advance as realised in the present study among the four combinations in  $F_2$  generation is very encouraging. Substantial yield improvement appears to be possible through selection. However, it must be remembered that high heritability and genetic advance for BLB score has to be understood, in as much as the selection for low score is the desirable direction. It appears to be possible through selection for low BLB score, a population could be established within a few generations possessing a very high degree of resistance to BLB besides high yields.

#### 5.1.5.1 Correlations and path-coefficients in $F_2$ generation:

Correlations between characters in parents have been estimated twice in the present study. In the experiment

conducted with parents and  $F_1$ 's, larger number of characters were considered and only five characters have been taken into consideration in the experiment involving  $F_2$  generation. A comparison of values obtained in parents reveals several differences like plant height was negatively associated with single plant grain yield in the first experiment whereas it was positively associated in the 2nd experiment. In fact plant height alone showed significant positive association with single plant grain yield in the second experiment, whereas panicle length and several characters which have not been taken into consideration in the second experiment exhibited significant association either positively or negatively in the first experiment. Similarly in the  $F_2$  generation, only panicle length has exhibited significant positive association and BLB score a significant negative association with single plant grain yield. It was gratifying to note that panicle length was also significantly and negatively associated with BLB score as also with earbearing tillers per plant genotypically. These associations would mean that plants with greater susceptibility to bacterial leaf blight would have lesser number of earbearing tillers and shorter panicles resulting in lower single plant grain yield. On the other hand selection for higher number of earbearing tillers with longer panicles would result in identification of individuals with greater resistance to bacterial leaf blight and high single plant grain yield. Since all these characters have high

heritability and genetic advance, it is possible to rapidly increase yield of single plants through appropriate selection.

Path-coefficient studies however, revealed that panicle length rather than earbearing tillers per plant would be a better character to rely upon while selection, as it possesses highest positive direct contribution to single plant grain yield in  $F_2$  generation. It must be remembered that the relative amount of contribution and the direction of contribution varies with different generations and the genetic nature of material under selection. The importance associated with the component will have to be changed keeping in view the character association while advancing the material from one generation to the next. Several earlier studies at identifying a single or few characters associated with yield found that no character was consistently associated through generations with yield. Hence, two consecutive generations should be taken into consideration at a time while breeding for yield improvement through selection of component characters.

#### 5.1.5.2 Studies on grain yield performance of 5 dwarf parents and 10 $F_2$ populations (dwarf x dwarf):

An experiment was conducted to evaluate the performance of five parents and their 10  $F_2$  populations for grain yield per plot. An attempt to establish a relationship between gca effects of parents and sca effects, heterosis and

heterobeltiosis of  $F_1$ 's with the performance of  $F_2$  generation of individual crosses was not successful. However, the only parent possessing positive gca effects for single plant grain yield i.e., IET 8320 was one of the parents in the top three  $F_2$  progenies. Analysis of variance revealed significant differences, between replications and treatments which include parents,  $F_2$  populations and parents vs.  $F_2$  populations. As the  $F_2$  generation is segregating one, differences in replications are expected. The analysis of variance reveals the significant difference among dwarf parents and between the 10  $F_2$  populations. When the parents and  $F_2$  generations were ranked on the basis of mean grain yield per plot (also, as t/ha), the top five ranks were occupied by the  $F_2$  generations of different crosses indicating the greater potential of the  $F_2$  generation over the parents. From such superior performing early generations, it would be possible to practice selection for yield improvement with impressive gains in yields as generations advance. Thus, the results obtained in the present study are very encouraging from both bacterial leaf blight resistance as well as grain yield points of view.

#### 5.1.6 Inheritance of resistance to bacterial leaf blight :

Genetic studies of resistance to bacterial leaf blight disease on rice caused by Xanthomonas campestris pv. oryzae have been mainly carried out in Japan, International Rice Research Institute, philippines, and in India at

Directorate of Rice Research (AICRIP), Hyderabad and Central Rice Research Institute, Cuttack.

Systematic studies on host plant resistance to bacterial leaf blight were started in Japan in the early 1930's and numerous cultivars resistant to Japanese strains were identified (Mizukami, 1966; Ezuka and Horino, 1974). Inheritance of resistance to the Japanese strains was investigated and three loci for resistance were identified (Nishimura and Sakaguchi, 1959; Sakaguchi, 1967 ; Ezuka et al., 1975). These loci were designated Xa 1, Xa 2 and Xa 3. In the tropics, systematic studies on bacterial leaf blight were started at the early 1960's. Based on the inheritance studies conducted at IRRI Xa 4, xa 5, Xa 6, Xa 7, xa 8, xa 9 and Xa 10 genes for resistance to Philippine strains of the bacterium were identified (Petpisit et al., 1977; Olufowote et al., 1977; Sidhu and Khush, 1978; Sidhu et al., 1978; Singh et al., 1983 ; Yoshimura et al., 1983). Xa 1 and Xa 2 are closely linked and are located on chromosome 11. Xa 6, xa 9 and Xa 10 are linked to Xa 4 (Sidhu et al., 1978; Singh et al., 1983 ; Yoshimura et al., 1983). The research work in Japan was mostly on Japanese isolates of bacterial cultures on Japonica, subspecies of Oryza sativa L.

Initially, in India, the same Japanese isolates and Japanese differentials have been utilized to identify the nature of local isolates (Sidhu et al., 1986). The research work in IRRI was more comprehensive in as much as isolates,

as well as the hosts employed were from all over the world. This has led Khush (1977) to identify gene centres from where these resistant genes originated. For example, gene centre I consists of India and Bangladesh from where xa 5 originated. Gene centre II consists of South India and Sri Lanka where xa 4 originated and gene centre III consists of Indonesia, Java etc. This was possible due to availability of large germplasm, production of large number of crosses and utilization of large number of isolates from all over the world. Thus, the work at IRRI provides by far the most comprehensive literature on the number and nature of genes involved and their specific reaction to different inoculums.

It is obvious, that there are large number of genes designated as Xa 1, Xa 2, Xa 3 etc., and some of these genes have multiple alleles like Xa-4a and Xa-4b (Librojo et al., 1976). Consequently there were attempts in the past as well as in the present study to observe the host reaction against a particular pathotype at different stages like seedling stage, maximum tillering stage, pre-boot stage, flowering stage etc. In the present study pathotype I (derived from H. 561) was employed to study the inheritance. In the first group of crosses IR 8 was used as susceptible parent and crossed with six resistant parents namely IET 8320, IR 19660-274-3-3-1-3, IR 54, Cisadane, Kuntlan and Nigeria 5. The  $F_1$ 's were resistant at both seedling and adult plant stages in all these crosses indicating that the resistance was dominant over susceptibility. Frequency distribution in

$F_2$  generation revealed in general, there was wider distribution at adult plant stage than at seedling stage. This might be due to differences in the physiological status of the plant at these two stages and/or operation of modifying genes. These in general have not drastically changed the genetics of inheritance in any cross except in IR 8/Kuntlan where the presence of a recessive gene conferring resistance in addition to the dominant gene conferring resistance could be identified at the adult plant stage. The  $F_2$  segregation indicates the presence of one dominant and one recessive gene in IET 8320 and Cisadane at both the plant stages and at adult plant stage in Kuntlan; one dominant gene in IR 19660-274-3-3-1-3 and at seedling stage of Kuntlan; and dominant duplicate genes conferring resistance in IR 54 and Nigeria 5.

Panda and Chaudhary (1978) working with varieties whose genetic status regarding resistance to bacterial leaf blight was established, could identify additional genes in the very same varieties, whose presence was not identified earlier. This was possible because of employment of different inoculums and different scale other than the one employed earlier. This would mean that as refinements in techniques improve, better understanding of the number and nature of genes governing resistance would result. Sidhu et al. (1978) analysed the  $F_1$  and  $F_2$  data obtained at maximum tillering and flowering stages and found some  $F_1$ 's which were susceptible at maximum tillering stage exhibiting resistance

reaction at flowering stage. In all such cases the  $F_2$  segregation ratios could not be explained satisfactorily without assuming operation of additional genes at flowering stage.

Yamada and Horino (1981) observed that varietal resistances evaluated at maturing stage were not always expressed at seedling stage and this nature of disease resistance had given rise to some difficulties on nursery selection of resistant plants and breeding for resistance. In the present study also the presence of a recessive gene in IR 8/Kuntlan could not be identified at seedling stage but could be detected at adult plant stage.

Studies on allelic relationship among the genes conferring resistance so far resulted in identification of about 11 genes responsible for governing resistance to bacterial leaf blight. Some of them, as already mentioned are closely linked and Xa 1 and Xa 2 were identified to be located on chromosome 11. Among the genes governing resistance, xa 5, xa 8 and xa 9 confer resistance in their recessive states, whereas Xa 4 is known to possess multiple alleles (Sidhu *et al.*, 1986). In crosses among resistant parents made to understand allelic relationships in the present study, no segregation at both seedling and adult plant stages was recorded in IET 8320/IR 19660-274-3-3-1-3, IET 8320/IR 54, IET 8320/Cisadane, IR 19660-274-3-3-1-3/IR 54, IR 19660-274-3-3-1-3/Kuntlan and IR 54/Cisadane. No

segregation was also encountered at the adult plant stage of the cross IR 54/Kuntlan. Genes conferring resistance in these parents are expected to be same or allelic as there was no segregation. Similar lack of segregation in crosses between IR 22 and parents possessing single dominant gene for resistance to bacterial leaf blight was earlier reported by Sidhu et al. (1978 , 1979), Sivasubramanian and Khush (1983), Singh et al. (1983), Ogawa and Yamamoto (1986) and Sidhu et al. (1986).

Single dominant gene conferring resistance was identified in the crosses between IET 8320/Kuntlan, IR 19660-274-3-3-1-3/Cisadane and Cisadane/Kuntlan at seedling stage. It is surprising that such a segregation was encountered in crosses between two resistant parents where  $F_1$  was also resistant. Such situations would warrant assumptions of factors brought into the cross by either of the parents which inactivate functioning of resistance mechanism in a portion of  $F_2$  population or alternately the segregation of modifying genes which could be noticed only in  $F_2$  generation. In the absence of  $F_3$  studies, as in the present studies, it is however, difficult to identify factors responsible for such a behaviour.

The ratio of segregation in  $F_2$  generation in crosses IET 8320/Nigeria 5, IR 19660-274-3-3-1-3/Nigeria 5 at both the stages, in adult plant stage of IET 8320/Kuntlan and seedling stages of Cisadane/Nigeria 5 and Kuntlan/Nigeria 5

was 63 resistant: 1 susceptible indicating the operation of three dominant genes of which any one could confer resistance. In the adult plant stage of IR 54/Kuntlan, Cisadane/Kuntlan and Kuntlan/Nigeria 5 two dominant duplicate genes were identified with a segregating ratio of 15 resistant : 1 susceptible. Ratios involving two or more genes as seen in the present study in crosses involving resistant parents have been earlier reported by Mishra et al. (1971), Vasantha Krishna (1971), Jayaraj et al. (1972), Moses et al. (1974), IRRI (1976), Watanabe (1976), Sidhu et al. (1979), Horino and Yamada (1980), Tembhurnikar and Padmanabhan, (1980, 1981 a, 1981 b), Sukla and Panda, (1981), Wasano and Dhanapala (1982), Singh et al. (1983) and Ogawa and Yamamoto (1986).

It is clear from the results obtained in the present study that several genes are involved in the inheritance of bacterial leaf blight resistance which are yet to be identified and as more and more material gets tested more and more genes conferring resistance would become apparent. Genes for resistance appear to have specific stages at which they function rather than pleiotropic effect as stated by Yamada and Horino (1981). The type of interaction usually met with is duplicate gene action which suggests segmental duplications of chromosomes. However, this does not rule out unrelated loci being involved in conferring resistance. The number of genes and the nature of genes conferring resistance

not only depend on the resistant parent but also depend on the susceptible parent.

It is not necessary for a plant breeder to understand the genetics of resistance to pest or pathogen before that resistance can be exploited in the development of resistant varieties. Indeed, many of the most successful programmes of breeding for resistance have been carried out without detailed information concerning the number of resistance genes involved and whether they are dominant or recessive etc. (Russel, 1978).

A single gene codes for a production of certain protein which fulfils a particular metabolic function in the cell. For example, catalysing a specific chemical reaction. Such a reaction may trigger off several other reactions so that many different compounds are eventually produced as a result of initial reaction. One or more of these compounds may be involved in resistance to a pest or pathogen so that monogenically controlled resistance may involve several distinct resistant mechanisms.

A different major resistant gene may trigger off a different reaction or chain of reactions in which the same or different compounds would be formed. Thus, two non-allelic major genes for resistance to a particular pest or disease might control two different resistant mechanisms or the same mechanism.

Resistance breaking types of a pest or pathogen circumvent or neutralise, a resistance mechanism; they do not overcome the resistant genes themselves, but the mechanisms that the genes control directly or indirectly (Russel, 1978).

The number and type of mechanisms involved in resistance to pest or a pathogen affect the stability or durability of resistance and are therefore much more important than the number of genes which control these mechanisms. Presumably, it is more difficult for a pest or a pathogen to overcome several independent resistance mechanisms than one mechanism and the presence of several mechanisms in a variety may thus delay or stop the development of resistance breaking types (Russel, 1978).

It would be worthwhile to investigate the action of each of these diverse genes in bringing about resistance, in the light of the present understanding of biochemical nature of resistance and biosynthetic pathways leading to production of the chemicals responsible for resistance rather than identifying genes by number.

Recessive loci controlling various stages of the biosynthetic path ways would result in identification of large number of genes which are essentially controlling the same mechanism of resistance. The aspect of resistance breeding needs thorough investigation before attempting pyramiding of genes through multiple crossing and other means of accumulating favourable genes.

## 5.2 Conclusions :

From the present study based on the performance of the parents, a diallel set of crosses among them in  $F_1$  generation and selected crosses in  $F_2$  generation, certain generalised conclusions could be drawn on breeding for improvement and bacterial leaf blight resistance in rice.

Inspite of high magnitude of gca variances than sca variances, component analysis will only bring out the real nature of factors governing the inheritance of important quantitative characters i.e., whether additive gene action or non-additive gene action is predominant in the inheritance of these characters. Characters governed by predominantly non-additive factors would generally record very low narrow sense heritability even though the broad sense heritabilities may be high. There would be a great reduction in these two estimates for such characters. These characters which may include ultimate yield of the crop are likely to record very high heterosis which in turn may necessitate heterosis breeding for proper exploitation. High heterosis for ultimate character like single plant grain yield might be brought about due to high heterosis for several component characters. Incidentally there could be several combinations of these characters for which high heterosis might be recorded. In other words there are several ways by which high heterosis for compound character like single plant grain yield be brought about. It is unlikely that any single

parent might possess desirable gca effects for all characters and as such an assessment of desirability or otherwise, of a parent might have to be made on the basis of results obtained for several component characters. The agreement between the gca effects and per se performance of parents might depend upon the genetic nature of characters. Those characters that are rather simply inherited with very high narrow sense heritability might show complete agreement but characters whose inheritance is complex with low narrow sense heritability may not record complete agreement between these two values. There appears to be greater possibility of agreement between per se performance and sca effects hybrids.

Few characters might consistently show correlation with single plant grain yield when a population is subjected to analysis in several ways. The characters which show positive correlation may have positive direct contribution but characters which are negatively correlated did not necessarily have negative direct contribution. Since there is a change in the magnitude and direction in correlations and path-coefficient analysis, a fresh assessment might be needed in every generation while making selections to obtain correlated responses. These relationships appear to be dependent on genetic nature of material under test and what had been obtained in one generation may not necessarily hold true in the subsequent or earlier generations.

Studies on resistance to bacterial leaf blight revealed that there are several major genes which govern resistance to this disease. They may show several interactions among themselves and might govern resistance in their dominant or recessive state. Evidences were also obtained to show that some of these genes may specifically function at certain stage of life cycle of the host plant. In contrast to the studies on number and nature of genes governing resistance to this disease, it would be more appropriate to study the mechanism of disease resistance. Several mechanisms operating simultaneously might bring about greater and prolonged resistance than several genes operating the same mechanism.

Selected crosses need to be advanced to further generations to identify crosses with greater potential for yield, individual segregants with desirable yield and resistance and to assess the character associations which might be different in different generations. This would help rice breeders to concentrate on lesser number of crosses with greater chance of success in isolating disease resistant high yielding lines.

## SUMMARY

## CHAPTER VI

### SUMMARY

The present investigation was taken up to genetically analyse as to the combining ability, heritability, heterosis, correlation of characters and path-coefficient analysis in some breeding lines and varieties possessing diverse characters for various quantitative characters like plant height, days to 50% flowering, total tillers per plant, earbearing tillers per plant, panicle length, number of fertile spikelets per panicle, number of sterile spikelets per panicle, sterility percentage, L/B ratio of kernel, 1000-grain weight, BLB score and single plant grain yield. Seven parents and the resulting 21  $F_1$  hybrids were evaluated in randomized replicated trial for understanding the inheritance and interrelationship of various quantitative characters among themselves as well as with yield. The generation was advanced to  $F_2$  to study the inheritance of resistance to bacterial leaf blight and evaluate the  $F_2$  progenies for their performance of certain selected quantitative characters.  $F_2$  generation was also studied in selected crosses for their yield performance and were compared with their parents. The results obtained are summarized below.

Analysis of variance revealed that significant differences existed among parents for all the characters except for total tillers per plant and single plant grain

yield and among crosses for all characters. Comparison between parents and crosses revealed that significant differences existed between them for all characters except for fertile spikelets per panicle and BLB score.

Studies on heterosis and heterobeltiosis revealed that among 21 hybrids, several crosses showed significant values in the desired direction. For single plant grain yield 19 crosses out of 21 possessed positive heterosis of which 13 were significant. Similarly 18 crosses exhibited significant heterobeltiosis. The range of heterosis and heterobeltiosis in general was large and most crosses possessed either significant heterosis or heterobeltiosis for several characters even though for certain characters like days to 50% flowering the range was rather restricted for which none of the hybrids possessed either significant heterosis or heterobeltiosis. Thus, these studies have brought out clearly the existence of large amount of heterosis and heterobeltiosis for single plant grain yield (156.62% and 108.97% respectively) in a highly self pollinating crop like rice warranting renewed efforts towards commercial exploitation of this phenomenon.

Combining ability analysis brought out importance of both additive and non-additive variances in the inheritance of almost all the characters. Genetic component analysis revealed that for characters like days to 50% flowering, plant height, panicle length, L/B ratio and 1000-grain weight

additive factors are predominant while for characters like total tillers per plant, earbearing tillers per plant, fertile spikelets per panicle, sterile spikelets per panicle, sterility (%), BLB score and single plant grain yield non additive factors are more predominant.

An analysis of gca effects of seven parents involved, revealed that no parent possessed desirable gca effects for all the characters. However, some varieties like IET 8320 and Nigeria 5 had desirable gca effects for single plant grain yield as a result of possessing desirable gca effects for more than two characters. An attempt at correlating per se performance with gca effects revealed that a good agreement between these two is possible for characters rather inherited simply than for characters whose inheritance is complex.

Specific combining ability effects in the 21  $F_1$  hybrids revealed several crosses possessing highly desirable significant effects for many characters including single plant grain yield. However, no relationship was discernible between the nature of parents and hybrids and as such, it may not be possible to predict the performance of hybrids based on either per se performance or gca effects of parents. No single hybrid possessed desirable significant sca effects for all the characters, but several crosses like Kuntlan/Nigeria 5, IET 8320/IR 54 and others possessed desirable sca effects for different combination of characters.

Studies on heritability revealed that narrow sense heritability was larger for characters controlled by additive factors and was small for those governed by non-additive factors. For characters like single plant grain yield which is of primary concern, the narrow sense heritability was as low as 5.88%. A comparison of heritability in broad sense and narrow sense revealed large differences between these two estimates for characters like total tillers per plant, earbearing tillers per plant, fertile spikelets per plant, sterile spikelets per plant, sterility percent, BLB score and single plant grain yield. Incidentally these characters are governed by predominantly non-additive factors which account for large portion of broad sense heritability which is not fixable and consequently of little use in varietal improvement. This, however could be utilized in a programme of heterosis breeding.

Correlation studies among quantitative characters in parents,  $F_1$  generation and parents with  $F_1$  generation together revealed that fertile spikelets alone was consistently and positively correlated with single plant grain yield while 1000-grain weight was consistently negatively correlated with single plant grain yield. Several other significant correlations among the characters were identified which could be utilized in a practical breeding programme like the ones existing between total tillers per plant and earbearing tillers per plant with single plant grain yield. However, the information obtained cautions as

there was negative significant relationship between number of total tillers per plant with fertile spikelets warranting need to properly balance the relationships in such a way as to obtain maximum gains through correlated responses through selection.

Path-coefficient analysis revealed the position of eminence occupied by fertile spikelets per panicle followed by earbearing tillers per plant and total tillers per plant. Panicle length and 1000-grain weight also had surprisingly positive direct contribution. Negative direct effects were by plant height, sterile spikelets per panicle, L/B ratio of kernel and BLB score. The importance of characters changing their direction in different generations was clearly brought out like the case of earbearing tillers per plant having negative direct effect in  $F_1$  generation. The importance of indirect contribution through other characters was clearly brought out which in some cases resulted in retaining the correlations and in some other cases reducing or changing the direction of correlation.

Studies on the performance of five dwarf parents including IR 8, the bacterial leaf blight susceptible parent and their four  $F_2$  progenies revealed significant differences for the five characters in parents and three characters in  $F_2$  populations namely plant height, earbearing tillers per plant and single plant grain yield (except for panicle length and BLB score). Broad sense heritability in general was very

high for all these characters with substantial genetic advance as percent of mean. Correlation studies brought out the existence of negative association between BLB score and single plant grain yield and positive association between panicle length and single plant grain yield in the  $F_2$  generation. Panicle length and BLB score are mutually negatively associated indicating the possibility that bacterial leaf blight disease might reduce the length of panicle resulting in the reduction of single plant grain yield. Path-analysis has brought out the importance of panicle length in this generation substantiating the results obtained in correlation studies.

Evaluation of five dwarf parents and their ten hybrids for their plot yields revealed the superiority of five  $F_2$  populations as they occupied the top five ranks on the basis of grain yield. The results obtained are encouraging from the point of view of the yield improvement with bacterial leaf blight resistance in the material used in the present study.

Studies on inheritance of resistance to bacterial leaf blight revealed the presence of two dominant duplicate genes, (one dominant gene and one dominant and one recessive gene) governing the inheritance in crosses involving resistant / susceptible parents at seedling and adult plant stages. In the analysis involving crosses of resistant / resistant types, segregation was not recorded in several

crosses indicating the presence of same or allelic genes governing resistance to bacterial leaf blight in the parents. Segregation ratios such as 63 R : 1 S, 15 R : 1 S and 3 R : 1 S obtained in some crosses indicate the operation of three, two and a single dominant gene(s) conferring resistance. Evidence was also obtained to show that some of these genes are functional at some stage of the host life cycle and non-functional at the other stages.

The present study has clearly brought out the importance of several features in the genetics of rice crop which could be utilized for rapid improvement of yield levels which are presently stagnant with additional features like bacterial leaf blight resistance through genetic manipulations and proper selection.

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## LITERATURE CITED

- Agrawal, P.K., LAL, J.P. and Richharia, A.K, 1978. Note on selection indices and path-coefficients in semi dwarf rice varieties. Indian J. agric. Sci. 48(1): 58-10.
- Ahmed, K.M. and Rao, R.S. 1967. studies in the correlations between yield and yield components in hybrid rice. Indian J. Agron. 12(1) : 34-36.
- AICRIP. 1968. Progress report of All India coordinated Rice Improvement, Project. rabi 1968, 53-61.
- AICRIP 1969. Progress report of All India Coordinated Rice Imporvement Project. Kharif 1969. 3:1.1-2.19.
- Al-Jibouri, H.A., Miller, P.A. and Robinson, H.F. 1950. Genotypic and Environmental variances and covariances in upland cotton cross of inter specific origin. Agron.J. 50 : 633-37.
- Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and sons, Inc., New York. p.485.
- Aly, A.E. 1979. correlation and path-coefficient analysis in some short statured rice cultivars and strains. IRC. Newsl. 28(1): 19-21.
- Amirthadevarathinam, A. 1983. Combining ability and heterosis in dry and semi-dry paddy. Madras agric.J.70(4):233-37.
- Anand, I.J. and Murthy, B.R. 1968. Gentic divergence and hybrid performance in linseed. Indian J. Genet. 28 : 178-85.
- Anandakumar, C.R. and Sreerangasamy, S.R. 1984a. Combining ability of dwarf lines of Indica rice. Oryza 21 : 218 - 24.
- Anandakumar, C.R. and Sreerangasamy, S.R. 1984 b. Studies on heterosis in rice hybrids involving different dwarfs. Madras agric.J.71(3) : 189 - 90.
- Anandakumar, C.R. and Sreerangasami, S.R. 1986 a. Heterosis and inbreeding depression in rice. Oryza 23 : 96 - 101.
- Anandakumar, C.R. and Sreerangasamy, S.R. 1986 b. Causal influence of back ground traits on yield and plant height in rice. Oryza 23 : 23 -26.

- A.S.I., 1986. Agricultural Situation in India Directorate of Economic Statistics. Dept. of Agri. & Coop. Ministry of Agri. New Delhi. 41(8) 688 -90.
- Athwal, D.S. 1965. Hybrid Bajra-1 makes a new era. Inian Farming 15(5):6-7.
- Athwal, D.S. and Virmani, S.S. 1972. Cytoplasmic male sterility and hybrid breeding in rice. In Rice breeding, Int. Rice Res. Inst., Los Banos, Laguna, Philippines, p.615-20.
- Baldi, G. and Malagoni, p. 1975. Preliminary studies on rice hybrids. Riso 24(2) 99-116.
- Benerjee, S.P. and Sinha, M.K. 1977. Path analysis of yield and yield components in rice. Pl. Breed. Abstr. January, 1977.
- Bardhan Roy, S.K., Mitra, A.K. and Mukherji, D.K. 1975. Hybrid vigour in five cross combinations in rice (Oryza sativa L.). Sci. and Cult. 41(3):118-19.
- Bhapkar, D.G., Kulkarni, N.B. and Chavan, V.M. 1960. Bacterial leaf blight of paddy. Poona Agri. College Magazine. p.36-46.
- Briggle, L.W. 1963. Heterosis in wheat - A review. Crop Sci. 3: 407-12.
- \* Brown, F.B. 1953. Hybrid vigour in rice. Malay. agric.J. 36:226-36.
- Burton, G.W. 1965. Pearl millet Tift 23A released. Crops and Soils 17(5):19
- Capinpin, J.M. and Punyasingh, K. 1938. A study of varietal crosses and hybrid vigour in rice. Philipp. agric.J. 27:255-77.
- Carnahan, H.L., Erickson, J.R., Tseng, S.T. and Rutger, J.N. 1972. Out look for hybrid rice in USA. In: Rice breeding, Int. Rice Res. Inst., Los Banos, Philippines, p.603-60.
- Chandraratna, M.F. 1964. Genetics and Plant Breeding in Rice. Longmans Green & Co. Ltd., London, p.282.
- Chang, T.M. 1977. Studies on quantitative characters of rice.1. A diallel cross involving semidwarf rice varieties. J. Taiwan agric. Res. 20:9-26.

- Chang, T.T. and Tagumpay, O. 1970. Genotypic association between grain yield and six agronomic traits in a cross between rice varieties of contrasting plant type. *Euphytica* 19:356-63.
- Chang, T.T. and Vergara, B.S. 1971. Ecological and genetic aspects of photoperiod sensitivity and thermo-sensitivity in relation to the regional adaptability of rice varieties. *IRC. NewsL.* 20(2):1-10.
- \* Chang, W.L., Lin, E.H. and Yaung, C.N. 1971. Manifestation of hybrid vigour in rice. *J. Taiwan Agric.Res.* 20(4):8-23.
- Chaudhary, D., Ratho, S.N., Mishra, R.N. and Rao, M.J.B.K. 1976. Variation and correlation studies in the  $F_2$  of two inter-varietal crosses in rice. *Riso* 25(2):103-11.
- Chaudhary, D., Rao, M.J.B.K., Prasad, A.B. and Rao, A.V.S. 1980. Heritability and correlation in rice. *Oriza* 17(3): 194-99.
- Chaudhary, D., Srivastava, D.P., Ghosh, A.K. and Seetaraman, R. 1973. Genetic variability and correlation for yield components in rice. *Indian J. agric.Sci.* 43(2):181-84.
- \* Chaudhury, S.D. and Sen, J.L. 1953. Correlation of quantitative characters in paddy. *Pakist. J.Sci.* 5 : 142-44.
- Chauhan, J.S. and Nanda, J.S. (1983). Genetic variability for physico-chemical characters of rice grain in segregating *Oryza sativa* L. *Oryza* 20 : 209-15.
- Chauhan, V.S. and Tandon, J.P. 1984. Genetic variability and character association in hill rices. *Oryza* 21 : 138-42.
- Davis, M.D. and Rutger, J.N. 1976. Yield of  $F_1$ ,  $F_2$  and  $F_3$  hybrids of rice (*Oryza sativa* L.). *Euphytica* 25 : 587-95.
- Devadath, S. 1985. Management of bacterial blight and bacterial leaf streak of rice. *Cent. Rice Res. Inst. Cuttack, 753006. Orissa, India.* p.143.
- Dewey, D.R. and Lu, K.K. 1959. A correlation and path-coefficient analysis of components of crested wheat grass seed production. *Agron. J.* 51 : 515-18.
- Dora, B.K. and Venkateswarlu, B. 1976. Physiological considerations of promising rice selections to suit the deltaic regions of Andhra Pradesh. *Indian J. agric. Sci.* 45(1): 9-11.

- D.R.R.1986. Progress report of Directorate of Rice Research, Rajendranagar, Hyderabad, India 1986. p288-312.
- Dwivedi, J.L. 1985. Heterosis in rice and its exploration. Paper presented in Nat. Symp. on Genet. and Rice Improv. DRR, Rajendranagar, Hyderabad, India. 17-18 April, 1985.
- Dwivedi, J.L., Nanda, J.S. and Chaudhury, R. 1978. Efficiency of early selection for yield and yield components in rice. Pantnagar J. Uni. agric. & Tech. Pantnagar. 4(5) : Abst. 20101.
- Eunus, M., Atkins, I.M. and Stansel, J.W. 1976. Inter-relations among quantitative characters in rice. Indian J. agric. Sci. 44(10):673-75.
- \* Ezuka, A. and Horino, O. 1974. Classification of rice varieties and Xanthomonas oryzae strains on the basis of their differential interactions. Bull. Tokai-Kinki Natl. Agric. Exp. Stn. 27 :1-19.
- \* Ezuka, A., Horino, O., Toriyama, K., Shinoda, H. and Morinaka, T. 1975. Inheritance of resistance of rice variety Wase Aikoku 3 to Xanthomonas oryzae. Bull. Tokai-Kinki Natl. Agric. Exp. Stn. 28: 124-30.
- Fansecò, S. and Peterson, F.L. 1968. Hybrid vigour in a seven parent diallel cross in common wheat (T. aestivum L.). Crop Sci. 8: 85-8.
- Finlay, K.W. 1963. Adaptations, its measurement and significance in barley breeding. Proc. First Int. Barley Genet. Symp. Wageningen. 315-19.
- Fisher, R.A. and Yates, F. 1967. Statistical tables for biological, agricultural and medical research, Longman Group Ltd., London.
- Gardener, C.O. 1963. Estimates of genetic parameters in cross fertilizing plants and their implications in plant breeding. In: Statistical Genetics and Plant Breeding (ed.W.D. Hanson and H.F. Robinson) NAS-NRC. Publ. 982, Washington, D.C. pp. 225-50.
- Ghorai, D.P. and Pande, K. 1982. Inheritance of yield and yield components and their association in rice cross 1063 x Ac27. Oryza 19: 185-87.
- Ghosh, S., Saran, S. and Chaudhary, R.C. 1983. Correlated response of photo and thermosensitivity on certain developmental characters of rice. Oryza 20: 243-46.
- Gilbert, N.E.G. 1958. Diallel cross in plant breeding. Heredity 12: 477-92.

- Grafius, J.E. 1959. Heterosis in barley. *Agron.J.* 51:551-54.
- Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian J. biol.Sci.* 9:463-93.
- Haque, M.M., Faridi, M.N.I., Razzaque, C.A. and Newaz, M.A. 1981. Combining ability for yield and component characters in rice. *Indian J. agric. Sci.* 51(10):417-24.
- Have, H. ten. and Kauffman, H.E. 1972. Effect of nitrogen and spacing on bacterial leaf blight of rice. *Indian Farming* 21(10):8-13.
- Hayes, H.K., Immer, F.R. and Smith, D.C. 1955. Methods of plant breeding. Mc Grow-Hill Book Co., New York. pp.339-51.
- Hayward, A.C. 1960. A method of characterising Pseudomonas solanacearum. *Nature*, 186: 405.
- Horino, O. and Yamada, T. 1980. Inheritance of resistance of IR26 to bacterial groups I,II,III,IV and V of Xanthomonas campestris pv. oryzae (Ishiyama, 1922). Dye 1978 from Japan. *Annals of the pathol.Soc. Japan* 46(4): 504-9.
- IMD. 1978. Agro-climatic Atlas of India. Indian Meteorological Department, Pune, India.
- IRRI. 1967. International Rice Research Institute. Annual Report for 1966. Los Banos, Philippines p. 59-105.
- IRRI. 1970. International Rice Research Institute, Annual Report for 1969, Los Banos, Philippines p. 81-85.
- IRRI. 1976. International Rice Research Institute. Annual Report for 1975. Los Banos, Philippines p. 37-50.
- IRRI. 1978. International Rice Research Institute. Annual Report for 1977. Los Banos, Philippines p. 51-59.
- IRRI. 1980. Standard evaluation system for rice. The International Rice Testing programme. IRRI. Los Banos, Philippines p.44.
- Ishkumar, and Saini, S.S. 1973. Path analysis in short statured rice varieties. *Indian J. Genet.* 33(1):13-15
- Jayaraj, D., Seshu, D.V. and Shastry, S.V.S. 1972. Genetics of resistance to bacterial leaf blight in rice. *Indian J. Genet.* 32:77-89.

- Jennings, P.R., Coffman, W.R. and Kauffman, H.E. 1979. Rice Improvement, International Rice Research Institute, Los Banos, Philippines p.186.
- Jenson, N.F. 1970. A diallel selective mating system for cereal breeding. *Crop Sci.* 10:629-35.
- Jinks, J.L and Jones, M.R. 1958. Estimation of components of heterosis. *Genetics* 43:223-34.
- Johnson, H.W., Robinson, H.F. and Comstock.1955. Estimates of genetic and environmental variability in soybean. *Agron. J.* 47 :314-18.
- Jones, J.W. 1926 Hybrid vigour in rice. *J.Amer. Soc. Agron.* 7 :118-26.
- Jun, B.T., Cho, S.Y. and Chang, K.V. 1986. Studies on the inheritance of quantitative characters in rice. Analysis of days to heading in the F1 and F2 generations of diallel cross. *Res. Reports. Rural Development Admn. Korea Republic, Crops* 28(1): 55-62.
- Kaku, H. and Kimura, T. 1987. Difference in resistance expression of rice to Xanthomonas campestris pv. oryzae as controlled by resistance genes. Resistance expression controlled by resistance gene xa-1. *Ann. Phytopathol. Soc. Japan.* 53 : 14-20.
- \* Kang, He. 1985. Experience of China. Address at the 25th Anniversary Symposium, June 5-8 1985. IRRI, Los Banos, Laguna, Philippines.
- Kauffman, H.E., Reddy, A.P.K., Hsieh, S.P.Y. and Merca, S.D. 1973. An improved technique for evaluating resistance of rice varieties to Xanthomonas oryzae. *Plant Dis. Reprtr.* 57 : 537-41.
- Kaul, M.L. and Kumar, V. 1982. Genetic variability in rice. *Genet. Agraria* 36(3/4) : 257-68.
- Kaul, M.L.H. and Bhan, A.K. 1974. Studies on some genetic parameters of rice. *Theo. and Appld. Genet.* 44(4) : 178-82.
- Kaushik, R.P. and Sharma, K.D. 1986. Extent of heterosis in rice (Oryza sativa L.) under cold stress conditions Yield and its Components. *Theo. and Appld. Genet.* 73(1) : 136-40.
- Kaw, R.N. and Khush, G.S. 1987. Estimates of combining ability for cold stability in rice. *Oryza* 24 : 19-23.

- Khaleque, M.A., Joarder, O.I. and Eunos, A.M. 1977. Heterosis and Combining ability in a diallel cross in rice (Oryza sativa L.). Bangladesh J. agric. Sci. 4(2) : 137-45.
- Khaleque, M.A., Joarder, O.I. and Eunos, A.M. 1978. Interrelationship and path-coefficient for agronomic traits in rice. Cereal Res. Commun. 6(2):205-14.
- Khaleque, M.A., Joarder, O.I., Eunos, A.M. and Islam, A.K.M.N. 1978. Nature of gene interaction in the inheritance of yield and yield components in some rice Crosses. Oryza, 15(2) : 157-72.
- Khush, G.S. 1977. Disease and insect resistance in rice. Advances in Agron., 29:265-340.
- Khush, G.S. 1985. Rice varietal improvement. IRC news I. Special issue 34(2) : 111-26.
- Lal, J.P., Richharia, A.K. and Agrawal, R.K. 1983. Co-heritability, correlation and genetic parameters in semi-dwarf cultures of rice. Oryza 20 : 195-203.
- Latif, A. and Zaman, S.M.H. 1965. A study on heritability of four yield contributing characters of rice. Pakist. J. Biol. agric. Sci. 8 : 219-25.
- Lenka, D. Misra, B. 1973. Path-Coefficient analysis of yield in rice varieties Indian J. agric. Sci. 43(4) : 376-79.
- Li, C.C. and Chang, T.T. 1970. Diallel analysis of agronomic traits in rice (Oryza sativa L.). Bot. Bull. Acad. Sinica. 11 : 67-78.
- Librojo, V., Kauffman, H.E. and Khush, G.S. 1976. Genetic analysis of bacterial leaf blight resistance in four varieties of rice. SABRAO J. 8(2) : 105-10.
- Lin, S.C. and Yuan, L.P. 1980. Hybrid rice breeding in china. In: Innovative approaches to rice breeding, Int. Rice Res. inst., Los Banos, Philippines p. 35-51.
- Mahajan, R.K., Rao, A.V. and Aggarwal, D.K. 1981. Principal component analysis in some late-maturing rice varieties. Indian J. agric. Sci. 51(1) : 9-12.
- Mallick, E.H., Ghosh, H.N. and Bairagi, P. 1978. Heterosis in indica rice. Indian J. agric. Sci. 48(7) : 384-87.
- Mandal, B.K. 1982. Note on the estimate of heterosis for nine quantitative characters in rice. Indian J. agric. Sci. 52(10) : 699-700.

- Maurya, D.M. 1976. Heritability and genetic advance in rice. *Oryza* 13(2) :97-100.
- Maurya, D.M. and Singh, D.P. 1978. Heterosis in rice. *Indian J. Genet.* 38(1) :71-76.
- Maurya, D.M. and Singh, D.P. 1977. Combining ability in rice for yield and fitness. *Indian J. agric. Sci.* 47(2):65-70.
- Maurya, D.M. Singh, K.S. and Singh, R.S. 1986. Genetic variability in 48 low land rice cultivars of Uttar Pradesh, India. *IRRI Newsl.* 11(4):13.
- Misal, M.B., Nerker, Y.S. and Honrao, R.S. 1985. Genetic analysis of yield and yield contributing characters in dry land rice grown on black soils. Paper presented in Natl. Sympo. on Genet. and rice Improv. 17-18, April 1985. at D.R.R., Rajendranagar, Hyderabad, India.
- Mishra, K.N., Nanda, J.S. and Chaudhary, R.C. 1973. Correlation, path-coefficient and selection indices in dwarf rice. *Indian J. agric. Sci.* 43(3) :306-11.
- Mishra, R.K., Devadath, S. and Padmanabhan, S.Y. 1971. Breeding for bacterial blight resistance. *Oryza* 8:121-28.
- Mizukami, T. 1966. Resistance of rice plant to bacterial leaf blight and strains of causal bacteria. *JARQ.* 1(3):6-11.
- Mizukami, T. and Wakimoto, S. 1969. Epidemiology and control of bacterial leaf blight of rice. *Annual Review of Phytopathol.* 7 :51-72.
- Moeljopawiro, S. 1986. Genetic relationships between grain type and agronomic traits in rice (*Oryza sativa* L.) *Dissertation Abstracts International, B (Sciences and Engineering)* 47(5) :1800 B.
- Mohanty, H.K. and Singh, S.C. 1969. Biometrical studies in rice with special reference to nitrogen response. *Oryza* 6(2) : 23-35.
- Mohanty, H.K. and Mohapatra, K.C. 1973. Diallel analysis of yield and its components in rice. *Indian J. Genet.* 33 (2) 264-70.
- Mohapatra, K.C. and Mohanty, H.K. 1986. Inheritance of some quantitative characters including heterosis in rice by combining ability analysis. In: *Rice Genetics, Proc. of int. Rice Genet. Symp.* 27-31 May 1985, IRRI., Philippines p. 579-87.

- Moses, G.J., Rao, Y.P. and Siddiq, E.A. 1974. Inheritance of resistance to bacterial leaf blight in rice. *Indian J. Genet.* 34 : 271-79.
- Mukharji, D.K. and Mandal, B.K. 1973. Correlation of some yield attributes in rice varieties. *Indian J. Genet.* 33(3):426 - 29.
- Murai, M. and Kinoshita, T. 1986. Diallel analysis of traits concerning yield in rice. *Japan J. Breed.* 36: 7-15.
- Murayama, S. 1973. Fundamental studies on the utilization of heterosis in rice. I. Degree of heterosis and its manifestation. *Jap. J. Breed.* 23: 22-26.
- Murayama, S., Omura, T. and Miyazata, K. 1974. Basic studies on utilization of hybrid vigour in rice. Heterosis under different cultural conditions. *Japan J. Breed.* 24:287-90.
- Nakayama, R. and Saito, K. 1976. Variability of rice characters in particular with in plant variability. *Bull. Faculty of agriculture, Hirosaki Univ. Japan.* 29: 50-63.
- Namoodri, K.M.N. 1963. Hybrid vigour in rice, *Rice News Teller* 11: 92-96.
- Nanchariah, D., Nanda, J.S. and Chaudhary, R.C. 1974. Genetics of yield and components in rice. *Indian J. agric. Sci.* 44:437.
- Nanchariah, D., Nanda, J.S. and Chaudhary, R.C. 1976. Genetics of some characters associated with yield in dwarf rice. *Indian J. agric. Sci.* 44(11):736
- Nayak, P., Ratho, S.N., Sahoo, K.M. and Misra, R.N. 1978. Diallel analysis of bacterial leaf blight resistance in rice 11. Combining ability and heterosis. *Riso* 27 : 27-31.
- Nijaguna, G. and Mahadevappa, M. 1983. Heterosis in intervarietal hybrids of rice. *Oryza* 20 :159-61.
- Nishimura, Y. 1961. Studies on the reciprocal translocations in rice and barley. *Bull. Natl. Inst. Sci. (Japan) Ser. D.9* :171-235.
- Nishimura, Y. and Sakaguchi, S. 1959. Inheritance of resistance in rice to bacterial leaf blight Bacterium oryzae (Uyeda. et Ishiyama) Nakata. *Japan J. Breed.* 9:58(Abstr.).

- Ogawa, T., Morinaka, T., Fujii, K. and kimura, T. 1978. Inheritance of resistance of rice varieties of kogyoku and Java 14 to bacterial group V of Xanthomonas oryzae. Ann. Phytopathol. Soc. Japan 44 : 137-41.
- Ogawa, T. and Yamamoto, T. 1986. Bacterial leaf blight in rice In: Rice Genet. proc. 1985. IRRI., Philippines.
- Olufowote, J.O., Khush. G.S. and Kauffman, H.E. 1977. Inheritance of bacterial blight resistance in rice. Phytopathol. 67: 772-75.
- Ou, S.H. 1973. A hand book of rice diseases in the tropics. Int. Rice Res. Inst., Los Banos, Philippines p. 58.
- Palaniswamy., K.M. 1974. Correlation studies in rice under different plant densities and fertilizer levels. Madras agric. J. 61(9):663-65.
- Palaniswamy, K.M. and Palaniswamy, S. 1973. Heterosis, growth and variability in rice. Madras agric. J. 60 : 1145-48.
- Panda, A. and Chaudhary, R.C. 1978. Inheritance of resistance in rice to bacterial blight disease. Oryza 15(2):194-200.
- Panse. V.G. and Sukhatme, P.V. 1961. Statistical methods for agricultural workers. ICAR, New Delhi. p. 361.
- Panwar, D.V.S. and Paroda, R.S. 1983. Combining ability for grain characters in rice Indian J. agric. Sci. 53(9) : 763-66.
- Panwar, D.V.S., Paroda, R.S. and Rana, R.S. 1985. Combining ability for grain yield and related characters in rice. Indian J. agric. Sci. 55(7): 443-48.
- Paramasivan, K.S. 1979. Study of heterosis in hybrids of rice varieties. Madras agric. J. 66(12):833-36.
- Paramasivan, K.S. 1981. Heritability and genetic advance in hybrids of dwarf and tall indica rice (oryza sativa L.). Madras agric. J. 68(2):135-37.
- Paroda, R.S. and Joshi, A.B. 1970. Combining ability in wheat. Indian J. Genet. 30 : 630-37.
- Perera, A.L.T., Senadhira, D. and Laurence, M.J. 1986. Genetic architecture of agronomically important characters and prediction of performance of recombinant inbred lines in rice In: Rice Genetics. IRRI, Philippines p. 565-78.

- Petpisit, V., Khush, G.S. and Kauffman, H.E. 1977. Inheritance of resistance to bacterial blight in rice. *Crop Sci.* 17 : 551-54.
- Pham Van Ro. 1982. Studies on comparative performance of progeny of dwarfs isolated in F<sub>3</sub> and F<sub>4</sub> generations in two crosses of rice (*Oryza sativa* L.) M.Sc.(Ag) Thesis, A.P. Agri. Univ. Hyderabad, India.
- Poehlman, J.M. and Borthakur, D. 1972. Breeding Asian field crops. Oxford & IBH Publishing Co., New Delhi, p. 37-39.
- Prakash, B.G. and Mahadevappa, M. 1987. Evaluation of some experimental rice hybrids for field performance and standard heterosis. *Oryza* 24 : 75-78.
- Purohit, D.C. 1972. Heterosis in rice. *Madras agric. J.* 59 : 335-38.
- Ragaiah, B. 1971. Genetic studies in some intervarietal crosses of rice (*Oryza sativa* L.). Msc.(Ag.) Thesis, A.P. Agri. Univ. Hyderabad, India.
- Rahman, M., Patwary, A.K. and Miah, A.J. 1981. Combining ability in rice. *Indian J. agric. Sci.* 51(8) 540-46.
- Rajagopalan, K., Chandramohan, J. and Narayana swamy, P. 1973. Studies on crosses between dwarf and tall *indica* rice varieties. *Madras agric. J.* 60(2) : 104-10.
- \* Ramiah, K. 1935. Madras agricultural station's reports. Paddy breeding station, Coimbatore, Madras, 1931-35.
- Ramiah, K. and Ramaswamy, K. 1941. Hybrid vigour in rice (*Oryza sativa* L.). *Indian J. Genet.* 1:4-12.
- Ranganathan, T.B., Madhavamenon, P. and Sreerangasamy, S.R. 1973. Combining ability of earliness and yield in dwarf varieties of rice. *Madras agric. J.* 60(9/12):1134-38).
- Rao, A.V., Rao, C.S. and Prasad, A.S.R. 1980 a. Path-coefficient analysis in some late maturing rice varieties. *Indian J. agric. Sci.* 50(2): 135-38.
- Rao, A.V., Saikrishna, T. and Prasad, A.S.R. 1980 b. combining ability analysis in rice. *Indian J. agric. Sci.* 50(3):193-97.
- Rao, C.S., Sahu, K. and Ghosh, A.K. 1976. Association of morphological characters and path-coefficient analysis in rice. *Oryza* 13(2):81-85.

- Rao, G.M. 1965. Studies on hybrid vigour in intervarietal hybrids of rice (*Oryza sativa* L.). Andhra agric. J. 12:1-12.
- Rao, M.J.B.K., Chaudhary, D., Ratho, S.N. and Mishra, R.N. 1973. Variability and correlation studies in upland rice. *Oryza* 10(1): 15-21.
- Rao, M.R., Reddy, M.V. and Nagur, T. 1977. Genetic studies in three crosses of rice involving hybrid varieties of GEB 24 x T(N)1 and Mahsuri as parents. Andhra agric. J. 24 (5&6) : 151-55.
- Rao, N.G. 1983. Statistics for agricultural sciences. Mohan Primalai for Oxford & IBH publishing Co. New Delhi 110001, India. p.376.
- Rao, P.U., Rao, A.V. and Srinivasan, T.E. 1979. Combining ability of short statured rice cultivars from North east India. Indian J. Genet. 39(3) : 511-15.
- Rao, T.S. 1970. A note on the relationship between yield and yield components in paddy (*Oryza sativa* L.). Mysore J. agric. sci. 4(1) : 101.
- Reddy, A.P.K. and Kauffman, H.E. 1972. An improved technique for evaluating resistance of rice varieties to *Xanthomonas oryzae*. Rice pathol. News L. 1:3-5.
- Reddy, A.P.K., Saxena, N.P. and Reddy, A.V.R. 1978. Analysis of loss in yield due to incidence of bacterial blight disease of rice. Indian Phytopathol. 31:444-47.
- Reddy, A.P.K., Srinivasan, T.E., John, V.T. and Seetharaman, R. 1980. Breeding for bacterial leaf blight resistance in rice. Paper presented at Natl. Seminar on disease resistance in crop plants. TNAU., Coimbatore 22-23, Dec. 1980.
- Reddy, N.M. 1978. Studies on the inheritance of resistance to bacterial leaf blight in rice (*Oryza sativa* L.). M.Sc.(Ag). Thesis, A.P. Agric. Univ. Hyderabad. India.
- Reddy, O.R. and Rao, A.V. 1978. Diallel analysis of resistance to bacterial blight in rice, RISO 27 (2): 137-42.
- Reddy, R.N.S. Prasad, R. 1977. Effect of variety rates and sources of nitrogen on growth characters, yield components and yield of rice. Riso 26(3) : 217-24.
- Reitsma, J. and Schure, P.S.J. 1950. "Kresek", a bacterial disease of rice. Centr. Res. Inst. Agric. Bogor 117 : 1-17.

- Roychoudhury, A.K. 1967. Genotypic variability and heritability of quantitative characters of aman paddy. Trans. Bose Res. Inst. Calcutta 301 : 13-20.
- Russel, G.E. 1978. Plant breeding for pest and disease resistance. Butter worth & Co. Ltd. London, Boston. p.47 - 195.
- Saini, S.S. and Gagneja, 1975. Interrelationship between yield and some agronomic traits in short statured rice cultures. Indian J. Genet. 35(3) : 441-45.
- Saini, S.S. and Ishkumar, 1973. Hybrid vigour for yield and yield components in rice. Indian J. Genet. 33: 197-200.
- Saini, S.S., Ishkumar and Gagneja, M.R. 1974. A study on heterosis in rice (Oryza sativa L.). Euphytica. 23 : 219-24.
- \* Sakaguchi, S., Suwa, T. and Murata, N. 1968. Studies on the resistance to bacterial leaf blight, Xanthomonas oryzae (Uyeda et Ishiyama) Dowson in the cultivated and wild rices. Bull. Natl. Inst. Agric. Sci. Japan, Ser. D. 18 : 1-29. (Japanese, English summary).
- \* Sakaguchi, S. 1967. Linkage studies on the resistance to bacterial leaf blight, Xanthomonas oryzae (uyeda et Ishiyama) Dowson, in rice. Bull. Natl. Inst. Agric. Sci. (Japan) Ser. D.16 " 1-18.
- Sarathe, M.L. and Singh, S.P. 1986. Combining ability for yield and related characters in rice. Oryza 23 :224-28.
- Sardana, S. and Borthakur, D.N. 1987. Combining ability for yield in rice. Oryza 24 : 14-18.
- Sastry, N.S., Rao, M.J.B.K. and Rawloo, S. 1967. The relationship between grain yield and associated characters in some short statured high yielding rice varieties. IRC. News L., 16(4) : 20-42.
- Seetharaman, R. Srivastava, D.P. and Ghosh, A.K. 1971. Priliminary genetic studies in crosses with T(N)1 and IR 8 rice. Indian J. agric. Sci. 41(10): 798-802.
- Sen, P.K. and Mitra, G.N. 1958. Inheritance of photoperiodic reaction in rice. Nature 182 : 119.
- Shanmugasundaram, P. and Sivasubramaniam, P. 1983. Heterosis of yield components in rice (Oryza sativa L.) hybrids. In:pre-congress Sci. meeting on genetics and improvement of heterotic systems. School of genetics T.N.A.U., Coimbatore. India 3-4.

- \* Shamsuddin, A.K.M., Newaz, M.A. and Rezzaque, C.A. 1980. Genetic analysis of leaf yield and component characters in tobacco (Nicotiana tabacum L.) Z. pfziicht 84 : 139-147.
- Sharma, D.K. Shrivastava, M.N. and Shrivastava, P.S. 1986. Nature of gene interaction in the inheritance of grain yield, harvest index and their component characters in rice. Indian J. agric. Sci. 56(6): 397-403.
- Shashi, V.N., Mandal, B.K., Chatterjee, S.K. and Chaudhary, I.C. 1986. Heterosis of grain quality characters in some hybrid rices. Oryza 23 : 182-84.
- \* Shinjyo, C. and Omura, T. 1966. Cytoplasmic male sterility and fertility restoration in rice (Oryza sativa L.). Sci. Bull. Coll. Agric. Univ. Ryukyus 22 : 1-57.
- Shiro, Okabe 1972. Breeding for high yielding varieties in Japan. In: Rice breeding, IRRI, Los Baños, Philippines p. 738.
- Shukla, S.N. and Panda, A. 1981. Inheritance of bacterial leaf blight resistance in rice. In: Thrid Int. Symp. on Plant Pathology, IARI, New Delhi, India, 14 December, 18 : 42-43 (Abstr.).
- Sidhu, G.S., Gagneja, M.R., Raina, G.L., Saini, R.K. and Gill, K.S. 1986. Genetics of bacterial blight resistance in rice genetics. Proc. Int. Genet. Symp. 27-31 May 1985. IRRI., Philippines.
- Sidhu, G.S. and Khush, G.S. 1978. Dominance reversal of bacterial blight resistance gene in some rice varieties. Phytopathol. 68 : 461-63.
- Sidhu, G.S., Khush, G.S. and Mew, T.W. 1978. Genetic analysis of bacterial blight resistance in seventy four cultivars of rice, (Oryza sativa L.). Theor. Appl. Genet. 53 : 105-11.
- Sidhu, G.S., Khush, G.S. and Mew, T.W. 1979. Genetic analysis of resistance to bacterial blight in seventy cultivars of rice, (Oryza sativa L.) from Indonesia. Crop Improv. 6 (1) : 19-25.
- Sindhu, J.S. 1973. Correlation in paddy. Indian J. Genet. 33 : 314-18.
- Singh, D.P. and Nanda, J.S. 1975. Combining ability and heritability in rice. Indian J. Genet. 36(1) : 10-15.
- Singh, D.P. and Nanda, J.S. 1976 a. Combining ability and heritability in rice. Indian J. Genet. 36(1) 10-5.

- Singh, D.P. and Nanda, J.S. 1976 b. Inheritance of yield and yield contributing characters in rice. Indian J. agric. Sci. 46(7) : 323-26.
- Singh, D.P. and Nanda, J.S. 1976 c. Correlation and path analysis of yield and yield components and incidence of bacterial leaf blight in rice. IRC. News L. 24 : 23-27.
- Singh, D.P. and Nanda, J.S. 1977. Allelism of bacterial leaf blight resgenes in rice. Indian J. Genet. 37 : 335-40.
- Singh, N.B. and Singh, H.G. 1985. Heterosis and combining ability for kernel size in rice. Indian J. Genet. 45(2) : 181-85.
- Singh, R.B. 1985. Rice paddy production in the Asia-pacific Region - past performance and future prospects. IRC. News L. special issue 34 (2) : 53-76.
- Singh, R.J., Kush, G.S. and Mew, T.W. 1983. A new gene for resistance to bacterial blight in rice. Crop Sci. 23(3): 558-60.
- Singh, R.K. and Choudhary, B.D. 1985. Biometrical methods in quantitative genetic analysis. Kalyani publishers, New Delhi p-318.
- Singh, R.P. 1980. Association of grain yield and its components in  $F_1$  and  $F_2$  populations of rice. Oryza 17(3):200-204.
- Singh, R.P., Rao, M.J.B.K. and Rao, S.K. 1984. Genetic evaluation of upland rice germplasm. Oryza 21:132-37.
- Singh, R.P., Singh, R.R., Singh, S.P. and Singh, R.V. 1979. Combining ability for yield and yield componenets in rice. Oryza 16(2):115-18.
- Singh, R.S. 1977. Combining ability for grain yield and panicle characters in rice. Indian J. Genet. 37:384-87.
- Singh, R.S. and Richharia, A.K. 1978. Combining ability for certain characters in rice. Oryza 15(1) : 34-37.
- Singh, R.S. and Richharia, A.K. 1980. Diallel lanalysis for grain yield and its components in rice. Indian J. agric. Sci. 50(1):1-5.
- Singh, S.P. and Singh, H.G. 1978. Heterosis in rice. Oryza 15(2):173-75.
- Singh, S.P., Singh, R.R., Singh, R.P. and Singh, R.V. 1980 a. Combining ability in rice. Oryza 17(2): 104-108.

- Singh, S.P., Singh, R.R., Singh, R.P. and Singh, R.V. 1980 b. Heterosis in rice. *Oryza* 17(2):109-13.
- Sivasubramaniam, S. and Madhavamenon, P. 1973 a. Combining ability in rice. *Madras agric.J.* 60(6)419-21.
- Sivasubramaniam, S. and Madhavamenon, P. 1973 b. Genotypic and phenotypic variability in rice. *Madras agric J.* 60(9/12) 1093-96.
- Sivasubramaniam, S. and Madhavamenon, P. 1973 c. Heterosis and inbreeding depression in rice. *Madras agric.J.* 60:1139-44.
- Sivasubramaniam, S., Swaminathan, R. and Srinivasa, V. 1968. Study of variation in yield components. *Madras agric.J.* 55(4): 177-81.
- Sivasubramaniam, V. and Khush, G.S. 1983. Genetic analysis of resistance to bacterial blight in 27 varieties of rice. *Oryza* 20 : 151-155.
- Sprague, G.F. and Tatum, L.A. 1942. General Vs. specific combining ability in single cross of corn. *J. Amer.Soc.Agron.* 30:923-32.
- Sreerangasamy, S.R. and Murugesan, M. 1973. Genotypic association and path analysis in diploid and tetraploid rice. *Madras agric.J.* 69(9/12):1139-44.
- Srivastava, D.N. 1972. Bacterial blight of rice. *Indian Phytopathol.* 25: 1-16.
- Srivastava, D.N. and Rao, Y.P. 1963. Epidemic of bacterial leaf blight disease of rice in North India. *Indian Phytopathol.* 16: 393-94.
- Srivastava, M.N. and Seshu, D.V. 1982. Heterosis in rice involving parents with resistance to various stresses. *Oryza* 19:172-77.
- Srivastava, M.N. and Seshu, D.V. 1983. Combining ability for yield and associated characters in rice. *Crop sci.* 23:741-44.
- Srivastava, R.B., Singh, H.G. and Chauhan, Y.S. 1978. Genetic architecture of some quality traits in  $F_2$  populations of rice. *Indian J.agric. sci.* 48(10): 568-72.
- Stephens, J.C. and Holland, R.F. 1954. Cytoplasmic male-sterility for hybrid Sorghum seed production. *Agron. J.* 46 : 20-23.

- Sukanyasubramanian, and Madhavamenon, P. 1973. Pattern of variation in plant attributes and yield in the hybrids of rice (Oryza sativa L.). Madras agric. J. **60**(9/12) : 1118-24
- Swaminathan, M.S., Siddique, E.A. and Sharma, S.D. 1972. Outlook for hybrid rice in India. In: Rice Breeding, IRRI. Los Banos, pp. 609-13.
- \* Tagami, Y. and Mizukami, T. 1962. Historical review of the researches on bacterial leaf blight of rice caused by *Xanthomonas oryzae* (Uyeda et Ishiyama) Dowson. Special Repr. Plant Dis. and Insect Pest Forecasting Serv. Minist. Agric. for., Japan **10**:1-112 (English translation by H. Fujii).
- Takeda, K. and Saito, K. 1983. Heritability and genetic correlation of kernel weight and white belly frequency in rice. Japan J. Breed. **33** (4) : 468-80.
- Talwar, S.N. and Goud, J.V. 1974. Pattern of association between yield and yield attributes in rice. Indian J. agric. Sci. **44**(1) : 712-17.
- Tembhurnikar, S.T. and Padmanabhan, S.Y. 1980. Genetic studies on inheritance of bacterial blight resistance in rice in a cross Lacrosse x Zenith-Nira x T. 1242. *Oryza* **17** : 114-19.
- Tembhurnikar, S.T. and Padmanabhan, S.Y. 1981 a. Inheritance of resistance to bacterial leaf blight of rice in a cross BJ 1 x Taichung Native 1. *Oryza* **18** : 22-23.
- Tembhurnikar, S.T. and Padmanabhan, S.Y. 1981 b. Inheritance to bacterial blight of rice. *Oryza* **18** : 153-57.
- Toriyama, K. 1972. Breeding for resistance to major rice diseases in Japan. In: Rice Breeding. IRRI. Los Banos, Philippines. p. 253-80.
- \* Tsai, K.H. 1971. General studies on heading date and other characters in crosses between the rice variety Taichung 65 and early strains of Tatungtsailai. J. agric. Assoc. China. **74** : 7-18.
- Vander plank, J.E. 1984. Disease Resistance in plants. Acad. Press, Inc. Ltd. London. p. 194.
- Vasantha Krishna, P.V. 1971. Studies on inheritance of resistance to bacterial leaf blight in rice. (Oryza sativa L.). M.Sc. Thesis, A.P. Agric. Univ. Hyderabad. p. 57.

- Vinaya Rai, R.S. and Murthy, R.S. 1979. Path analysis of grain yield in rice under different nitrogen rates. *Oryza* **16** (1) : 62-63.
- Virmani, S.S. 1985. Prospects of hybrid rice in developing countries. IRC. Newsl. special issue. **34**(2) : 143-52.
- Virmani, S.S., Choudhary, R.C. and Khush, G.S. 1981. Current outlook on hybrid rice. *Oryza* **18** : 67-84.
- Virmani, S.S. and Edwards, I.B. 1983. Current status and future prospects for breeding hybrid rice and wheat. *Advances in Agron.* **36** : 145-214.
- \* Wakimoto, S. and Yoshii, H. 1954. On the variability of virulence of *Xanthomonas oryzae* under successive infection against the resistant or the susceptible variety of rice. *Sci. Bull. Fac. Agr. Kyushu Univ.* **14** : 479-84.
- Wang, M.K. 1965. Studies on the genetics of quantitative characters. in rice crosses between different types. *J. Taiwan Agric. Res.* **14**(4) : 11-18.
- Wisudharaman, S. and Weerapath, P. 1974. Inheritance of grain yield and its components in two crosses of rice (*Oryza sativa* L.) *Kasetsart J.* **8**(2) : 78-81.
- Wright Sewall. 1921. Correlation and Causation. *J. agric. Res.* **20** : 557-85.
- Yadav, B. and Singh, H.G. 1979. Correlated response and path analysis in semi-dwarf rice varieties. *Indian J. agric. sci.* **49**(10) : 756-58.
- Yamada, T. 1984. Inheritance of quantitative resistance of the variety IR 28 to bacterial groups II, III and IV of *Xanthomonas campestris* pv. *oryzae* of Japan. Studies on genetics and breeding of resistance to bacterial leaf blight in rice. *Japan J. Breed.* **34** : 181-89.
- Yamada, T. and Horino, O. 1981. Studies on genetics and breeding of resistance to bacterial leaf blight in rice. V. The multiple alleles resistant to bacterial groups I and V of *Xanthomonas campestris* pv. *oryzae* of Japan in the varieties IR 28, IR 29, and IR 30. *Japan J. Breed.* **31** : 423-31.
- Yap, T.C. and Chang, S.C. 1976. Heterosis of rice hybrids under wetland and dryland conditions. *SABRAO J.* **8**(1) : 35-40.

- Yoneza, K. and Yamagata, H. 1981. Selection strategy in breeding of self fertilized crops. 1. Theoretical considerations on the efficiency of single plant selections in early segregating generations. Japan J. Breed. 31 (31) : 35-48.
- Yoshimura, A., Mew, T.W., Khush, G.S. and Omura, T. 1983. Inheritance of resistance to bacterial blight in rice cultivar CAS 209. Phytopathol. 7 : 1409-19.
- Yoshimura, A., Mew, T.W., Khush, G.S. and Omura, T. 1984. Genetics of bacterial blight resistance in a breeding line of rice. Phytopathol. 74 (7) : 773-77.
- Zhou, S.M. 1983. A study on heritable variation in rice varieties. Application of atomic energy in Agriculture 1 : 14-18.

\* Originals not seen.

## VITA

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I served the Department of Agriculture and the Andhra Pradesh Agricultural University from 1960 to 1984 as Instructor, Agricultural Extension Officer, Research Assistant (Rice), Assistant Rice Specialist and Rice Breeder. I joined the Ph.D. programme in December, 1983 and worked on Genetic analysis of quantitative Characters and Inheritance of bacterial leaf blight under the guidance of Dr.V.V.S. Murthy and Dr.C.A. Jagdish. During the course of this investigation, I received ICAR Senior Fellowship. I have six publications to my credit. I was chiefly associated in evolving and releasing two popular high yielding rice varieties for general cultivation in Andhra Pradesh, viz., 'Dhanyalakshmi' (BPT 1235) for rabi and 'Sona Mahsuri' (BPT 3291) for Kharif and five other minikit cultures in rice.