

**Heterosis and Combining ability estimates using  $L \times T$  analysis  
and Genetic divergence using SSR markers in Rice**

**THESIS**

**Submitted in partial fulfillment of the requirements for the  
award of the degree of**

**DOCTOR OF PHILOSOPHY  
IN  
GENETICS AND PLANT BREEDING**

**BY**

**B. JALANDHAR RAM**

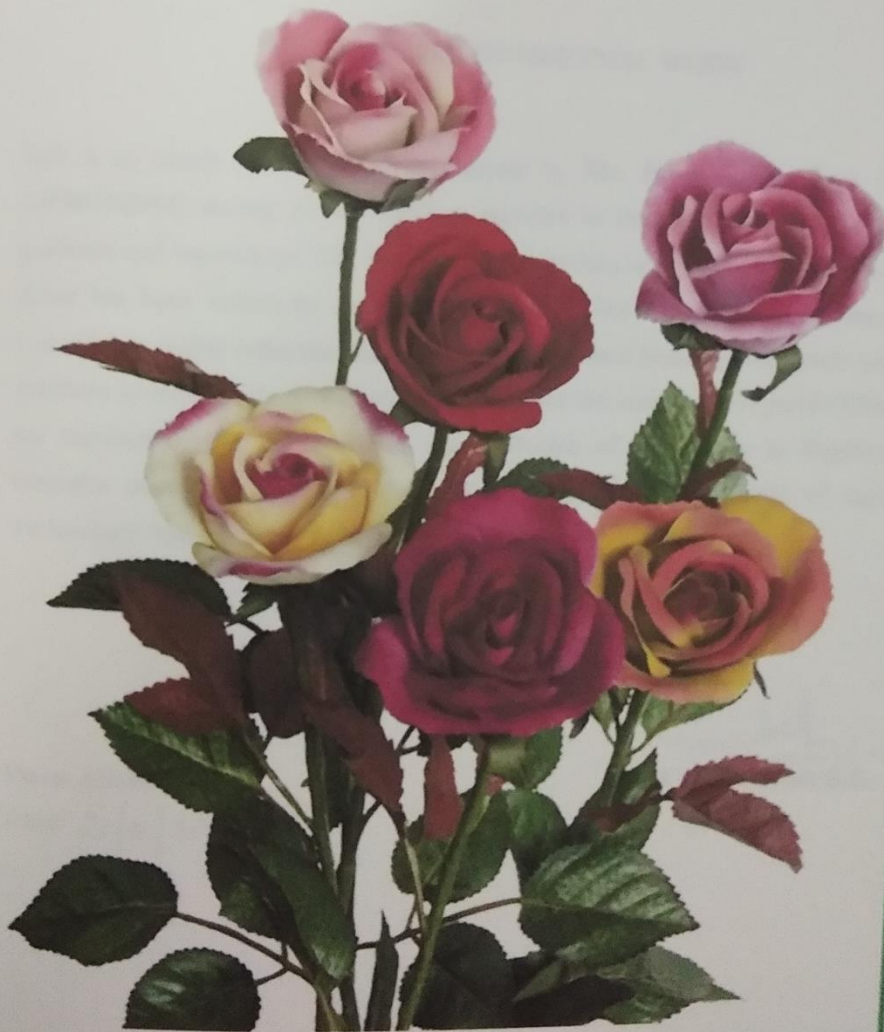


**DEPARTMENT OF GENETICS AND PLANT BREEDING  
NAINI AGRICULTURAL INSTITUTE  
SAM HIGGINBOTTOM UNIVERSITY OF AGRICULTURE,  
TECHNOLOGY AND SCIENCES  
ALLAHABAD (U.P.)-211007**

**2017**

**I.D. No: 14PHGPB101**

**Dedicated to my beloved Parents  
Sri. (Late) B. Jagannadha Rao and Smt. Ch. Lakshmi  
Sowbhagyam to their effection, everlasting  
love, continuous support, encouragement  
and sacrifices made me what I am today**





**Sam Higginbottom University of Agriculture, Technology And Sciences**  
**सैम हिगिन्बॉटम कृषि, प्रौद्योगिकी एवं विज्ञान विश्वविद्यालय**  
(U.P. State Act No. 35 of 2016, as passed by the Uttar Pradesh Legislature)  
Allahabad - 211 007, U.P., India

ISO 9001:2008 Certified

Office : 91-532-2684281, 2684781  
Fax : 91-532-2684394  
Website : www.shuats.edu.in  
E-mail : info@shuats.edu.in

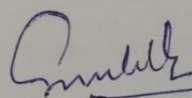
**Prof. (Dr.) Suresh B.G.**  
Professor and I/c AICRIP on Rice  
Department of Genetics and Plant Breeding  
SHUATS, Allahabad  
(Advisor)

### CERTIFICATE OF ORIGINAL WORK

This is to certify that the study conducted by **Mr. B. Jalandhar Ram (I.D. No. 14PHGPB101)** during 2014 - 2017 as reported in the present thesis was under my guidance and supervision. The results reported by him are genuine and the script of the thesis has been written by the candidate himself. His thesis entitled "**Heterosis and Combining ability estimates using  $L \times T$  analysis and Genetic divergence using SSR markers in Rice**" is therefore being forwarded for the acceptance in partial fulfilment of the requirements for the award of degree **Doctor of Philosophy in Department of Genetics and Plant Breeding** from, Sam Higginbottom University of Agriculture, Technology And Sciences, Allahabad, (U.P.). 211007

Place: Allahabad

Date: 21/11/2017

  
**Prof. (Dr.) Suresh B.G.**  
(Advisor)



**Sam Higginbottom University of Agriculture, Technology And Sciences**  
**सम हिगिन्बॉटम कृषि, प्रौद्योगिकी एवं विज्ञान विश्वविद्यालय**  
(U.P. State Act No. 35 of 2016, as passed by the Uttar Pradesh Legislature)  
Allahabad - 211 007, U.P., India

ISO 9001:2008 Certified

Office : 91-532-2684281, 2684781  
Fax : 91-532-2684394  
Website : www.shuats.edu.in  
E-mail : info@shuats.edu.in

**CERTIFICATE OF RECOMMENDATION BY STUDENT ADVISORY COMMITTEE**

This thesis, entitled "**Heterosis and Combining ability estimates using L × T analysis and Genetic divergence using SSR markers in Rice**", has been prepared and submitted by **Mr. B. Jalandhar Ram (I.D. No. 14PHGPB101)** in partial fulfilment of the requirements for the award of degree of **Doctor of Philosophy in Genetics and Plant Breeding**, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad (U.P.).

| Name, Designation and Department                                                                                                                  | Evaluation                                 | Signature |
|---------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------|
| <b>Prof. (Dr.) Suresh B.G.</b><br>Professor and I/c AICRIP on Rice<br>Department of Genetics and Plant Breeding<br>SHUATS, Allahabad<br>(Advisor) | Satisfactory/<br><del>Unsatisfactory</del> |           |
| <b>Dr. O. N. Singh</b><br>Principal Scientist & Head,<br>Division of Crop Improvement<br>ICAR-NRRI, Cuttack, Odisha<br>(Co-Advisor)               | Satisfactory/<br><del>Unsatisfactory</del> |           |
| <b>Prof. (Dr.) P.W. Ramteke</b><br>Professor & Head,<br>Department of Genetics and Plant Breeding<br>SHUATS, Allahabad<br>(Member)                | Satisfactory/<br><del>Unsatisfactory</del> |           |
| <b>Dr. Joy Dawson</b><br>Associate Professor & Head,<br>Department of Agronomy<br>SHUATS, Allahabad<br>(Member)                                   | Satisfactory/<br><del>Unsatisfactory</del> |           |
| <b>Dr. (Mrs.) G. Roopa Lavanya</b><br>Associate Professor<br>Department of Genetics and Plant Breeding<br>SHUATS, Allahabad<br>(Member)           | Satisfactory/<br><del>Unsatisfactory</del> |           |

This thesis has been examined by the evaluation committee and here by accepted for the award of Ph.D. degree in Genetics and Plant Breeding.

**Prof. (Dr.) Ravi Pratap Singh**  
Professor & Principal Rice Breeder  
Dept. of Genetics and Plant Breeding  
Institute of Agricultural Sciences, BHU,  
Varanasi- 221005 (U.P.)  
**External Examiner**  
Date: 20.11.2017

**Prof. (Dr.) George Thomas**  
Professor,  
Dept. of Molecular and Cellular Engineering  
SHUATS, Allahabad-211007(U.P.)  
**Chairman, Final Defense Examination**



କେନ୍ଦ୍ରୀୟ ଧାନ ଉଦ୍ବେଷଣା ଅନୁସନ୍ଧାନ, କଟକ (ଓଡ଼ିଶା) ୭୫୩୦୦୬  
केन्द्रीय चावल अनुसंधान संस्थान, कटक (उड़ीसा) ୭୫୩୦୦୬



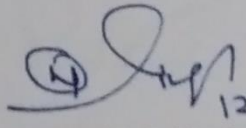
ICAR - National Rice Research Institute, Cuttack (Odisha) 753 006

Phone: 0671-2367757; Fax: 0671-2367663; Email: crrietc@ori.nic.in; URL : www.crrri.nic.in

Dr. Onkar Nath Singh  
Principal Scientist & Head  
Crop Improvement Division  
NRRI, Cuttack

**TO WHOM SOEVER IT MAY CONCERN**

This is to certify, that **Mr. B. Jalandhar Ram (ID No. 14PHGPB101)** student of SHUATS Allahabad pursuing his PhD under the guidance of Prof. Dr. Suresh Babu, G., has raised his offseason research crop at ICAR-National Rice Research Institute, Cuttack during Rabi 2016-17 and completed successfully his laboratory work on estimation of genetic diversity among the parents and hybrids under the supervision of Dr. O.N.Singh.

  
(Dr. Onkar Nath Singh) 12/05/17

*Dr. O. N. Singh*  
Principal Scientist & Head  
Division of Crop Improvement  
Central Rice Research Institute  
Cuttack - 753 006, Odisha (India)

## SELF ATTESTATION

This is to certify that I have personally worked on the thesis entitled, **“Heterosis and Combining ability estimates using  $L \times T$  analysis and Genetic divergence using SSR markers in Rice.”** The data mentioned in the manuscript have been generated during the work and are genuine. Data or information obtained from the other sources has been duly acknowledged. None of the findings/ information pertaining to the work has been concealed. The results embodied in this manuscript have not been submitted to any other university or institute for the award of any Degree or Diploma.

**Date: -**

**(B. Jalandhar Ram)**

**Place: - Allahabad**

**14PHGPB101**

## **ACKNOWLEDGEMENTS**

First and foremost, praise goes to Almighty **God** and my heartfelt thanks to My **Parents** who have been kind to me in the entire sphere of my life and without whose blessings. I would have never been at the position what I am.

My vocabulary fails in expressing my indebtedness to **Prof. (Dr.) Rajendra B. Lal**, Honourable Vice-Chancellor, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad for giving me an opportunity to continue my studies, encouragement and providing all facilities required to accomplish this great task in my life.

With an utmost degree of sincerity, I avail this opportunity to express my heartfelt thanks to my able, inspirational, role model and worthy advisor **Prof. (Dr.) Suresh B. G.**, Professor & I/c AICRIP Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad for his keen interest, valuable guidance, consideration, criticism and unceasing encouragement through the thesis work. He has not only been a knowledge and wisdom to me but most of all his words of care and hands of blessing has been my pillar of strength and courage to complete this work in time. My fortune may not give anything more but has given me the opportunity to work under this great teacher and human being ..... “Thank you so much sir”

My duty is to bestow my deep and heartfelt sense of gratitude to my **Co-Advisor (Dr.) O. N. Singh** Head and Division of Crop Improvement, ICAR-NRRI, Cuttack, Odisha for his valuable suggestions and for providing all facilities for conducting of my research and Lab work at NRRI Cuttack and active encouragement during course of research work .

I extend my heartfelt thanks to extraneous academicians my sincere gratitude to **Prof. (Dr.) P. W. Ramteke Head**, Department of GPB and Dean P.G. Studies, Sam

Higginbottom University of Agriculture, Technology & Sciences, Allahabad, for his guidance and suggestions extended to me during the entire course of study.

I express my sincere gratitude to **Dr. Joy Dawson Head**, Department of Agronomy, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad, for his worthy guidance and suggestions extended to me during the entire course of study.

I wish to express my heartfelt thanks and deep sense of gratitude to my Member (**Mrs. G. Roopa Lavanya**), Associate Professor, Department of Genetics and Plant Breeding for her guidance, valuable suggestions and constant encouragement throughout the period of my study, during the course of this investigation and for her valuable help for the completion of my thesis work.

My heartfelt thanks is to **Prof. (Dr.) Shailesh Marker**, Director Research, Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad for his worthy guidance and suggestions extended to me during the entire course of this study.

I would like to express my heartfelt indebtedness to **Dr. G. M. Lal, Dr. P. K. Rai, Dr. Abhinav Dayal, Mrs. Bineeta Bara, Mr. Sucel John, and Mr. James** and other faculty members of Department of Genetics and Plant Breeding, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad, for their kind co-operation and support.

I am very much grateful and thankful to Sri **Sura Balakrishna, IDES, Vice Chairman & Managing Director (APSSDC Ltd.)** entrusted in me the spirit of confidence to successfully complete this task.

I equally owe my deep sense of gratitude to **Mr. Prabhakar Rao, Dr. P. Satish Kumar and Dr. U. Prasada Rao** of NSPL giving me the first job opportunity and meticulous suggestions for my career advancement and stand as a pillar of inspiration for my life.

I gratefully record my indebtedness **Ram Lakhan Verma sir**, Senior Scientist NRRI, Cuttak for his constant encouragement and support.

I have also to express my gratitude to seniors **G. K. Mohan Reddy, P.V.Koteswara Rao, K. L. Sailaja, and M. C. Latha** and all my seniors and batch mates of Seed officers of A.P and T.S who always encouraged me to complete this task.

My gratitude is extended to all the teaching and non-teaching staff for their help and cooperation and the higher authorities of the Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad, for their kind co-operation and support.

I think words would not be enough to depict on this paper, my feelings about **my loving all family members** for their love, blessings, continuous encouragement and inspiration. They are the pillars of strength and inspiration, which makes me to strive for a bright future.

People to whom I owe my thanks, love, respect and regards are my good **friends Bezzipuram, Mouli, Madhu, Kalyan, Murali, Satish Reddy, Mahesh, Teja, Jami, Manmadha, Girish, Sivasankar, Sahidullah, Sudheer, Himansu, Prasanna, Bixam, Santhi, Spandana, Swarna, Latha, Neha Thomas, Neha Srivastav , Sanjay, Prudhvi, Phani, Dhatri** who have always taken care of me, helped and supported me to reach this height. Their pure affection, concern, inspirations have always been my lifeline and the joy of living. Last but not the least I thank everyone who is related in any way directly or indirectly with my thesis work for their help and encouragement.

**Date:**  
**RAM**

**B.JALANDHAR**

**Place: Allahabad**

**ID No. 14PHGPB101**

## ABSTRACT

### Heterosis and Combining ability estimates using $L \times T$ analysis and Genetic divergence using SSR markers in Rice

**B. Jalandhar Ram**

**Prof (Dr.) Suresh. B.G.**

**Researcher**

**Advisor**

---

The present investigation was carried out with the objective to collect the basic information on heterosis, combining ability and genetic divergence at morphological and molecular level by using SSR markers. Ten genotypes (7 lines and 3 testers) were selected based on *per se* performance for grain yield/plant after evaluating 100 genotypes during *khari*f, 2014. Selected lines and testers used for further experimentation and crossing programme initiated by using line x tester mating design in *khari*f, 2015 to generate 21 hybrids at Field Experimentation Centre, Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Allahabad . Twenty one hybrids along with ten parents and three checks, a total of 34 genotypes evaluated during *Rabi*, 2015-16 at National Rice Research Institute, (formerly Central Rice Research Institute), Cuttack. Data recorded on different yield and yield attributing traits.

The analysis of variance for heterosis revealed significant differences for all the characters studied. The differences among the parents were observed to be significant for all the characters studied while parents vs. crosses were observed to be significant for all the characters except flag leaf length and crosses were observed to be significant for all the characters except panicle length and Harvest Index.

Economic heterosis for grain yield/plant was observed in four crosses namely NLR 34449 x SHIATS Dhan1 followed by Sahabhagi dhan x SHIATS Dhan1, BPT 2615 x NDR-359 and MTU 1010 x BM 71 compared to the checks Jaya and IR-64.

The analysis of variance for combining ability showed high significance of crosses for all the traits studied. The variance due to lines and testers were significant for all the characters studied. All the traits were observed significant for line  $\times$  tester interaction. The SCA variances were higher than GCA variances for all the characters indicating the predominance of non-additive gene action.

The lines Sahabhazi dhan and MTU 1010 and the tester SHIATS Dhan1 possessed significant positive gca effects implying that they are good general combiners and may serve as useful source for improvement hybridization programmes.

Three hybrids MTU 1010 x BM 71 (high x low), MTU 1001 x NDR 359 (low x high) and NLR 34449 x SHIATS Dhan1 (low x high) were identified as good specific cross combinations based on positive sca effects and per se performance.

Based on per se performance, significant sca effects and heterosis for yield the crosses NLR 34449 x SHIATS Dhan1, Sahabhazi dhan x SHIATS Dhan1, BPT 2615 x NDR 359 and MTU 1010 x BM 71 recorded high heterosis over the best check IR-64 for grain yield /plant were identified as promising heterotic hybrids.

The hybrids BPT 5204 x NDR 359 considered as best genotype for hulling followed by MTU 1010 x SHIATS Dhan1 and NLR 34449 x SHIATS Dhan1.

The 34 genotypes, (21 hybrids ,10 parents and 3 checks) were grouped into six clusters using the Tocher's method of clustering the distribution was at random with maximum number of 17 genotypes in cluster I, Cluster IV is the second largest with 9 genotypes followed by cluster III with 5 genotypes. The cluster II, V and VI were solitary clusters. The parents and hybrids in clusters II, V and VI are divergent to other parents and hybrids.

Among the fifteen quantitative characters studied the most important characters contributing to the divergence was days to maturity followed by days to 50% flowering, test weight , number of grains /panicle , grain yield/plant and plant height.

A total 86 alleles were detected using 25 SSR markers with an average of 4.12, which ranged from 2 (RM 10123, RM 20354 and RM 223) to 7 (RM 232 and RM 18571). Polymorphism information content (PIC) denotes the polymorphic informativeness of a marker.

Among the set of 34 rice genotypes, six rare alleles were found. The PIC values, which are a reflection of allele diversity and frequency among the genotypes, were not uniformly high for all the SSR loci tested. The average PIC value was 0.50 at a range from 0.11 (RM 10123) to a maximum of 0.75 (RM 232). This high amount of PIC values was an indication that SSR markers are more polymorphic and of more diversity existed among the genotypes.

The dendrogram based on the UPGMA analysis of NTSYS software grouped the studied rice genotypes into five major clusters. The cluster I comprised of 11 genotypes, cluster II comprised of

nine genotypes, whereas cluster III comprised of four genotypes. The cluster IV and V comprised of seven and three genotypes respectively.

The hybrids MTU 1010 x NDR 359, MTU 1001 x NDR 359, and MTU 1001 x SHIATS Dhan1 were grouped together by both morphological and molecular dendrogram methods.

# CONTENTS

| <b>CHAPTERS</b> | <b>PARTICULARS</b>                                                           | <b>PAGE</b>                                           |
|-----------------|------------------------------------------------------------------------------|-------------------------------------------------------|
|                 | List of Tables<br>List of Figures<br>List of Plates<br>List of Abbreviations | <b>i-ii</b><br><b>iii</b><br><b>iv</b><br><b>v-vi</b> |
|                 | ABSTRACT                                                                     |                                                       |
| <b>1</b>        | INTRODUCTION                                                                 | <b>1-4</b>                                            |
| <b>2</b>        | REVIEW OF LITERATURE                                                         | <b>5-43</b>                                           |
| <b>3</b>        | MATERIALS AND METHODS                                                        | <b>44-89</b>                                          |
| <b>4</b>        | RESULTS                                                                      | <b>90-151</b>                                         |
| <b>5</b>        | DISCUSSION                                                                   | <b>152-170</b>                                        |
| <b>6</b>        | SUMMARY& CONCLUSION                                                          | <b>171-175</b>                                        |
|                 | BIBLIOGRAPHY                                                                 | <b>176-203</b>                                        |

## LIST OF TABLES

| Table Number | Particulars                                                                                                       | Page Number |
|--------------|-------------------------------------------------------------------------------------------------------------------|-------------|
| 3.1          | List of 100 Rice genotypes                                                                                        | 47          |
| 3.2          | Meteorological Data Recorded During Experimental Period <i>Kharif</i> -2014                                       | 48          |
| 3.3          | List of 10 genotypes                                                                                              | 49          |
| 3.4          | Genotype and important features                                                                                   | 50          |
| 3.5          | Meteorological Data Recorded During Experimental Period. <i>Kharif</i> -2015, Allahabad                           | 52          |
| 3.6          | List of Hybrids, Parents and Checks                                                                               | 53-54       |
| 3.7          | Meteorological Data Recorded During Experimental Period month wise <i>Rabi</i> , 2015-16                          | 55          |
| 3.8          | List of SSR primers                                                                                               | 78          |
| 4.1          | Mean performance of 100 genotypes for 15 quantitative characters in Rice ( <i>Oryza sativa</i> L.)                | 97-99       |
| 4.2          | Anova for heterosis of various quantitative traits in Rice                                                        | 100         |
| 4.3          | Mean performance of 34 rice genotypes (Hybrids, Parents and Checks)                                               | 101-102     |
| 4.4          | Quality parameters of hybrids, parents and checks                                                                 | 105         |
| 4.5 -4.12    | Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in Rice             | 112-119     |
| 4.13         | Best 5 best hybrids based on <i>per se</i> and economic heterosis (Hc) for quantitative characters in Rice        | 120         |
| 4.14         | Analysis of variance for combining ability for 15 quantitative characters in rice.                                | 126         |
| 4.15         | General Combining Ability effects of parents for fifteen quantitative characters in rice                          | 127         |
| 4.16         | Specific Combining Ability effects of hybrids for 15 quantitative characters in rice                              | 128         |
| 4.17         | Promising parental lines of rice on the basis of <i>per se</i> and GCA effects for important yield related traits | 129         |

|      |                                                                                                                                                       |     |
|------|-------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 4.18 | Promising hybrids identified on the basis of <i>Per se</i> , performance combining ability effects and economic heterosis in for yield related traits | 130 |
| 4.19 | Proportional contribution of lines, testers and interactions to total variance in Rice                                                                | 132 |

## LIST OF FIGURE

| <b>Fig. no.</b> | <b>Particulars</b>                                        | <b>Page no.</b> |
|-----------------|-----------------------------------------------------------|-----------------|
| 1               | Cluster diagram based on morphological characters in rice | <b>142</b>      |
| 2               | SSR based UP GMA Dendrogram                               | <b>151</b>      |

## LIST OF PLATES

| Plate no. | Particulars                                                                                   | Page no. |
|-----------|-----------------------------------------------------------------------------------------------|----------|
| 1         | Field Preparation during <i>Kharif</i> , 2014 at SHUATS                                       | 84       |
| 2         | Crop growth stages during <i>kharif</i> , 2014                                                | 85       |
| 3         | Crossing programme done during <i>kharif</i> , 2015 at SHUATS                                 | 86       |
| 4         | Off season experiment at NRRI Cuttack during <i>Rabi</i> , 2015-16                            | 87       |
| 5         | Field view during <i>Rabi</i> , 2015-16 at NRRI                                               | 88       |
| 6         | Molecular analysis at NRRI lab                                                                | 89       |
| 7         | SSR profiling of the 34 rice genotypes using the primers RM 572, RM 22321, RM 11184, RM 23181 | 144      |
| 8         | Panicles view of best Rice hybrids                                                            | 167      |

## LIST OF SYMBOLS AND ABBREVIATIONS

|                     |   |                                    |
|---------------------|---|------------------------------------|
| ANOVA               | : | Analysis of Variance               |
| $^{\circ}\text{C}$  | : | Degree centigrade                  |
| $^{\circ}\text{E}$  | : | Degree East                        |
| $^{\circ}\text{N}$  | : | Degree North                       |
| $^{\circ}\text{S}$  | : | Degree South                       |
| $^{\circ}\text{W}$  | : | Degree West                        |
| CD                  | : | Critical Difference                |
| Cm                  | : | Centimeter                         |
| CTAB                | : | Cetyl Trimethyl Ammonium bromide   |
| Df                  | : | Degrees of freedom                 |
| <i>et al</i>        | : | and coworkers                      |
| EDTA                | : | Ethylene diamine tetra acetic acid |
| $F_1$               | : | First filial generation of a cross |
| g                   | : | Gram                               |
| &                   | : | and                                |
| gca                 | : | General combining ability          |
| Ha                  | : | Heterosis                          |
| Hb                  | : | Heterobeltiosis                    |
| Hc                  | : | Standard or Economic heterosis     |
| Ha                  | : | Hectare                            |
| Kg                  | : | Kilogram                           |
| $\text{kg ha}^{-1}$ | : | Kilogram per hectare               |
| L x T               | : | Line x Tester                      |

|        |   |                            |
|--------|---|----------------------------|
| L/B    | : | Length/ Breadth            |
| L      | : | Line                       |
| MSS    | : | Mean Sum of Squares        |
| mha    | : | milllion hectare           |
| Max.   | : | Maximum                    |
| Min    | : | Minimum                    |
| mm     | : | millli meter               |
| mt     | : | million tones              |
| No     | : | Number                     |
| Nacl   | : | Sodium chloride            |
| Per se | : | As such with mean          |
| PCR    | : | Polymerase chain reaction  |
| RBD    | : | Randomized block design    |
| sca    | : | Specific Combining ability |
| SEm    | : | Standard error of mean     |
| SSR    | : | Simple Sequence Repeats    |
| t/ha   | : | Tonnes per hectare         |
| T      | : | Tester                     |
| Tris   | : | Tris borate EDTA           |
| Te     | : | Tris EDTA                  |
| %      | : | per cent                   |
| viz.,  | : | Namely                     |
| /      | : | per                        |

## INTRODUCTION

Rice (*Oryza sativa*,  $2n = 24$ ) is one of the world's most important staple cereal food crop growing in at least 114 countries under diverse conditions (**Anon., 2013**). The rice plant belongs to the genus *Oryza* of *Poaceae* family. The genus *Oryza* has 24 species, of which 22 are wild form and two species viz., *Oryza sativa* and *Oryza glaberrima* are cultivated. All the varieties found in Asia, America and Europe belongs to *Oryza sativa* varieties found in West Africa belong to species *Oryza glaberrima*. Further *sativa* rice varieties of the world are grouped into three sub-species viz. *indica*, *japonica* and *javanica*. Rice grown in India belongs to the *indica* sub-species. The varieties predominant in Korea, Japan and Northern China belong to *Japonica* where as *Javanica* are cultivated mainly in Indonesia.

Rice is also called “**Grain of Life**”, because it is not only the staple food for more than 70 per cent of the Indians but also a source of livelihood for millions of rural households. Globally it is cultivated in an area of 161.8 m ha with an annual production of about 748.0 million tonnes and an average productivity of  $4.6 \text{ t ha}^{-1}$  (**FAO, 2016**). Among the rice producing countries India ranks first in the world in area of rice cultivation with 44.2 mha and second in production with 104.32 million tons (**Directorate of Economics and Statistics, 2016-17**).

In Uttar Pradesh area, production and productivity is 5.98 million hectare, 14.63 million tonnes, and 2447 kg/ha respectively. Thus, it is understood that there is an extreme need to enhance the rice productivity in Uttar Pradesh, which will be achieved only by developing high yielding varieties (**Agricultural statistics, 2016**).

The population growth in most of the Asian countries, except China, continues to be around 2% per year. Hence it is very pertinent to critically consider whether the rice production can be further increased to keep pace with population growth. To meet the demand of rapidly increasing population of our country, at the current rate of population growth of 1.58% in India, the requirement of rice by 2025 is estimated to be around 140.7 million tonnes (**[http:// worldfood.apionet.or.jp](http://worldfood.apionet.or.jp)**) which can be achieved by increasing rice production by over 2.0 million tonnes per year in the coming decades. With the current green revolution technologies, it is estimated that by 2020 at least 115-120 million tons of milled rice is to be produced in India to maintain the present level of self-sufficiency. There is need for a

paradigm shift in rice research to meet the challenges of the future decades for ensuring food security.

To make India self sufficient in rice, it is needed to improve the productivity to a greater extent (**Hossain, 1996**). The task is quite challenging and the options available are very limited. True to the strategy of converting constraints into opportunities, existence of wide yield gaps found across ecologies and zones should be regarded as potential opportunities for raising the yield level and achieving thereby the future targets.

The success of any crop breeding depends on the magnitude of genetic variability and the extent to which the desirable genes are heritable nature and amount of variability existing in the germplasm. Heritability along with genetic advance would be more useful tool in predicting the resultant effect from selection of the best genotypes for yield and some of its components in rice. A critical survey of the genetic variability, correct understanding of the gene effects and knowledge on the extent of heritability of these traits would help in planning an effective breeding programme. It will facilitate the identification of proper genotypes for a particular agro-climate.

Heterosis refers to the manifestation of superiority of  $F_1$  performance over its parent in respect to yield, growth rate, vigour etc. The exploitation of heterosis is primarily depend on the screening and selection of available germplasm that could be produced better combination of important agronomic characters. In the modern era hybridization is the most common method applied in crop improvement and large numbers of varieties have been developed in various crops by hybridization.

Heterosis was first reported by (**Jones, 1926**). The expression of heterosis varied with crosses, also with characters. Both positive and negative heterosis is useful in crop improvement. In general positive heterosis is for yield and negative heterosis is for early maturity and plant height (**Singh et al., 1995**). In high yielding varieties of crop plant, the breeder face with the problem of selecting parents and crosses. Heterosis and combining ability are thus, excellent tools which help discern the goal and direction in a breeding programme.

In plant breeding programme, exploitation of heterosis is vital and considered to be one of the greatest outstanding achievements. The  $F_1$  hybrids can be exploited commercially or can

be used for selecting promising recombinants in the subsequent generations to release the best variety when it attained homozygosity. Rice being a self pollinated crop, the commercial exploitation of hybrid vigour depends on magnitude of heterosis for grain yield. The prospects of exploiting hybrid vigour in rice catapulted the rice growing countries following the suggestions for its commercial exploitation by several researchers (**Virmani *et al.*, 1983**). The magnitude of heterosis depends on the degree of genetic distinctiveness of the parental lines used and the genetic diversity between parents has profound influence on the magnitude of heterosis for yield and other traits.

Mating design Line x Tester (L x T) analysis is a very flourishing approach of measurement for the identification and selection of superior genetically recombined material. Line x Tester analysis provides information about General combining ability (GCA), Specific combining ability (SCA) of parents and is helpful in estimating various types of gene action that governs the inheritance of character. The knowledge of nature and magnitude of gene action controlling yield and yield components is very useful for crop improvement.

Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aids in selecting the desired parent and crosses for the exploitation of heterosis. Therefore, gathering information on nature of gene effects and their expression in terms of combining ability is necessary. Additive and non-additive gene actions in the parents estimated through combining ability analysis are useful in determining the possibility for commercial exploitation of heterosis.

Conventional breeding programmes coupled with modern agricultural practices resulted in the loss of genetic diversity in most of the cultivated crops. Hence estimation of the genetic diversity present in the breeding material is essential before proceeding to the further steps of the breeding programme. Inclusion of more diverse parents in hybridization is supposed to increase the chance of obtaining maximum heterosis and gives broad spectrum of variation in segregating generations. Traditionally a combination of morphological and agronomic traits has been used to evaluate the genetic diversity. It requires a large set of phenotypic data.

Genetic diversity can be evaluated with morphological traits, seed proteins, isozymes and DNA markers. Out of these molecular marker technology is the powerful tool for determining genetic variation **(Xu and Wang, 1974)**. In contrast to morphological traits, molecular markers can reveal abundant difference among genotypes at the DNA level, providing a more direct, reliable and efficient tool for germplasm screening at characterization, cataloguing conservation, management as these are unaffected by environmental influence.

Among various PCR based markers, SSR markers are class of repetitive DNA sequences usually 2-6 bp co-dominant, robust, reproducible, and reasonably easy to use that are distributed throughout whole genome and are flanked by highly conserved region **(Chambers and Avoy, 2000)**. These markers which are available in abundance offer significant advantages in DNA finger printing, genetic diversity analysis, gene/QTL mapping and molecular assisted breeding in crops. SSR markers are more popular in rice because they are highly informative, and genome-wide coverage **(Gracia et al., 2004)**. SSR profiling of the elite lines aids in unambiguous differentiation of genotypes and assessment of genetic diversity. Such information, coupled with phenotypic data, would aid in planned utilization of genotypes in breeding programmes.

Keeping in view the above perspectives the present study **“Heterosis and Combining ability estimates using L × T analysis and Genetic divergence using SSR markers in Rice”** was carried with the following objectives.

### **OBJECTIVES**

- 1 To estimate the extent of heterosis, heterobeltiosis and economic heterosis for yield and its component characters.
- 2 To estimate gca effects of parents and sca effects of cross combinations for further exploitation and gene actions prevailed in the inheritance pattern of yield and yield component traits.
- 3 To identify good general combiners and specific combiners for improvement yield and quality traits.
- 4 To assess genetic diversity among parents and their hybrids through morphological and molecular markers (SSR).

## REVIEW OF LITERATURE

The review of earlier works carried out by various aspects in India and abroad, pertaining to the present investigation is prompted under the following heads.

### 2.1 Genetic Variability

### 2.2 Heterosis, Heterobeltiosis and Standard heterosis

### 2.3 Combining ability

### 2.4 Heritability and Genetic Advance

### 2.5 Quality parameters

### 2.6 Morphological diversity

### 2.7 Molecular diversity

### 2.1 Genetic Variability

Variability is the most important characteristics and distinct feature of any population. A plant population with higher variability provides greater opportunity for the improvement. Hence, it is essential to study and utilize the existing variability in the population. **Johnson (1955)** gave the basic idea of variability, while developing concept of pure line. **Vavilov (1957)** ascertaining that greater variability more the chance of obtaining desirable types and prove it to be the basic fundamental for improvement of crop plant through selection.

**Fisher (1918)** portioned the total phenotypic variance into genotypic variance and environmental variance. He further divided the genotypic variance into additive, dominance and epistatic effects. However, it is only the genetic variation, which is heritable. Selection is effective when genetic variation is significant among the individual population. Hence genetic variability is of paramount importance of plant breeder for starting a breeding programme in any crop.

**Burton (1952)** suggested that genotypic coefficient of variation together with heritability estimates would give best picture about the extent of advance to be expected by selection. High heritability along with high genetic advance arises due to action of additive gene.

**Yadav (2000)** reported high genotypic and phenotypic coefficient of variation for spikelets per panicle, grain yield and harvest index in nine rice cultivars.

**Bidhan *et al.* (2001)** evaluated 25 medium duration genotypes for eight traits and observed high phenotypic and genotypic variances for grain yield, followed by number of filled grains per panicle. Number of filled grains per panicle, 1000-grain weight, grain length and breadth exhibited less environmental effect.

**Mohammad *et al.* (2002)** reported that phenotypic and genotypic coefficient of variation was of comparable magnitudes except for grain yield/plant and grains per panicle.

**Nayak *et al.* (2002)** studied genetic variability for grain yield and nine yield contributing characters in 200 scented rice genotypes in Cuttack, Orissa. They obtained high estimates of genetic and phenotypic coefficients of variation for number of spikelets per panicle, number of panicles per plant, number of grains per panicle and grain yield per plant.

**Chaudhary and Motiramani (2003)** evaluated 54 traditional aromatic rice accessions for genetic variability and character association of grain quality and yield attributes. Grain yield per plant showed significant positive correlation with effective tillers per plant, spikelet density and biological yield per plant.

**Satish *et al.* (2003)** studied genetic variability in 200 scented rice genotypes including one non-scented check, Ratna for grain yield and its nine attributing characters. High GCV and PCV values spikelets/panicle, number of grains/panicle and grain yield/plant.

**Singhara *et al.* (2003)** determined genetic variability and association of different panicle components in 36 genotypes of rice grown under Kashmir conditions. The PCV and GCV values were high for number of secondary branches, panicle and grains borne primary branch and less for days to 50% flowering, panicle length, kernel length and kernel breadth.

**Nayak *et al.* (2004)** studied over four environments for yield and yield attributes in 28 scented genotypes along with one non-scented check Ratna. The results clearly indicated that the GCV, PCV, heritability and genetic advance (percentage of mean) were high for number of grains/panicle and harvest index in all the 4 environments as well as in pooled analysis.

**Zafar et al. (2004)** evaluated rice genotypes for seven quantitative and 8 qualitative characters. A significant amount of variation was observed for all traits. The coefficient of variation was more than 10% for all characters examined except for the grain length.

**Sinha et al. (2004)** estimated variability, heritability and genetic advance and their correlation coefficient *Kharif* seasons from 19 local midland rice landraces, with IR-36 as the standard control, for yield and its attributing characters. A high genotypic coefficient of variation was observed in grain yield followed by test weight and panicles per plant.

**Singh and Singh (2005)** studied seven characters in 20 rice genotypes including a local check during *kharif*, 2004. High estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were recorded for grain yield (t/ha) and biological yield (t/ha), particle density/sq. m and harvest index (%).

**Vivek et al. (2005)** observed 39 “new plant” tropical Japonica lines during the wet season of 2000 in Pantnagar. High genotypic and phenotypic coefficient of variation was observed for grain yield, followed by harvest index and biological yield.

**Vanaja et al. (2006)** reported genetic variability of 10 quality parameters in a set of 56 high yielding diverse rice genotypes was evaluated. Phenotypic and genotypic coefficients of variation revealed the existence of large variability in alkali-spreading value and moderate variability in L/B ratio of grain, milling percentage, amylose content, water uptake, and volume expansion.

**Kumar et al. (2007)** estimated genotypic and phenotypic coefficient of variation in the  $F_2$  and  $F_3$  segregating populations of six crosses of rice for six yield and yield component characters. The  $F_2$  populations of the cross  $P_1$  and  $P_3$  showed high PCV, GCV for number of filled grains per panicle, 100-grain weight, biomass per plant and grain yield per plant.

**Majumder et al. (2008)** studied 20 spring wheat varieties to find out genetic variability and genetic association for grain yield and its component characters. Both genotypic and phenotypic variances were highly significant in all the traits.

**Padmaja et al. (2008)** revealed the genetic variability, coefficient of variation, for eleven characters in 150 genotypes including five check varieties of rice. The estimates of GCV and PCV were high for all characters except days to 50% flowering and panicle length.

**Pandey et al. (2009)** studied to estimate genetic diversity in different accessions of rice for various agro economically important characters. The higher magnitude of genotypic, phenotypic coefficients of variation and high heritability along with high genetic advance was recorded for plant height, grain yield per hill, harvest index and biological yield per hill.

**Singh et al. (2011)** studied 81 rice (*Oryza sativa* L.) genotypes were evaluated during *kharif*, 2010 for thirteen quantitative traits to examine the nature and magnitude of variability. Among the all traits number of spikelets per panicle exhibited high estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) followed by harvest index, grain yield per hill and number of panicles per hill.

**Singh et al. (2012)** evaluated 38 rice germplasm accessions for 12 traits to assess genetic variability and character association for grain yield with yield attributing traits. The highest values for PCV and GCV were observed for total grains per panicle followed by grain yield per plot and test weight.

**Sohrabi et al. (2012)** evaluated upland rice accessions for 12 growth traits, yield and yield components. The higher magnitudes of GCV and PCV were recorded for flag leaf length to width ratio, spikelet fertility, and days to flowering.

**Bhadru et al. (2012)** evaluated 21 rice genotypes for their variability. The highest genotypic and phenotypic coefficient of variation, heritability and genetic advance % of mean corresponded to grains per panicle, seed yield, 1000 grain weight and plant height and direct selection for these traits would be useful for yield improvement in rice.

**Kumar et al. (2013)** experimented on Indian and Exotic rice germplasm to study the genetic variability in Allahabad agroclimate. Genotypic coefficient of variation was played a major role for the expression of the traits ranged from 7.9 (panicle length) to 37.78 (total biomass per plant), plant height (32.91) followed by days to 50 percent flowering (29.45), total

biomass/plant (12.14) and spikelet per panicle (8.60), suggesting that these traits should be given top priority during selection.

**Singh et al. (2013)** experimented with 11 genotypes of upland rice during *Kharif*, 2009 and 2010. Maximum genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) was observed only for number of spikelets per panicle, while plant height, flag leaf length, flag leaf width, panicle length, harvest index and grain yield per plant showed moderate GCV and PCV.

**Gangashetty et al. (2013)** investigation was carried out to know the extent of genetic variability present in the local non-basmati aromatic genotypes of rice. The results found that the higher values of genotypic and phenotypic coefficient of variability was observed for plant height, number of tillers per plant, number of productive tillers per plant, panicle weight, grain length, test weight, iron and zinc content and grain yield per plant. The days to 50 per cent flowering had recorded lower values of genotypic and phenotypic variance.

**Lingaiah et al. (2014)** estimated the variability parameters for quantitative traits in 33 rice cultures. Analysis of variance revealed the existence of significant differences among genotypes for all traits studied. The genotypic and phenotypic coefficients of variations were moderate to high for no. of grains/panicle, test weight and Yield.

**Dhurai et al. (2014)** revealed significant differences among the genotypes for the all the nine quantitative and five quality traits in rice indicating that enough variability is present in the studied material. The magnitude of difference between PCV and GCV were relatively low for all the traits revealing little influence of the environment in the expression of these traits. The higher magnitude of PCV and GCV was recorded for number of grains per panicle (23.85%; 23.10%) and grain yield per plant (23.17%; 22.04%). 1000-grain weight (89.97%; 26.22%), harvest index (79.02%; 26.25%) and grain yield per plant (90.48%; 43.20%) indicates the preponderance of additive gene action and such characters could be improved through selection.

**Dwivedi et al. (2015)** investigation was under taken with the objectives to estimate heritability and genetic advance in percent of mean for yield and other characters on grain

yield. All the characters revealing over dominance except kernel length, kernel breadth and L:B ratio in both conditions, while panicle length and spikelets fertility in normal condition is less than unit and more than unit in saline condition.

**Meena *et al.* (2015)** evaluated 38 indigenous rice cultivars at Rice section farm for thirteen qualitative characters and observed magnitude of phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) for all the character. High heritability was observed for 1000 seed weight followed by grain yield per plant, plant height, kernel breath, kernel length and number of filled grains per panicle.

**Bitew *et al.* (2016)** study was carried out to assess the extent of genetic variability for yield and yield related traits. The higher phenotypic and genotypic variance were obtained from number of filled grains, plant height, days for 50% heading, days for 85% maturity and biomass yield indicating high influence of the environment on the traits.

## **2.2 Heterosis, Heterobeltiosis and Standard heterosis**

The term heterosis as defined by **Shull (1914)** refers to superiority of the hybrids over its parents in terms of vigour, growth, yield or other characteristics that result from crossing genetically diverse individuals. The term relative heterosis and heterobeltiosis refer to the heterosis over mid and better parental value respectively. **Jones (1926)** first reported heterosis in rice when he observed that some F<sub>1</sub> hybrids had more culms and higher yields than their parents. Subsequently, other workers also reported the occurrence of this phenomenon in various agronomic traits of rice such as yield, grain weight, number of grains per panicle, number of panicles per plant, plant height, days to flowering and general plant vigour. A critical pre-requisite for the successful production of hybrid varieties is that sufficient hybrid vigour (heterosis) be available through specific parental combinations, so that yields of hybrids would significantly exceed those obtained from the best conventionally bred varieties available (standard heterosis).

**Tiwari and Sarathe (2000)** observed that a high magnitude of positive and significant heterosis and heterobeltiosis for grain yield per plant was manifested in four crosses. Highly significant heterosis and heterobeltiosis was observed for plant height and filled spikelets

per panicle in all the crosses while average heterobeltiosis was negative for 100-grain weight.

**Nuruzzaman *et al.* (2002)** reported significant heterosis in respect of mid-parent; better parent and standard heterosis for most the characters studied. The hybrids also exhibited earliness and vigour.

**Sarker *et al.* (2002)** recorded the highest heterosis (100.7%) for the cross IR 62829A/IR44675 R followed by 17 others for yield and most of its related traits. Bhorali (2004) also reported significant heterosis in the desired direction for all the characters studied. However, only two hybrids namely IR 62829A/Lachit and PMS 2A/Luit exhibited over 20% standard heterosis for yield over the check Satyaranjan.

**Banumathy *et al.* (2003)** reported the predominance of non-additive gene action over additive gene action in the inheritance of grain yield and the associated traits. The lines, IR 58025A, IR 69616A and IR 70364A and testers, CB 95066, IR 10198-66-2R, IR 65515-47-2-1-19, TNAU 94241, TNAU 94301 and TNAU 841434 were good general combiners for grain yield per plant. The cross combinations, IR 68888A x CB 95066, IR 68888A x IR 10198-66-2R, IR 69616A x TNAU 841434, IR 70364A x TNAU 80030 and IR 70370 x CO 47 exhibited high SCA effects for grain yield.

**Bisne and Motiramani (2005)** in their study reported the predominance of non-additive gene action over additive gene action for plant height, effective tillers per plant, total number of spikelets per panicle, total number of filled spikelets per panicle, spikelet fertility percentage, grain yield per plant, days to 50% flowering, panicle length, total number of chaffy spikelets per panicle, 100-grain weight, harvest index, length and breadth of paddy. The lines, DRR 2A and PMS 10A and testers, BKP 232, R 827-287, R 1060-1674-2-103 and R 714-2-103 were good general combiners for grain yield. The crosses, DRR 2A x R 827-287 and DRR 2A x R 1060-1674-1-1 exhibited higher specific combining ability with high standard heterosis for grain yield.

**Anandkumar *et al.* (2006)** conducted line x tester interaction study, found that mean squares due to parent vs crosses differed significantly for majority of the traits. Among the

CMS lines, IR 68886A for earliness and IR 58025A for yield and its component traits were found to be superior general combiners. Four testers viz., Pusa 1040, PSRM-1-16-48-11, RAU 1411-4 and RAU 1414-10 were rated as good general combiners for yield. The crosses, IR 68886A x Pusa 1040, IR 58025A x RAU 1411-10 and IR 68886A / PSRM-1-16-48-11 recorded significant heterosis for yield and yield contributing traits.

**Hariprasanna *et al.* (2006)** reported that significant specific combining ability (sca) and general combining ability (gca) effects for yield and its characters indicating the role of both additive and non-additive gene action.

**Kumar *et al.* (2006)** revealed the variance due to lines effects and crosses were highly significant for fruit shelf life (days). In respect of GCA effects, Arka Alok observed highest for shelf life and L121 for total yield per plant. Among the crosses, Vaibhav x RIL-160 and L121 x RIL-108 were the most valuable combiners for fruit shelf life and total yield per plant. Thus, these two cross combinations revealed good potential to be used as a hybrid.

**Raju *et al.* (2006)** indicated that the amount of heterosis for leaf area index (LAI) at tillering stage, crop growth rate (CGR) from tillering to heading, harvest index, 100-grain weight and grain yield per plant was high and the inheritance of LAI, CGR, net assimilation rate (NAR), harvest index (HI), days to 50 per cent flowering, productive tillers per plant, filled grains per panicle and grain yield per plant were predominantly under the control of non-additive gene action, whereas, 100-grain weight was largely governed by additive gene action. The parents, IR 20 for LAI, RDR 763 for LAI, NAR and productive tillers per plant and Lunisree for CGR, HI, Biological yield and 100-grain weight were identified as good general combiners. The *per se* performance of the parents was found to be good indicator of their general combining ability. The best specific crosses with high SCA effects mostly involved parents with high x low or low x low GCA effects, hence heterosis breeding would be more rewarding to achieve another quantum jump in rice yields through exploitation of physiological traits.

**Narasimman *et al.* (2007)** revealed that ADT 44 was good general combiner for all the six traits studied. The parent, CR 1009 was also observed to be good combiner for all the traits except harvest index. The cross, ADT 4 x CR 1009 exhibited highly significant positive sca

effects coupled with highly significant positive heterobeltiosis and standard heterosis for number of filled grains per panicle, biomass per plant and grain yield per plant.

**Kumar *et al.* (2007)** found that both GCA and SCA variances were highly significant for all the characters indicating the importance of both additive and non-additive gene actions. However, preponderance of additive gene action was recorded for the traits viz., plant height, days to 50 per cent flowering and 100-seed weight. While, both additive and non-additive gene effects were almost equally important for grain yield per plant, leaf area index, preponderance of non-additive gene action was recorded for panicle length and grain length. The parents, HPR 2047, VL 93-3613 and J08 were good general combiners for grain yield and other related characters. The parents, HPR 1164 and J08 were good general combiners for shortest plant height and earliness. These crosses involving the above mentioned parents were promising as revealed by their sca effects. The cross combinations, HPR 2047 x VL93-3613, HPR 1164 x IR 57893-8, VL 91-1754 x J08, VL 93-3613 x J08 and VL 91-1754 x VL 93-3613 showed significant positive specific effects for grain yield per plant and some associated characters.

**Sarma and Sharma (2007)** observed that additive genetic variance was higher in magnitude for plant height, panicle length and all other quality parameters. Non-additive gene action on the other hand was predominant for grain yield and its components viz., effective tillers, panicle weight and grain weight.

**Ashok *et al.* (2007)** reported that out of four, two CMS lines, IR 58025A and PMS 3A were identified as good general combiners for grain yield and other traits. The specific combiners characterized with high SCA effects were IR 58025A x Basmati 385, IR 62829A x Basmati 385, IR 62829A x HKR 241 and PMS 3A x P1031-8-5-1 for grain yield, biomass per plant and effective tillers per plant.

**Munisonnappa and Vidyachandra (2007)** reported that all the hybrids showed significant positive heterosis in one or the other environment. None of the hybrids showed significant positive standard heterosis over the check variety Jaya for spikelet fertility per cent. Most of the hybrids showed negative standard heterosis over both the checks for thousand grain weight. Heterosis for grain yield was due to simultaneous heterosis for more than one component.

**Tu et al. (2008)** reported that eleven CMS lines and six restorer lines were crossed to study the specific combining ability (SCA) and general combining ability (GCA) for eight yield characters of indica rice. The GCA and SCA for eight yield characters were highly significant.

**Babu et al. (2010)** reported five crosses exhibiting significant positive heterobeltiosis and standard heterosis for grain yield per plant. The top three heterotic combinations exhibiting 38.78, 36.72 and 33.36% of standard heterosis for yield, respectively, over the check variety Vijetha .

**Torres and Geraldi (2011)** made crosses between six tropical *indica* rice cold susceptible genotypes and seven *japonica* or *indica/japonica* cold tolerant rice genotypes in a partial diallel fashion. The results showed significant mid-parent heterosis for all the characters namely plant height, tiller number, days to 50% flowering, panicle length, grains per panicle, sterility, and one-hundred grain weight.

**Vennila et al. (2011)** studied heterosis in rice for yield and component traits in 32 hybrids. The high manifestation of heterosis for grain yield per plant was evident by significant superiority of hybrids over mid parent ranging from -19.75 to 30.33 % in several crosses. The high heterobeltiosis for yield per plant was observed in the cross ASD 17/IR 50. Similarly, the cross IR 55408-01/IR 50 showed superiority over standard variety for grain yield and also showed significant heterosis for almost all the characters.

**Dwivedi and Pandey (2012)** reported heterosis over mid-parent, better parent and standard variety ranged between -54.17 to 169.70, -58.31 to 150.32 and -64.55 to 146.15% respectively. The trend of magnitude of heterosis for grain yield and plant height were *indica/japonica* > *indica/indica* > *japonica/japonica* and days to 50% flowering were *indica/japonica* > *japonica/japonica* > *indica/indica* hybrids. Most of the heterotic cross combinations identified involved indica and tropical japonica lines having wide compatibility gene as their parents and such interspecific hybrids exhibited high heterobeltiosis and economic heterosis.

**Sreedhar *et al.* (2012)** found that in most of the heterotic crosses, significant positive standard heterosis for single plant yield achieved due to positive and significant standard heterosis for component characters like panicle length, panicle weight, number of productive tillers per plant, number of filled grains per panicle, 1000-grain weight.

**Kunkerkar *et al.* (2012)** observed the extent of heterosis for 8 characters over standard check Sahyadri in 40 hybrids. They reported that 7 hybrids expressed highly significant positive heterosis for grain yield over standard check.

**Latha *et al.* (2013)** reported the magnitude of relative heterosis, heterobeltiosis and standard heterosis estimated for different characters. For grain yield, a high degree of relative heterosis was observed from 20.45 to 82.37% while a higher degree of heterobeltiosis was from 13.60 to 68.37%. A high degree of standard heterosis was observed for grain yield in the hybrid CRMS 32A/R 1099-2569-1-1. The hybrid CRMS 32A/R 1099-2569-1-1 recorded a high degree of relative heterosis (62.01%), heterobeltiosis (57.35%) and standard heterosis (15.05 and 25.51% over the check hybrids, Mahamaya and Indirasona, respectively).

**Sharma *et al.* (2013)** studied the magnitude of heterosis of 48 hybrids. The result indicated that the magnitude of heterobeltiosis for grain yield was significantly superior in 28 hybrids ranging from 10.85 to 66.35% and only in 2 hybrids over the standard hybrid (Arize-6444) with the magnitude of 11.87 and 20.60 percent respectively. These crosses also exhibited significant heterosis for days to maturity, number of spikelets per panicle and number of grains per panicle.

**Neelam *et al.* (2013)** investigated 4 lines and 19 testers crossed in a line x tester fashion. Three crosses exhibited the highest heterosis along with *per se* performance and SCA effects for productive tillers per plant, number of filled grains per panicle and panicle length along with grain yield per plant over the standard check KRH 2.

**Jarwar *et al.* (2013)** evaluated heterotic performance of 21 F<sub>1</sub> hybrids and their 10 parents in two environments. Under lowland environment, grain yield showed the high relative mid parent heterosis from 12.69 to 17.45%, while in upland environment grain yield showed the high relative mid parent heterosis from 13.37 to 27.69 percent.

**Jain et al. (2014)** assessed heterosis in 64 rice F1 cross combination under water-limited rainfed condition revealed scope of exploiting hybrid vigour and developing heterotic hybrids for non-irrigated rainfed lowland environment. Significant standard heterosis over commercial hybrid checks (KRH 2 and PA 6444) observed in many cross combinations for various traits viz., filled grain per panicle, spikelet fertility percent, grain yield per plant, biomass per plant and harvest index highlight the importance of these traits in selecting parents based on above traits and developing hybrids with drought tolerance and high yield for water limited rainfed lowland.

**Veerasha et al. (2015)** reported magnitude and direction of heterosis, general and specific combining ability for yield and productivity traits in rice. In majority of the experiments high specific combining ability (SCA) variances than general combining ability (GCA) variances for most of the traits were reported which indicate the predominance of non-additive gene action in the inheritance of these traits. The researchers also found some correspondence between good general combiners and per se performance for some of the traits. Therefore, analysis of combining ability has been the most important and efficient tool in selecting the desirable parents for a hybridization programme.

**Huang et al. (2016)** examined the genetic basis of heterosis for yield in rice, here we generate, sequence and record the phenotypes of 10,074 F<sub>2</sub> lines from 17 representative hybrid rice crosses. We classify modern hybrid rice varieties into three groups, representing different hybrid breeding systems. find support for partial dominance of heterozygous locus for yield-related traits and better-parent heterosis for overall performance when all of the grain-yield traits are considered together. These results inform on the genomic architecture of heterosis and rice hybrid breeding.

**Bora et al. (2016)** evaluated sixty F1 hybrids along with their 23 parents and three standard varieties was evaluated in a randomized complete block design with three replications during Sali, 2013. Significant variation was observed for parents, hybrids and hybrids versus parents for most of the yield and yield related characters. Grain yield exhibited mid parent heterosis varying from -88.7 (IR 79156A/IET 19916) to 151.5% (IR 58025A/Prafulla), heterobeltiosis from -91.9 (IR 79156A/IET 19916) to 128.2% (IR 58025A/Prafulla) and

standard heterosis ranging from -91.3 to 56.5% over the late maturing check Ranjit, -86.2 to 148.3% over medium duration check TTB 404 and -91.9 to 44.4% over the hybrid check JKRH 401.

**Sahu et al. (2017)** studied heterosis for yield and yield traits in rice (*Oryza Sativa* L.) under rainfed condition on three WA CMS lines (Pusa 6A, IR 79156A and IR 68897A) and 31 male genotypes. They found top two high yielding heterotic crosses over the standard variety (NDR-97) were Pusa-6A x HUR-105 (116.48%) and Pusa-6A x Pantdhan-12 (114.74%).

### 2.3 COMBINING ABILITY

Evaluation of combining ability of genotypes helps in identification of suitable parents for further exploitation. **Sprague and Tatum (1942)** first proposed the concept of combining ability in maize. They defined the term general combining ability (GCA) as an average performance of a line in hybrid combinations and specific combining ability (SCA) as the combinations which do relatively better or worse than that would be expected on the basis of the average performance of lines involved. According to **Griffing (1956)**, the GCA is related to additive as well as additive x additive interaction, whereas SCA is related to the dominance variance and all three types of interactions (additive x additive, additive x dominance and dominance x dominance). It has been observed that varieties with good *per se* performance may not necessarily produce desirable progenies when used in hybridization. Combining ability analysis helps in evaluation of lines in terms of their genetic value and in the selection of parents for hybridization.

There are several reports about combining ability studies conducted by rice researchers for different traits in rice.

**Lokaprakash et al. (1991)** found that both GCA and SCA variances were highly significant for the traits like plant height, number of productive tillers per plant, panicle weight, number of fertile spikelets per panicle, thousand grain weight, yield per plant and harvest index indicating the importance of both additive and non-additive gene action. However, preponderance of additive gene action was recorded for plant height, while for others non-

additive type was prominent. The parents, HP 19 and HP 11 were good general combiners for yield and yield components except plant height.

**Manuel and Prasad (1992)** noticed that additive gene action was important for straw yield per plant, while both additive and non additive gene actions were important for the inheritance of dry matter production, harvest index and grain yield per plant. The parents, ASD 16 and IR 50 were the best general combiners for grain yield, straw yield and dry matter production and their hybrid, ASD 16 x IR 50 recorded the highest SCA effects for the above three traits as well as harvest index.

**Ghosh *et al.* (1993)** carried out combining ability analysis in rice for yield and its attributing traits. The parents *viz.*, Annada, IET 8674 and IET 7255 were identified as good general combiners for yield per plant. The crosses, IET 7255 x Prasanna, IET 8674 x Dular, IET 8674 x Annada, Dular x IET 10899, Annada x Prasanna and Annada x Dular exhibited higher SCA effects for yield per plant.

**Vijayakumar *et al.* (1994)** observed predominance of additive gene action for plant height, productive tillers per plant, number of grains per panicle, grain yield per plant, grain elongation after cooking and 1000-grain weight. Based on the GCA effects, the lines MH/Prakash and Intan/Gowri were found as good general combiners for yield components. The hybrid (Intan/Gowri) x Mahsuri was identified as good specific combiner.

**Rogbell and Subbaraman (1998)** revealed that the magnitude of variance due to SCA was predominant over GCA for all the eight traits studied. Among the parents, CNA 4121, IR 61457-8-3-3-1, IR 10198-66-2 and IR 54717-C10-113-1-2-2-2 were found to be good general combiners for grain yield. Six crosses were identified as the best hybrids based on their *per se* performance, high heterosis and high SCA effects.

**Manonmani and Ranganathan (1998)** reported the importance of non additive- gene action for days to flowering, plant height, number of productive tillers, panicle length, number of grains per primary ear, 100-grain weight and grain yield. Among the parents, IR 50 and Kalyani II possessed high GCA effect for earliness and IR 50, CO 37, ASD 17 for grain yield. The crosses, ASD 16 x Kalyani II, IR 50 x ASD 8 and ASD 16 x ASD 17 were

identified with good SCA effect for days to flowering, number of productive tillers and grain yield, respectively.

**Lavanya (2000)** studied the combining ability for yield and its components, and reported that dominance of gene effects for characters like productive tillers per plant, filled grains per panicle, per cent spikelet fertility, harvest index and grain yield and additive gene effects for days to 50% flowering, plant height, panicle length and test weight. The lines, IR 58025A and IR 62829A were identified as good general combiners for grain yield.

**Sarker *et al.* (2002)** observed that in a line x tester mating design experiment using 2 lines and 13 testers, contribution of tester was higher than that of the interaction of line x tester which revealed the higher estimates of GCA implying additive gene action among the testers used except panicle weight. In several cases, cross between high x high general combiners did not produce high specific cross. Rather good specific crosses were obtained from high x high, high x low, low x high and low x low general combiners indicating predominance of non-additive gene action.

**Swain *et al.* (2003)** found that both GCA and SCA variances were highly significant for all the traits studied, indicating the importance of both additive and non-additive gene actions for expression of these traits. However, predominance of non additive gene action was recorded for days to flowering, number of panicles per plant and grain yield per plant, while additive type of gene action was predominant for plant height, panicle length, spikelets per panicle, 1000-grain weight, harvest index and straw yield per plant. Ketanangka ranked first as good general combiner, followed by Rahaspanjar, for the yield and yield components, except for plant height. The parent, CR 1006 appeared as good general combiner for plant height. The crosses, Rahaspanjar x Swarna and CR-260-77 x Ketanangka appeared to be the best for grain yield, with high SCA effects.

**Swamy *et al.* (2003)** conducted a study on combining ability of 24 rice hybrids involving 3 new CMS lines and 8 testers for grain yield and its 11 attributing characters. Among the new CMS lines IR 70370A was identified as good general combiner for seed yield per plant, plant height, filled spikelet per panicle, total spikelet per panicle and spikelet fertility per cent.

**Bhorali (2004)** studied combining ability of restorer lines over four environments and reported that best combiners among lines for grain yield per plant were Pant 2B and IR 69616B, and among the testers were *Luit*, *Gobind*, IR 36, IR 50 and IR 64. He found a good number of cross combinations having significant SCA effects in the desirable direction for different characters. Significant SCA effects were reported in all kinds of cross combinations like high x high, high x low and low x low. Faiz *et al.* (2006) evaluated line x tester crosses involving 2 CMS lines and 2 testers for 6 yield and yield traits. Significant differences were observed in lines, testers and line x testers.

**Chakraborty *et al.* (2009)** observed significant GCA and SCA effects for all the traits indicating the importance of both additive and non-additive gene effects in their inheritance. They reported superior SCA from high x high, high x low, low x high and low x low GCA combinations.

**Salgotra *et al.* (2009)** crossed five genetically diverse varieties with 3 well adapted varieties in a line x tester design. The preponderance of dominant gene action was observed for plant height, effective tillers plant, panicle length, number of grain panicle, spikelet sterility, 1000-grain weight and grain yield plant.

**Akter *et al.* (2010)** reported highly significant mean squares for parents in all the traits except yield per plant, for crosses excluding panicle weight and for parent vs. cross baring leaf area index. The ratio of GCA and SCA variances were found less than unity for all the characters except plant height, days to maturity and panicles per square metre. The panicle weight contributed the highest followed by thousand grain weight, yields per plant, panicle per metre square in their hybrids. Six hybrid combinations were found with significant positive SCA effects.

**Rahimi *et al.* (2010)** found significant SCA and GCA for all studied traits which revealed that both additive and non-additive gene effects contributed to the inheritance of the traits.

**Saidaiah *et al.* (2010)** observed higher SCA variance than GCA variance for all the traits indicating the prevalence of non-additive gene action.

**Torres *et al.* (2011)** reported the predominant direction of dominance effects as negative for days to 50% flowering and as positive for all the other characters. General combining ability and specific combining ability were significant for all the characters studied.

**El-Namaky *et al.* (2012)** reported that GCA and SCA variances were highly significant for all agronomic and physiological characters studied. Their results also indicated importance of additive gene action for most of the studied characters. However, both additive and non-additive gene action played a major role in the inheritance of chlorophyll content.

**Dwivedi and Pandey (2012)** evaluated 45 rice hybrids. Both additive and non-additive gene action were found to control the expression of all the characters. The ratio of GCA to SCA variances exhibited greater relevance of non-additive gene action governing yield and its associated traits. Two parents were found to be the best general combiners for maximum characters including grain yield per plant. Five cross combinations recorded the highest SCA effects for yield per plant.

**Ghosh *et al.* (2012)** reported that the SCA variance was greater than the GCA variance for grain yield and yield components suggesting the preponderance of dominance and epistatic gene action in expression of these traits.

**Thakare *et al.* (2012)** reported that IR 68886A and IR 68897A among females and among males IR-44, IR-60, IR-9761, IR-4266-29-4-2-2-2, IR-5638-139-2-2, IR-69701-9-3-1 and IR-71138-49-2-2 were the good general combiners for grain yield per plant. High SCA effects were observed in 5 crosses. They were found to be the best combinations for grain yield per plant and quality traits.

**Latha *et al.* (2013)** studied the nature and magnitude of heterosis and combining ability in 18 F<sub>1</sub> rice hybrids. The analysis of variance for combining ability of all the traits showed that variances due to treatments, parents, hybrids were highly significant. The line CRMS 32A and the testers namely Super rice-8, R 1099-2569-1-1 and *Jitpiti* were identified as good general combiners. The significant differences between line x tester interaction indicated that SCA attributed heavily in the expression of the traits and demonstrated the importance of dominance or non additive variances for all the traits.

**Sahu *et al.* (2013)** conducted combining ability analysis for yield and yield traits in rice. The analysis of variance for combining ability revealed that the variation among lines were only for grain weight/panicle; whereas contribution of testers towards combining ability was significant in respects of majority of the traits.

**Ilieva *et al.* (2013)** reported highly significant values of GCA and SCA in the F<sub>1</sub> and F<sub>2</sub> generations for all analyzed traits. Superior hybrid combinations were obtained in which one parental variety having good and the other one having moderate GCA.

**Sanghera and Hussain (2013)** found preponderance of non-additive gene effects as realized by higher values of SCA compared to GCA, ratio of variances of SCA to GCA and average degree of dominance. The proportional contribution of testers was observed to be lower than that of line x tester interactions, thus resulted in higher estimates of SCA variances.

**Prasad *et al.* (2013)** crossed four lines with four testers in line x tester mating design. The resultant 16 F<sub>1</sub>s were used to determine the heterosis. The genotypes IR-64, Ujala Depama and Malida were identified as good general combiners. The crosses IR64 /Ujala Depama, IR64/Malida and MTU-1010/ Ujala Depama were good specific combiners.

**Veerasha *et al.* (2013)** studied combining ability in rice (*Oryza sativa* L.) for eight characters by following the line x tester analysis, involving four CGMS lines, 11 testers and resulting 44 rice hybrids. Eight cross combinations exhibited high SCA effects for grain yield per plant. These crosses were found to involve at least one parent with high GCA effect and other parents having either high or low GCA effect indicating the involvement of additive as well as non-additive gene action.

**Latha *et al.* (2013)** studied the nature and magnitude of heterosis and combining ability was studied in 18 F<sub>1</sub> rice hybrids involving three CMS lines and six testers using line × tester analysis. The analysis of variance for combining ability of all the traits showed that variances due to treatments, parents, hybrids were highly significant. The line ‘CRMS 32A’ and testers viz. ‘Super rice-8’, ‘R 1099-2569-1-1’ and ‘Jitpiti’ were identified as good general combiners. The significant differences between lines x testers interaction indicates

that SCA attributed heavily in the expression of these traits and demonstrates the importance of dominance or non additive variances for all the traits.

**Bedi *et al.* (2014)** GCA variances of parents and SCA variances of hybrids produced for thirteen different yield and yield contributing characters are the basic criteria for selection or hybridization programme. The study for combining ability analysis of 15 F1's produced under (L × T) manner by 3 lines and 5 testers are studied in RBD fashion with two checks viz., Mahamaya and Indira sona.

**Hasan *et al.* (2014)** studied combining ability for yield and yield contributing character of rice was studied using five lines IR79156A, BRRI7A, BRRI33A, BRRI21A and IR75608A and four testers BRRI20R, BRRI31R, BRRI26R and BAU521R to produce 20 F1 in line × tester fashion. The variances due to SCA were larger than the variance due to GCA for all the characters which indicate the prevalence of non-additive gene action. BRRI7A/BRRI31R cross combination was the best specific combiner for grain yield/plant. The predominance of non-additive genetic components was observed for all the traits which indicated that the improvement of the characters with greater non-additive genetic component could be contemplated for the exploitation of heterosis.

**Bhatti *et al.* (2015)** carried out studies to determine combining ability and heterosis for yield and its component traits in rice. The material consisted of F1 hybrids of 30 crosses developed by crossing 10 lines with three testers. The cross HPR 2639 X HPR 2143 is good specific combination for grain yield/plant, panicle length, spikelets/panicle, grains/panicle, biological yield/plant, days to 50% flowering and plant height. Another hybrid, HPR 2529 X HPR 1156 also shows high heterosis over standard check for grain yield/plant biological yield/plant, grain fertility and plant height.

**Thalapati *et al.* (2015)** evaluated parental line for developing high yielding rice hybrids. 36 hybrids were phenotyped for yield and its components along with parental lines [6 cytoplasmic male sterile (CMS) lines, 5 KMR3/*Oryza rufipogon* derived ILs and KMR3 as control]. The performance of hybrids was estimated based on relative heterosis, heterobeltiosis and standard heterosis for yield and its contributing characters along with

analysis of variance for combining ability and identified a set of good general combiners for yield traits (testers: IL50-7, IL86-18, IL50-12 and CMS lines:

**Khute *et al.* (2015)** studied combining ability in New Plant Type (NPT) lines of rice for hybrid rice breeding programme has been carried out in line x tester mating design involving 3 CMS lines and 6 testers. The analysis further revealed highly significant differences for all the characters among the lines, testers and line X tester and parents vs hybrids. The significant difference between lines x tester interaction indicates that SCA attributed heavily in the expression of these traits and demonstrates the importance of dominance or non additive variances for all the traits.

**Veerasha *et al.* (2015)** studied the extent of heterosis, general and specific combining ability for yield and productivity traits in rice. Identification of genetically superior parents is an important prerequisite in for the development of hybrids in rice. In majority of the experiments high specific combining ability (SCA) variances than general combining ability (GCA) variances for most of the traits were reported which indicate the predominance of non-additive gene action in the inheritance of these traits. Therefore, analysis of combining ability has been the most important and efficient tool in selecting the desirable parents for a hybridization programme.

**Santha *et al.* (2016)** studied line x tester analysis with twelve high yielding genotypes viz., ADT 39, ADT 42, ADT 43, ADT (R) 45, ADT (R) 46, ADT (R) 47, TNAU Rice ADT 49, CO 47, ASD 16, TKM 11, TKM 12 and TRY 2 and five testers viz., Pusa 1460, Improved Samba Mahsuri, Ajaya, IRBB 60 and IRBB 21 revealed that the ratio of GCA:SCA variances computed for all the six yield and yield component traits showed the predominance of non- additive gene action. Improved Samba Mahsuri which were considered as the next best general combiners since they exhibited desirable gca effects for three characters including hundred grain weight.

**Bhati *et al.* (2017)** evaluated 32 hybrids developed from crossing two cytoplasmic male sterile lines (IR 79156A and Pusa6A) with 16 restores were studied along with two checks (BPT 5204 and Arize 6444) for 15 yield and yield attributing characters. The analysis of variance for combining ability revealed variation for plant height; whereas, contribution of

testers was significant in respects of majority of the traits. Among the male parental lines, MTU-7029, IET 22202, Danteswari, BPT 5204 and Akshaya Dhan were found to be best general combiners for grain yield and most of the component characters.

## 2.4 Heritability and Genetic Advance

The efficiency of selection in improving a plant character depends largely on the extent of transmissibility of the character. The presence of high magnitude of variability in the germplasm or breeding materials only indicates the greater possibility of improvement through selection but the existence of high transmissibility is an important pre-requisite for realization of such possibility. The direct selection parameters like heritability in broad sense (**Burton and Devane, 1953**), genetic advance in percent of mean (**Johnson et al. 1955**) are helpful in assessment of transmissibility of characters and role of environment.

**Bidhan et al. (2001)** studied 25 medium rice genotypes for eight traits are recorded heritability which ranges from 50% (grain yield per hill) to 90% (grain breadth). Genetic advance as percent of mean was highest for number of filled grains per panicle (70.34) followed by grain yield (68.72). Number of filled grains per panicle, 1000-grain weight, grain length and breadth exhibited less environmental effect and high heritability coupled with moderate to high genetic advance.

**Singh et al. (2002)** found that heritability in broad sense ranged from 3.61 for number of effective tillers per plant to 99.55 for grain length. High heritability with high genetic advance was recorded for number of grains per panicle followed by panicle weight and grain yield per plant in an experiment conducted in Meghalaya including 52 genotypes of low land rice.

**Nayak et al. (2002)** observed high heritability and high genetic advance for number of spikelets per panicle, number of grains per panicle and grain yield per plant in study including 200 scented rice genotypes grown in Cuttack, Orissa.

**Satish et al. (2003)** studied heritability and genetic advance in 200 scented rice genotypes including one non-scented check, Ratna for grain yield and its nine attributing characters.

High heritability along with high genetic advance were observed for number of spikelets per panicle, number of grains per panicle, grain yield/plant followed by other characters.

**Elayaraja *et al.* (2005)** observed high heritability associated with moderate to high genetic advance as a percent of mean for number of productive tillers, panicle length, number of grains per panicle, 100grain weight and grain yield per plant in M<sub>2</sub> generation.

**Padmaja *et al.* (2008)** studied the heritability and genetic advance were high for all characters except days to 50% flowering and panicle length, which had moderate genetic advance along with high heritability including involvement of additive variance in controlling these characters.

**Khriedinuo *et al.* (2011)** studied upland rice germplasm for genetic analysis of yield and nineteen other component traits. Heritability ( $h^2$ ) estimates were generally high except for flag leaf angle. The broad sense heritability and genetic advance as percentage of mean indicated that panicle weight and grain yield/plant are the two most important yield components and selection based on these traits would be very effective in upland rice grown under acid soil conditions.

**Singh *et al.* (2011)** examined the nature and magnitude of heritability (broad sense) and genetic advance. Broad sense heritability was the highest for biological yield per hill. Maximum genetic advance as per cent of mean was recorded for number of spikelets per panicle with high value of heritability.

**Sohrabi *et al.* (2012)** evaluated 50 rice accessions for 12 characters showed high heritability along with high genetic advance for yield of plant, days to flowering and flag leaf length-to width ratio.

**Singh *et al.* (2012)** evaluated 38 rice germplasm accessions for 12 traits to assess genetic variability and character association for grain yield with yield attributing traits. The highest values heritability coupled with genetic advance were observed for grain yield per plot and test weight.

**Chanbeni *et al.* (2012)** reported high heritability coupled with high genetic advance was recorded for spikelets per panicle in 70 rice germplasm accessions.

**Kumar *et al.* (2013)** observed heritability in broad sense ranged from 0.72 (panicle length) to 1.00 (days to 50 percent flowering and plant height). High genetic advance was observed for the traits, plant height (35.44), 1000 grain weight (40.23), harvest index (48.05), spikelet/panicle (53.12), grain yield/plant (64.98) and total biomass/plant (77.54), coupled with high heritability.

**Singh *et al.* (2013)** experimented with 11 genotypes of upland rice during *Kharif* 2009 and 2010. High estimates of heritability coupled with high genetic advance as per cent of mean was observed for plant height, flag leaf length, flag leaf width, number of spikelets per panicle and grain yield per plant..

**Gangashetty *et al.* (2013)** reported high heritability with high genetic advance was observed for all traits except days to 50 per cent flowering. All traits were found to be higher values of variance and selection for such traits will be practiced based on phenotypic observation.

**Ogunbayo *et al.* (2014)** observed in 48 genotypes that high heritability estimates for days to flowering, days to maturity, plant height, number of tillers, and panicles per meter and panicle length. High genetic advance was recorded in grain yield.

**Nirmala devi *et al.* (2015)** reported the highest broad sense heritability and genetic advance was obtained for head rice recovery (89% and 29%), milling (84% and 21%), water uptake (90% and 24%), amylose content (93% and 29%) and gel consistency (90% and 31%) which suggested that these traits would respond to selection owing to their high genetic variability and transmissibility. High estimates of heritability in association with medium genetic advance observed for KLAC (89% and 13%), elongation ratio (86% and 11%) and alkali spreading value (80% and 19%) suggested the role of both additive and non-additive gene action in their inheritance.

**Bitew *et al.* (2016)** estimated heritability and genetic advance in rainfed upland 22 rice genotypes. Heritability estimates were moderately high for days to maturity (66.01%), and thousand-grain weight (66.80%). High genetic advance as percent of means was observed

for biomass yield per plot, unfilled grains per panicle, grain yield per plot, and fertile tiller per plant.

## 2.5 Quality parameters

**Vanaja and Babu (2006)** evaluated genetic variability of quality parameters in a set of 56 high yields diverse. Phenotypic and genotypic coefficient of variation revealed the existence of a large variability in alkali spreading value and moderate variability in L/B ratio of grain, milling percentage and volume expansion ratio.

**Sharma *et al.* (2007)** observed on characterization of Ahu rice for quality traits showed wide variability with respect to 12 quality traits, observation on physical grain quality and cooking quality attributed revealed that ahu varieties were mostly of long bold, grain type with poor alkali digestion, high gelatinization temperature volume expansion ratio.

**Shahidullah *et al.* (2008)** recorded 40 genotypes of aromatic rice in variability for grain quality characters viz., grain length, grain breadth, milling percentage, kernel length, kernel breadth, L/B ratio of kernel, volume expansion ratio. Roy *et al.* (2009) evaluated on quality parameters which were analysed to assess the genetic variability and character association. Phenotypic and Genotypic coefficient of variation for grain quality parameters revealed the existence of large amount of variability in alkali spreading value, brown kernel L/B ratio and moderate variability in brown and cooked kernel length.

**Farohmandfor *et al.* (2010)** conducted 22 milled rice varieties, results obtained that the Tarom, Mahali and Champa varieties have the highest head rice yield as 60.58 and 66.39% and total milling recovery as 69.96 and 71.38% respectively.

**Pandey and Anurag (2010)** observed high heritability coupled with high genetic advance were recorded for hulling%, milling% and head rice recovery.

**Sharifi *et al.* (2010)** reported that Genetic components controlling some of cooking quality related traits in rice (*Oryza sativa* L.) Analysis of variance showed significant differences among genotypes for traits of interest including; amylose content (AC), gel consistency (GC), gelatinization temperature (GT) and grain elongation.

**Ghorbanipour *et al.* (2011)** studied that the gene actions and heritability of the physical and chemical characteristics associated with appearance and cooking quality of rice grain. Twelve chemical and physical traits including: paddy length, paddy width, paddy length to width ratio, head rice percent, broken rice percent, white grain length, white grain width, white grain length to width ratio, 100-grain weight, amylose content, gelatinization temperature and protein content were measured. The analysis of variance showed significant differences between generations for all studied traits.

**Umadevi (2012)** studied genetic variability and correlation 110 genotypes of rice. Estimates of genotypic variance, phenotypic variance, and genotypic coefficient of variation, phenotypic coefficient of variation, heritability in broad sense, genetic advance and association for grain yield with floral, quantitative and quality characters were computed. The characters, viz., stigma exertion percent, anther length, outcrossing rate, number of grains per panicle, single plant yield, volume expansion ratio, gel consistency, gelatinization temperature and amylose content possessing high GCV, heritability and genetic advance ,were effectively used in selection.

**Babu *et al.* (2012)** carried investigation to study the genetic parameters for yield, yield attributing, quality and nutritional characters in twenty one rice hybrids. Analysis of variance revealed significant differences for all the traits under study. The characters viz., number of filled grains per panicle, number of chaffy grains per panicle and iron content exhibited high Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV). Small differences between GCV and PCV were recorded for all the characters studied which indicated less influence of environment on these characters.

**Subudhi *et al.* (2012)** studied forty one rice varieties of different ecologies are evaluated at Central Rice Research Institute, Cuttack to find out varieties having better quality characters and yield. It is revealed that hulling percentage is very good in all the genotypes and ranged from 71.0 (Vanaprava) to 81.0 (Ajay).

**Chamundeswari *et al.* (2012)** evaluated that Physical quality characters viz., hulling (%), milling (%), head rice recovery (%), kernel length (mm), kernel breadth (mm) and kernel L/B ratio were studied. Of all the three scaling tests one or more tests were highly significant

indicating inadequacy of additive dominance model to explain the inheritance of the characters studied. Though both additive and non-additive gene actions were significant, non-additive gene actions played predominant role in the inheritance of the traits.

**Babu *et al.* (2013)** studied genotypic differences in grain quality including protein, micronutrient concentrations and few of the yield attributing parameters of twenty one popular rice hybrids was assessed. The data revealed huge variations in grain quality among the hybrids.

**Oladi *et al.* (2014)** assessed grain quality currently represents a major problem in high yielding rice production in Iran and many other rice producing areas of the world. Quality assessment of rice involves the function of sensory tests and physicochemical determinations based on the chemical composition, cooking quality, gelatinization temperature and physical properties of cooked rice. Lines, parental and controls varieties to assess the physiochemical properties such as the milling, grain length before cooking, grain length after cooking, elongation after cooking, gelatinization temperature, gel consistency, amylase content and aromatic were used. Cluster analysis has shown that Domsiah, sangtarom and Shastak of local check varieties located as first group, Neda and Ghaem in the second group, Fajr in Third group and Nemat in Fourth group.

**Rafii *et al.* (2014)** evaluated 17 rice genotypes consisted of 12 F1 progenies and five parental lines were evaluated for performance of grain qualities, yield and yield components and vegetative traits at the Malaysian Agricultural Research and Development Institute (MARDI) Research Station in Seberang Perai, Penang. Except grain length, all other grain quality characters, yield components and vegetative traits varied significantly among the genotypes.

**Gokulakrishnan *et al.* (2014)** estimated heritability, genetic advance, phenotypic and genotypic coefficient of variation among yield, quality and its component characters in twenty three genotypes of rice were worked out at Experimental Farm, Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University, Annamalainagar (Tamil Nadu), India. A high degree of variation was observed for all characters studied. Panicle weight, number of grains per panicle, grain L/B ratio, plant

height, 1000 grain weight and grain breadth were recorded moderate phenotypic and genotypic coefficients of variation.

**Nagaraju *et al.* (2015)** studied among fifteen F1 hybrids generated from crossing of six pure lines by using half diallel analysis excluding reciprocals were studied along with parents for combining ability for grain yield and grain quality traits. Variances of general and specific combining ability were highly significant for all the traits studied indicating the involvement of both additive and non-additive types of gene action. The predominance of non-additive gene action was recorded for plant height, total number of productive tillers per plant, panicle length, number of grains per panicle, harvest index, test weight, grain yield per plant, milling percentage and kernel L/B ratio.

**Nirmala devi *et al.* (2015)** evaluated ninety-two rice (*Oryza sativa* L.) genotypes were evaluated during *kharif*, 2013 to estimate the genetic variability, heritability. Highest broad sense heritability and genetic advance was obtained for head rice recovery (89% and 29%), milling (84% and 21%), water uptake (90% and 24%), amylose content (93% and 29%) and gel consistency (90% and 31%) which suggested that these traits would respond to selection owing to their high genetic variability and transmissibility.

**Devi *et al.* (2016)** revealed highly significant differences among 27 genotypes for all the yield components and most of the kernel quality traits except hulling percent, volume expansion ratio and water uptake indicating that enough variability is present in the studied material. The magnitude of difference between PCV and GCV was less for the traits indicating little influence of environment.

## 2.6 Morphological Diversity

The expression “divergence in character” was used by **Darwin (1859)** for the variation in genera and species. Another term “morphism” was used by **Huxley (1955)** for genetic diversity implying “genetic polymorphism” which means the coexistence of distant genetic forms in population.

Genetic diversity determines the inherent potential of a cross for heterosis and frequency of desirable recombinants in advanced generations. It is of greatest interest to plant breeder as it plays a vital role in farming a successful breeding programme. The nature and magnitude of genetic divergence in a population is essential for selection of diverse parents which upon hybridization leads to a wide spectrum of gene recombination's for quantitatively inherited traits.

In the present study, genetic divergence was assessed by Mahalanobis  $D^2$  statistics and Tocher's method. Mahalanobis  $D^2$  statistics was used for the quantitative assessment of genetic divergence for all the twelve characters. It is essential for increasing crop productivity through breeding. Multivariate analysis is a powerful tool in quantifying the degree of divergence in germplasm collection of crop plants. **(Rao, 1952).**

**Mishra *et al.* (2003)** studied the nature and magnitude of the genetic diversity for 20 quantitative and qualitative characters in 16 rice cultivars and their 72  $F_1$  hybrids. The genotypes were grouped in 12 clusters based on the relative magnitude of multivariate  $D^2$  values. Based on the cluster means, plant height, flag leaf width, ear bearing tillers per plant, 100 seed weight, panicle length, biological yield, harvest index were highly significant.

**Cheema *et al.* (2004)** observed deviations by Metroglyph method regarding the number of cluster formed, number of genotypes in the cluster and superimposition of the genotypes within the cluster. It can be interpreted that hybridization between group-I and group-II is expected to give better rice varieties.

**Nayak *et al.* (2004)** studied the nature and magnitude of genetic divergence among 200 genotypes of scented rice accessions using Mahalanobis  $D^2$  statistics. The genotypes were grouped into 10 clusters. Cluster I showed maximum intra cluster distance with cluster IV. Among all the characters grain length and days to 50% flowering played important role in formation of clusters.

**Das et al. (2004)** studied genetic divergence in fifty land race collections of rice. The genotypes were grouped in 10 clusters. Days to 50% flowering, grain yield per plant, grain length, kernel breadth and 100-kernel weight recorded highest divergence.

**Awasthi et al. (2005)** conducted a field experiment to determine the genetic divergence of 21 Indian aromatic rice genotypes. The genotypes were grouped into 6 clusters for different characters. The inter-cluster distance was observed to be highest between clusters II and III, indicating that the genotypes of these 2 clusters were genetically more diverse. The number of grains per panicle, grain yield per plant, days to 50% flowering, leaf length and leaf width showed high percent contribution towards total genetic divergence.

**Bhutia (2005)** revealed the genetic divergence using Mahalanobis  $D^2$  statistics was carried out on 41 high yielding and local genotypes of rice (*Oryza sativa* L.). The genotypes were grouped into six clusters. The desirable yield and quality characteristics were distributed mainly in clusters III and IV and cluster V.

**Bose and Pradhan (2005)** assessed the nature and magnitude of genetic divergence among 35 deep water rice genotypes from India using Mahalanobis  $D^2$  statistics. The genotypes were grouped into 10 clusters showing fair degree of relationship between geographic distribution and genetic divergence. Traits such as plant yield, days to 50% flowering, and plant height were the major contributors to genetic divergence.

**Chand et al. (2005)** studied 19 genotypes of Aman rice for their genetic divergence using Mahalanobis  $D^2$  statistics for 12 characters. The genotypes were grouped into six clusters. The maximum inter-cluster distance was found in cluster I and III. The major part of total divergence was imported by single trait *i.e.* 1000-grain weight and panicle length, grain length and plant height were also very important in this regard.

**Pankaj et al. (2006)** reported the genetic divergence of 52 traditional lowland rice (*Oryza sativa* L.) genotypes. Based on 15 agro-morphological characters, these genotypes were grouped into six clusters using Mahalanobis  $D^2$  statistic. Clusters II, III, and IV exhibited high values for most of the characters. Plant height followed by leaf angle and leaf area, highly contributed (32.43%) to the formation of clusters.

**Sarawgi *et al.* (2007)** studied 81 scented rice germplasm and grouped into 9 clusters based on Mahalanobis  $D^2$  statistic. A wide range of variation was observed in cluster means for all characters. Cluster II has desired mean for hulling per cent, panicle length, cluster VII having for kernel length, L/B ratio and Cluster V for grain yield (kg/ha).

**Bisht *et al.* (2007)** investigated 13 landraces of paddy, collected from the Nanakosi micro watershed in Almora district of Uttarakhand, were evaluated for the pattern of genetic diversity using multivariate analysis of Mahalanobis  $D^2$  statistics. Characters such as intermediate maturity, tall to medium stature, aroma, slender grain type, red or white grain colour, and had 1:1 grain to straw ratio; but they were mostly not tolerant to drought. These landraces formed seven distinct clusters.

**Kumar *et al.* (2008)** revealed genetic diversity among 71 red rice genotypes was worked out using Mahalanobis  $D^2$  statistic. On the basis of genetic distance, these genotypes were grouped into 10 clusters. The maximum inter cluster distance (38.09) was highest between Cluster II and cluster V.

**Shahidullah *et al.* (2009)** studied to assess the genetic divergence of aromatic rice for grain quality and nutrition aspects. Enormous variations were observed in majority of characters viz. grain length, breadth, kernel weight, milling yield, kernel length, L/B ratio of kernel, volume expansion ratio (VER), protein content, amylose content, elongation ratio (ER) and cooking time. The inter-cluster  $D^2$  value was maximum (26.53) between I and VI followed by 21.28 (between I and V). Minimum  $D^2$  value was found (5.90) between II and III.

**Asish *et al.* (2010)** studied to assess the genetic divergence of fifty one breeding lines/cultivars of rice was studied for fourteen physico-chemical quality characteristics. High inter-cluster distance was observed between cluster XII and other clusters. Cluster VII and XII were identified as genetically most divergent which include the varieties and hybrids viz., MDU 5, TNRH 50 and PM 0200022.

**Ahmed *et al.* (2010)** experimented with 36 accession of traditional boro rice germplasm to identify morph-agronomic characters. On the basis of  $D^2$  values genotypes were grouped into 6 clusters. The highest mean value for seedling height (21.68 cm), 1000-grain weight

(20.97 g) and grain yield/hill (6.87 g) were observed in cluster I, II for days to 50% flowering (116), panicle length (22.80 cm), grains/panicle (74), and grain length (8.35 mm), cluster IV for tillers/hill (16.44) and panicles/hill (14.17), cluster V for harvest index (0.32) along with cluster I and VI, and cluster VI for plant height (117.17 cm) and flag leaf area (30.68 cm<sup>2</sup>).

**Banumathy *et al.* (2010)** reported that rice genotypes were evaluated for eight yield attributing characters using D<sup>2</sup> analysis, to study the diversity pattern among the genotypes. Among the eight traits studied, maximum contribution was made by grain yield (50.87%) followed by days to 50 per cent flowering (15.02%), total grains per panicle (10.52%) and plant height (10.23%). Hence, grain yield, days to 50% flowering, total grains per panicle and plant height together contribute 86.62% towards total divergence.

**Sabesan *et al.* (2010)** evaluated 12 morphological and quality characters of rice genotypes. Clusters VI, III, and XII exhibited high values for most of the characters. The intra cluster distance was maximum (D = 100.90) in cluster I. The maximum inter cluster distance (D<sup>2</sup> = 8235.56) was recorded between clusters II and III.

**Singh *et al.* (2012)** studied 30 aromatic rice genotypes and grouped them into six clusters by both Tocher's and Euclidian methods of divergence. The most diverse parent combination for the component characters of grain yield improvement have been identified on the basis of 3D diagram of PCA scores and Euclidian distance matrix, which were JGL 15336 x Taroari Basmati for effective tillers per plant.

**Chakravorty and Ghosh (2012)** studied 51 land races of rice and grouped them into 11 clusters. The grouping showed 6 multigenotypic, 3 digenotypic, and two monogenotypic clusters. The maximum intra cluster D<sup>2</sup> value was shown by the cluster X followed by cluster IX, III and I, while the intra cluster distance was maximum between genotypes present in cluster IX. Maximum contribution towards genetic divergence came from the characters, culm length and grain length. Cluster VII recorded highest mean value for plant height, ligule length, culm length, culm diameter, culm number, panicle length and maturity. Hybridization among these genotypes from the cluster I, III and IX which had maximum inter cluster distances and desirable values for flag leaf angle, grain breadth, grain weight,

kernel weight, no of primary branches for panicle, likely to produce heterotic combinations and wide variability in segregating generations.

**Ashfaq *et al.* (2012)** carried out to assess the genetic diversity for various rice traits and their association with yield. Forty rice genotypes were evaluated on the basis of various morphological traits in a field experiment. The results indicated that the highest genetic variability was observed in plant height, spikelets per panicle, panicle length, days to heading and days to maturity. The combined variation among these traits was 67.7%.

**Chakma *et al.* (2012)** conducted experiment to determine the genetic diversity among 39 rice genotypes. Maximum inter cluster distance was recorded between cluster II and cluster III. The highest inter genotypic distance was observed between Tharakdhan and BRRI dhan 45.

**Dutta *et al.* (2013)** studied the genetic divergence in 62 aromatic rice genotypes by using Mahalanobis  $D^2$  statistic and grouped into eight clusters where, cluster I was the largest containing 38 genotypes followed by cluster II with 9 genotypes. Based on the inter cluster distance, the entries viz., Pankey, 60-Chali, Dudheswar, Sitabhog, Kalonunia, MTU-7029, Netaisail, Bhutmuri (Kelias) were selected which could be intercrossed to obtain high heterotic effect and also to recover desirable transgressive segregants.

**Tushara *et al.* (2013)** studied genetic divergence of 19 medium duration genotypes of rice for 20 characters and grouped them into five clusters. Protein percentage (43.27) showed maximum contribution towards genetic divergence followed by alkali digestion value (27.49), amylose content (9.94), grain length (5.26), grain width (5.26), water uptake (2.92), kernel breadth (1.17), test weight (1.17), days to 50% flowering (1.17), filled grains per panicle (0.58), kernel length after cooking (0.58), panicle length (0.58) and tillers per plant (0.58). The maximum inter cluster  $D^2$  values was observed between clusters II and III, followed by clusters II and V and clusters I and II.

**Singh *et al.* (2013)** reported the genetic variation in basmati rice production. The cultivars were grouped into 5 clusters through  $D^2$  analysis. The diversity among clusters measured by

intercluster distance was adequate for the improvement of basmati rice by hybridization and selection.

**Roy *et al.* (2013)** assessed a detailed morphological study based on quantitative traits for the genetic diversity in 110 lentil germplasm. The accession from ICARDA gene bank showed high diversity. Group B3, B4 and F were important as they comprised accessions with higher yield per plant, higher number of pods per plant and higher number of seeds per pod separated by higher inter cluster distance.

**Rajput *et al.* (2014)** examined the genetic diversity existing among 41 genotypes of rice, during *khariif*-2013. Cluster V and VII are most diverse to each other and the genotypes in these clusters may be used as parents for future hybridization.

**Dhurai *et al.* (2014)** studied 32 diverse rice genotypes and the genotypes were grouped into six clusters. Cluster II had fourteen genotypes, while cluster I and cluster III had nine and six genotypes, respectively. Single genotype was included in cluster IV, cluster V and cluster VI. Based on clustering pattern, the maximum genetic distance among genotypes existed between cluster V and cluster VI followed by cluster IV and VI, cluster II and cluster VI and cluster III and cluster V.

**Haque *et al.* (2014)** studied 76 rice genotypes, landraces and popular varieties consisting of both indigenous and exotic collection were studied for yield and yield related traits. Based on D<sup>2</sup> analysis, the genotypes were grouped into eight clusters. The maximum inter cluster distance was observed between cluster VI and VII (35.02) followed by between cluster III and VII (34.68) and between cluster I and VIII possessing wider genetic diversity among the genotypes between these groups. The maximum intra cluster distance was observed in cluster III (6.46) followed by cluster IV (6.32).

**Devi *et al.* (2015)** evaluated genetic diversity in grain quality among 92 rice cultivars using Mahalanobis D<sup>2</sup> statistic. The maximum intra cluster distance (D = 14066.5) was found in cluster VI consisting of two traditional varieties AS 100 and Chittimutyalu. Kernel breadth (0.01%), volume expansion ratio (0.39 %) and elongation ratio (0.30%) failed to contribute significantly towards genetic diversity. Amylose content (25.2%), gel consistency (20.4 %),

1000 grain weight (12.6 %) and head rice recovery (10.1%) were found to be the most contributing traits towards genetic diversity.

**Bharathi et al. (2016)** studied Genetic divergence among 32 rice (*Oryza sativa* L.) genotypes using D2 technique for ten characters. The 32 genotypes were grouped into 9 clusters containing 1 to 12 genotypes. The random distribution of genotypes indicated absence of parallelism between geographical diversity and genetic diversity. Cluster I was the largest with 12 genotypes and cluster III, V, VI, VII and VIII were lowest with one genotype each. In D2 analysis, filled grains per panicle followed by ear bearing tillers per panicle and days to 50% flowering contributed maximum for the divergence. The inter-cluster distance was maximum between clusters V and IX and between clusters V and VII. Based on these studies, crosses may be made between genotypes of clusters IX (MTU 1010, BPT 2741, and MTU 1001) and V (BPT 1768) followed by clusters VII (RGL 2537) and cluster V (BPT 1768) to obtain new desirable recombinants in rice.

**Dhutmal et al. (2017)** worked out in 73 upland rainfed rice genotypes consisting traditional varieties, local selections, advanced breeding lines and popular varieties. The maximum number of genotypes (23) was grouped in cluster IV followed by cluster V, I, VIII, II, IX, III, VI and I. Days to 50% flowering contributed maximum towards genetic divergence (40.64%) followed by effective tillers per m<sup>2</sup> (12.21%), yield per hectare (11.72%), spikelet fertility (10.69%) and plant height (8.98%).

## 2.7 Molecular Diversity

Polymorphism refers to different forms of the same basic structure. In the context of a population, these differences in DNA sequences are called polymorphisms; they may occur in coding regions (exons) or non-coding regions of genes. If modifications of a gene exist at a specific locus in a population, the locus is polymorphic. At the molecular level, polymorphism ranges from a single nucleotide base change to the number of tandem repeats in a repetitive DNA sequence. Assessment of genetic relationships using molecular markers provides polymorphism information about a germplasm pool, which is useful for developing, mapping and breeding populations or lines (**Beer et al., 1997**). Polymorphism

information is also useful for selecting and identifying parents to be used in future breeding programme.

Many diversity studies have been undertaken in the past using morpho-physiological and agronomic traits, but with little success, because of the limited number of traits, influence of environment and genotype x environment interaction. Thus, understanding both morphological and genetic diversity of a germplasm collection provides a basis for improvement of crops.

Simple sequence repeats (SSR) are the most widely used DNA marker type to characterize germplasm collections of crops. The desirable features that make SSRs suitable for assessing the genetic diversity include co-dominance, multiallelism locus specificity, and high reproducibility (**Jones *et al.*, 2007 and Smith *et al.*, 1996**). SSRs have been effectively used to identify genetic variation among rice cultivars. These positive aspects of SSRs have attracted the attention of several workers to utilize them across crop species for studying genetic variability based on DNA polymorphism. It has also been shown that limited number of SSRs is adequate to discriminate the most closely related genotypes

**Temnykh *et al.* (2000)** while reporting the current level of average genome-wide coverage provided by microsatellites in rice, stated that one marker every 6 centimorgans is sufficient to be useful for assessment of hybrid seed purity and for genotype identification.

**Rajguru *et al.* (2002)** used SSR markers for differentiating rice and red rice which had been utilized in hybridization between rice and red rice in Arkansas.

**Ravi *et al.* (2003)** assessed the genetic diversity among the 45 rice genotypes. Out of 38 SSR primer pairs used, only one locus RM 115 was monomorphic. The average Polymorphism Information Content (PIC) value was 0.578 and it ranged from a low of 0.0 to 0.890. The Mantel matrix correspondence test was used to compare the similarity matrices ( $r=0.582$ ). The test indicated that clusters produced based on RAPD and SSR markers were not conserved. SSR analysis resulted in a more definitive separation of clusters of genotypes indicating a higher level of efficiency of SSR markers for the accurate determination of relationships between accessions.

**Zeng *et al.* (2004)** used SSR markers to characterize a sub set of rice germplasm with different adaptations to saline soils for their genetic diversity. Saker *et al.* (2005) observed the genetic diversity of 7 Egyptian rice genotypes using 8 RAPD, 6 SSR and 8 AFLP primer combinations and concluded that some varieties originated from closely related ancestors possessing high degree of genetic similarity.

**Chakravarthi *et al.* (2006)** analyzed the genetic variation and DNA fingerprinting of 15 elite rice genotypes using 30 SSR primers. They found all the primers polymorphic indicating their robust nature.

**Semagn *et al.* (2006)** grouped 18 NERICA varieties with 102 SSR markers. This revealed the presence of a wide range of genetic differences among all the NERICAs.

**Brondani *et al.* (2006)** indicated that SSR markers are fundamental in determining the relationship between Brazilian rice land races.

**Jalaluddin *et al.* (2007)** determined the DNA fingerprints of the Bangladeshi cultivars of rice using SSR marker and observed large differences in the polymorphism between *indica* and *japonica* rice sub-species.

**Ram *et al.* (2007)** reported that allelic variability among the SSR markers was high enough to categorize cultivars, landraces and wild relatives of the rice germplasm.

**Alvarez *et al.* (2007)** analyzed the genetic variance of Cuban traditional rice cultivars using microsatellite markers and the microsatellite loci revealed a poor relation of improved varieties with majority of traditional varieties.

**Gholizadeh *et al.* (2007)** evaluated genetic diversity of 29 rice genotypes using 30 SSR markers. Average numbers of observed alleles in total genotypes were 3.53. They found that information from SSR data could complement the information obtained from quantitative methods.

**Sheethal *et al.* (2008)** assessed the rice genotypes using physio-morphological, SSR and ISSR markers and found that SSR and ISSR marker systems revealed higher levels of polymorphism.

**Seetharam *et al.* (2009)** characterized 30 rice genotypes by SSR markers and morphological characters. The PIC value ranged from 0.064 to 0.72 with an average of 0.46. The Jaccard's similarity coefficient ranged from 0.42 to 0.90. At the genetic similarity of 56% the genotypes were grouped into 5 clusters. PCA components explained 41.6% of variation. The average taxonomic distance ranged from 1.5 to 7.78. At a Euclidean distance of 3.49, the 30 genotypes were grouped into 4 clusters. The clustering pattern clearly grouped the genotypes based on their response to salinity and clustering was not based on their geographical origin.

**Prabakaran *et al.* (2010)** evaluated the genetic divergence of 12 rice land races using 5 SSR markers. The dendrogram based on SSR marker analysis grouped the 12 rice accession into 6 clusters, where cluster VI was the largest with 3 accessions.

**Umadevi *et al.* (2010)** studied 110 rice genotypes representing different origins for genetic diversity on the basis of quantitative and quality traits using Mahalanobis  $D^2$  statistics and SSR marker analysis. Two distinct groups resulted from SSR marker data analysis.

**Selvaraj *et al.* (2010)** predicted heterosis and performance of  $F_1$  hybrids from genetic divergence of their parents based on molecular markers reported in various crops. They concluded that genetic distances based on RAPD markers would be useful for prediction of heterotic combinations in rice.

**Rahman *et al.* (2011)** analyzed genetic diversity of 21 rice varieties in respect of 13 morphological and 14 physiological traits along with 34 SSR markers. From the rank correlation values, it was found that SSR marker based genetic diversity was the most effective in genetic distance determination and grouping of the genotypes, followed by morphological genetic diversity analysis. From the result of this study, it was found that combination of morphological and molecular markers might be useful in studying genetic diversity of rice for conservation, breeding and other crop improvement activities.

**Kanawapee *et al.* (2011)** evaluated 30 rice cultivars using 20 SSR markers. A total of 190 SSR alleles were produced which revealed 89.47% polymorphism. Mean genetic similarity coefficient was 0.70 for SSR. Cluster analysis separated rice cultivars into groups based on genetic relatedness.

**Vanniarajan *et al.* (2012)** tested rice genotypes to ascertain their genetic diversity structure. Pattern of molecular differentiation separated *indica* and *japonica* genotypes; *indica* genotypes had two subpopulations within.

**Onaga *et al.* (2013)** observed a low correlation between the observed molecular and morphological datasets. Choudhary *et al.* (2013) studied genetic diversity in representative sets of high yielding varieties of rice released in India between 1970 and 2010 at molecular level. Cluster analysis clearly grouped the 100 genotypes into their respective decadal periods. Jamil *et al.* (2013) investigated genetic diversity of 24 rice genotypes. The similarity matrix clearly revealed the most closely genotypes and the most dissimilar genotypes. Dendrogram divided the genotypes into 4 main clusters and each cluster was subdivided into 2 further groups.

**Shahria *et al.* (2014)** carried out an experiment to assess the genetic diversity of advanced rice (*Oryza sativa* L.) breeding lines using three SSR markers viz., RM 147, RM 167 and RM 215. Polymorphism information content (PIC) ranged from 0.47 to 0.88 with an average of 0.71. A dendrogram was constructed based on total microsatellite polymorphism and 34 genotypes were grouped into four major clusters at 0.36 similarity co-efficient differentiating the early maturing genotypes from the late maturing types. The information about the genetic diversity might be utilized in future breeding programs for developing rice varieties with much shorter growth duration.

**Ramada *et al.* (2015)** evaluated seven rice genotypes differed in drought tolerance for genetic diversity by using 46 SSR markers related to drought. Three genotypes were drought tolerant (Azucena, Moroberekan and IRAT 170), two were moderately tolerant (IET 1444 and Giza 178) and two were drought susceptible (IR 64 and Giza 177). The results indicated that among SSR markers used, 43 SSR loci were polymorphic and produced 127 alleles.

**[Singh \*et al.\* \(2016\)](#)** evaluated small set of rice genotypes and reported a loss in genetic diversity especially after green revolution. However, a detailed study of the trend of diversity in Indian rice varieties is lacking. SSR markers have proven to be a marker of choice for studying the genetic diversity. Therefore, the present study was undertaken with

the aim to characterize and assess trends of genetic diversity in a large set of Indian rice varieties (released between 1940–2013), conserved in the National Gene Bank of India using SSR markers.

**Swain *et al.* (2017)** studied the genetic diversity of Wild Rice of Eastern India Using SSR Markers on 26 accessions of *O. rufipogon* and *O. nivara* collected from different districts of Orissa, West Bengal and Tripura. They concluded that the SSR markers used were found to be equally informative for the genetic diversity study between and among the accessions of two wild species such as *O. rufipogon* and *O. nivara* collected from different locations of Orissa, West Bengal & Tripura.

**Becerra *et al.* (2017)** assessed the genetic diversity in temperate japonica rice germplasm using SSR markers among 1200 accessions, mainly temperate japonica rice accessions, well adapted to the local conditions. Total number of alleles scored across 249 genotypes was 183 with an overall mean of 6.1 alleles per locus, ranging 2-14.

## MATERIALS AND METHODS

The edaphic and climatic conditions under which the present study was carried out, along with the techniques applied, materials utilized and the methodologies adopted in the present investigation to achieve the desired objectives are described under the following major heads.

- 3.1 Experimental site
- 3.2 Topography and climate
- 3.3 Experimental materials
- 3.4 Experimental details
- 3.5 Observations recorded
- 3.6 Statistical analysis

The present investigation entitled “**Heterosis and Combining ability estimates using L×T analysis and Genetic divergence using SSR markers in Rice**” is undertaken to obtain information on Heterosis, combining ability and Morphological diversity and molecular diversity by using SSR Markers.

### 3.1 Experimental site

The experiments were conducted in *Kharif*, 2014, *Kharif*, 2015 and *Rabi*, 2015-16 at the field experimentation centre of Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Allahabad and National Rice Research Institute (NRRI), formerly Central Rice Research Institute, Cuttack. All types of facilities necessary for cultivation of successful crop including field preparation, inputs, irrigation facilities and labours were provided from the Department of Genetics and Plant Breeding and NRRI Cuttack.

### 3.2 Topography and climate

Allahabad is situated at an elevation of 98 meter above the sea level at 25.87 °N latitude and 81.25 °E longitudes. The region is located in the south eastern part of Uttar Pradesh and has a subtropical climate with extremes of summer and winter. During the winter season especially in the month of December and January the temperature drops down to as low as 1°C while during the summer temperature reaches up to 48-50°C. The average rainfall in this area is around 1013.4 mm annually and maximum concentration during July to September with a few occasion showers and drizzles in winter also. Soil type of experimental site was sandy loam.

The National Rice Research Institute is located in Cuttack in Odisha state (20°N, 86°E) at 24 meters above mean sea level (MSL). Cuttack experiences a tropical wet and dry climate. The summer season is from March to June when the climate is hot and humid. The temperature around this season is 35 °C to 40 °C Thunderstorms are common at the height of the summer. The monsoon months were from July to October when the city receives most of its rainfall from the South West Monsoon. The annual rainfall is around 144 cm. Temperatures are considerably lower during the rainy season, averaging around 30 °C. The winter season from November to February is characterised by mild temperatures and occasional showers. The winter months feature chilly northerly winds which bring down the temperature to around 15 °C, though the bright sunshine helps maintain the pleasant weather. Temperatures may exceed 45°C at the height of summer and may fall below 10 °C in winter.

### 3.3 Experimental materials

Experimental material, for the research study consists of 100 rice genotypes obtained from the Department of Genetics and Plant breeding, SHUATS, Allahabad and ANGRAU, Bapatla during *Kharif*, 2014.

### 3.4 Experimental Details

#### 3.4.1 Details of experiment: 1 (*Kharif* 2014)

During *Kharif* 2014, one hundred rice genotypes were evaluated for yield and yield contributing traits followed by selection of parents for future hybridization.

##### 3.4.1.2 Experimental details

|                         |   |                               |
|-------------------------|---|-------------------------------|
| Design of experiment    | : | RBD (Randomized Block Design) |
| No. of Genotypes        | : | 100                           |
| Number of Replication   | : | 3                             |
| Gross area              | : | 1800m <sup>2</sup>            |
| Net cultivated area     | : | 1600 m <sup>2</sup>           |
| Plot size               | : | 5 m <sup>2</sup>              |
| Row to Row Distance     | : | 20 cm                         |
| Plant to Plant Distance | : | 15 cm                         |
| Fertilizer dose         | : | NPK@ 120: 60: 40 kg/ha        |
| Date of sowing          | : | 20 <sup>th</sup> June 2014    |
| Date of planting        | : | 15 <sup>th</sup> July 2014    |

Recommended package of agronomic practices were followed to raise a healthy crop.

**Table 3.1 List of 100 Rice genotypes**

| S. No. | Name of genotype | S. No. | Name of genotype         | S. No. | Name of genotype  |
|--------|------------------|--------|--------------------------|--------|-------------------|
| 1      | WGL 536          | 35     | MTU 1155                 | 69     | RGL7009           |
| 2      | NLR 3350         | 36     | WGL 821                  | 70     | IRRI105           |
| 3      | BPT 2676         | 37     | MTU-1190                 | 71     | RNR-15048         |
| 4      | NLR 3276         | 38     | WGL-14                   | 72     | KNM118            |
| 5      | MTU 1075         | 39     | NLR 3350                 | 73     | BPT-5204          |
| 6      | BPT2411          | 40     | WGL-810                  | 74     | Lakshmi           |
| 7      | BPT 2618         | 41     | NDR-2064                 | 75     | LSD-1             |
| 8      | JGL 19621        | 42     | NDR-2065                 | 76     | OR 2560-6         |
| 9      | MTU 1175         | 43     | NDR-3112-1               | 77     | MTU 126-1-6-1     |
| 10     | MTU 11365-62-1-1 | 44     | BPT-3292                 | 78     | MTU 1182          |
| 11     | RP 4978-60-3-2-2 | 45     | BPT-2231                 | 79     | RGL2536           |
| 12     | RPHR 650-2-5     | 46     | MTU 1064                 | 80     | MTU 2152-5-1-1-5  |
| 13     | OR 2560-3        | 47     | NLR-33654                | 81     | BM-71             |
| 14     | SHIATS DHAN-1    | 48     | PLA-1100                 | 82     | MOTIGOLD          |
| 15     | IRRI 104         | 49     | BPT 1768                 | 83     | SONAM             |
| 16     | MTU1010          | 50     | RGL-11226                | 84     | NDR359            |
| 17     | IRRI 154         | 51     | RNR-M7                   | 85     | RGL 2624          |
| 18     | MTU 2051-3-2-3   | 52     | ERRAMALLELU<br>WGL-20471 | 86     | BPT 2570          |
| 19     | NLR 3302         | 53     | INDRA-1061               | 87     | MTU 1177          |
| 20     | JGL 11727        | 54     | JGL-11470                | 88     | MTU 1155          |
| 21     | BPT 3291         | 55     | JGL-3844                 | 89     | AD09493           |
| 22     | NLR 3213         | 56     | JGL-1798                 | 90     | MTU 1181          |
| 23     | OR 2542-12       | 57     | NDLR-8                   | 91     | BPT 2613          |
| 24     | NLR 3238         | 58     | RAMAPPA-WGL-<br>23985    | 92     | SHAHBHAGI<br>DHAN |
| 25     | JGL 20171        | 59     | PANTHDHAN-10             | 93     | NLR34449          |
| 26     | MTU1001          | 60     | AKSHYA                   | 94     | RNR 2465          |
| 27     | WGL 580          | 61     | PANTHDHAN-11             | 95     | JGL 17004         |
| 28     | MTU 1161         | 62     | Suvarna                  | 96     | SWETHA            |
| 29     | MTU 1121         | 63     | PUSHYAMI                 | 97     | WGL14             |
| 30     | NLR 3349         | 64     | MTU 7006                 | 98     | KNM115            |
| 31     | NLR 3353         | 65     | RGL-7004                 | 99     | RGL2539           |
| 32     | JGL 18629        | 66     | RGL-7005                 | 100    | BPT-2615          |
| 33     | OR 2573-4        | 67     | RGL-7006                 |        |                   |
| 34     | RGL 2538         | 68     | Zhonghou 1               |        |                   |

**Table 3.2 Meteorological Data Recorded During Experimental Period, Kharif-2014**

| Months                | Week     | Temperature (°C) |       | Relative humidity (%) |       | Total rainfall (mm) |
|-----------------------|----------|------------------|-------|-----------------------|-------|---------------------|
|                       |          | Max.             | Min.  | Max.                  | Min.  |                     |
| <b>July 2014</b>      | I week   | 37.34            | 28.71 | 74.71                 | 33.86 | 37.40               |
|                       | II week  | 38.37            | 28.37 | 71.43                 | 35.00 | 7.0                 |
|                       | III week | 35.53            | 28.01 | 88.14                 | 60.29 | 118.60              |
|                       | IV week  | 34.17            | 27.25 | 82.56                 | 60.9  | 39.80               |
| <b>August 2014</b>    | I week   | 34.05            | 27.10 | 86.88                 | 61.63 | 124.0               |
|                       | II week  | 33.88            | 28.05 | 88.75                 | 60.25 | 34.80               |
|                       | III week | 36.98            | 28.43 | 83.0                  | 51.75 | 5.40                |
|                       | IV week  | 38.09            | 29.80 | 81.29                 | 50.43 | 0.10                |
| <b>September 2014</b> | I week   | 35.43            | 26.51 | 87.29                 | 54.71 | 13.90               |
|                       | II week  | 35.26            | 25.97 | 86.0                  | 49.29 | 14.10               |
|                       | III week | 34.89            | 26.69 | 87.43                 | 48.57 | 12.40               |
|                       | IV week  | 36.62            | 26.44 | 85.33                 | 46.89 | 0.00                |
| <b>October 2014</b>   | I week   | 35.25            | 25.28 | 86.63                 | 47.63 | 0.00                |
|                       | II week  | 33.26            | 23.63 | 85.75                 | 60.88 | 110.6               |
|                       | III week | 33.18            | 20.56 | 86.0                  | 52.50 | 0.00                |
|                       | IV week  | 32.60            | 20.31 | 86.0                  | 53.86 | 0.00                |
| <b>November 2014</b>  | I week   | 33.17            | 20.09 | 86.29                 | 45.57 | 0.00                |
|                       | II week  | 32.71            | 17.06 | 87.14                 | 46.17 | 0.00                |
|                       | III week | 29.67            | 12.20 | 85.71                 | 45.71 | 0.00                |
|                       | IV week  | 30.53            | 11.31 | 81.89                 | 43.0  | 0.00                |

**Source:** Agro meteorological unit, college of Forestry and Environment SHUATS Allahabad.

### 3.4 DETAILS OF EXPERIMENT: 2 (*Kharif*, 2015)

A crossing programme initiated with 7 lines and 3 testers following line x tester analysis (Kempthorne 1957) to obtain 21 F<sub>1</sub> hybrids during *kharif* 2015 at Departmental Research Farm, SHUATS, Allahabad, UP.

**Table 3.3 List of 10 Rice genotypes**

| S.No. | Lines          |          |
|-------|----------------|----------|
| 1.    | MTU-1010       | Line 1   |
| 2.    | MTU-1001       | Line 2   |
| 3.    | Sahabhagi dhan | Line 3   |
| 4.    | BPT-5204       | Line 4   |
| 5.    | BPT-2411       | Line 5   |
| 6.    | BPT-2615       | Line 6   |
| 7.    | NLR-34449      | Line 7   |
|       | Testers        |          |
| 1.    | NDR-359        | Tester 1 |
| 2.    | BM-71          | Tester 2 |
| 3.    | SHIATS Dhan 1  | Tester 3 |

#### Layout of crossing plan

| FEMALE         | MALES          |                |                |
|----------------|----------------|----------------|----------------|
|                | T <sub>1</sub> | T <sub>2</sub> | T <sub>3</sub> |
| L <sub>1</sub> | X              | X              | X              |
| L <sub>2</sub> | X              | X              | X              |
| L <sub>3</sub> | X              | X              | X              |
| L <sub>4</sub> | X              | X              | X              |
| L <sub>5</sub> | X              | X              | X              |
| L <sub>6</sub> | X              | X              | X              |
| L <sub>7</sub> | X              | X              | X              |

**Table 3.4 Genotype and important features**

| Sl no | Used as | Name of the genotype | Pedigree                   | Salient features                                                                                                                                                             |
|-------|---------|----------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1     | Line    | MTU-1010             | Krishnaveni x IR-64        | Shorter duration, hence, requires less water and suitable for double cropped area Tolerant to BPH, BLB, Semi-dwarf (108 cm) , grains long slender, Yield: 6.5t /ha. Dormancy |
| 2     | Line    | MTU-1001             | Vajram x MTU 7014)         | Semidwarf Suitable for double cropped areas Tolerant to BPH and Blast Non lodging 6.5t/ha. Dormancy                                                                          |
| 3     | Line    | Sahabhagi dhan       | IR74371-70-1-1)            | Early, Dwarf, Drought tolerance, Non lodging                                                                                                                                 |
| 4     | Line    | BPT-5204             | Geb-24X (TN-1 x Mashuri    | Semi dwarf, grains: MS, Yield: 5.5-6 t/ha.                                                                                                                                   |
| 5     | Line    | BPT-2411             | BPT 5204/BPT 4358          | High yielder 7t/ha, Medium slender Resistance to blast and BPH                                                                                                               |
| 6     | Line    | BPT-2615             | IR 20 x Tulasi             | Cold tolerance, Drought tolerance, Non lodging Medium slender, Resistance to blast and BPH, yield 5t/ha                                                                      |
| 7     | Line    | NLR-34449            | R-72XBPT-5204              | Dwarf (70-85 cm), grains – MS, resistant to leaf blast and tolerant to neck blast. Blast endemic areas Yield: 6t/ha                                                          |
| 8     | Tester  | NDR-359              | BG-90-2-4/OE677            | Semidwarf, Drought tolerance grains LB Yield: 6t/ha resistant to blast and BPH                                                                                               |
| 9     | Tester  | BM-71                | MTU4569/ARC6 650/Shan/ir64 | Resistance to blast and BPH                                                                                                                                                  |
| 10    | Tester  | SHIATS Dhan 1        | AAIO3 (mutant)             | Semidwarf, grains MS, Resistance to blast and Brown spot, yield 6.5t/ha                                                                                                      |

### 3.4.1 Experimental details

|                         |   |                             |
|-------------------------|---|-----------------------------|
| Mating design           | : | Line X Tester               |
| No. of Genotypes        | : | 10 (7 lines and 3 testers)  |
| Gross area              | : | 240 m <sup>2</sup>          |
| Net cultivated area     | : | 150 m <sup>2</sup>          |
| Plot size               | : | 5 m <sup>2</sup>            |
| Row to Row Distance     | : | 20 cm                       |
| Plant to Plant Distance | : | 15 cm                       |
| Fertilizer dose         | : | NPK @ 120: 60: 40 kg/ha     |
| Date of sowing          | : | 22 <sup>nd</sup> June, 2015 |
| Date of Transplanting   | : | 18 <sup>th</sup> July, 2015 |

Recommended package of agronomic practices were followed to raise a healthy crop.

**Table 3.5 Meteorological Data Recorded During Experimental Period, *Kharif*-2015, Allahabad**

| Month         | Week     | Temperature ( $^{\circ}\text{C}$ ) |       | Humidity (%) |       | Rainfall (mm) |
|---------------|----------|------------------------------------|-------|--------------|-------|---------------|
|               |          | Max.                               | Min.  | Max.         | Min   |               |
| June 2015     | III week | 40.14                              | 29.6  | 76.86        | 36    | 0.08          |
|               | IV week  | 40.28                              | 28.51 | 78.71        | 32.14 | 0.28          |
| July 2015     | I week   | 34.71                              | 27.57 | 91           | 50.42 | 2.4           |
|               | II week  | 34.4                               | 27.31 | 91.86        | 52.71 | 14.51         |
|               | III week | 32.41                              | 28.14 | 91.71        | 68.14 | 5.08          |
|               | IV week  | 34.11                              | 28.11 | 90.86        | 65.43 | 0.57          |
| August 2015   | I week   | 34.2                               | 27.94 | 91.43        | 56.28 | 2.51          |
|               | II week  | 35.71                              | 27.46 | 90.71        | 53.57 | 1.8           |
|               | III week | 33.63                              | 27.14 | 94           | 58.57 | 15.68         |
|               | IV week  | 35.14                              | 27.43 | 51.14        | 54.28 | 3.45          |
| September2015 | I week   | 36.68                              | 27.11 | 89           | 52    | 0             |
|               | II week  | 37.46                              | 27.57 | 86.28        | 46.57 | 0             |
|               | III week | 35.4                               | 28.05 | 87.43        | 56.14 | 0.6           |
|               | IV week  | 36.54                              | 27.8  | 90           | 47.14 | 0.2           |
| October2015   | I week   | 35.94                              | 27.88 | 90           | 48.71 | 0             |
|               | II week  | 35.94                              | 26.71 | 91.57        | 53.28 | 0             |
|               | III week | 35.28                              | 22.17 | 92.14        | 50.85 | 0             |
|               | IV week  | 36.4                               | 20    | 92.42        | 50.5  | 0             |

**Source:** Agro meteorological unit, college of Forestry and Environment, SHUATS, Allahabad.

### 3.4.2 DETAILS OF EXPERIMENT: 3 (*Rabi* 2015-16)

The experiment was conducted at NRRI Cuttack during *Rabi* 2015-16 to evaluate the twenty one crosses along with ten parents and three checks a total 34 genotypes.

**Table 3.6 List of hybrids, parents and checks**

| Sl.No | List of genotypes              | Used as F <sub>1</sub> |
|-------|--------------------------------|------------------------|
| 1     | MTU 1010X NDR 359              | F <sub>1</sub>         |
| 2     | MTU 1010 X BM 71               | F <sub>1</sub>         |
| 3     | MTU 1010 X SHIATS Dhan 1       | F <sub>1</sub>         |
| 4     | MTU 1001 X NDR 359             | F <sub>1</sub>         |
| 5     | MTU-1001 X BM-71               | F <sub>1</sub>         |
| 6     | MTU-1001 X SHIATS Dhan 1       | F <sub>1</sub>         |
| 7     | Sahabhaagi dhan X NDR 359      | F <sub>1</sub>         |
| 8     | Sahabhagi dhan X BM 71         | F <sub>1</sub>         |
| 9     | Sahabhagi dhan X SHIATS Dhan 1 | F <sub>1</sub>         |
| 10    | BPT 5204X NDR 359              | F <sub>1</sub>         |
| 11    | BPT 5204 X BM71                | F <sub>1</sub>         |
| 12    | BPT 5204 X SHIATS Dhan1        | F <sub>1</sub>         |
| 13    | BPT 2411 XNDR 359              | F <sub>1</sub>         |
| 14    | BPT 2411X BM 71                | F <sub>1</sub>         |
| 15    | BPT 2411 XSHIATS Dhan1         | F <sub>1</sub>         |
| 16    | BPT-2615 X NDR-359             | F <sub>1</sub>         |
| 17    | BPT 2615X BM 71                | F <sub>1</sub>         |
| 18    | BPT 2615X SHIATS Dhan1         | F <sub>1</sub>         |
| 19    | NLR-34449 X NDR359             | F <sub>1</sub>         |

|    |                           |                |
|----|---------------------------|----------------|
| 20 | NLR 34449 XBM-71          | F <sub>1</sub> |
| 21 | NLR 34449 X SHIATS Dhan 1 | F <sub>1</sub> |
| 22 | MTU 1010                  | Line           |
| 23 | MTU 1001                  | Line           |
| 24 | Sahabhagi dhan            | Line           |
| 25 | BPT 5204                  | Line           |
| 26 | BPT 2411                  | Line           |
| 27 | BPT 2615                  | Line           |
| 28 | NLR 34449                 | Line           |
| 29 | NDR 359                   | Tester         |
| 30 | BM 71                     | Tester         |
| 31 | SHIATS Dhan 1             | Tester         |
| 32 | Jaya                      | Check          |
| 33 | IR 64                     | Check          |
| 34 | Anjali                    | Check          |

### Layout description

The details of field layout are given below:

|                      |   |                               |
|----------------------|---|-------------------------------|
| Design of experiment | : | RBD (Randomized Block Design) |
| No. of Genotypes     | : | 34                            |
| No. of Replication   | : | 3                             |
| Gross area           | : | 725 m <sup>2</sup>            |
| Net cultivated area  | : | 510 m <sup>2</sup>            |
| Plot size            | : | 5 m <sup>2</sup>              |
| Row to Row Distance  | : | 20 cm                         |

Plant to Plant Distance : 15 cm

Fertilizer dose : NPK@ 120: 60: 40 kg/ha

Date of sowing : 10<sup>th</sup> December 2015, D/P 5<sup>th</sup> January 2016

Recommended package of agronomic practices were followed to raise a healthy crop.

**Table 3.7 Meteorological data recorded during experimental period during *Rabi* season 2015-16**

|        | Maximum Temp (°c) | Minimum Temp (°c) | Daily RF (mm) | RH I (%) | RH-II (%) | Wind Speed (kmph) | E (mm) | Sun ShineHrs |
|--------|-------------------|-------------------|---------------|----------|-----------|-------------------|--------|--------------|
| Dec-15 | 27.73             | 17.62             | 12.4          | 93.32    | 54.19     | 2.613             | 2.26   | 3.87         |
| Jan-16 | 28.61             | 15.83             | 0             | 95.39    | 46.55     | 2.165             | 2.46   | 6.34         |
| Feb-16 | 32.32             | 21.47             | 3.1           | 95.28    | 48.38     | 3.428             | 3.05   | 5.51         |
| Mar-16 | 34.54             | 23.52             | 0             | 94.03    | 46.06     | 4.210             | 4.03   | 6.64         |
| Apr-16 | 39.02             | 26.94             | 1.7           | 91.67    | 42.27     | 8.293             | 6.37   | 7.47         |

**Source:** Meteorological department, National Rice Research Institute, (formerly CRRI), Cuttack.

### 3.5 Observations Recorded

The data was recorded on five randomly selected plants from each genotype in each replication leaving the first two border rows from all the four sides, in order to avoid the sampling error. The observations were recorded as per the following procedure.

### QUANTITATIVE CHARACTERS

1. Days to 50% flowering.
2. Plant height (cm).
3. Number of tillers / plant.
- 4 Number of panicles / plant
5. Panicle length (cm)
6. Flag leaf length (cm).
7. Flag leaf width (cm)
8. Number of grains/ panicle

9. Days to maturity
10. Spikelet Fertility%
11. Spikelet Sterility%
12. Biological yield (g)
13. Harvest index (%)
14. Test weight (g)
15. Grain yield / plant (g)

#### **Qualitative characters**

1. Hulling %
2. Kernel length (mm)
3. Kernel width (mm)
4. L/B Ratio (mm)
5. Kernel length after cooking (mm)
6. Kernel width after cooking (mm)
7. Elongation ratio (mm)

#### **3.5.1 Days to 50% flowering**

Data for days to 50 percent flowering were recorded on plot basis. Number of days were counted from the date of sowing to the date of emergence of spikelet in 50% plants of experimental plot and averaged.

#### **3.5.2 Plant height (cm)**

Plant height was measured in centimeters from the ground level to the top of the tallest panicle (excluding awn) at the time of maturity and the mean was calculated.

#### **3.5.3 Number of tillers / plant**

The total number of tillers in each of the five selected plants from each replication were counted and averaged.

#### **3.5.4 Number of panicles/plant**

The total number of panicles in each of the five selected plants were counted and averaged.

#### **3.5.5 Flag leaf length (cm)**

The uppermost leaf below the panicle is the flag leaf. The flag generally differ from the others in shape, size and angle. Its length was measured from the base to the tip of the leaf in centimeters and the mean was calculated.

#### **3.5.6 Flag leaf width (cm)**

Flag leaf width was measured in centimeters at three places of the leaf. The average of these three readings was considered as flag leaf width.

#### **3.5.7 Panicle length (cm)**

Length of main panicle (mother spike) was recorded to the top most spikelet excluding awn in centimeter.

#### **3.5.8 Number of grains /panicle**

The average number of spikelet in panicle were counted and recorded in each replication as number of spikelet per panicle.

#### **3.5.9 Days to Maturity**

Days to Maturity were recorded after 25 to 30 days from days to 50% flowering.

$$\text{3.5.10 Spikelet Fertility\%} = \frac{\text{Total No of filled spikelets} - \text{Total no. of spikelets}}{\text{Total no of spikelets}} \times 100$$

$$\text{3.5.11 Spikelet Sterility\%} = \frac{\text{Total no of unfilled spikelets} - \text{Total no. of spikelets}}{\text{Total no Spikelets}} \times 100$$

### 3.5.12 Biological yield (g)

After drying of plants in the field the weight of plants was taken to record to biological yield.

### 3.5.13 Harvest index (%)

For total biological yield, the entire plant above the ground level was observed, sun dried and weighed (g) at maturity. The value of harvest index (HI) was calculated from the following formula:

The value of harvest index (HI) was calculated from the following formula given by **Donald and Hamblin (1976)**.

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Total biological yield (grain yield + straw)}} \times 100$$

### 3.5.14 Test weight (g) (1000 grain weight)

One thousand sun-dried seeds were taken as representative sample from bulk seed of each plant and were weighed on electronic balance to record test weight in grams

### 3.5.15 Grain yield / plant (g)

Grain yield of five randomly selected plants was recorded in grams separately and averaged for each replication after threshing.

## Qualitative Characters

### 1 Hulling %

A sample of 100 g of rice will be dehusked in a dehusker (SATAKE THU 35A) and then weight of each of the sample taken and hulling percentage will be calculated as per the following formula.

$$\text{Hulling \%} = (\text{weight of the dehusked grain} / \text{weight of the paddy}) \times 100$$

## **2 Kernel length (mm)**

Kernel length of 10 unbroken milled rice grains selected at random from each sample measured in milli meters separately by the help of graph paper and then averaged for each treatment.

## **3 Kernel Breadth (mm)**

Kernel breadth of 10 unbroken milled rice grains selected at random from each sample measured in milli meters separately by the help of graph paper and then averaged for each treatment.

## **4 L/B ratio**

Length/breadth ratio worked out by using the following formula:

$$\text{L/B ratio} = [\text{Mean length of kernel (mm)}/\text{mean breadth of kernel (mm)}]$$

## **5 Kernel length after cooking (mm)**

A sample of 5 g of whole grain milled rice soaked in 15 ml of distilled water for 10 minutes in a 50 ml test tube. The test tubes placed in beaker containing distilled water and heated for 20 minutes. The cooked rice transferred to a cooked kernel measured using a graph paper.

## **6 Kernel breadth after cooking (mm)**

A sample of 5 g of whole grain milled rice soaked in 15 ml of distilled water for 10 minutes in a 50 ml test tube. The test tubes placed in beaker containing distilled water and heated for 20 minutes. The cooked rice transferred to a cooked kernels breadth measured using a graph paper.

## **7 Elongation ratio**

Elongation ratio calculated by using the following formula:

$$\text{Elongation ratio} = \frac{\text{Average length of cooked kernels (mm)}}{\text{Average length of uncooked kernels (mm)}}$$

### 3.6 Statistical Analysis

The statistical analysis was done by using replication mean values based on the recorded data. The different statistical procedures followed were as under:

3.6.1 Analysis of variance ,CD,CV, and SD

3.6.2 Estimation of Heterosis, Heterobeltiosis and Economic heterosis

3.6.3 Combining ability analysis

3.6.4 Morphological diversity

3.6.5 Molecular diversity

The data obtained for each character in  $F_1$ 's and parents were analyzed for each statistical procedure given by **Panse and Sukhatme (1967)**, 'F' test and 't' test were worked out by the analysis of variance to test the significance. It was carried out according to the procedure of RBD analysis for each character as per methodology of **Fisher and Yates (1938)**. The total variance and degree of freedom were portioned into three components namely replications, genotypes and error. Significance of variance was determined by F-test. Analysis of variance for experiment design was performed to test the significant differences between genotypes for all the character with fixed effect model. The statistical method for randomized block design is:

Analysis of variance was done under the fixed effect model given below:

$$Y_{ij} = \mu + g_i + r_j + e_{ij}$$

**Where,**

- $Y_{ij}$  = Phenotypic Observation in the  $i^{\text{th}}$  (treatment) and  $j^{\text{th}}$  (Replication)
- $\mu$  = Overall Mean
- $g_i$  = Effect of the  $i^{\text{th}}$  treatment
- $e_{ij}$  = Random Error Associated with the  $i^{\text{th}}$  treatment and  $j^{\text{th}}$  Replication

**Here,**  $i = 1, 2, 3, \dots, 20$

$j = 1, 2$

$H_0 = g_1 - g_2 - \dots - g_{20}$

The sum of squares was arranged in the following manner to test the Significance of difference between treatments.

### 3.6.1 Skeleton of Analysis of variance (ANOVA)

| Source of variation | Degree of freedom (d.f.) | Sum of squares (S.S.) | Mean sum of squares (M.S.S).           | Variance ratio |
|---------------------|--------------------------|-----------------------|----------------------------------------|----------------|
| Replications        | $(r-1)$                  | RSS                   | $RSS/(r-1) = V_r$                      | $V_r/EMS$      |
| Treatments          | $(t-1) = n_1$            | TSS                   | $TSS/(t-1) = V_t$                      | $V_t/EMS$      |
| Error               | $(r-1)(t-1) = n_2$       | ESS                   | $ESS/(r-1)(t-1) = EMS \text{ or } V_e$ |                |
| Total               | $(rt - 1)$               |                       |                                        |                |

**Where,**

$r$  = Number of Replications

$t$  = Number of Genotypes / Treatments

RSS = Replication Sum of Square

MSS = Mean Sum of Square

EMS = Error Mean Sum of Square

### Standard error of mean

Standard error of mean was calculated by the following formula.

$$SEm = \sqrt{2EMS/r}$$

### Critical difference

Critical difference was calculated by the following formula.

$$C.D. = \sqrt{2EMS/r} \times t_{\text{edf at 5\%}}$$

**Where,**

r = Number of Replications

EMS = Error Mean Sum of Squares

t = Table Value of 'T' at Error Degrees of Freedom at 0.05 Level of Significance.

### Test of significance

If the variance ratio (calculated F) was greater than the tabulated F value at 5% level of significance the difference between the different genotypes in terms of different character was considered to be significant and if it was lower than the tabulated value, it was considered to be non-significant.

### 3.6.2 Mean

Mean value of each character was worked out by dividing the totals by the corresponding number of observations.

$$\text{Mean} = \frac{\sum X}{N}$$

**Where,**

$\sum X$  = Sum of All the Observations for Each Character in Each Replication

N = Corresponding Number of Observations

### 3.6.3 Range

Range is the difference between the lowest and highest mean values for each character were taken in the observation in a sample.

$$R = R_2 - R_1$$

Where:  $R_1$  = Highest Mean

$R_2$  = Lowest Mean

### 3.6.4 Variance

It is defined as the average of the square deviation from the mean on it is the square of the standard deviation; it is an effective measure of variability, which permits partition of variance into various components.

#### Genotypic variance

The genotypic variance (VG or  $\sigma_g^2$ ) is the variance due to the genotypes present in the population. The formula used for calculation of genotypic variance was

$$VG = \frac{V_t - EMS}{r}$$

**Where,**

$V_t$  = MSS due to Treatment

EMS = Error Mean Sum of Squares

#### Phenotypic variance

Phenotypic variance (VP or  $\sigma_p^2$ ) denotes the total variance present in a population for particular character and is calculated by following formula

$$VP = \text{Genotypic variance (VG)} + \text{Error variance (VE)}$$

### Environmental or error variance

The environmental variance (VE or  $\sigma_e^2$ ) is the variance due to environmental deviation.

$$VE = EMS$$

### 3.6.5 Coefficient of variation

It is the measure of variability evolved. Coefficient of variation is the ratio of standard deviation of a sample to its mean and expressed in percentage.

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

In the present investigation three types of coefficient of variations were estimated viz., phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV) and error/environmental coefficient of variation (ECV). The formulae used to calculate PCV, GCV and ECV were given by **Burton (1952)**.

$$\begin{aligned} PCV (\%) &= \frac{\text{Phenotypic standard deviation}}{\text{Grand mean}} \times 100 \\ &= \frac{\sqrt{VP}}{\bar{X}} \times 100 \end{aligned}$$

$$\begin{aligned} GCV (\%) &= \frac{\text{Genotypic standard deviation}}{\text{Grand mean}} \times 100 \\ &= \frac{\sqrt{VG}}{\bar{X}} \times 100 \end{aligned}$$

$$\text{ECV (\%)} = \frac{\text{Error standard deviation}}{\text{Grand mean}} \times 100$$

$$= \frac{\sqrt{\text{VE}}}{\bar{X}} \times 100$$

|          |   |               |
|----------|---|---------------|
| Low      | = | Less than 10% |
| Moderate | = | 10-20%        |
| High     | = | More than 20% |

### 3.6.6. Heritability in broad sense [ $h^2$ (b)]

Heritability in broad sense was estimated as per **Allard (1960)**.

$$h^2 (b) = \frac{\text{Genotypic variance } (\sigma_g^2)}{\text{Phenotypic variance } (\sigma_p^2)} \times 100$$

As suggested by Johnson *et al.* (1955),  $h^2$  (b) estimates were categorized

|          |   |                |
|----------|---|----------------|
| Low      | = | 0 – 30 %       |
| Moderate | = | 31-60 %        |
| High     | = | 61 % and above |

### 3.6.7. Genetic advance as per cent of mean (GAM)

Genetic advance was estimated as per the formula proposed by **Lush (1940)** and **Johnson et al. (1955)**.

$$\text{Genetic Advance (GA)} = K \times \sigma_p \times h^2 (b)$$

Where,

K = Selection differential at 5% selection intensity which accounts to a constant value of 2.06.

$h^2$  (b) = heritability in broad sense.

$\sigma_p^2$  = phenotypic standard deviation.

$$GAM = \frac{GA}{\text{Grand mean } (\bar{X})} \times 100$$

The range of genetic advance as per cent of mean was classified as suggested by Johnson *et al.* (1955).

|          |   |               |
|----------|---|---------------|
| Low      | = | Less than 10% |
| Moderate | = | 10-20%        |
| High     | = | More than 20% |

### 3.6.2 ESTIMATION OF HETEROSIS

Heterosis was estimated for 21 hybrids for 15 quantitative characters using the following formulae.

#### 3.6.2.1 Heterosis over mid parent

Heterosis was expressed as per cent increase or decrease observed in the  $F_1$  over the mid-parent as per the following formula.

$$\text{Heterosis (\%)} (H_{MP}) = \frac{F_1 - MP}{MP} \times 100$$

Where,

F<sub>1</sub> = Mean of F<sub>1</sub>

MP = Mean of parents

### 3.6.2.2 Heterosis over better parent

Heterobeltiosis was expressed as per cent increase or decrease observed in F<sub>1</sub> over the better parent as per the formula of **Liang *et al.* (1971)**.

$$\text{Heterobeltiosis (\%)} (H_{BP}) = \frac{F_1 - BP}{BP} \times 100$$

Where,

BP= Mean of better parent

### 3.6.2.3 Heterosis over standard checks

Standard heterosis was expressed as per cent increase or decrease observed in F<sub>1</sub> over standard checks.

$$SH (\%) = \frac{F_1 - \text{Mean of check}}{\text{Mean of check}} \times 100$$

Where, F<sub>1</sub> = Mean of F<sub>1</sub>, MP = Mean of the two parent, BP = Mean of the better parent.

### 3.6.2.4 Test of significance of heterosis

To test the significance for different types of heterosis needs computation of standard error (SEm). For relative heterosis and heterobeltiosis, SEm were calculated based on error mean squares (EMS) from the ANOVA tables consisting parents and crosses, whereas, EMS from the RBD ANOVA ( $\sigma^2_e$ ) table based on all treatments (parents, crosses and check) was used for standard heterosis.

The significance of heterosis viz., relative heterosis, heterobeltiosis and standard heterosis was then tested by comparing the calculated 't'-value with the tabulated student's 't'-value for appropriate error degrees of freedom at 5 per cent and 1 per cent level of significance (0.05 and 0.01 level of probability), respectively. 't'<sub>cal</sub> for

$$\text{Heterosis and heterobeltiosis} = \frac{\bar{F}_1 - \text{Mean of mid parents or better parent}}{\text{SEM}}$$

Where, SEM =  $\sqrt{2\text{EMS}/r}$

EMS = Error mean of squares

r = Number of replications

$$t'_{\text{cal for Standard heterosis}} = \frac{F_1 - \text{Mean of check}}{\text{SEM SC}}$$

Where, SEM SC =  $\sqrt{2\sigma_e^2 / r}$

### 3.6.2.5 Least significance difference (critical difference) for heterosis

The significance of the difference between two estimates of heterosis were tested by computing the least significant difference (LSD) by multiplying the SEM with the appropriate student's 't' value of respective error degrees of freedom at desired level of probability.

$$\text{CD} = \text{SEM} \times \text{'t' table value at error degrees of freedom}$$

**ANOVA for Line  $\times$  Tester analysis**

| Source                                | d.f         | MS               |
|---------------------------------------|-------------|------------------|
| Replications (r)                      | (r-1)       |                  |
| Genotypes (g)                         | (g-1)       |                  |
| Parents (p)                           | (p-1)       |                  |
| Crosses (c)                           | (c-1)       |                  |
| Parents vs. crosses                   | 1           |                  |
| Males (m)                             | (m-1)       | Mm               |
| Females (f)                           | (f-1)       | Mf               |
| Males $\times$ females (m $\times$ f) | (m-1) (f-1) | M (m $\times$ f) |
| Error                                 | (r-1) (g-1) | Me               |

Where,

r = number of replications

g = number of genotypes

p = number of parents

c = number of crosses

m = number of males

f = number of females

Mm = mean sum of squares of males

Mf = mean sum of squares of females

|                    |                                            |
|--------------------|--------------------------------------------|
| M ( $m \times f$ ) | = mean sum of squares of males and females |
| Me                 | = mean sum of squares of error             |
| d. f               | = degrees of freedom                       |
| MS                 | = mean sum of squares                      |

The significant differences among the genotypes and replications were verified by applying 'F' test (Fisher and Yates, 1967)

## ii) Line x Tester analysis

The data recorded on the material generated as per Line  $\times$  Tester model of **Kempthorne (1957)** was subjected to analysis of variance as per the Line  $\times$  Tester model.

### 3.6.3 Combining ability analysis

Combining ability was estimated based on the method of Kempthorne (1957). The estimates of general and specific combining ability and their variances were obtained by using covariance of half sibs and full sibs.

| ANOVA                  |             |               |   |             |       |                                                                             |  |
|------------------------|-------------|---------------|---|-------------|-------|-----------------------------------------------------------------------------|--|
| Source                 | d.f         | SS            |   |             | MS    | Expected mean squares                                                       |  |
| Replications           | (r-l)       | $X^2_{..k}$   | - | $X^2_{...}$ |       |                                                                             |  |
|                        |             | Mf            |   | mfr         |       |                                                                             |  |
| Hybrids                | (mf-l)      | $X^2_{ij.}$   | - | $X^2_{...}$ |       |                                                                             |  |
|                        |             | R             |   | Mfr         |       |                                                                             |  |
| Males                  | (m-l)       | $X^2_{i..}$   | - | $X^2_{...}$ | $M_1$ | $\sigma^2 + r [\text{Cov (F.S)} - 2\text{Cov (H.S)} + \text{fr Cov (H.S)}]$ |  |
|                        |             | Fr            |   | mfr         |       |                                                                             |  |
| Females                | (f-l)       | $X^2_{.j.}$   | - | $X^2_{...}$ | $M_2$ | $\sigma^2 + r [\text{Cov (F.S)} - 2\text{Cov (H.S)} + \text{mrCov (H.S)}]$  |  |
|                        |             | Mr            |   | mfr         |       |                                                                             |  |
| Males $\times$ Females | (m-l)(f-l)  | $X^2_{(ij)}$  | - | $X^2_{i..}$ | $M_3$ | $\sigma^2 + r [\text{Cov(F.S)} - 2 \text{Cov (H.S)}]$                       |  |
|                        |             | R             |   | fr          |       |                                                                             |  |
|                        | -           | $X^2_{.j.}$   | + | $X^2_{...}$ |       |                                                                             |  |
|                        |             | Mr            |   | mfr         |       |                                                                             |  |
| Error                  | (r-l)(mf-l) | By difference |   |             | $M_4$ | $\sigma^2$                                                                  |  |
| Total                  | (mfr-l)     | $X^2_{(ij)k}$ | - | $X^2_{...}$ |       |                                                                             |  |

Where,

$X \dots$  = Sum of all the (ij) hybrid combinations

$X_{..k}$  = Sum of  $k^{\text{th}}$  replication

$X_{(ij)}$  = Sum of  $ij^{\text{th}}$  hybrid combination over all replications

$X_{.j.}$  = Sum of  $j^{\text{th}}$  female parent over all males and replications

$X_{ijk}$  =  $ij^{\text{th}}$  observation in  $k^{\text{th}}$  replication

### 3.6.3.1 Degree of dominance

Degree of dominance was estimated by adopting the formula:

$$\sqrt{\frac{\sigma^2_{sca}}{2 \sigma^2_{gca}}}$$

### 3.6.3.2 Estimation of combining ability effects

The additive model used to estimate the *gca* and *sca* effects of the *ijk* observations were

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

Where,

- $\mu$  = population mean
- $g_i$  = *gca* effect of  $i^{\text{th}}$  male parent
- $g_j$  = *gca* effect of  $j^{\text{th}}$  female parent
- $s_{ij}$  = *sca* effect of  $ij^{\text{th}}$  combination
- $e_{ijk}$  = error associated with the observation  $X_{ijk}$
- $i$  = number of male parents
- $j$  = number of female parents
- $k$  = number of replications

The estimation of individual effects was as follows:

$$\mu = \frac{X_{...}}{mfr}$$

Where,

$X_{...}$  = Total of all hybrid combinations over all replications

**(i) Lines:**

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

Where,

$X_i$  = Total of  $i^{th}$  male parent over all females and replications

**(ii) Testers :**

$$g_j = \frac{X_{.j.}}{mr} - \frac{X_{...}}{mfr}$$

Where,

$X_{.j.}$  = Total of  $j^{th}$  female parent over all male parents and replications

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

Where,

$X_{ij.}$  =  $ij$ th combination total over all replications

### 3.6.3.3 Standard errors for combining ability effects

The standard errors (SE) pertaining to  $gca$  and  $sca$  effects of different combinations were calculated as follows:

$$SE(g_i) \text{ female } (gca \text{ for line}) = \left( \frac{\text{Error of variance}}{rm} \right)^{\frac{1}{2}}$$

$$\text{Error of variance } \frac{1}{2} \text{ SE } (g_j) \text{ males (} gca \text{ for tester)} = \left( \frac{\text{-----}}{rf} \right)$$

$$\text{Error of variance } \frac{1}{2} \text{ SE } (s_{ij}) \text{ male } \times \text{ female combination} = \left( \frac{\text{-----}}{r} \right)$$

Where,

$r$  = number of replications

$m$  = number of males

$f$  = number of females

The *gca* and *sca* effects were tested against zero for significance by calculating t-value, by using the following formula.

$$t\text{-cal} = \frac{g_i - 0}{SE(g_i)}; \quad t\text{-cal} = \frac{g_j - 0}{SE(g_j)};$$

$$t\text{-cal} = \frac{S_{ij} - 0}{SE(S_{ij})}$$

t-cal value is compared with table value at error degree of freedom.

### 3.6.4. GENETIC DIVERGENCE

#### 3.6.4.1. Mahalanobis' $D^2$ analysis

The data collected on different characters was analyzed using Mahalanobis'  $D^2$  analysis to determine the genetic divergence among the genotypes (**Mahalanobis, 1936**).

$D^2$  value between  $i^{\text{th}}$  and  $j^{\text{th}}$  genotypes for 'P' characters was calculated as

$$D^2_{ij} = \sum (Y_i^t - Y_j^t)^2$$

$t = 1$

where,

$Y_i^t$  is uncorrelated mean value of  $i^{\text{th}}$  genotype for 't' characters

$Y_j^t$  is uncorrelated mean value of  $j^{\text{th}}$  genotype for 't' characters

$D_{ij}^2$  is  $D^2$  between  $i^{\text{th}}$  and  $j^{\text{th}}$  genotypes.

The various steps involved in estimation of  $D^2$  values are given below.

### 3.6.4.2 Test of significance

Variances were calculated for all the characters investigated and test of significance was done. Analysis of covariance for the character pairs was estimated on the basis of mean values (**Panse and Sukhatme, 1967**). After testing the difference between genotypes for each of the characters, a simultaneous test of significance for differences in the mean values of a number of correlated variables with regard to the pooled effect of characters was carried out using 'V' statistic, which in turn utilizes Wilk's criterion. The sum of squares and sum of products of error and error + variety, variance and covariance matrix were used for this purpose. The estimation of Wilk's criterion was done using the following relationship.

$$(E)^{\wedge} = \frac{\text{Determinant of error matrix}}{(E+V) \text{ Determinant of error + variety matrix}}$$

Where,

$(E)^{\wedge}$  = Wilk's criterion

(E) = Determinant of error matrix and

(E+V) = Determinant of error + variety sum of squares and sum of product matrix.

$$V_{(\text{Stat})} = -m \log_e^{\wedge} = -[n-(p+q+1)/2] \log_e^{\wedge}$$

Where,

$m = n-(P+Q+1)/2$

$n$  = Degrees of freedom for error + varieties

$\log_e^{\wedge} = 2.3026 \log_{10}^{\wedge}$

$P$  = Number of variables or characters (9)

$Q$  = Number of variables – 1 (or d.f for varieties) (40-1=39)

$V$  (Stat) is distributed as  $\chi^2$  with PQ (351 = 9 x 39) degrees of freedom.

### **Transformation of correlated variables**

In the present model, computation of  $D^2$  values were reduced to simple summation of the differences in the mean values of various characters of the two genotypes i.e.  $\sum d_i^2$ . Therefore, transformation of the correlated variables into uncorrelated ones was done before working out the  $D^2$  values. Transformation was done using pivotal condensation method.

#### **3.6.4.3 Computation of $D^2$ values**

For the given combination of  $i$  and  $j$  genotype, the mean deviation i.e.,  $Y_i^t - Y_j^t$  for  $t=1, 2, \dots, p$  variables are computed and the  $D^2$  values were calculated as

$$D_{ij}^2 = \sum_{t=1}^p (Y_i^t - Y_j^t)^2$$

Where,

$Y_i^t$  is uncorrelated mean value of  $i^{\text{th}}$  genotype for character 't'

$Y_j^t$  is uncorrelated mean value of  $j^{\text{th}}$  genotype for character 't'

$D_{ij}^2$  is  $D^2$  between  $i^{\text{th}}$  and  $j^{\text{th}}$  genotype.

#### **3.6.4.4 Testing the significance of $D^2$ values**

The  $D^2$  value obtained for a pair of population is taken as calculated value of  $\chi^2$  and is tested against the tabulated value of  $\chi^2$  for  $P$  degrees of freedom where  $P$  is the number of characters considered.

#### **3.6.4.5 Contribution of individual characters towards divergence**

In all combinations, each character was ranked on the basis of its contribution towards divergence between two entries ( $d_i = Y_i^t - Y_j^t$ ). Rank 1 is given to the highest mean difference and the rank  $P$  to the lowest difference, where,  $P$  is the total number of characters. Percentage contribution towards genetic divergence was calculated using the following formula.

$$\text{Percentage contribution of the character} = X = \frac{N}{M} \times 100$$

Where, N= Number of genotype combinations where the character was ranked first.

M = All possible combinations of number of genotypes considered.

#### **3.6.4.6 Grouping of genotypes into various clusters**

The grouping of genotypes into different clusters was done using the Tocher's method as described by **Rao (1952)**. The criterion was that the two varieties belonging to the same cluster at.

#### **3.6.4.7 Average intra- cluster distance**

For the measurement of intra-cluster distances, the formula used was  $\Sigma D^2_i/n$  where,  $\Sigma D^2_i$  was the sum of distances between all possible combinations (n) of the populations included in a cluster.

#### **3.6.4.8 Average inter cluster distance**

Clusters were taken one by one and the distances from other clusters were calculated. The distance between two clusters was the sum of  $D^2$  values between the members of one cluster to each of the members of the other clusters divided by the product of number of genotypes in both the clusters under consideration.

$$\text{Average inter-cluster distance} = \frac{D^2}{(n_1 \times n_2)}$$

Where,  $n_1$  and  $n_2$  are number of genotypes of two clusters.

‘  $D^2$  = Difference in mean value between two populations when all the characters are considered simultaneously.

### 3.6.5 Molecular Diversity analysis

**Table 3.8. List of SSR primers**

| S. No. | SSR loci | Forward sequence                   | Reverse sequence           | Annealing temperature | Repeat motif |
|--------|----------|------------------------------------|----------------------------|-----------------------|--------------|
| 1      | RM 10123 | ACACATCCCTCATCATCATCTCC            | GAATCCGATCTTGTCTGATACCC    | 55                    | (CTC)8       |
| 2      | RM550    | CTGAGCTCTGGTCCGAAGTC               | GGTGGTGGAAGAACAGGAAG       | 55                    | (CCT)8       |
| 3      | RM21918  | ACGTGGCCGACATATGGAACG              | GGTTCGTCTTCTCCCTCATCATCG   | 54                    | (CCG)7       |
| 4      | RM24152  | GAGCTCATCAGCATCACACACC             | TCTCTCTAAAGGCAGATCGATGG    | 50                    | (ACG)7       |
| 5      | RM19454  | AGCGTACCGATTACGAAGTTGC             | AGGACATGAGCTGCCTGAGATCC    | 52                    | (AGA)18      |
| 6      | RM232    | CCGGTATCCTTCGATATTGC               | CCGACTTTTCCTCCTGACG        | 55                    | (CT)24       |
| 7      | RM20773  | TTGCCAATATTCCCTCCAGTGC             | GTGTGTGTGGGACCTTGATTGC     | 55                    | (TAA)32      |
| 8      | RM22321  | GAGATAGTGGTGGAGGTGGATGC            | GCACTTGTA TCTCCATTTCTCAACC | 53                    | (AGA)23      |
| 9      | RM572    | CGGTTAATGTCATCTGATTGG              | TTCGAGATCCAAGACTGACC       | 54                    | (TC)14       |
| 10     | RM28520  | GCATGACCAATGAGGAAACATGG            | CGTCGTCTCCTTCGATTTATTCTCC  | 54                    | (TC)16       |
| 11     | RM20354  | GTCCAGCACACTGCATCACTGC             | CACACTGGATTTGCTGGATTTCG    | 54                    | (GA)10       |
| 12     | RM223    | GAGTGAGCTTGGGCTGAAAC               | GAAGGCAAGTCTTGGCACTG       | 52                    | (CT)25       |
| 13     | RM27644  | CGGCAGCGCTAGCATCATCG               | GTCACACTGCACACGGCGTAGC     | 52                    | (CT)11       |
| 14     | RM18571  | GCCAGTAGCTTAGAGCATTCTAGAGG         | TAGACCGATCCACGCATACACC     | 52                    | (GGT)7       |
| 15     | RM21478  | TAACACAGTTCTTCTCGCAACG             | AAGTTCCCTTGTGTGATTGACC     | 50                    | (GAA)28      |
| 16     | RM23181  | TGTTGTTGTGAGCTAGCCAGTCG            | CCGAATCACATTTCTCCAGTGC     | 50                    | (AG)12       |
| 17     | RM 18434 | GTCACA A C T A C T T T T A C A C G | CTACTAACAGAAGGCTATGG       | 50                    | (AT)17       |
| 18     | RM24240  | ATGCAACCTCCTCCATCATAAGG            | TGCTGCTCCTACCTCACTCACC     | 55                    | (GA)15       |
| 19     | RM11361  | TGCTAGCTGCCTACCCTCGAAGC            | AGGCAGGCATCGGCTATATTCTCG   | 55                    | (CT)15       |
| 20     | RM12119  | CCTCCTCCTCTTCTTCTAGCTTCC           | TCCACCACCACATCACTTTTCG     | 55                    | (CT)32       |
| 21     | RM22284  | GCGCTAATAAAGCCATCAAGTGC            | GCAGCCTTGTCTCTCTCACATGG    | 54                    | (GGAT)5      |
| 22     | RM18334  | TCCAACAAAGCAAGAGCAAGAGG            | CTGGCCTTCCAGAAATATCAAGG    | 54                    | (AC)10       |
| 23     | RM11184  | GCGGAGAAGTAGGAGTCCAAGG             | GTCAACCTCCGCTTCCATCG       | 53                    | (CGG)7       |
| 24     | RM26116  | CGCACTGAACGGTTTATATGATGTGC         | ACAGCAGAAACCAGAAACTCCATGC  | 54                    | (TA)16       |
| 25     | RM22880  | ACAGCTTAGGGCTTACCGAGAGC            | CTCAAATCCTCCAGCCCTATCC     | 55                    | (GGGA)5      |

### 3.6.5.1 DNA isolation

Genomic DNA from the leaf samples were isolated using the procedure of **Zhenget al. (1991)** with some modifications which is detailed below:

1. Leaves were taken from 10-15days old rice seedlings during *Rabi* 2015-16.
2. Leaves were cut into 3-4 small bits and placed in the well of a spot test plate (Thomas Scientific, USA) and 400 µl of extraction buffer (50 mMTrisHCl, pH 8.0, 25 mM EDTA, 300 mMNaCl and 2% CTAB) was added.
3. Leaf bits were ground using an alcohol sterilized blunt ended glass rod and 400 µl more of extraction buffer was added.
4. This entire content was transferred from the well of spot test plate into a sterile 1.5 ml micro centrifuge tube by using a micropipette tip of 1 ml capacity and about half volume (300-400 µl) of Chloroform:Isoamyl alcohol (24:1) was added. These contents were mixed well by inversion for about 10 minutes and centrifuged at 13000 rpm for about 10 minutes at room temperature.
5. After centrifugation, the supernatant was transferred into another sterile 1.5 ml micro centrifuge tube and it was ensured that the intermediate layer was not disturbed. To the supernatant, 10µl of RNase (10mg/ml) was added and incubated for 30-45 minutes at 37°C and were given one more extraction with equal volume of chloroform (400 µl).
6. To the clear aqueous supernatant, equal volume (500-600 µl) of chilled Isopropyl alcohol was added and placed in freezer (-20 °C) for 10 minutes to accentuate precipitation and then contents were mixed gently and centrifuge at 13000 rpm for 10 minutes at room temperature.
7. Supernatant was poured off and pellet was washed with 70% ethanol and the pellet was dried at 37°C in an oven and was dissolved in 50-100 µl of sterile T.E. buffer (10 mMTris-HCl, pH 8.0 and 1 mM EDTA).
8. Load 5 µl of DNA in a 0.8% gel and check the quality and quantity.

### 3.6.5.2. Quantification of genomic DNA

The isolated genomic DNA was quantified using UV Spectrophotometer (Beckmann, DU 650). The reagents used in this procedure were:

1. 10X buffer (TrisHCl 100 mM, NaCl 2M, pH 7.4)
2. Calf thymus standard DNA
3. Genomic DNA

The instrument was switched on and stabilized for 15 min. About 2 ml of the 10X buffer was taken in a cuvette and calibrated to zero (blank). Two ml of calf thymus standard DNA was added to the blank and calibrated to 100 mg/ml at 260 nm. Then, 2 ml of unknown DNA sample was added to cuvette and the reading was taken in mg per ml. The DNA concentration was calculated as follows:

Concentration of DNA = OD 260 x 50 x dilution factor (mg/ml)

### 3.6.5.3 Electrophoresis of genomic DNA in agarose gel

The isolated genomic DNA was verified for size, intactness, homogeneity and purity by the following technique. The materials used were:

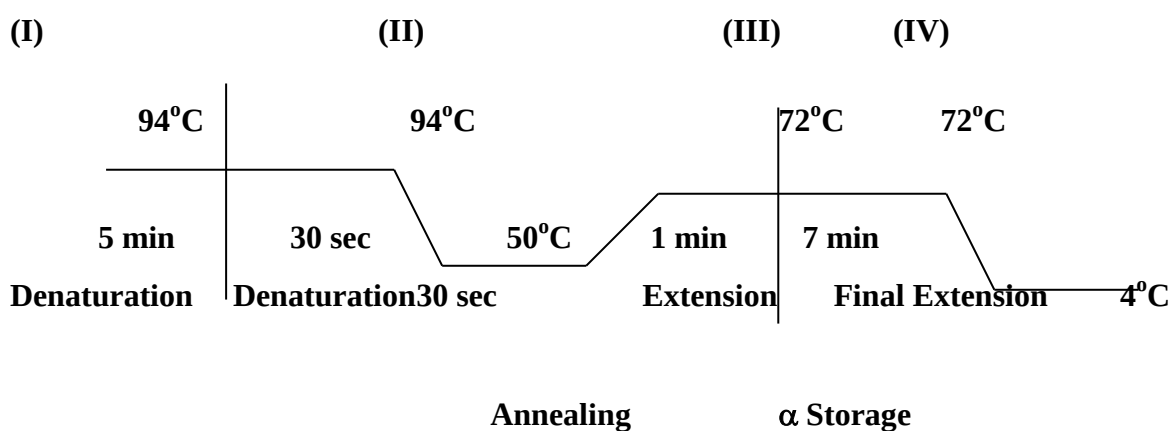
- Tris-Borate buffer (TBE) – 0.5X (0.9 M Tris-HCl, 0.025M EDTA Na<sup>2+</sup>, 0.9M boric acid)
- Agarose 0.8 per cent w/v in TBE 0.5X
- Gel loading buffer: (40 per cent w/v sucrose: 0.25 per cent w/v bromophenol blue; 0.25 per cent w/v xylene cyanol FF in sterile distilled water)
- Staining solution: [one mg of ethidium bromide per ml of TBE (IX)]

Agarose 0.8% was melted to dissolve completely and the gel was casted using the gel casting plate. Genomic DNA samples of rice genotypes were loaded in each well along with 2 µl of tracking dye and run at a constant voltage of 90 volts. The gel was stained using ethidium bromide and placed over an UV trans-illuminator and viewed at 300 nm. The bands appeared as orange-coloured intact bands owing to the florescence of ethidium bromide and the gel

was photographed using ALPHA IMAGER Gel documentation System (Alpha innotech, USA).

#### 3.6.5.4 Polymerase Chain Reaction (PCR) amplification

The genomic DNA of the 17 rice genotypes isolated as described earlier were subjected to PCR amplification Briefly, 10 µl reaction mixture contained 0.2 µM of each primer, 200 µM of deoxyribo nucleotides, 50 mM KCl, 10 mM TrisHCl (pH 8.3), 1.5 mM MgCl<sub>2</sub>, 0.1 per cent gelatin, 40-50 ng of DNA and 0.5 unit of *Taq* DNA polymerase (Bangalore Genei Pvt. Ltd., Bangalore). The following thermal profile was followed:



PCR amplification conditions were set as initial denaturation at 94°C for 5 minutes, 40 cycles of denaturation at 94°C for 30 seconds; annealing temperature varies with the specific primer as given in table 5, extension at 72 °C for one minute, and a final extension at 72 °C for 7 minutes. Polymerase Chain Reaction (PCR) was performed in 96-well plate thermal cycler.

#### 3.6.5.5 Agarose Gel Electrophoresis of PCR products

PCR amplified products were resolved in 1.5% super fine resolution (SFR) agarose (EMRESCO) gels in 0.5X TBE buffer at 200V for 3 hrs using Submarine Horizontal Electrophoresis Unit (CBS Scientific, USA). Before loading, the PCR amplified products were mixed with 1/6<sup>th</sup> volume of gel loading dye (40% sucrose; 0.25% bromophenol blue). The sizes of amplified fragments were determined by comparing with 100 bp ladder (MBI Fermentas). The gels were stained in ethidium bromide (10mg/ml) for 3 min, destained in distilled water for another 2 min, placed over the UV-transilluminator and documented at 300 nm using ALPHA IMAGER gel documentation system (M/s Alpha innotech).

### 3.6.5.6: Data Analysis

#### Scoring

Qualitative multistate traits that depict an array of characters were converted into binary characters (**Sneath and Sokal, 1973**) based on the variations present. Only the clear and unambiguous bands were scored. Markers were scored for the presence and absence of the corresponding band among the genotypes. The score 1 and 0 indicates the presence and absence of the bands respectively. A data matrix comprising of '1' and '0' were formed depending upon the character and this data matrix was subjected to further analysis.

#### Marker polymorphism

To measure the informativeness of the markers, the polymorphism information content (PIC) for each ISSR primer was calculated according to the formula:

$$PIC = \sum (1-p_i^2)/n$$

where 'n' is the total number of band positions analysed in the set of genotypes and 'p<sub>i</sub>' is the frequency of the i<sup>th</sup> pattern (band position, since each band is considered as one diallelic locus in ISSRs which are dominant markers). The PIC value was calculated using the online software- 'Polymorphic Information Content Calculator' available at [www.agri.huji.ac](http://www.agri.huji.ac).

## **Cluster analysis**

The binary data matrix was subjected to cluster analysis. Sequential Agglomerative Hierarchical Non-overlapping (SAHN) clustering was performed on Squared Euclidean distance matrix and similarity matrix using Jaccard's coefficient utilizing the Unweighted Pair Group Method with Arithmetic Averages (UPGMA) method. Data analysis was done using the software NTSYSpc version 2.1.1 (**Rohlf, 2002**)

**Plate 1 Field Preparation during *Kharif* 2014 at SHUATS**



**Sowing of rice seeds on seed bed**



**20 days old nursery**



**Uprooting of Rice seedlings**



**Transplanting of Rice in main field**

## Plate 2 Crop growth stages during *Kharif* 2014



Experimental Board



Interacting with Prof. (Dr.) Suresh B.G



Field view of rice experiments and observations recording at the time of maturity.

**Plate 3 Crossing programme during *Kharif* 2015 at SHUATS**



**Labelling in main field**



**Emasculation**



**Crossing block during *Kharif* 2015 at SHUATS**

**Plate 4 Off season Experiment at NRRI Cuttack during *Rabi* 2015-16**



**Sowing  $F_1$  seeds in Petri plates in pots**



**Sowing of parents and checks**



**Raising nursery at NRRI, Cuttack during *Rabi* 2015-16 for evaluation of hybrids**



**Plate 5 Field view during *Rabi* 2015-16 at NRRI**



**Evaluating Rice hybrids, Parents and Checks and data collection during *Rabi* 2015-16**

## Plate 6 Molecular analysis at NRRI lab



## Molecular analysis of Rice hybrids and parents

## RESULTS

The experimental findings of the present investigation entitled “**Heterosis and Combining ability estimates using L × T analysis and Genetic divergence using SSR markers in Rice**” was carried out using 100 genotypes of rice evaluated during *kharif*, 2014 at SHUATS, Allahabad for yield and yield attributing traits and identified 10 genotypes for further experimentation. Identified 7 lines and 3 testers were used to develop 21 F<sub>1</sub> hybrids in line x tester mating design during *kharif*, 2015 at Field Experimentation Centre, Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Allahabad. Twenty one hybrids derived during *kharif*, 2015 along with ten parents and three checks namely (*viz.*, Jaya, IR 64 and Anjali) a total 34 genotypes were evaluated in *Rabi*, 2015-16 at NRRI Cuttack. With the objective to collect the magnitude of heterosis, combining ability and Genetic diversity. The data was recorded on 15 quantitative characters *viz.*, days to 50% flowering, plant height, number of tillers/plant, number of panicles/plant, panicle length, flag leaf length, flag leaf width, number of grains/panicle, days to maturity, spikelet fertility %, spikelet sterility %, biological yield, harvest index, test weight and grain yield/plant.

The experimental results obtained from the present investigation on different characters are presented under the following heads.

- 4.1 Selection of parents for hybridization programme
- 4.2 Analysis of variance
- 4.3 *Per se* performances of hybrids, parents, and checks
- 4.4 Quality parameters
- 4.5 Heterosis
- 4.6 Combining ability analysis
- 4.7 Estimation of genetic parameters
- 4.8 Morphological diversity
- 4.9 Molecular diversity

#### **4.1 Selection of parents for Hybridization programme**

For the selection of parents for hybridization programme seven lines namely MTU 1010 (Line 1), MTU 1001 (Line2) Sahabthagidhan (Line3), BPT 5204 (Line4), BPT 2411 (Line5), BPT 2615 (Line6), NLR34449 (Line7), and three testers NDR 359 (Tester 1), BM 71 (Tester2) and SHIATS Dhan1 (Tester3) were selected based on the mean performance of grain yield/plant from 100 rice genotypes which have been evaluated for yield and yield related traits during *Kharif*, 2014 are presented in (table 4.1).

#### **4.2 Analysis of variance**

The analysis of variance for fifteen quantitative characters is presented in (table 4.2). The treatments, parents and hybrids showed significant differences among all genotypes for all the characters studied. The differences among the parents were observed to be significant for all the characters studied while parents vs. crosses were observed to be significant for all the characters except flag leaf length and crosses were observed to be significant for all the characters except panicle length and Harvest Index. The interaction due to lines x testers were significant for all the traits studied except panicle length. Interaction effects of Parents Vs. crosses were significant for all the characters, except flag leaf length.

#### **4.3 Perse performance of hybrids, parents and checks**

On the basis of mean performance (table 4.3) the mean values, range, grand mean (GM), critical difference (CD) and coefficient of variation (CV) of parents, hybrids and standard checks for the 15 characters are presented character wise.

##### **4.3.1 Days to 50 % flowering**

The mean performance of days to 50% flowering ranged from 78.67 to 108.67 days with an overall mean of 96.23 days. Among the lines, days to 50% flowering ranged from 78.67 (BPT 2615) to 105.33 (BPT 5204) and among the testers it ranged from 102.33 (BM 71) to 105.00 days (NDR 359 and SHIATS Dhan1). The hybrid Sahabthagidhan x SHIATS Dhan1 flowered earliest (79.67 days) followed by MTU 1010 x BM 71 (86.00 days), Sahabthagidhan x NDR 359 and NLR 34449 x NDR 359 (89 days). Only one hybrid Sahabthagidhan x SHIATS Dhan1 earlier to the earliest flowered check Anjali (85.33 days).

### **4.3.2 Plant height (cm)**

The plant height among the genotypes ranged between 99.00 cm and 127.60 cm with a general mean of 115.44 cm. The plant height for lines ranged from 99.00 cm in (NLR 34449) to 127.60 cm in (Sahabgadh) while in the testers, the range was from 120.33 cm in (SHIATS Dhan1) to 125.00 cm in (BM 71). Among the hybrids, plant height ranged from 100.13 cm in BPT 2411 x NDR 359 to 123.97 cm in BPT 2615 x SHIATS Dhan1. BPT 2411 x NDR 359 (100.13 cm) was the shortest hybrid in stature followed by BPT 2615 x NDR 359 (100.97 cm) and on par with best check Anjali (99.83 cm).

### **4.3.3 Number of Tillers / plant**

The mean value for number of tillers /plant ranged from 9.70 to 17.53 with a general mean of 15.06 cm. It ranged from 13.10 (BPT 2615) to 16.50 (BPT 5204) among the lines and from 9.70 (BM 71) to 16.63 (SHIATS Dhan1) among the testers. Among the hybrids mean number of tillers / plant ranged from 13.80 (NLR 34449 x BM 71) to 17.53 (MTU 1001 x BM71). The highest number of tillers/plant was recorded by the hybrid MTU 1001 x BM71 (17.53) and as many as 6 hybrids were significantly superior to the best check Jaya (14.80).

### **4.3.4 Number of panicles/plant**

The values for number of panicles /plant exhibited a grand mean 12.85 with a range of 7.97 to 15.67. Among the lines, Number of panicles /plant the range was from 10.83 (BPT 2615) to 14.77 (BPT 5204) and among the testers the range was from 7.97 (BM 71) to 14.60 (SHIATS Dhan1). Among the hybrids ranged from 11.33 to 15.67, the hybrid MTU 1001 x BM71 had the maximum 15.67 number of panicles /plant followed by MTU 1001 x BM 71 (15.67), MTU 1010 x SHIATS Dhan1 (15.53), BPT 5204 x SHIATS Dhan1 (15.53), BPT 5204 x NDR 359 (14.67) and MTU 1001 x SHIATS Dhan1 (14.00), these six hybrids were significantly superior to the best check Anjali, which had 12.13 number of panicles / plant.

#### **4.3.5 Panicle length (cm)**

Panicle length varies from 26.05 cm with a range of 17.60 cm to 30.03 cm. Among the lines, the range of panicle length was from 21.62 cm (MTU 1010) to 26.28 cm (Sahabghidhan). In testers panicle length ranging from 17.60 cm (BM 71) to 25.80 cm (NDR 359). The range of panicle length among the hybrids from 25.60 cm to 30.03 cm. The hybrid BPT 5204 x SHIATS Dhan1 recorded the highest panicle length of 30.03 cm followed by BPT 2411 x BM 71 (29.13 cm), and NLR 34449 x SHIATS Dhan 1 (28.37 cm), 14 hybrids had significantly higher panicle length compared to the best check Anjali (26.27 cm).

#### **4.3.6 Flag leaf length (cm)**

The mean value for Flag leaf length varied from 25.87 cm to 34.27 cm with a general mean of 29.93 cm. Among the lines, it varied from 25.87 cm (MTU 1010) to 34.27 cm (Sahabghidhan) and among the testers it varied from 28.22 cm (NDR 359) to 30.80 cm (BM 71). The hybrids exhibited a flag leaf length range from 26.43 cm (NLR 34449 x SHIATS Dhan 1) to 32.30 cm (NLR 34449 x NDR 359). Four hybrids viz., MTU 1010 x SHIATS Dhan1 (31.70 cm), BPT 2411 x SHIATS Dhan1 (31.30 cm), BPT 2615 x NDR 359 (30.90 cm), BPT 2615 x BM 71 (30.80 cm) and BPT 2615 x SHIATS Dhan 1 (29.30 cm) recorded significantly higher flag leaf length than the best check Jaya (28.30 cm).

#### **4.3.7 Flag leaf width (cm)**

The mean value for flag leaf width was 1.50 cm with a range of 1.25 cm to 1.72 cm. Flag leaf width ranged from 1.30 cm (MTU 1010) to 1.57 cm (MTU 1001) among the lines and from 1.56 cm (SHIATS Dhan1) to 1.37 (BM 71) among the testers. The hybrids exhibited a range for flag leaf width from 1.26 cm to 1.72 cm. The hybrid MTU 1001 x SHIATS Dhan1 exhibited the highest flag leaf width of 1.72 cm followed by MTU 1010 x BM 71 (1.69 cm), Sahabghi dhan x BM 71 (1.67 cm), BPT 2615 x BM 71 (1.64 cm), and NLR 34449 x NDR 359 (1.62 cm). All these hybrids were significantly superior to the best check Jaya (1.25 cm).

#### **4.3.8 Number of grains / panicle**

The mean value for the number of grains/panicle is an important yield contributing trait which has direct effect on grain yield. The mean filled grains/panicle were higher in case of hybrids than the lines and testers.

The general mean of filled grains per panicle was 179.27 with a range of 78.83 to 223.33. The range for filled grains per panicle varied from 117.83 (Sahabhagi dhan) to 185 (BPT 2411) among the lines and in testers ranged from 78.83 (BM 71) to 206.97 (SHIATS Dhan1). Among the hybrids, number of grains/panicle ranged from 153.23 (NLR 34449 x BM 71) to 223.33 (BPT 5204 x SHIATS Dhan1). Only two hybrids BPT 5204 x NDR 359 (208.50), NLR 34449 x SHIATS Dhan1 (206.27) were statistically at par with the best hybrid 223.33 (BPT 5204 x SHIATS Dhan1). 13 hybrids were significantly superior to the best check Jaya (182.50).

#### **4.3.9 Days to maturity**

The mean value for days to maturity was 127.05 with a range of 111.67 to 138.67. The range for maturity varied from 111.67 (BPT 2615) to 138.67 (BPT 5204) among the lines and in testers it ranged from 135 (NDR 359) to 137 (BM-71). Among the hybrids, days to maturity ranged from 115 (MTU 1010 x BM 71) to 137.33 (BPT 2411 x BM 71). 6 hybrids were significantly superior to the best check Jaya (129.87).

#### **4.3.10 Spikelet fertility (%)**

The mean value for spikelet fertility % was 89.62 % with a range of 84.23 to 94.35% spikelet fertility% with a range from 85.68% (BPT 2411) to 90.89% (BPT 5204) in lines and among the testers from 84.23 (BM 71) to 91.45% (SHIATS Dhan1). Among the hybrids, the mean spikelet fertility % with a range from 87.35% (MTU 1010 x BM 71) to 94.35% (NLR 34449 x SHIATS Dhan1). Hybrid NLR 34449 x SHIATS Dhan1 (94.35) recorded the maximum spikelet fertility % followed by BPT 5204 x SHIATS Dhan 1 (93.21), NLR 34449 x NDR 359 (92.89), and BPT 2411 x BM 71 (92.35%), compared to the best check Jaya (88.23%).

#### **4.3.11 Spikelet sterility (%)**

The mean value for spikelet sterility % was 10.37 per cent with a range of 5.65 to 15.77 per cent. The mean spikelet sterility % of the lines with a range from 9.11 per cent (BPT 5204) to 12.68 per cent (Sahabhagi dhan) and in testers from 8.55 (SHIATS Dhan1) to 15.77 per cent (BM 71). Among the hybrids the mean spikelet sterility % with a range from 5.65% (NLR 34449 x SHIATS Dhan 1) to 12.65% (MTU 1010 x BM 71). Hybrid NLR 34449 x SHIATS Dhan1 (5.65) recorded less spikelet sterility % followed by, BPT 5204 x SHIATS Dhan1 (6.79) compared to the best check Jaya (11.77).

#### **4.3.12 Biological yield**

The mean value for Biological yield ranged from 54.0g to 84.66g with grand mean of 74.53g. The range for Biological yield varied from 61.8 (MTU 1001) to 78.78 (BPT 5204) among the lines and in testers from 54.0 (BM 71) to 73.12 (NDR 359). Among the hybrids, Biological yield ranged from 66.28 (MTU 1001 x BM 71) to 84.66 (Sahabhagi dhan x SHIATS Dhan 1). The maximum biological yield per hill recorded in NLR 34449 x SHIATS Dhan1 (83.99) followed by MTU 1001 x NDR 359 (81.38), which were statistically at par with each other 15 hybrids were significantly superior to the best check Jaya (73.19).

#### **4.3.13 Harvest index (%)**

The mean value for Harvest index ranged from 37.80 to 45.20% with a grand mean of 42.79%. The range for harvest index varied from 40.50 (BPT 2615) to 43.20 (MTU1010) among the lines and in testers from 37.80 (BM 71) to 42.87 (SHIATS Dhan1). Among the hybrids, Harvest index ranged from 41.47 (BPT 5204 x BM 71) to 45.2 (BPT 2615 x NDR 359). The maximum harvest index recorded in NLR 34449 x SHIATS Dhan1 (44.63) followed by MTU 1010 x BM71 (44.37), which were statistically at par with each other. 18 hybrids were significantly superior to the best check Jaya (42.43).

#### **4.3.14 Test weight (g)**

The mean value for test weight ranged from 14.92g to 24.93g with a general mean of 19.80g. The grain weight among the lines varied from 14.92g (BPT 2615) to 23.90g (MTU 1001) and

among the testers it varied from 16.60 g (BM 71) to 17.56 g (NDR 359). The hybrids possessed test weight from 16.80 g (MTU 1001 x BM 71) to 24.93 g (MTU 1010 x NDR 359). IR 64 had the highest test weight (21.20 g) among the checks and nine hybrids with more than 21.20 g of test weight were significantly superior to IR 64 (21.20 g).

#### **4.3.15 Grain yield / plant (g)**

The mean value for grain yield/plant ranged from 20.30 g to 37.46 g with a general mean of 32 g. The grain yield ranged from 26.60 g (MTU 1001) to 33.23 g (BPT 5204) among lines and among the testers it varied from 20.30 g (BM 71) to 31.13 g (SHIATS Dhan1) the grain yield among the hybrids varied from 29.33 to 37.46 g. The highest grain yield/ plant was recorded by the hybrid NLR 34449 x SHIATS Dhan1 (37.46 g) with one hybrid Sahabhagi dhan x SHIATS Dhan1 (36.17 g) was at par with it. Ten hybrids with more than 32.93 g grain yield/plant were significantly superior to the best check IR 64 (32.93g).

**Table 4.1 Mean performance of 100 genotypes for 15 quantitative characters in rice (*Oryza sativa* L.)**

| Sl. No | Character        | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/Plant | Number of panicles/plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/Plant(g) |
|--------|------------------|-----------------------|-------------------|-------------------------|--------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|----------------------|
| 1      | WGL 536          | 99.00                 | 130.70            | 13.30                   | 8.93                     | 22.39               | 30.40                 | 1.45                 | 234.26                     | 132.92           | 87.30                  | 12.70                  | 48.08                | 41.80             | 18.38           | 20.10                |
| 2      | NLR 3350         | 98.00                 | 107.82            | 11.65                   | 8.94                     | 23.45               | 28.70                 | 1.50                 | 194.50                     | 129.25           | 84.50                  | 15.50                  | 40.76                | 42.00             | 20.94           | 17.11                |
| 3      | BPT 2676         | 108.00                | 132.96            | 12.05                   | 10.03                    | 26.33               | 30.00                 | 1.35                 | 182.34                     | 137.04           | 86.21                  | 13.79                  | 46.54                | 42.85             | 29.80           | 19.94                |
| 4      | NLR 3276         | 98.00                 | 107.24            | 14.50                   | 10.39                    | 24.72               | 32.00                 | 1.40                 | 200.60                     | 129.42           | 88.80                  | 11.20                  | 34.86                | 44.10             | 19.99           | 15.39                |
| 5      | MTU 1075         | 105.50                | 108.46            | 9.00                    | 9.68                     | 25.36               | 33.70                 | 1.40                 | 213.70                     | 134.96           | 86.25                  | 13.75                  | 52.46                | 42.20             | 24.04           | 22.14                |
| 6      | BPT2411          | 89.00                 | 115.75            | 13.05                   | 9.70                     | 22.10               | 29.05                 | 1.56                 | 170.45                     | 125.20           | 86.55                  | 13.45                  | 70.05                | 44.25             | 18.55           | 31.00                |
| 7      | BPT 2618         | 104.00                | 117.20            | 15.50                   | 12.00                    | 22.25               | 27.20                 | 1.48                 | 170.20                     | 134.70           | 87.55                  | 12.45                  | 73.40                | 40.00             | 18.50           | 29.35                |
| 8      | JGL 19621        | 102.50                | 127.20            | 14.20                   | 13.25                    | 23.80               | 34.00                 | 1.35                 | 140.20                     | 133.75           | 85.05                  | 14.95                  | 57.12                | 42.45             | 20.50           | 24.25                |
| 9      | MTU 1175         | 99.00                 | 122.20            | 12.75                   | 10.25                    | 19.65               | 31.00                 | 1.42                 | 156.10                     | 131.95           | 86.30                  | 14.70                  | 55.97                | 41.10             | 22.10           | 23.00                |
| 10     | MTU 11365-62-1-1 | 103.00                | 112.55            | 14.05                   | 9.60                     | 23.54               | 31.15                 | 1.35                 | 179.30                     | 132.33           | 83.60                  | 16.40                  | 57.33                | 42.05             | 24.07           | 24.10                |
| 11     | RP 4978-60-3-2-2 | 98.50                 | 95.57             | 10.20                   | 8.24                     | 20.85               | 29.85                 | 1.25                 | 133.67                     | 131.17           | 89.40                  | 10.60                  | 40.13                | 42.15             | 23.20           | 16.92                |
| 12     | RPHR 650-2-5     | 96.50                 | 124.50            | 12.35                   | 9.85                     | 27.60               | 30.00                 | 1.40                 | 137.14                     | 126.50           | 88.40                  | 11.60                  | 36.99                | 42.75             | 26.99           | 15.80                |
| 13     | OR 2560-3        | 98.50                 | 125.58            | 11.70                   | 10.20                    | 25.25               | 28.20                 | 1.35                 | 172.11                     | 129.17           | 86.95                  | 14.05                  | 47.11                | 40.55             | 24.13           | 19.10                |
| 14     | SHIATS DHAN-1    | 105.50                | 129.00            | 15.95                   | 15.12                    | 27.08               | 29.35                 | 1.44                 | 241.10                     | 132.50           | 89.05                  | 10.95                  | 83.83                | 47.36             | 17.17           | 39.71                |
| 15     | IRRI 104         | 105.00                | 119.75            | 17.30                   | 14.51                    | 24.90               | 25.13                 | 1.02                 | 142.57                     | 123.00           | 89.00                  | 11.00                  | 85.91                | 46.12             | 26.13           | 25.75                |
| 16     | MTU1010          | 95.50                 | 105.68            | 16.35                   | 13.36                    | 23.65               | 27.05                 | 1.20                 | 160.15                     | 124.50           | 84.95                  | 15.05                  | 77.57                | 46.82             | 21.73           | 36.25                |
| 17     | IRRI 154         | 94.00                 | 119.45            | 17.50                   | 16.01                    | 27.30               | 32.15                 | 1.29                 | 170.20                     | 129.45           | 84.50                  | 15.50                  | 52.11                | 47.57             | 22.65           | 24.75                |
| 18     | MTU 2051-3-2-3   | 104.00                | 115.17            | 12.45                   | 9.00                     | 25.20               | 31.50                 | 1.45                 | 193.46                     | 134.58           | 83.05                  | 16.95                  | 55.40                | 43.00             | 22.02           | 23.83                |
| 19     | NLR 3302         | 97.00                 | 102.82            | 12.00                   | 9.65                     | 21.16               | 30.00                 | 1.45                 | 170.55                     | 129.92           | 88.40                  | 11.60                  | 32.39                | 43.25             | 20.03           | 14.02                |
| 20     | JGL 11727        | 98.00                 | 115.96            | 11.30                   | 10.86                    | 23.78               | 33.65                 | 1.45                 | 188.92                     | 130.92           | 84.65                  | 15.35                  | 34.75                | 42.10             | 21.89           | 14.64                |
| 21     | BPT 3291         | 99.00                 | 95.76             | 12.05                   | 9.65                     | 20.86               | 32.20                 | 1.15                 | 181.10                     | 129.00           | 89.10                  | 10.90                  | 38.90                | 44.10             | 22.56           | 17.18                |
| 22     | NLR 3213         | 98.00                 | 122.99            | 11.05                   | 8.65                     | 24.85               | 31.65                 | 1.15                 | 146.50                     | 126.13           | 87.20                  | 13.80                  | 47.68                | 41.65             | 23.90           | 19.85                |
| 23     | OR 2542-12       | 99.50                 | 137.38            | 13.95                   | 9.43                     | 25.84               | 30.50                 | 1.40                 | 149.46                     | 128.13           | 89.50                  | 11.50                  | 41.83                | 40.35             | 24.36           | 16.88                |
| 24     | NLR 3238         | 97.50                 | 111.30            | 14.05                   | 10.75                    | 19.00               | 32.80                 | 1.58                 | 140.80                     | 128.00           | 88.90                  | 11.10                  | 64.37                | 42.28             | 17.10           | 27.20                |
| 25     | JGL 20171        | 99.50                 | 96.80             | 14.35                   | 9.85                     | 22.40               | 29.50                 | 1.35                 | 178.25                     | 134.75           | 87.30                  | 12.70                  | 67.49                | 44.10             | 17.00           | 29.75                |
| 26     | MTU1001          | 100.00                | 99.43             | 13.70                   | 10.25                    | 28.60               | 28.05                 | 1.51                 | 172.30                     | 132.00           | 87.45                  | 12.55                  | 61.32                | 42.00             | 21.00           | 39.68                |
| 27     | WGL 580          | 89.00                 | 96.70             | 12.05                   | 10.90                    | 27.05               | 34.00                 | 1.69                 | 140.40                     | 125.00           | 84.80                  | 15.20                  | 63.08                | 42.75             | 17.00           | 26.90                |
| 28     | MTU 1161         | 91.00                 | 99.40             | 13.65                   | 11.10                    | 24.55               | 33.05                 | 1.60                 | 128.90                     | 125.00           | 85.95                  | 14.05                  | 68.15                | 43.95             | 22.10           | 29.95                |
| 29     | MTU 1121         | 97.50                 | 112.38            | 11.55                   | 8.84                     | 25.87               | 29.95                 | 1.55                 | 187.20                     | 128.63           | 89.50                  | 10.50                  | 54.30                | 43.85             | 22.39           | 23.84                |
| 30     | NLR 3349         | 99.50                 | 109.26            | 12.40                   | 9.45                     | 20.55               | 33.90                 | 1.35                 | 172.25                     | 130.08           | 85.65                  | 14.35                  | 43.14                | 43.65             | 22.04           | 18.78                |
| 31     | NLR 3353         | 98.50                 | 92.70             | 17.50                   | 16.22                    | 19.09               | 27.05                 | 1.45                 | 115.70                     | 127.50           | 87.95                  | 12.05                  | 29.21                | 44.25             | 19.86           | 12.96                |
| 32     | JGL 18629        | 96.00                 | 124.51            | 14.10                   | 9.30                     | 23.47               | 29.10                 | 1.45                 | 159.63                     | 127.74           | 88.05                  | 11.95                  | 32.34                | 41.20             | 21.69           | 13.32                |
| 33     | OR 2573-4        | 98.00                 | 139.60            | 11.50                   | 9.66                     | 25.67               | 29.00                 | 1.45                 | 148.10                     | 129.64           | 89.50                  | 10.50                  | 50.45                | 42.55             | 32.72           | 21.42                |
| 34     | RGL 2538         | 98.50                 | 113.26            | 15.00                   | 12.18                    | 22.14               | 30.85                 | 1.20                 | 129.66                     | 128.25           | 88.15                  | 11.85                  | 41.31                | 43.05             | 23.02           | 17.77                |
| 35     | MTU 1155         | 105.00                | 119.42            | 11.30                   | 8.82                     | 25.04               | 31.95                 | 1.55                 | 180.71                     | 133.64           | 89.70                  | 10.30                  | 46.58                | 41.95             | 22.08           | 19.53                |
| 36     | WGL 821          | 105.50                | 127.75            | 11.95                   | 9.43                     | 27.94               | 32.40                 | 1.45                 | 167.00                     | 136.17           | 85.00                  | 17.00                  | 45.60                | 43.30             | 21.91           | 19.74                |
| 37     | MTU-1190         | 110.50                | 124.00            | 15.50                   | 11.91                    | 23.61               | 35.60                 | 1.45                 | 171.50                     | 136.50           | 87.40                  | 12.60                  | 47.57                | 42.80             | 20.17           | 20.34                |
| 38     | WGL-14           | 102.00                | 125.08            | 13.90                   | 10.06                    | 29.79               | 28.90                 | 1.20                 | 192.50                     | 135.50           | 86.95                  | 13.05                  | 44.65                | 41.30             | 19.80           | 18.44                |
| 39     | NLR 3350         | 99.50                 | 126.42            | 15.50                   | 11.19                    | 22.87               | 28.60                 | 1.30                 | 171.50                     | 129.33           | 85.90                  | 14.10                  | 37.32                | 43.00             | 17.80           | 16.04                |

Cont..

| Sl. No | Character             | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles/plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant(g) |
|--------|-----------------------|-----------------------|-------------------|--------------------------|--------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|-----------------------|
| 40     | WGL-810               | 103.50                | 119.70            | 11.35                    | 11.83                    | 29.81               | 27.40                 | 1.35                 | 199.20                     | 133.00           | 87.90                  | 12.10                  | 36.56                | 42.60             | 16.83           | 15.59                 |
| 41     | NDR-2064              | 99.00                 | 111.30            | 12.50                    | 10.80                    | 22.30               | 31.80                 | 1.45                 | 170.00                     | 129.00           | 85.00                  | 15.00                  | 48.71                | 42.80             | 23.20           | 20.85                 |
| 42     | NDR-2065              | 97.00                 | 113.55            | 13.95                    | 11.05                    | 22.55               | 33.00                 | 1.35                 | 172.50                     | 127.00           | 89.45                  | 10.55                  | 53.95                | 41.15             | 24.16           | 22.20                 |
| 43     | NDR-3112-1            | 102.00                | 122.95            | 11.45                    | 9.90                     | 19.95               | 36.45                 | 1.45                 | 175.35                     | 134.50           | 87.45                  | 12.55                  | 54.83                | 42.05             | 22.57           | 23.00                 |
| 44     | BPT-3292              | 105.00                | 117.55            | 12.35                    | 9.95                     | 21.55               | 37.40                 | 1.40                 | 135.00                     | 134.00           | 86.25                  | 13.75                  | 57.47                | 42.00             | 22.90           | 24.15                 |
| 45     | BPT-2231              | 117.00                | 108.95            | 12.00                    | 11.10                    | 23.95               | 35.45                 | 1.45                 | 161.50                     | 144.00           | 84.40                  | 15.60                  | 44.09                | 42.50             | 17.85           | 18.75                 |
| 46     | MTU 1064              | 118.00                | 113.55            | 13.05                    | 10.95                    | 24.90               | 34.10                 | 1.35                 | 187.50                     | 149.00           | 87.00                  | 13.00                  | 46.90                | 42.95             | 19.10           | 20.15                 |
| 47     | NLR-33654             | 104.50                | 109.05            | 11.00                    | 9.45                     | 22.55               | 33.25                 | 1.40                 | 150.00                     | 130.00           | 89.05                  | 10.95                  | 50.44                | 43.15             | 17.35           | 21.75                 |
| 48     | PLA-1100              | 134.50                | 114.50            | 13.00                    | 8.95                     | 25.50               | 28.80                 | 1.50                 | 195.50                     | 159.00           | 87.20                  | 12.80                  | 69.95                | 42.35             | 16.85           | 29.60                 |
| 49     | BPT 1768              | 133.50                | 108.50            | 14.45                    | 11.00                    | 27.40               | 38.25                 | 1.35                 | 138.50                     | 154.00           | 87.50                  | 12.50                  | 52.78                | 44.00             | 18.00           | 23.20                 |
| 50     | RGL-11226             | 129.00                | 116.50            | 14.80                    | 11.90                    | 26.55               | 38.00                 | 1.15                 | 162.50                     | 160.00           | 88.45                  | 11.55                  | 70.37                | 42.15             | 18.50           | 29.65                 |
| 51     | RNR-M7                | 105.50                | 113.00            | 13.85                    | 11.00                    | 24.10               | 32.60                 | 1.25                 | 150.00                     | 133.50           | 87.45                  | 13.55                  | 65.73                | 41.75             | 17.95           | 27.45                 |
| 52     | Erramallelu wgl-20471 | 85.00                 | 116.10            | 12.45                    | 9.90                     | 22.95               | 29.75                 | 1.35                 | 118.00                     | 114.00           | 87.75                  | 12.25                  | 60.22                | 43.60             | 20.70           | 26.25                 |
| 53     | INDRA-1061            | 119.50                | 113.75            | 12.85                    | 10.05                    | 22.40               | 34.10                 | 1.35                 | 140.00                     | 145.00           | 88.50                  | 11.50                  | 63.16                | 40.95             | 17.85           | 25.90                 |
| 54     | JGL-11470             | 105.00                | 104.20            | 13.00                    | 9.50                     | 20.45               | 28.95                 | 1.30                 | 139.00                     | 134.00           | 85.45                  | 14.55                  | 65.14                | 41.05             | 18.00           | 26.75                 |
| 55     | JGL-3844              | 99.00                 | 104.25            | 11.50                    | 9.65                     | 20.85               | 29.45                 | 1.15                 | 151.00                     | 132.00           | 85.60                  | 14.40                  | 45.72                | 42.55             | 18.95           | 19.45                 |
| 56     | JGL-1798              | 94.00                 | 106.00            | 13.65                    | 11.10                    | 22.10               | 30.25                 | 1.50                 | 170.45                     | 134.50           | 85.45                  | 14.55                  | 52.12                | 43.10             | 21.10           | 22.45                 |
| 57     | NDLR-8                | 104.00                | 109.10            | 15.50                    | 10.95                    | 24.05               | 32.25                 | 1.35                 | 157.00                     | 134.00           | 88.35                  | 11.65                  | 55.51                | 43.60             | 22.05           | 24.15                 |
| 58     | RAMAPPA-WGL-23985     | 94.00                 | 107.25            | 13.35                    | 12.35                    | 29.15               | 33.15                 | 1.30                 | 180.50                     | 128.50           | 89.10                  | 10.90                  | 57.35                | 42.10             | 23.75           | 24.15                 |
| 59     | PANTHDHAN-10          | 89.00                 | 109.20            | 14.05                    | 11.00                    | 28.95               | 28.65                 | 1.35                 | 149.50                     | 125.50           | 88.45                  | 11.55                  | 73.13                | 42.10             | 21.10           | 30.80                 |
| 60     | AKSHYA                | 117.00                | 114.05            | 15.40                    | 11.35                    | 29.90               | 33.45                 | 1.25                 | 140.00                     | 149.00           | 87.45                  | 12.55                  | 61.08                | 45.15             | 16.90           | 27.60                 |
| 61     | PANTHDHAN-11          | 99.00                 | 111.30            | 15.55                    | 14.60                    | 27.05               | 31.00                 | 1.70                 | 176.00                     | 131.00           | 83.20                  | 16.80                  | 69.60                | 43.95             | 17.00           | 30.60                 |
| 62     | Suvarna               | 104.00                | 115.90            | 13.05                    | 13.00                    | 25.70               | 32.90                 | 1.30                 | 184.50                     | 134.50           | 89.35                  | 10.65                  | 48.38                | 41.25             | 19.60           | 19.95                 |
| 63     | PUSHYAMI              | 109.00                | 116.30            | 15.75                    | 12.75                    | 30.05               | 31.10                 | 1.10                 | 164.50                     | 135.50           | 84.45                  | 15.55                  | 45.75                | 44.20             | 21.80           | 20.20                 |
| 64     | MTU 7006              | 98.50                 | 119.51            | 13.35                    | 10.20                    | 21.17               | 28.25                 | 1.65                 | 139.50                     | 129.33           | 89.10                  | 10.90                  | 52.65                | 42.15             | 29.99           | 22.18                 |
| 65     | RGL-7004              | 97.50                 | 119.00            | 13.80                    | 10.82                    | 25.01               | 31.60                 | 1.35                 | 152.80                     | 128.17           | 85.05                  | 14.95                  | 36.02                | 43.10             | 25.29           | 15.58                 |
| 66     | RGL-7005              | 98.50                 | 114.59            | 12.00                    | 11.07                    | 21.76               | 32.15                 | 1.35                 | 170.50                     | 130.04           | 84.45                  | 15.55                  | 33.03                | 41.25             | 18.90           | 13.61                 |
| 67     | RGL-7006              | 99.00                 | 117.90            | 13.45                    | 9.40                     | 25.44               | 30.00                 | 1.55                 | 192.75                     | 128.00           | 85.15                  | 14.85                  | 39.76                | 41.20             | 23.90           | 16.38                 |
| 68     | Zhonghau 1            | 99.50                 | 110.35            | 17.90                    | 16.01                    | 24.73               | 28.70                 | 1.12                 | 153.39                     | 124.00           | 87.70                  | 12.30                  | 59.22                | 42.06             | 21.98           | 24.92                 |
| 69     | RGL7009               | 100.00                | 115.45            | 15.35                    | 13.42                    | 22.30               | 31.10                 | 1.41                 | 152.70                     | 131.00           | 89.40                  | 10.60                  | 59.30                | 47.97             | 21.25           | 28.45                 |
| 70     | IRRI105               | 90.00                 | 119.25            | 15.55                    | 15.76                    | 22.85               | 25.30                 | 1.21                 | 137.70                     | 123.50           | 89.01                  | 11.00                  | 62.46                | 45.30             | 20.88           | 28.28                 |
| 71     | RNR-15048             | 97.00                 | 124.75            | 15.65                    | 14.05                    | 28.05               | 32.72                 | 1.33                 | 139.05                     | 127.00           | 89.57                  | 11.42                  | 49.98                | 41.55             | 22.92           | 20.40                 |
| 72     | KNM118                | 99.00                 | 117.25            | 15.10                    | 13.05                    | 24.55               | 42.18                 | 1.33                 | 165.70                     | 119.80           | 83.33                  | 16.67                  | 72.90                | 37.39             | 21.33           | 27.29                 |
| 73     | BPT-5204              | 108.00                | 115.43            | 16.5                     | 14.00                    | 24.61               | 39.58                 | 1.41                 | 175.20                     | 134.00           | 85.10                  | 14.90                  | 82.90                | 46.00             | 16.31           | 42.71                 |
| 74     | Lakshmi               | 92.00                 | 126.00            | 17.35                    | 14.00                    | 22.00               | 33.63                 | 1.33                 | 128.70                     | 123.95           | 84.63                  | 15.38                  | 66.81                | 41.88             | 25.08           | 27.95                 |
| 75     | LSD-1                 | 107.00                | 125.20            | 15.90                    | 14.07                    | 24.45               | 30.88                 | 1.34                 | 159.20                     | 133.00           | 84.41                  | 15.59                  | 57.38                | 43.58             | 24.34           | 24.95                 |
| 76     | OR 2560-6             | 99.50                 | 127.84            | 13.50                    | 11.06                    | 24.14               | 28.40                 | 1.45                 | 152.63                     | 128.50           | 88.35                  | 11.65                  | 49.54                | 41.05             | 28.98           | 20.35                 |
| 77     | MTU 126-1-6-1         | 97.50                 | 115.62            | 14.00                    | 9.31                     | 21.55               | 30.80                 | 1.35                 | 147.96                     | 129.67           | 85.65                  | 14.35                  | 51.22                | 43.05             | 26.25           | 22.05                 |
| 78     | MTU 1182              | 103.00                | 117.71            | 12.90                    | 8.43                     | 24.08               | 33.10                 | 1.40                 | 199.40                     | 135.50           | 89.90                  | 10.10                  | 51.35                | 42.85             | 26.85           | 21.97                 |
| 79     | RGL2536               | 99.00                 | 122.33            | 13.00                    | 10.00                    | 23.17               | 32.10                 | 1.50                 | 105.42                     | 105.50           | 87.80                  | 13.20                  | 43.10                | 42.00             | 30.94           | 18.09                 |
| 80     | MTU 2152-5-1-1-5      | 103.00                | 123.92            | 13.05                    | 11.14                    | 26.79               | 34.05                 | 1.50                 | 189.65                     | 132.50           | 85.70                  | 14.30                  | 49.90                | 44.10             | 28.15           | 22.02                 |

Cont..

| Sl. No | Character     | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles/plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant(g) |
|--------|---------------|-----------------------|-------------------|--------------------------|--------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|-----------------------|
| 81     | BM-71         | 98.50                 | 126.55            | 12.05                    | 8.95                     | 19.00               | 28.20                 | 1.32                 | 80.45                      | 136.95           | 87.76                  | 12.24                  | 65.40                | 36.30             | 20.17           | 23.70                 |
| 82     | MOTIGOLD      | 101.50                | 128.95            | 14.00                    | 13.70                    | 24.80               | 28.20                 | 1.57                 | 156.55                     | 130.25           | 85.50                  | 14.50                  | 55.06                | 44.37             | 22.02           | 24.38                 |
| 83     | SONAM         | 104.00                | 117.00            | 15.35                    | 14.07                    | 21.30               | 30.92                 | 1.65                 | 122.20                     | 131.45           | 86.26                  | 13.75                  | 68.19                | 42.46             | 22.24           | 28.95                 |
| 84     | NDR359        | 100.50                | 115.20            | 11.30                    | 10.80                    | 24.80               | 31.10                 | 1.30                 | 140.80                     | 130.15           | 87.90                  | 12.10                  | 75.04                | 42.00             | 20.00           | 31.50                 |
| 85     | RGL 2624      | 84.50                 | 127.70            | 14.85                    | 11.75                    | 26.00               | 29.15                 | 1.51                 | 150.30                     | 116.50           | 89.30                  | 10.70                  | 65.79                | 44.00             | 22.85           | 28.95                 |
| 86     | BPT 2570      | 92.00                 | 119.25            | 14.40                    | 13.30                    | 27.15               | 31.00                 | 1.52                 | 160.30                     | 125.00           | 89.55                  | 10.45                  | 63.07                | 44.10             | 18.25           | 27.80                 |
| 87     | MTU 1177      | 88.00                 | 124.20            | 17.35                    | 13.60                    | 26.10               | 26.20                 | 1.38                 | 182.20                     | 124.20           | 89.40                  | 10.60                  | 71.13                | 42.05             | 21.50           | 29.90                 |
| 88     | MTU 1155      | 98.00                 | 117.33            | 11.25                    | 8.15                     | 25.42               | 29.05                 | 1.50                 | 139.80                     | 130.21           | 87.75                  | 12.25                  | 46.45                | 42.90             | 27.33           | 19.93                 |
| 89     | AD09493       | 111.00                | 133.20            | 9.50                     | 9.05                     | 25.74               | 33.05                 | 1.55                 | 209.00                     | 138.14           | 89.40                  | 10.60                  | 45.71                | 42.10             | 22.15           | 19.24                 |
| 90     | MTU 1181      | 102.50                | 110.30            | 12.10                    | 11.05                    | 23.68               | 35.15                 | 1.50                 | 144.90                     | 129.39           | 86.35                  | 13.65                  | 41.41                | 41.80             | 26.88           | 17.39                 |
| 91     | BPT 2613      | 101.00                | 107.00            | 13.00                    | 10.72                    | 20.94               | 32.10                 | 1.75                 | 151.26                     | 132.17           | 84.45                  | 15.55                  | 39.57                | 41.00             | 21.95           | 16.23                 |
| 92     | Sababhadghan  | 83.50                 | 127.05            | 13.00                    | 10.80                    | 24.76               | 41.25                 | 1.27                 | 122.95                     | 114.25           | 88.65                  | 11.35                  | 80.59                | 40.56             | 22.22           | 22.70                 |
| 93     | NLR34449      | 93.00                 | 104.35            | 12.20                    | 12.00                    | 23.70               | 29.00                 | 1.48                 | 140.75                     | 123.30           | 85.00                  | 15.00                  | 77.07                | 44.10             | 18.10           | 34.00                 |
| 94     | RNR 2465      | 103.00                | 107.85            | 16.35                    | 12.75                    | 28.90               | 27.75                 | 1.52                 | 149.25                     | 134.00           | 88.90                  | 11.10                  | 71.38                | 41.90             | 18.90           | 29.90                 |
| 95     | JGL 17004     | 76.50                 | 106.35            | 17.25                    | 13.80                    | 25.55               | 31.05                 | 1.58                 | 129.50                     | 105.70           | 86.35                  | 13.65                  | 69.22                | 43.00             | 17.75           | 29.75                 |
| 96     | SWETHA        | 91.00                 | 113.50            | 15.45                    | 12.15                    | 27.25               | 31.60                 | 1.60                 | 149.65                     | 127.40           | 83.90                  | 16.10                  | 61.33                | 44.00             | 20.15           | 27.00                 |
| 97     | WGL14         | 91.50                 | 112.00            | 13.45                    | 12.25                    | 21.80               | 32.00                 | 1.32                 | 162.95                     | 123.00           | 89.01                  | 11.99                  | 60.40                | 41.96             | 17.10           | 25.33                 |
| 98     | KNM115        | 76.50                 | 116.30            | 14.45                    | 14.45                    | 23.65               | 32.58                 | 1.69                 | 169.70                     | 137.00           | 87.31                  | 12.69                  | 70.17                | 37.68             | 15.18           | 26.51                 |
| 99     | RGL2539       | 103.00                | 128.70            | 12.70                    | 11.38                    | 25.20               | 26.77                 | 1.38                 | 174.90                     | 130.00           | 87.68                  | 12.32                  | 58.92                | 46.74             | 24.15           | 27.53                 |
| 100    | BPT-2615      | 104.00                | 127.20            | 15.15                    | 12.71                    | 23.05               | 29.40                 | 1.29                 | 149.35                     | 129.95           | 88.90                  | 11.10                  | 77.32                | 47.00             | 18.00           | 36.35                 |
|        | Mean          | <b>100.46</b>         | <b>116.02</b>     | <b>13.60</b>             | <b>11.25</b>             | <b>24.30</b>        | <b>31.35</b>          | <b>1.40</b>          | <b>161.02</b>              | <b>130.84</b>    | <b>87.08</b>           | <b>13.01</b>           | <b>55.48</b>         | <b>42.76</b>      | <b>21.67</b>    | <b>23.66</b>          |
|        | Range Lowest  | 76.50                 | 92.70             | 9.00                     | 8.15                     | 19.00               | 25.13                 | 1.02                 | 80.45                      | 105.50           | 83.05                  | 10.11                  | 29.21                | 36.30             | 15.18           | 12.96                 |
|        | Range Highest | 134.50                | 139.60            | 17.90                    | 16.22                    | 30.05               | 42.18                 | 1.75                 | 241.10                     | 160.00           | 89.05                  | 17.00                  | 82.90                | 47.97             | 32.72           | 42.71                 |
|        | C.V.          | 1.47                  | 2.00              | 9.55                     | 7.32                     | 5.99                | 3.76                  | 8.92                 | 5.59                       | 1.14             | 3.59                   | 10.11                  | 11.76                | 2.49              | 3.22            | 11.32                 |
|        | C.D. 5%       | 2.93                  | 4.61              | 2.58                     | 1.63                     | 2.89                | 2.34                  | 0.25                 | 17.84                      | 2.97             | 5.26                   | 5.26                   | 12.94                | 2.11              | 1.39            | 5.34                  |

## 4.2 Analysis of variance for heterosis of various quantitative traits in rice.

| Source of variation | df | Days to 50% Flowering | Plant Height (cm) | Total no of Tillers/ Plant | Number of panicles/ plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Total no of Grains/ panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant (g) |
|---------------------|----|-----------------------|-------------------|----------------------------|---------------------------|---------------------|-----------------------|----------------------|-----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|------------------------|
| Replicates          | 2  | 1.8                   | 4.31              | 0.72                       | 0.24                      | 5.29                | 0.67                  | 0.01                 | 25.02                       | 0.92             | 2.13                   | 4.92                   | 14.48                | 3.6               | 0.59            | 1.42                   |
| Treatments          | 30 | 177.01**              | 161.88**          | 8.26**                     | 8.7**                     | 20.66**             | 9.63**                | 0.04**               | 2383.4**                    | 144.73**         | 60.32**                | 72.14**                | 115.15**             | 5.78**            | 17.73**         | 32.12**                |
| Parents             | 9  | 279.06**              | 181.79**          | 12.95**                    | 13.57**                   | 27.42**             | 18.7**                | 0.02**               | 4192.1**                    | 272.21**         | 59.69**                | 60.31**                | 156.3**              | 7.75**            | 22.94**         | 38.79**                |
| Crosses             | 20 | 139.7**               | 147.97**          | 4.36**                     | 5.82**                    | 4.44                | 5.66**                | 0.04**               | 849.59**                    | 92.98**          | 19.03**                | 31.27**                | 61.15**              | 2.66              | 13.22**         | 14.74**                |
| Parents vs Crosses  | 1  | 4.64*                 | 260.92**          | 43.92**                    | 22.32**                   | 284.13**            | 7.29                  | 0.13**               | 16781.38**                  | 32.52**          | 891.8**                | 995.84**               | 824.62**             | 50.51**           | 61.09**         | 319.64**               |
| Error               | 60 | 1.03                  | 6.59              | 0.97                       | 1.18                      | 3.04                | 2.08                  | 0.01                 | 67.38                       | 1.32             | 6.03                   | 7.22                   | 17.03                | 1.68              | 0.39            | 2.37                   |
| Total               | 92 | 58.43                 | 57.18             | 3.34                       | 3.61                      | 8.83                | 4.51                  | 0.02                 | 821.68                      | 48.07            | 23.65                  | 28.34                  | 48.97                | 3.06              | 6.05            | 12.05                  |

\*significant at 5% level, \*\* significant at 1% level

**Table: 4.3 Mean performances of 34 rice genotypes (Hybrids, Parents and checks)**

| S.No. | Character                     | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles /plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant(g) |
|-------|-------------------------------|-----------------------|-------------------|--------------------------|---------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|-----------------------|
| 1.    | MTU1010X NDR-359              | 95.33                 | 115.00            | 15.13                    | 12.50                     | 28.37               | 31.20                 | 1.57                 | 191.00                     | 125.57           | 90.12                  | 9.88                   | 75.67                | 43.27             | 24.93           | 32.73                 |
| 2.    | MTU-1010 X BM-71              | 86.00                 | 110.83            | 15.67                    | 12.63                     | 27.43               | 28.80                 | 1.69                 | 205.20                     | 115.00           | 87.35                  | 12.65                  | 79.75                | 44.37             | 17.43           | 35.30                 |
| 3.    | MTU-1010 X SHIATS Dhan 1      | 95.00                 | 106.57            | 17.10                    | 15.53                     | 26.90               | 31.70                 | 1.61                 | 194.53                     | 125.00           | 89.63                  | 10.37                  | 73.93                | 44.27             | 21.40           | 32.73                 |
| 4.    | MTU-1001 X NDR-359            | 98.33                 | 114.03            | 13.90                    | 11.57                     | 28.07               | 30.03                 | 1.47                 | 194.00                     | 127.83           | 91.32                  | 8.68                   | 81.38                | 42.97             | 23.47           | 35.43                 |
| 5.    | MTU-1001 X BM-71              | 90.00                 | 113.67            | 17.53                    | 15.67                     | 27.03               | 29.17                 | 1.52                 | 174.97                     | 122.00           | 90.15                  | 9.85                   | 66.28                | 44.30             | 16.80           | 29.33                 |
| 6.    | MTU-1001 X SHIATS Dhan 1      | 98.00                 | 109.53            | 16.63                    | 14.00                     | 26.50               | 30.70                 | 1.72                 | 174.90                     | 127.67           | 91.23                  | 8.77                   | 77.99                | 43.13             | 22.00           | 33.60                 |
| 7.    | Sahabhagi dhan X NDR-359      | 89.00                 | 122.57            | 15.63                    | 11.53                     | 27.10               | 29.57                 | 1.55                 | 170.57                     | 117.17           | 87.65                  | 12.35                  | 78.46                | 43.03             | 22.40           | 35.37                 |
| 8.    | Sahabhagi dhan X BM-71        | 94.87                 | 122.23            | 15.17                    | 13.50                     | 25.60               | 28.77                 | 1.67                 | 185.97                     | 122.67           | 89.74                  | 10.26                  | 72.87                | 43.07             | 21.77           | 31.37                 |
| 9.    | Sahabhagi dhan X SHIATS Dhan1 | 79.67                 | 116.27            | 15.53                    | 13.80                     | 25.53               | 29.10                 | 1.40                 | 170.57                     | 123.47           | 90.35                  | 9.65                   | 84.66                | 42.73             | 21.43           | 36.17                 |
| 10.   | BPT-5204X NDR-359             | 102.00                | 116.30            | 16.87                    | 14.67                     | 27.73               | 28.10                 | 1.46                 | 208.50                     | 131.00           | 91.32                  | 8.68                   | 73.45                | 44.03             | 17.90           | 32.33                 |
| 11.   | BPT-5204 X BM-71              | 104.00                | 109.70            | 17.03                    | 13.57                     | 27.27               | 29.17                 | 1.54                 | 172.93                     | 133.00           | 88.65                  | 11.35                  | 72.03                | 41.47             | 20.53           | 29.87                 |
| 12.   | BPT-5204 X SHIATS Dhan1       | 102.67                | 121.07            | 17.50                    | 15.53                     | 30.03               | 31.00                 | 1.26                 | 223.33                     | 134.53           | 93.21                  | 6.79                   | 76.90                | 44.10             | 18.90           | 33.90                 |
| 13.   | BPT-2411 XNDR-359             | 105.00                | 100.13            | 14.90                    | 12.37                     | 26.37               | 30.27                 | 1.58                 | 201.53                     | 135.67           | 90.18                  | 9.82                   | 72.93                | 43.77             | 19.23           | 32.90                 |
| 14.   | BPT-2411X BM-71               | 108.67                | 123.50            | 14.30                    | 13.40                     | 29.13               | 29.07                 | 1.33                 | 190.80                     | 137.33           | 92.35                  | 7.65                   | 74.91                | 43.07             | 21.60           | 32.23                 |
| 15.   | BPT-2411 XSHIATS Dhan1        | 98.00                 | 118.30            | 15.63                    | 13.80                     | 28.07               | 31.30                 | 1.59                 | 207.87                     | 126.23           | 90.25                  | 9.75                   | 80.57                | 42.47             | 18.63           | 34.17                 |
| 16.   | BPT-2615 X NDR-359            | 94.33                 | 100.97            | 14.67                    | 11.50                     | 27.53               | 30.90                 | 1.55                 | 191.27                     | 124.00           | 90.64                  | 9.36                   | 78.79                | 45.20             | 18.67           | 35.60                 |
| 17.   | BPT-2615X BM-71               | 100.00                | 118.83            | 14.20                    | 11.50                     | 25.73               | 30.80                 | 1.64                 | 179.67                     | 130.33           | 91.57                  | 8.43                   | 72.54                | 41.73             | 19.03           | 30.27                 |
| 18.   | BPT-2615X SHIATS Dhan1        | 97.00                 | 123.97            | 15.57                    | 13.40                     | 25.63               | 29.30                 | 1.52                 | 199.10                     | 127.53           | 91.36                  | 8.64                   | 80.39                | 43.40             | 20.83           | 34.87                 |
| 19.   | NLR-34449 X NDR-359           | 89.00                 | 108.67            | 16.17                    | 11.33                     | 28.30               | 32.30                 | 1.62                 | 176.63                     | 125.00           | 92.89                  | 7.11                   | 71.77                | 42.77             | 18.27           | 30.67                 |
| 20.   | NLR-34449 XBM-71              | 98.93                 | 119.07            | 13.80                    | 12.50                     | 26.27               | 29.07                 | 1.44                 | 153.23                     | 127.33           | 90.65                  | 9.35                   | 76.20                | 42.60             | 21.57           | 32.43                 |
| 21.   | NLR-34449 X SHIATS Dhan 1     | 97.67                 | 120.93            | 17.40                    | 14.40                     | 28.37               | 26.43                 | 1.50                 | 206.27                     | 127.23           | 94.35                  | 5.65                   | 83.99                | 44.63             | 19.57           | 37.46                 |
| 22.   | MTU-1010                      | 93.33                 | 120.17            | 16.13                    | 14.27                     | 22.87               | 25.87                 | 1.30                 | 145.00                     | 121.67           | 88.65                  | 11.35                  | 71.14                | 43.20             | 20.72           | 30.73                 |

| S.No. | Character            | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles/ plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant(g) |
|-------|----------------------|-----------------------|-------------------|--------------------------|---------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|-----------------------|
| 23.   | MTU-1001             | 101.67                | 118.13            | 13.83                    | 11.43                     | 21.62               | 28.40                 | 1.57                 | 174.67                     | 131.17           | 89.56                  | 10.44                  | 61.82                | 43.07             | 23.90           | 26.60                 |
| 24.   | Sahabhagi dhan       | 83.33                 | 127.60            | 13.53                    | 11.10                     | 26.28               | 34.27                 | 1.41                 | 117.83                     | 115.13           | 87.32                  | 12.68                  | 70.00                | 42.10             | 21.92           | 29.43                 |
| 25.   | BPT-5204             | 105.33                | 115.50            | 16.50                    | 14.77                     | 25.87               | 30.67                 | 1.45                 | 172.67                     | 138.67           | 90.89                  | 9.11                   | 78.78                | 42.20             | 17.21           | 33.23                 |
| 26.   | BPT-2411             | 102.00                | 117.40            | 15.47                    | 13.50                     | 25.20               | 33.57                 | 1.44                 | 185.00                     | 132.00           | 85.68                  | 14.32                  | 73.83                | 41.50             | 18.68           | 30.63                 |
| 27.   | BPT-2615             | 78.67                 | 118.00            | 13.10                    | 10.83                     | 26.03               | 31.65                 | 1.53                 | 168.00                     | 111.67           | 88.45                  | 11.55                  | 76.02                | 40.50             | 14.92           | 30.80                 |
| 28.   | NLR-34449            | 91.67                 | 99.00             | 14.00                    | 11.33                     | 24.50               | 30.57                 | 1.43                 | 184.33                     | 124.00           | 89.65                  | 10.35                  | 69.49                | 42.01             | 16.84           | 29.13                 |
| 29.   | NDR-359              | 105.00                | 123.33            | 13.70                    | 12.43                     | 25.80               | 28.22                 | 1.46                 | 171.17                     | 135.00           | 87.56                  | 12.44                  | 73.12                | 42.50             | 17.56           | 31.07                 |
| 30.   | BM-71                | 102.33                | 125.00            | 9.70                     | 7.97                      | 17.60               | 30.80                 | 1.37                 | 78.83                      | 137.00           | 84.23                  | 15.77                  | 54.00                | 37.80             | 16.60           | 20.30                 |
| 31.   | SHIATS Dhan 1        | 105.00                | 120.33            | 16.63                    | 14.60                     | 19.68               | 30.43                 | 1.56                 | 206.97                     | 135.67           | 91.45                  | 8.55                   | 72.60                | 42.87             | 17.35           | 31.13                 |
| 32.   | Jaya (check)         | 100.67                | 119.20            | 14.80                    | 12.00                     | 26.50               | 28.30                 | 1.25                 | 182.50                     | 129.87           | 88.23                  | 11.77                  | 73.19                | 42.43             | 20.87           | 31.07                 |
| 33.   | IR 64 (check)        | 94.00                 | 109.47            | 12.93                    | 11.87                     | 24.67               | 29.03                 | 1.52                 | 171.90                     | 125.50           | 87.36                  | 12.64                  | 79.78                | 41.27             | 21.20           | 32.93                 |
| 34.   | Anjali (check)       | 85.33                 | 99.83             | 11.47                    | 12.13                     | 26.27               | 29.17                 | 1.50                 | 163.50                     | 116.83           | 84.39                  | 15.61                  | 74.90                | 43.07             | 19.13           | 32.23                 |
|       | <b>Mean</b>          | <b>96.23</b>          | <b>115.44</b>     | <b>15.06</b>             | <b>12.85</b>              | <b>26.05</b>        | <b>29.93</b>          | <b>1.50</b>          | <b>179.27</b>              | <b>127.05</b>    | <b>89.62</b>           | <b>10.37</b>           | <b>74.53</b>         | <b>42.79</b>      | <b>19.80</b>    | <b>32.00</b>          |
|       | <b>Range Lowest</b>  | <b>78.67</b>          | <b>99.00</b>      | <b>9.70</b>              | <b>7.97</b>               | <b>17.60</b>        | <b>25.87</b>          | <b>1.25</b>          | <b>78.83</b>               | <b>111.67</b>    | <b>84.23</b>           | <b>5.65</b>            | <b>54.00</b>         | <b>37.80</b>      | <b>14.92</b>    | <b>20.30</b>          |
|       | <b>Range Highest</b> | <b>108.67</b>         | <b>127.60</b>     | <b>17.53</b>             | <b>15.67</b>              | <b>30.03</b>        | <b>34.27</b>          | <b>1.72</b>          | <b>223.33</b>              | <b>138.67</b>    | <b>94.35</b>           | <b>15.77</b>           | <b>84.66</b>         | <b>45.20</b>      | <b>24.93</b>    | <b>37.46</b>          |
|       | C.V.                 | 1.05                  | 2.31              | 6.40                     | 8.13                      | 6.59                | 5.08                  | 4.82                 | 4.51                       | 0.89             | 3.10                   | 11.59                  | 5.47                 | 2.95              | 3.12            | 4.86                  |
|       | C.D. 5%              | 1.64                  | 4.35              | 1.57                     | 1.70                      | 2.80                | 2.48                  | 0.12                 | 13.18                      | 1.84             | 3.93                   | 4.23                   | 6.64                 | 2.06              | 1.01            | 2.54                  |

## **4.4 Quality parameters of hybrids and parents.**

### **4.4.1 Hulling percent**

The range of hulling per cent was observed from 65.21 (BM 71) to 74.35 (SHIATS Dhan1) in parents and 66.74 (Sahabhagi dhan x NDR 359) to 79.65 (BPT 5204 x NDR 359) in hybrids with a mean of 72.46 and 73.60 in parents and hybrids respectively presented (table no 4.20).

### **4.4.2 Kernel length (mm)**

Kernel length ranged from 4.80 (NDR 359) to 7.1 mm (MTU 1010) with a mean of 5.55 mm in parents and 5.02 (NLR 34449 x NDR 359) to 6.09 mm (MTU1001 x BM 71) with a mean of 5.5 mm in hybrids.

### **4.4.3 Kernel breadth (mm)**

The range for kernel breadth varied from 1.5 (BPT 2411) to 2.98 mm (MTU 1010) with a mean of 1.82 mm in parents and 1.5 (MTU 1001 x SHIATS Dhan1) to 2.09 mm (BPT 2615 x BM 71) with a mean of 1.8 mm in hybrids.

### **4.4.4 Kernel L/B ratio**

The kernel L/B ratio ranged from 2.24 (BPT5204) to 3.6 (SHIATS Dhan1) with a mean of 3.10 in parents and 2.63 (BPT 2615 x BM71) to 3.73 (MTU 1001 x SHIATS Dhan1) with a mean of 3.2 in hybrids.

### **4.4.5 Kernel length after cooking**

The range of kernel length after cooking in the parents was varied from 7.14 (NDR 359) to 8.21 (MTU 1010) and for hybrids from 6.47 (MTU 1010 x NDR 359) to 9.21 mm (MTU1001 x BM71). The mean performance of the parental lines and hybrids for this trait was 7.91 and 8.1 mm respectively.

### **4.4.6 Kernel breadth after cooking**

The range of kernel breadth after cooking for the parents was varied from 2.00 (SHIATS Dhan1) to 3.24 (Sahabhagi dhan) and for hybrids from 2.54 (Sahabhagi dhan x SHIATS Dhan1) to 3.54 mm (BPT 2411 x NDR 359). The mean performance of the parental lines and hybrids for this trait was 2.89 and 3.0 mm respectively.

#### **4.4.7 Kernel Elongation ratio**

The kernel elongation ratio ranged from 2.27 (Sahabhagi dhan) to 3.85 (SHIATS Dhan1) with a mean of 2.79 in parents and 2.2 (MTU 1001 x NDR 359) to 3.23 (MTU 1001 X BM 71) with a mean of 2.7 in hybrid

**Table 4.4 Quality parameters of hybrids, parents and checks**

| Characters                   | Hulling % | Kernel Length (mm) | Kernel Width (mm) | L/B ratio | Kernel length after cooking (mm) | Kernel width after cooking (mm) | Elongation ratio(mm) |
|------------------------------|-----------|--------------------|-------------------|-----------|----------------------------------|---------------------------------|----------------------|
| <b>Hybrids</b>               |           |                    |                   |           |                                  |                                 |                      |
| MTU-1010 X NDR-359           | 68.76     | 5.45               | 1.65              | 3.3       | 6.47                             | 2.6                             | 2.49                 |
| MTU-1010 XBM-71              | 70.62     | 5.68               | 1.82              | 3.12      | 8.1                              | 3.2                             | 2.53                 |
| MTU-1010 X SHIATS Dhan 1     | 78.56     | 5.25               | 1.62              | 3.24      | 7.82                             | 2.57                            | 3.04                 |
| MTU-1001 X NDR-359           | 71.25     | 5.1                | 1.79              | 2.85      | 7.5                              | 3.41                            | 2.2                  |
| MTU-1001X BM-71              | 73.65     | 6.09               | 1.96              | 3.11      | 9.21                             | 2.85                            | 3.23                 |
| MTU-1001X SHIATS Dhan 1      | 67        | 5.6                | 1.5               | 3.73      | 7.46                             | 2.64                            | 2.83                 |
| Sahabagi dhanX NDR-359       | 66.74     | 5.56               | 1.89              | 2.94      | 8.12                             | 2.6                             | 3.12                 |
| Sahabagi dhanX BM-71         | 68.72     | 5.83               | 1.66              | 3.51      | 8.32                             | 3.14                            | 2.65                 |
| Sahabagi dhan XSHIATS Dhan 1 | 77.58     | 5.65               | 1.55              | 3.65      | 7.89                             | 2.54                            | 3.11                 |
| BPT-5204X NDR-359            | 79.65     | 5.36               | 1.75              | 3.06      | 7.56                             | 2.87                            | 2.63                 |
| BPT-5204XBM-71               | 74.65     | 5.81               | 1.85              | 3.14      | 8.34                             | 3.21                            | 2.6                  |
| BPT-5204XSHIATS Dhan 1       | 71.65     | 5.55               | 1.79              | 3.1       | 8.49                             | 2.87                            | 2.96                 |
| BPT-2411XNDR-359             | 69.74     | 5.86               | 1.96              | 2.99      | 8.5                              | 3.54                            | 2.4                  |
| BPT-2411XBM-71               | 75.6      | 5.72               | 1.56              | 3.67      | 8.7                              | 2.78                            | 3.13                 |
| BPT-2411XSHIATS Dhan 1       | 76.4      | 5.56               | 1.86              | 2.99      | 7.86                             | 2.96                            | 2.66                 |
| BPT-2615XNDR-359             | 76.56     | 5.5                | 1.85              | 2.97      | 8.47                             | 3.42                            | 2.48                 |
| BPT-2615XBM-71               | 76.74     | 5.5                | 2.09              | 2.63      | 8.68                             | 3.54                            | 2.45                 |
| BPT-2615XSHIATS Dhan 1       | 72.36     | 5.1                | 1.67              | 3.05      | 7.56                             | 2.76                            | 2.74                 |
| NLR-34449XNDR-359            | 75.98     | 5.02               | 1.6               | 3.14      | 7.64                             | 2.65                            | 2.88                 |
| NLR-34449X BM-71             | 76.42     | 5.57               | 1.82              | 3.06      | 8.78                             | 3.41                            | 2.57                 |
| NLR-34449X SHIATS Dhan 1     | 77.86     | 5.09               | 1.59              | 3.2       | 7.68                             | 2.68                            | 2.87                 |
| Mean                         | 73.6      | 5.5                | 1.8               | 3.2       | 8.1                              | 3.0                             | 2.7                  |
| Lowest                       | 66.74     | 5.02               | 1.5               | 2.63      | 6.47                             | 2.54                            | 2.2                  |
| Highest                      | 79.65     | 6.09               | 2.09              | 3.73      | 9.21                             | 3.54                            | 3.23                 |
| <b>Parents</b>               |           |                    |                   |           |                                  |                                 |                      |
| MTU-1010                     | 70.24     | 7.1                | 2.98              | 2.38      | 8.21                             | 2.7                             | 3.04                 |
| MTU-1001                     | 72.34     | 6.45               | 2.01              | 3.21      | 7.5                              | 3.21                            | 2.34                 |
| Sahabagi dhan                | 67.35     | 5.65               | 2                 | 2.83      | 7.34                             | 3.24                            | 2.27                 |
| BPT-5204                     | 65.78     | 5.2                | 2.32              | 2.24      | 8.14                             | 3.21                            | 2.54                 |
| BPT-2411                     | 68.49     | 5.21               | 1.52              | 3.43      | 7.25                             | 2.41                            | 3.01                 |
| BPT-2615                     | 71.34     | 5.15               | 1.75              | 2.94      | 7.65                             | 2.21                            | 3.46                 |
| NLR-34449                    | 70.21     | 5.28               | 1.65              | 3.2       | 7.45                             | 2.54                            | 2.93                 |
| NDR359                       | 69.74     | 4.82               | 1.77              | 2.72      | 7.14                             | 2.82                            | 2.53                 |
| BM-71                        | 65.21     | 5.82               | 2.06              | 2.83      | 7.68                             | 2.47                            | 3.11                 |
| SHIATS Dhan 1                | 74.35     | 5.4                | 1.5               | 3.6       | 7.7                              | 2                               | 3.85                 |
| Mean                         | 72.40     | 5.55               | 1.82              | 3.10      | 7.91                             | 2.89                            | 2.79                 |
| Lowest                       | 65.21     | 4.8                | 1.5               | 2.24      | 7.14                             | 2                               | 2.27                 |
| Highest                      | 74.35     | 7.1                | 2.98              | 3.6       | 8.21                             | 3.24                            | 3.85                 |
| Jaya (CHECK)                 | 71.62     | 5.85               | 2.8               | 2.09      | 8.45                             | 3.5                             | 2.41                 |
| IR64 (CHECK)                 | 69.72     | 5.8                | 1.95              | 2.97      | 7.9                              | 2.15                            | 3.67                 |
| Anjali (CHECK)               | 68.45     | 4.5                | 2.8               | 1.61      | 6.5                              | 3.5                             | 1.86                 |

## 4.5 Heterosis

Heterosis over mid parent average heterosis (AH), heterosis over better parent heterobeltiosis (HB) and heterosis over standard checks (Economic heterosis) *i.e.*, increased or decreased performance as desirable over the then mid parents, better parents and the best check (Anjali / Jaya / IR 64), respectively was estimated in 21 hybrids for 15 characters (*viz.*, days to 50% flowering, plant height, number of tillers/ plant, number of panicles/plant, panicle length, flag leaf length, flag leaf width, number of grains/panicle, days to maturity, spikelet fertility %, spikelet sterility %, biological yield, harvest index, test weight and grain yield/plant presented character wise. Presented in (table no 4.5 to 4.12).

### 4.5.1 Days to 50% flowering

Negative heterosis is desirable for days to 50% flowering because it indicates earliness in completion of life cycle. The observed range of average heterosis of hybrids was from -15.40 to 10.50 % and heterobeltiosis range was from -24.13 to 6.19%. Eleven hybrids exhibited significant negative heterosis ranging from -3.01 (BPT 5204 x NDR 359) to -15.40 % (Sahabhagi dhan x SHIATS Dhan1). Eighteen hybrids were with significantly superior negative heterobeltiosis ranging from -24.13 (Sahabhagi dhan x SHIATS Dhan1) to -2.28 % (BPT 2615 x BM 71). The standard heterosis over Jaya ranged from -20.86 (Sahabhagi dhan x SHIATS Dhan1) to 7.95 per cent (BPT 2411 x BM 71). Only 15 hybrids manifested significant superiority for earliness over Jaya.

The hybrids those recorded significant standard negative heterosis over Jaya were: Sahabhagi dhan x SHIATS Dhan1 (-20.86), MTU 1010 x BM 71 (-14.57), Sahabhagi dhan x NDR 359 (-11.59), MTU 1001 x BM 71 (-10.60). BPT 2615 x NDR 359 (-6.29).

### 4.5.2 Plant height (cm)

Negative heterosis is desirable in rice for plant height. Almost all the hybrids were found to be taller than their mid parents, better parents. The average heterosis ranged from -16.81 to 10.27 per cent. The heterobeltiosis ranged from -18.81 to 3.02 per cent. 16 hybrids were shorter than their better parents by exhibiting significant negative heterobeltiosis. Standard heterosis ranged from -16 per cent (BPT 2411 x NDR 359) to 4% (BPT 2615 x SHIATS Dhan1) and from -8.53 (BPT 2411 x NDR 359) to 13.25 % (BPT 2615 x SHIATS Dhan1) over check Jaya and IR-64.

#### **4.5.3 Number of tillers / plant**

The range of mid parental heterosis varied from -2.60 to 13.56 per cent and for heterobeltiosis it was ranged from -7.54 to 26.75 per cent. 11 hybrids recorded positive significant average heterosis, while 4 hybrids recorded positive significant heterobeltiosis. When compared to Jaya, 7 hybrids registered significant positive standard heterosis with a range varying from -6.76 (NLR 34449 x BM 71) to 18.47 per cent (MTU 1001 x BM 71).

#### **4.5.4 Number of panicles/plant**

The range of mid parental heterosis varied from -6.37 to 61.51 per cent and for heterobeltiosis it was ranged from -12.38 to 37.03 per cent. Six hybrids recorded positive significant average heterosis, while two hybrids recorded positive significant heterobeltiosis. When compared to check Jaya, Eight hybrids registered significant positive standard heterosis with a range varying from -5.56 (NLR 34449 x NDR 359) to 30.56 per cent (MTU 1001 x BM 71). Standard heterosis over IR 64 ranged from -4.49 (NLR 34449 x NDR 359) to 32.02 per cent (MTU 1001 x BM 71).

#### **4.5.5 Panicle length (cm)**

The range of average heterosis and heterobeltiosis among the hybrids was from 3.40 to 37.87 per cent and -1.54 to 25.06 per cent, respectively. Seventeen hybrids manifested significant positive average heterosis ranging from 3.69 (BPT 2411 x NDR 359) to 37.87 per cent (MTU 1001 x BM 71). As many as 7 hybrids registered positive superior heterosis over better parents. Hybrids recorded standard heterosis ranging from -3.27 (BPT 2615 x SHIATS Dhan1) to 18.11 per cent (BPT 2411 x BM 71) and from -2.79 (Sahabhagi dhan x SHIATS Dhan1) to 14.34 per cent (BPT 5204 x SHIATS Dhan1) over Jaya and Anjali, respectively. Two hybrids namely BPT 5204 x SHIATS Dhan1 (13.33%), and (14.34%), BPT 5204 x SHIATS Dhan1 manifested significant positive heterosis over both the standard checks.

#### **4.5.6 Flag leaf length (cm)**

The average heterosis ranged from -13.33 to 15.38 per cent and heterobeltiosis ranged from -16.05 to 10.57 per cent. Three hybrids recorded significant positive average heterosis for flag leaf length with a range from 9.90 per cent (NLR 34449 x NDR 359) to 15.38 per cent (MTU 1010 x NDR 359). One hybrid registered significant positive heterobeltiosis ranging from 10.57 per cent (MTU 1010 x NDR 359). Standard heterosis over Jaya ranged from -6.60 (NLR 34449 x SHIATS Dhan1) to 14.13 per cent (NLR 34449 x NDR 359). As many as 8 hybrids recorded significant positive standard heterosis over Jaya. Over IR-64, 2 hybrids registered significant positive standard heterosis with a range varying from 9.18 (MTU 1010 x SHIATS Dhan1) to 11.25 per cent (NLR 34449 x NDR359).

#### **4.5.7 Flag leaf width (cm)**

The range of average heterosis and heterobeltiosis among the hybrids was from -16.37 to 26.84 per cent and -19.23 to 23.30 per cent respectively. Ten hybrids manifested significant positive heterosis ranging from 7.66 (Sahabhagi dhan x NDR 359) to 26.84 per cent MTU 1010 x BM 71). 4 hybrids were positive and significantly superior over their respective better parents with a range from 9.79 (MTU 1001 x SHIATS Dhan1) to 23.30 per cent (MTU 1010 x BM 71). Heterosis over IR-64 ranged from -16.92 (BPT 5204 X SHIATS Dhan1) to 13.41 per cent (MTU 1001 x SHIATS Dhan1). Four hybrids manifested significant heterosis over the commercial check Anjali ranging from 9.09 (BPT 2615 x BM 71) to 14.41 per cent (MTU 1001 x SHIATS Dhan1).

#### **4.5.8 Number of grains / panicle**

The average heterosis ranged from -8.34 to 89.12 per cent and heterobeltiosis ranged from -17.59 to 57.82 per cent. Sixteen hybrids recorded significant positive mid parental heterosis for number of grains/panicle with a range from 6.06 per cent (BPT 2411 x SHIATS Dhan1) to 89.12 per cent (Sahabhagi dhan x BM 71). As many as eight hybrids registered significant positive heterobeltiosis ranging from 7.91 per cent (BPT 5204 x SHIATS Dhan1) to 57.82 per cent (Sahabhagi dhan x BM 71) over the better parents. Heterosis over Jaya ranged from -16.04 (NLR 34449 x BM 71) to 22.37 per cent (BPT 5204 x SHIATS Dhan1). Seven hybrids showed significant increase in number of grains/panicle over Jaya. 13 hybrids manifested significant positive standard heterosis over IR 64. The range varied from -10.86 (NLR 34449 x BM 71) to 29.92 per cent (BPT 5204 x SHIATS Dhan1).

#### **4.5.9 Days to Maturity**

The observed range of average heterosis of hybrids was from -11.08 to 4.83 per cent and heterobeltiosis range was from -16.06 to 0.49 per cent. Eleven hybrids exhibited significant negative heterosis ranging from -11.08 (MTU 1010 x BM 71) to 4.83 per cent (BPT 2615 x BM 71). Eighteen hybrids were with significantly superior negative heterobeltiosis ranging from -16.06 (MTU 1010 x BM 71) to 0.49 per cent (BPT 2499 x NDR 359). The standard heterosis over Jaya ranged from -11.45 (MTU 1010 x BM 71) to 5.75 per cent (BPT 2411 x BM 71).

#### **4.5.10 Spikelet fertility (%)**

The range of average heterosis for hybrids was from -0.62 to 21.56 per cent and from -2.18 to 15.56 per cent for heterobeltiosis. Twelve hybrids with a range from 2.88 (MTU 1001 x SHIATS Dhan1) to 21.56 (MTU 1010 x NDR 359) per cent manifested significant positive heterosis. Thirteen hybrids had significant positive superiority in respect of heterobeltiosis with a range varying from 5.37 (BPT 2615 x SHIATS Dhan1) to 15.56 (MTU 1010 x NDR 359). The range of standard heterosis was from -4 (MTU 1001 x BM 71) to 5.80 per cent (BPT 2615 x BM 71) over Jaya. Only six hybrids viz., registered significant positive standard heterosis over Jaya.

#### **4.5.11 Spikelet sterility (%)**

The observed average heterosis range of the hybrids was from -45.41 to 11.91 per cent and from -15.64 to 7.74 per cent for heterobeltiosis. The range of standard heterosis was from -26.19 (MTU1010 x SHIATS Dhan1) to 16.25 per cent (MTU 1001 x BM 71) over Jaya. Only one Hybrid viz., (MTU 1001 x BM 71) registered significant positive standard heterosis over IR-64.

#### **4.5.12 Biological yield (g)**

The range of average heterosis of the hybrids was from -3.29 to 27.47 per cent and from -8.57 to 16.60 per cent for heterobeltiosis. Twelve hybrids with a range from 8.18 (BPT 2615 x SHIATS Dhan1) to 27.47 (MTU 1010 x BM 71) per cent manifested significant positive heterosis. Four hybrids had significant positive superiority in respect of heterobeltiosis with a

range varying from 11.30 (MTU 10001 x NDR 359) to 16.60 (Sahabhagi dhan x SHIATS Dhan 1). The range of standard heterosis was from -9.44 (MTU 1001 x BM 71) to 15.67 per cent (Sahabhagi dhan x SHIATS Dhan1) over Jaya . The range of standard heterosis was from -10.05 (NLR 34449 x NDR 359) to 6.11 per cent (Sahabhagi dhan x SHIATS Dhan1) over IR-64.

#### **4.5.13 Harvest index**

The range of average heterosis of the hybrids was from 0.39 to 9.56 per cent and from -1.74 to 3.78 per cent for heterobeltiosis. Eight hybrids with a range from 5.18 (NLR 34449 x SHIATS Dhan1) to 9.56 (MTU 1001 x BM 71) per cent manifested significant positive heterosis. The range of standard heterosis was from -2.28 (BPT 5204 x BM 71) to 6.52 per cent (BPT 2615 x NDR 359) over Jaya. The range of standard heterosis was from 0.48 (BPT 5204 x BM 71) to 9.53 per cent (BPT 2615 x NDR 359) over IR-64.

#### **4.5.14 Test weight (g)**

The range of average heterosis of the hybrids varies -6.57 to 29.0 per cent and heterobeltiosis range from -29.71 to 28.09 per cent. Eighteen hybrids were found to be superior to their mid parental values with significant positive average heterosis range from 2.95 per cent (BPT 5204 x NDR 359) to 30.28 per cent (MTU 1010 x NDR 359), while 9 hybrids with a range varying from 6.30 (BPT 2615 x NDR 359) to 20.35 per cent (MTU 1010 x NDR 359) recorded significantly higher grain weight over their better parents. Three hybrids possessed significantly lower test weight over their mid parental, whereas 12 hybrids had significantly lower test weight over the better parents. Three hybrids showed higher grain weight than standard checks Jaya and IR-64, respectively. The standard heterosis range was from -16.45 (MTU 1010 x BM 71) to 12.46 percent (MTU 1001 x NDR 359) and from -20.75 (MTU 1001 x BM 71) to 17.61 per cent (MTU 1010 x NDR 359) over Jaya and IR-64, respectively.

#### **4.5.15 Grain yield /plant (g)**

The hybrids exhibited a relative average heterosis range from 0.57 to 38.34 per cent and heterobeltiosis range from -10.13 to 20.32 per cent. Fourteen hybrids expressed significant positive average heterosis ranging from 0.57 per cent (BPT 5204 x NDR 359) to 38.35 (MTU 1010 x BM 71) per cent and 10 hybrids manifested significant positive heterobeltiosis ranging from 9.74 per cent (BPT 2411 x SHIATS Dhan1) to 20.58per cent (NLR 34449 x SHIATS Dhan1). The heterosis over the standard checks Jaya and IR-64 ranged from -5.58 (MTU 1001 x BM 71) to 20.58 per cent (NLR 34449 x SHIATS Dhan1) and from -10.93 (MTU 1001 x BM 71) to 13.74 per cent (NLR 34449 x SHIATS Dhan1), respectively. High heterosis over Jaya and IR 64 was shown by the four hybrids NLR 34449 x SHIATS Dhan1 (20.58% and 13.74%) followed by Sahabhagi dhan x SHIATS Dhan1 (16.62% and 9.82%), BPT 2615 x NDR 359 (14.58% and 8.09 %) and MTU 1010 x BM 71 (13.63% and 7.19 %).

**Table :4.5 Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice**

| Cross                        | Days to 50% Flowering |          |          |          |          |         | Plant Height (cm) |          |          |          |         |         |
|------------------------------|-----------------------|----------|----------|----------|----------|---------|-------------------|----------|----------|----------|---------|---------|
|                              | Mean                  | Mid      | Better   | Jaya     | IR 64    | Anjali  | Mean              | Mid      | Better   | Jaya     | IR 64   | Anjali  |
| MTU-1010 X NDR-359           | 95.33                 | -3.87**  | -9.21**  | -5.30**  | 1.42     | 11.72** | 115.00            | -5.54**  | -6.76**  | -3.52    | 5.05*   | 15.19** |
| MTU-1010 XBM-71              | 86.00                 | -12.10** | -15.96** | -14.57** | -8.51**  | 0.78    | 110.83            | -9.59**  | -11.33** | -7.02**  | 1.25    | 11.02** |
| MTU-1010 X SHIATS Dhan 1     | 95.00                 | -4.20**  | -9.52**  | -5.63**  | 1.06     | 11.33** | 106.57            | -11.38** | -11.44** | -10.60** | -2.65   | 6.74**  |
| MTU-1001 X NDR-359           | 98.33                 | -4.84**  | -6.35**  | -2.32**  | 4.61**   | 15.23** | 114.03            | -5.55**  | -7.54**  | -4.33*   | 4.17*   | 14.22** |
| MTU-1001X BM-71              | 90.00                 | -11.76** | -12.05** | -10.60** | -4.26**  | 5.47**  | 113.67            | -6.50**  | -9.07**  | -4.64*   | 3.84    | 13.86** |
| MTU-1001X SHIATS Dhan 1      | 98.00                 | -5.16**  | -6.67**  | -2.65**  | 4.26**   | 14.84** | 109.53            | -8.14**  | -8.98**  | -8.11**  | 0.06    | 9.72**  |
| Sahabagi dhanX NDR-359       | 89.00                 | -5.49**  | -15.24** | -11.59** | -5.32**  | 4.30**  | 122.57            | -2.31    | -3.94*   | 2.82     | 11.97** | 22.77** |
| Sahabagi dhanX BM-71         | 94.87                 | 2.19**   | -7.30**  | -5.76**  | 0.92     | 11.17** | 122.23            | -3.22*   | -4.21*   | 2.54     | 11.66** | 22.44** |
| Sahabagi dhan XSHIATS Dhan 1 | 79.67                 | -15.40** | -24.13** | -20.86** | -15.25** | -6.64** | 116.27            | -6.21**  | -8.88**  | -2.46    | 6.21**  | 16.46** |
| BPT-5204X NDR-359            | 102.00                | -3.01**  | -3.16**  | 1.32     | 8.51**   | 19.53** | 116.30            | -2.61    | -5.70**  | -2.43    | 6.24**  | 16.49** |
| BPT-5204XBM-71               | 104.00                | 0.16     | -1.27    | 3.31**   | 10.64**  | 21.88** | 109.70            | -8.77**  | -12.24** | -7.97**  | 0.21    | 9.88**  |
| BPT-5204XSHIATS Dhan 1       | 102.67                | -2.38**  | -2.53**  | 1.99*    | 9.22**   | 20.31** | 121.07            | 2.67     | 0.61     | 1.57     | 10.60** | 21.27** |
| BPT-2411XNDR-359             | 105.00                | 1.45*    | 0.00     | 4.30**   | 11.70**  | 23.05** | 100.13            | -16.81** | -18.81** | -16.00** | -8.53** | 0.30    |
| BPT-2411XBM-71               | 108.67                | 6.36**   | 6.19**   | 7.95**   | 15.60**  | 27.34** | 123.50            | 1.90     | -1.20    | 3.61*    | 12.82** | 23.71** |
| BPT-2411XSHIATS Dhan 1       | 98.00                 | -5.31**  | -6.67**  | -2.65**  | 4.26**   | 14.84** | 118.30            | -0.48    | -1.69    | -0.76    | 8.07**  | 18.50** |
| BPT-2615XNDR-359             | 94.33                 | 2.72**   | -10.16** | -6.29**  | 0.35**   | 10.55** | 100.97            | -16.33** | -18.14** | -15.30** | -7.76** | 1.14    |
| BPT-2615XBM-71               | 100.00                | 10.50**  | -2.28**  | -0.66    | 6.38**   | 17.19** | 118.83            | -2.19    | -4.93**  | -0.31    | 8.56**  | 19.03** |
| BPT-2615XSHIATS Dhan 1       | 97.00                 | 5.63**   | -7.62**  | -3.64**  | 3.19**   | 13.67** | 123.97            | 4.03*    | 3.02     | 4.00*    | 13.25** | 24.17** |
| NLR-34449XNDR-359            | 89.00                 | -9.49**  | -15.24** | -11.59** | -5.32**  | 4.30**  | 108.67            | -2.25    | -11.89** | -8.84**  | -0.73   | 8.85**  |
| NLR-34449X BM-71             | 98.93                 | 1.99*    | -3.32**  | -1.72*   | 5.25**   | 15.94** | 119.07            | 6.31**   | -4.75**  | -0.11    | 8.77**  | 19.27** |
| NLR-34449X SHIATS Dhan 1     | 97.67                 | -0.68    | -6.98**  | -2.98**  | 3.90**   | 14.45** | 120.93            | 10.27**  | 0.50     | 1.45     | 10.48*  | 21.14** |

**Table :4.6 Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice**

| Cross                         | Number of Tillers/ Plant |         |         |         |         |         | Number of panicles / plant |         |         |         |         |         |
|-------------------------------|--------------------------|---------|---------|---------|---------|---------|----------------------------|---------|---------|---------|---------|---------|
|                               | Mean                     | Mid     | Better  | Jaya    | IR 64   | Anjali  | Mean                       | Mid     | Better  | Jaya    | IR 64   | Anjali  |
| MTU-1010 X NDR-359            | 15.13                    | 1.45    | -6.20   | 2.25    | 17.01** | 31.98** | 12.50                      | -6.37   | -12.38  | 4.17    | 5.34    | 3.02    |
| MTU-1010 XBM-71               | 15.67                    | 21.29** | -2.89   | 5.86    | 21.13** | 36.63** | 12.63                      | 13.64   | -11.45  | 5.28    | 6.46    | 4.12    |
| MTU-1010 X SHIATS Dhan 1      | 17.10                    | 4.37    | 2.81    | 15.54** | 32.22** | 49.13** | 15.53                      | 7.62    | 6.39    | 29.44** | 30.90** | 28.02** |
| MTU-1001 X NDR-359            | 13.90                    | 0.97    | 0.48    | -6.08   | 7.47    | 21.22** | 11.57                      | -3.07   | -6.97   | -3.61   | -2.53   | -4.67   |
| MTU-1001X BM-71               | 17.53                    | 49.01** | 26.75** | 18.47** | 35.57** | 52.91** | 15.67                      | 61.51** | 37.03** | 30.56** | 32.02** | 29.12** |
| MTU-1001X SHIATS Dhan 1       | 16.63                    | 9.19    | 0.00    | 12.39*  | 28.61** | 45.06** | 14.00                      | 7.55    | -4.11   | 16.67*  | 17.98*  | 15.38*  |
| Sahabhagi dhanX NDR-359       | 15.63                    | 14.81** | 14.11*  | 5.63    | 20.88** | 36.34** | 11.53                      | -1.98   | -7.24   | -3.89   | -2.81   | -4.95   |
| Sahabhagi dhanX BM-71         | 15.17                    | 30.56** | 12.07*  | 2.48    | 17.27** | 32.27** | 13.50                      | 41.61** | 21.62** | 12.50   | 13.76   | 11.26   |
| Sahabhagi dhan XSHIATS Dhan 1 | 15.53                    | 2.98    | -6.61   | 4.95    | 20.10** | 35.47** | 13.80                      | 7.39    | -5.48   | 15.00*  | 16.29*  | 13.74   |
| BPT-5204X NDR-359             | 16.87                    | 11.70*  | 2.22    | 13.96*  | 30.41** | 47.09** | 14.67                      | 7.84    | -0.68   | 22.22** | 23.60** | 20.88** |
| BPT-5204XBM-71                | 17.03                    | 30.03** | 3.23    | 15.09** | 31.70** | 48.55** | 13.57                      | 19.35** | -8.13   | 13.06   | 14.33   | 11.81   |
| BPT-5204XSHIATS Dhan 1        | 17.50                    | 5.63    | 5.21    | 18.24** | 35.31** | 52.62** | 15.53                      | 5.79    | 5.19    | 29.44** | 30.90** | 28.02** |
| BPT-2411XNDR-359              | 14.90                    | 2.17    | -3.66   | 0.68    | 15.21*  | 29.94** | 12.37                      | -4.63   | -8.40   | 3.06    | 4.21    | 1.92    |
| BPT-2411XBM-71                | 14.30                    | 13.64*  | -7.54   | -3.38   | 10.57   | 24.71** | 13.40                      | 24.84** | -0.74   | 11.67   | 12.92   | 10.44   |
| BPT-2411XSHIATS Dhan 1        | 15.63                    | -2.60   | -6.01   | 5.63    | 20.88** | 36.34** | 13.80                      | -1.78   | -5.48   | 15.00*  | 16.29*  | 13.74   |
| BPT-2615XNDR-359              | 14.67                    | 9.45    | 7.06    | -0.90   | 13.40*  | 27.91** | 11.50                      | -1.15   | -7.51   | -4.17   | -3.09   | -5.22   |
| BPT-2615XBM-71                | 14.20                    | 24.56** | 8.40    | -4.05   | 9.79    | 23.84** | 11.50                      | 22.34** | 6.15    | -4.17   | -3.09   | -5.22   |
| BPT-2615XSHIATS Dhan 1        | 15.57                    | 4.71    | -6.41   | 5.18    | 20.36** | 35.76** | 13.40                      | 5.37    | -8.22   | 11.67   | 12.92   | 10.44   |
| NLR-34449XNDR-359             | 16.17                    | 16.73** | 15.48*  | 9.23    | 25.00** | 40.99** | 11.33                      | -4.63   | -8.85   | -5.56   | -4.49   | -6.59   |
| NLR-34449X BM-71              | 13.80                    | 16.46** | -1.43   | -6.76   | 6.70    | 20.35** | 12.50                      | 29.53** | 10.29   | 4.17    | 5.34    | 3.02    |
| NLR-34449X SHIATS Dhan 1      | 17.40                    | 13.60** | 4.61    | 17.57** | 34.54** | 51.74** | 14.40                      | 11.05   | -1.37   | 20.00** | 21.35** | 18.68*  |

**Table :4.7 Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice**

| Cross                        | Panicle Length (cm) |         |         |        |         |        | Flag Leaf Length (cm) |          |          |         |         |        |
|------------------------------|---------------------|---------|---------|--------|---------|--------|-----------------------|----------|----------|---------|---------|--------|
|                              | Mean                | Mid     | Better  | Jaya   | IR 64   | Anjali | Mean                  | Mid      | Better   | Jaya    | IR 64   | Anjali |
| MTU-1010 X NDR-359           | 28.37               | 16.58** | 9.95    | 7.04   | 15.00*  | 7.99   | 31.20                 | 15.38**  | 10.57*   | 10.25*  | 7.46    | 6.97   |
| MTU-1010 XBM-71              | 27.43               | 35.58** | 19.97** | 3.52   | 11.22   | 4.44   | 28.80                 | 1.65     | -6.49    | 1.77    | -0.80   | -1.26  |
| MTU-1010 X SHIATS Dhan 1     | 26.90               | 26.44** | 17.64** | 1.51   | 9.05    | 2.41   | 31.70                 | 12.61**  | 4.16     | 12.01** | 9.18*   | 8.69*  |
| MTU-1001 X NDR-359           | 28.07               | 18.38** | 8.79    | 5.91   | 13.78*  | 6.85   | 30.03                 | 6.09     | 5.75     | 6.12    | 3.44    | 2.97   |
| MTU-1001X BM-71              | 27.03               | 37.87** | 25.06** | 2.01   | 9.59    | 2.92   | 29.17                 | -1.46    | -5.30    | 3.06    | 0.46    | 0.00   |
| MTU-1001X SHIATS Dhan 1      | 26.50               | 28.33** | 22.59** | 0.00   | 7.43    | 0.89   | 30.70                 | 4.36     | 0.88     | 8.48*   | 5.74    | 5.26   |
| Sahabagi dhanX NDR-359       | 27.10               | 4.08    | 3.13    | 2.26   | 9.86    | 3.17   | 29.57                 | -5.36    | -13.72** | 4.48    | 1.84    | 1.37   |
| Sahabagi dhanX BM-71         | 25.60               | 16.69** | -2.58   | -3.40  | 3.78    | -2.54  | 28.77                 | -11.58*  | -16.05** | 1.65    | -0.92   | -1.37  |
| Sahabagi dhan XSHIATS Dhan 1 | 25.53               | 11.11*  | -2.83   | -3.65  | 3.51    | -2.79  | 29.10                 | -10.05** | -15.08** | 2.83    | 0.23    | -0.23  |
| BPT-5204X NDR-359            | 27.73               | 7.34    | 7.19    | 4.65   | 12.43*  | 5.58   | 28.10                 | -4.56    | -8.37*   | -0.71   | -3.21   | -3.66  |
| BPT-5204XBM-71               | 27.27               | 25.44** | 5.39    | 2.89   | 10.54   | 3.81   | 29.17                 | -5.10    | -5.30    | 3.06    | 0.46    | 0.00   |
| BPT-5204XSHIATS Dhan 1       | 30.03               | 31.85** | 16.08** | 13.33* | 21.76** | 14.34* | 31.00                 | 1.47     | 1.09     | 9.54*   | 6.77    | 6.29   |
| BPT-2411XNDR-359             | 26.37               | 3.40    | 2.20    | -0.50  | 6.89    | 0.38   | 30.27                 | -2.02    | -9.83**  | 6.95    | 4.25    | 3.77   |
| BPT-2411XBM-71               | 29.13               | 36.14** | 15.61** | 9.94   | 18.11** | 10.91  | 29.07                 | -9.68**  | -13.41** | 2.71    | 0.11    | -0.34  |
| BPT-2411XSHIATS Dhan 1       | 28.07               | 25.06** | 11.38   | 5.91   | 13.78*  | 6.85   | 31.30                 | -2.19    | -6.75    | 10.60*  | 7.81    | 7.31   |
| BPT-2615XNDR-359             | 27.53               | 6.24    | 5.76    | 3.90   | 11.62   | 4.82   | 30.90                 | 3.23     | -2.37    | 9.19*   | 6.43    | 5.94   |
| BPT-2615XBM-71               | 25.73               | 17.95** | -1.15   | -2.89  | 4.32    | -2.03  | 30.80                 | -1.36    | -2.69    | 8.83*   | 6.08    | 5.60   |
| BPT-2615XSHIATS Dhan 1       | 25.63               | 12.14*  | -1.54   | -3.27  | 3.92    | -2.41  | 29.30                 | -5.61    | -7.42    | 3.53    | 0.92    | 0.46   |
| NLR-34449XNDR-359            | 28.30               | 12.52*  | 9.69    | 6.79   | 14.73*  | 7.74   | 32.30                 | 9.90**   | 5.67     | 14.13** | 11.25** | 10.74* |
| NLR-34449X BM-71             | 26.27               | 24.78** | 7.21    | -0.88  | 6.49    | 0.00   | 29.07                 | -5.27    | -5.63    | 2.71    | 0.11    | -0.34  |
| NLR-34449X SHIATS Dhan 1     | 28.37               | 28.40** | 15.78** | 7.04   | 15.00*  | 7.99   | 26.43                 | -13.33** | -13.52** | -6.60   | -8.96*  | -9.37* |

**Table :4.8 Estimates of heterosis, heterobeltiosis and standard heterosis for 15quantitative characters in rice**

|                              | Flag Leaf Width (cm) |          |          |         |          |          | Number of Grains/panicle |         |          |          |          |         |
|------------------------------|----------------------|----------|----------|---------|----------|----------|--------------------------|---------|----------|----------|----------|---------|
| Cross                        | Mean                 | Mid      | Better   | Jaya    | IR 64    | Anjali   | Mean                     | Mid     | Better   | Jaya     | IR 64    | Anjali  |
| MTU-1010 X NDR-359           | 1.57                 | 13.53**  | 7.06     | 25.33** | 3.30     | 4.21     | 191.00                   | 20.82** | 11.59**  | 4.66     | 11.11**  | 16.82** |
| MTU-1010 XBM-71              | 1.69                 | 26.84**  | 23.30**  | 35.47** | 11.65**  | 12.64**  | 205.20                   | 83.35** | 41.52**  | 12.44**  | 19.37**  | 25.50** |
| MTU-1010 X SHIATS Dhan 1     | 1.61                 | 12.72**  | 3.21     | 28.80** | 6.15     | 7.10     | 194.53                   | 10.54** | -6.01    | 6.59     | 13.17**  | 18.98** |
| MTU-1001 X NDR-359           | 1.47                 | -3.19    | -6.38    | 17.33** | -3.30    | -2.44    | 194.00                   | 12.19** | 11.07**  | 6.30     | 12.86**  | 18.65** |
| MTU-1001X BM-71              | 1.52                 | 3.17     | -3.19    | 21.33** | 0.00     | 0.89     | 174.97                   | 38.04** | 0.17     | -4.13    | 1.78     | 7.01    |
| MTU-1001X SHIATS Dhan 1      | 1.72                 | 10.02**  | 9.79*    | 37.60** | 13.41**  | 14.41**  | 174.90                   | -8.34** | -15.49** | -4.16    | 1.75     | 6.97    |
| Sahabagi dhanX NDR-359       | 1.55                 | 7.66*    | 5.69     | 23.73** | 1.98     | 2.88     | 170.57                   | 18.04** | -0.35    | -6.54    | -0.78    | 4.32    |
| Sahabagi dhanX BM-71         | 1.67                 | 19.76**  | 18.20**  | 33.33** | 9.89*    | 10.86**  | 185.97                   | 89.12** | 57.82**  | 1.90     | 8.18*    | 13.74** |
| Sahabagi dhan XSHIATS Dhan 1 | 1.40                 | -5.50    | -10.04*  | 12.27*  | -7.47    | -6.65    | 170.57                   | 5.03    | -17.59** | -6.54    | -0.78    | 4.32    |
| BPT-5204X NDR-359            | 1.46                 | -0.11    | -0.46    | 16.53** | -3.96    | -3.10    | 208.50                   | 21.28** | 20.75**  | 14.25**  | 21.29**  | 27.52** |
| BPT-5204XBM-71               | 1.54                 | 9.20*    | 6.19     | 23.47** | 1.76     | 2.66     | 172.93                   | 37.52** | 0.15     | -5.24    | 0.60     | 5.77    |
| BPT-5204XSHIATS Dhan 1       | 1.26                 | -16.37** | -19.23** | 0.80    | -16.92** | -16.19** | 223.33                   | 17.66** | 7.91*    | 22.37**  | 29.92**  | 36.60** |
| BPT-2411XNDR-359             | 1.58                 | 8.61*    | 7.74     | 26.13** | 3.96     | 4.88     | 201.53                   | 13.17** | 8.94*    | 10.43**  | 17.24**  | 23.26** |
| BPT-2411XBM-71               | 1.33                 | -5.21    | -7.41    | 6.67    | -12.09** | -11.31** | 190.80                   | 44.64** | 3.14     | 4.55     | 10.99**  | 16.70** |
| BPT-2411XSHIATS Dhan 1       | 1.59                 | 5.78     | 1.71     | 26.93** | 4.62     | 5.54     | 207.87                   | 6.06*   | 0.43     | 13.90**  | 20.92**  | 27.14** |
| BPT-2615XNDR-359             | 1.55                 | 3.45     | 1.09     | 24.00** | 2.20     | 3.10     | 191.27                   | 12.79** | 11.74**  | 4.80     | 11.27**  | 16.98** |
| BPT-2615XBM-71               | 1.64                 | 12.84**  | 6.96     | 31.20** | 8.13*    | 9.09*    | 179.67                   | 45.58** | 6.94     | -1.55    | 4.52     | 9.89*   |
| BPT-2615XSHIATS Dhan 1       | 1.52                 | -1.51    | -2.35    | 21.87** | 0.44     | 1.33     | 199.10                   | 6.20    | -3.80    | 9.10*    | 15.82**  | 21.77** |
| NLR-34449XNDR-359            | 1.62                 | 11.85**  | 10.71*   | 29.60** | 6.81     | 7.76     | 176.63                   | -0.63   | -4.18    | -3.21    | 2.75     | 8.03    |
| NLR-34449X BM-71             | 1.44                 | 2.38     | 0.23     | 14.93** | -5.27    | -4.43    | 153.23                   | 16.45** | -16.87** | -16.04** | -10.86** | -6.28   |
| NLR-34449X SHIATS Dhan 1     | 1.50                 | 0.45     | -3.63    | 20.27** | -0.88    | 0.00     | 206.27                   | 5.43    | -0.34    | 13.02**  | 19.99**  | 26.16** |

**Table: 4.9 Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice**

| Cross                        | Days to Maturity |          |          |          |         |         | Spikelet Fertility (%) |         |         |        |        |         |
|------------------------------|------------------|----------|----------|----------|---------|---------|------------------------|---------|---------|--------|--------|---------|
|                              | Mean             | Mid      | Better   | Jaya     | IR 64   | Anjali  | Mean                   | Mid     | Better  | Jaya   | IR 64  | Anjali  |
| MTU-1010 X NDR-359           | 125.57           | -2.16**  | -6.99**  | -3.31**  | 0.05    | 7.48**  | 80.47                  | 21.56** | 15.56** | 3.74   | 1.22   | -1.23   |
| MTU-1010 XBM-71              | 115.00           | -11.08** | -16.06** | -11.45** | -8.37** | -1.57   | 81.50                  | 17.95** | 8.03**  | 5.07   | 2.52   | 0.04    |
| MTU-1010 X SHIATS Dhan 1     | 125.00           | -2.85**  | -7.86**  | -3.75**  | -0.40   | 6.99**  | 81.27                  | 16.85** | 6.46*   | 4.77   | 2.22   | -0.25   |
| MTU-1001 X NDR-359           | 127.83           | -3.94**  | -5.31**  | -1.57*   | 1.86*   | 9.42**  | 80.10                  | 11.38** | 7.95**  | 3.27   | 0.75   | -1.68   |
| MTU-1001X BM-71              | 122.00           | -9.01**  | -10.95** | -6.06**  | -2.79** | 4.42**  | 74.47                  | -0.47   | -1.29   | -4.00  | -6.33* | -8.59** |
| MTU-1001X SHIATS Dhan 1      | 127.67           | -4.31**  | -5.90**  | -1.698*  | 1.73*   | 9.27**  | 77.43                  | 2.88    | 1.44    | -0.17  | -2.60  | -4.95   |
| Sahabagi dhanX NDR-359       | 117.17           | -6.32**  | -13.21** | -9.78**  | -6.64** | 0.29    | 84.07                  | 13.96** | 7.92**  | 8.38   | 5.74*  | 3.19    |
| Sahabagi dhanX BM-71         | 122.67           | -2.70**  | -10.46** | -5.54**  | -2.26** | 4.99**  | 76.20                  | -0.62   | -2.18   | -1.76  | -4.15  | -6.46*  |
| Sahabagi dhan XSHIATS Dhan 1 | 123.47           | -1.54*   | -8.99**  | -4.93**  | -1.62*  | 5.68**  | 81.87                  | 6.16**  | 5.09    | 5.54*  | 2.98   | 0.49    |
| BPT-5204X NDR-359            | 131.00           | -4.26**  | -5.53**  | 0.87     | 4.38**  | 12.13** | 77.20                  | 5.18*   | 0.04    | -0.47  | -2.89  | -5.24*  |
| BPT-5204XBM-71               | 133.00           | -3.51**  | -4.09**  | 2.41**   | 5.98**  | 13.84** | 77.13                  | 1.09    | -0.04   | -0.56  | -2.98  | -5.32*  |
| BPT-5204XSHIATS Dhan 1       | 134.53           | -1.92**  | -2.98**  | 3.598**  | 7.20**  | 15.15** | 83.33                  | 8.58**  | 7.99**  | 7.43** | 4.82   | 2.29    |
| BPT-2411XNDR-359             | 135.67           | 1.62*    | 0.49     | 4.47**   | 8.10**  | 16.12** | 78.00                  | 8.75**  | 5.66*   | 0.56   | -1.89  | -4.26   |
| BPT-2411XBM-71               | 137.33           | 2.11**   | 0.24     | 5.75**   | 9.43**  | 17.55** | 79.27                  | 6.21*   | 5.07    | 2.19   | -0.29  | -2.70   |
| BPT-2411XSHIATS Dhan 1       | 126.23           | -5.68**  | -6.95**  | -2.80**  | 0.58    | 8.05**  | 82.63                  | 10.07** | 8.25**  | 6.53*  | 3.94   | 1.43    |
| BPT-2615XNDR-359             | 124.00           | 0.54     | -8.15**  | -4.52**  | -1.20   | 6.13**  | 78.73                  | 10.27** | 7.61**  | 1.50   | -0.96  | -3.36   |
| BPT-2615XBM-71               | 130.33           | 4.83**   | -4.87**  | 0.36     | 3.85**  | 11.55** | 82.07                  | 10.45** | 8.78**  | 5.80*  | 3.23   | 0.74    |
| BPT-2615XSHIATS Dhan 1       | 127.53           | 3.13**   | -6.00**  | -1.80*   | 1.62*   | 9.16**  | 80.43                  | 7.60**  | 5.37*   | 3.70   | 1.17   | -1.27   |
| NLR-34449XNDR-359            | 125.00           | -3.47**  | -7.41**  | -3.75**  | -0.40   | 6.99**  | 79.47                  | 12.69** | 11.30** | 2.45   | -0.04  | -2.45   |
| NLR-34449X BM-71             | 127.33           | -2.43**  | -7.06**  | -1.95**  | 1.46    | 8.99**  | 78.30                  | 6.64**  | 3.79    | 0.95   | -1.51  | -3.89   |
| NLR-34449X SHIATS Dhan 1     | 127.23           | -2.00**  | -6.22**  | -2.03**  | 1.38    | 8.90**  | 82.00                  | 11.01** | 7.42**  | 5.72*  | 3.14   | 0.65    |

**Table: 4.10 Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice**

| Cross                        | Spikelet Sterility (%) |          |          |          |          |         | Biological yield(g ) |         |         |         |          |         |
|------------------------------|------------------------|----------|----------|----------|----------|---------|----------------------|---------|---------|---------|----------|---------|
|                              | Mean                   | Mid      | Better   | Jaya     | IR 64    | Anjali  | Mean                 | Mid     | Better  | Jaya    | IR 64    | Anjali  |
| MTU-1010 X NDR-359           | 18.67                  | -45.41** | -50.64** | -21.57*  | -10.54   | -3.11   | 75.67                | 4.91    | 3.49    | 3.39    | -5.15    | 1.03    |
| MTU-1010 XBM-71              | 18.17                  | -42.78** | -51.97** | -23.67*  | -12.94   | -5.71   | 79.75                | 27.47** | 12.11*  | 8.97    | -0.04    | 6.48    |
| MTU-1010 X SHIATS Dhan 1     | 17.57                  | -41.92** | -53.55** | -26.19** | -15.81   | -8.82   | 73.93                | 2.87    | 1.83    | 1.02    | -7.33    | -1.30   |
| MTU-1001 X NDR-359           | 22.10                  | -18.65*  | -27.70** | -7.14    | 5.91     | 14.71   | 81.38                | 20.61** | 11.30*  | 11.19*  | 2.00     | 8.65    |
| MTU-1001X BM-71              | 27.67                  | 11.91    | 7.74     | 16.25    | 32.59**  | 43.60** | 66.28                | 14.45** | 7.21    | -9.44*  | -16.93** | -11.51* |
| MTU-1001X SHIATS Dhan 1      | 21.47                  | -7.54    | -9.68    | -9.80    | 2.88     | 11.42   | 77.99                | 16.04** | 7.42    | 6.56    | -2.24    | 4.13    |
| Sahabagi dhanX NDR-359       | 15.20                  | -44.36** | -50.27** | -36.13** | -27.16*  | -21.11  | 78.46                | 9.64*   | 7.31    | 7.20    | -1.65    | 4.75    |
| Sahabagi dhanX BM-71         | 23.37                  | -6.06    | -9.01    | -1.82    | 11.98    | 21.28   | 72.87                | 17.53** | 4.10    | -0.43   | -8.66*   | -2.71   |
| Sahabagi dhan XSHIATS Dhan 1 | 17.80                  | -23.82** | -26.04** | -25.21** | -14.70   | -7.61   | 84.66                | 18.73** | 16.60** | 15.67** | 6.11     | 13.02** |
| BPT-5204X NDR-359            | 23.47                  | -14.51*  | -23.23** | -1.40    | 12.46    | 21.80   | 73.45                | -3.29   | -6.77   | 0.36    | -7.94    | -1.94   |
| BPT-5204XBM-71               | 22.43                  | -10.29   | -12.64   | -5.74    | 7.51     | 16.44   | 72.03                | 8.50    | -8.57   | -1.58   | -9.71*   | -3.83   |
| BPT-5204XSHIATS Dhan 1       | 14.90                  | -36.60** | -38.77** | -37.39** | -28.59** | -22.66  | 76.90                | 1.60    | -2.39   | 5.07    | -3.61    | 2.67    |
| BPT-2411XNDR-359             | 22.67                  | -22.23** | -25.85** | -4.76    | 8.63     | 17.65   | 72.93                | -0.75   | -1.23   | -0.36   | -8.59*   | -2.64   |
| BPT-2411XBM-71               | 23.00                  | -13.87   | -17.05*  | -3.36    | 10.22    | 19.38   | 74.91                | 17.20** | 1.46    | 2.35    | -6.11    | 0.01    |
| BPT-2411XSHIATS Dhan 1       | 16.93                  | -32.80** | -38.93** | -28.85** | -18.85   | -12.11  | 80.57                | 10.04*  | 9.12    | 10.08*  | 0.98     | 7.56    |
| BPT-2615XNDR-359             | 22.67                  | -20.56** | -25.85** | -4.76    | 8.63     | 17.65   | 78.79                | 5.66    | 3.64    | 7.65    | -1.25    | 5.18    |
| BPT-2615XBM-71               | 18.43                  | -29.35** | -30.44** | -22.55*  | -11.66   | -4.33   | 72.54                | 11.59*  | -4.57   | -0.89   | -9.08*   | -3.16   |
| BPT-2615XSHIATS Dhan 1       | 18.57                  | -24.47** | -29.94** | -21.99*  | -11.02   | -3.63   | 80.39                | 8.18*   | 5.75    | 9.83*   | 0.76     | 7.32    |
| NLR-34449XNDR-359            | 19.90                  | -33.22** | -34.90** | -16.39   | -4.63    | 3.29    | 71.77                | 0.65    | -1.85   | -1.94   | -10.05*  | -4.19   |
| NLR-34449X BM-71             | 22.30                  | -18.48*  | -23.19** | -6.30    | 6.87     | 15.74   | 76.20                | 23.41** | 9.66    | 4.11    | -4.50    | 1.73    |
| NLR-34449X SHIATS Dhan 1     | 17.27                  | -33.20** | -40.53** | -27.45** | -17.25   | -10.38  | 83.99                | 18.22** | 15.68** | 14.76** | 5.27     | 12.13*  |

**Table: 4.11** Estimates of heterosis, heterobeltiosis and standard heterosis for 15 quantitative characters in rice

| Cross                        | Harvest Index |        |        |       |        |        | Test Weight(g ) |          |          |          |          |          |
|------------------------------|---------------|--------|--------|-------|--------|--------|-----------------|----------|----------|----------|----------|----------|
|                              | Mean          | Mid    | Better | Jaya  | IR 64  | Anjali | Mean            | Mid      | Better   | Jaya     | IR 64    | Anjali   |
| MTU-1010 X NDR-359           | 43.27         | 0.97   | 0.15   | 1.96  | 4.85   | 0.46   | 24.93           | 30.28**  | 20.35**  | 19.49**  | 17.61**  | 30.31**  |
| MTU-1010 XBM-71              | 44.37         | 9.55** | 2.70   | 4.56  | 7.51** | 3.02   | 17.43           | -6.57**  | -15.85** | -16.45** | -17.77** | -8.89**  |
| MTU-1010 X SHIATS Dhan 1     | 44.27         | 2.87   | 2.47   | 4.32  | 7.27** | 2.79   | 21.40           | 12.43**  | 3.30     | 2.56     | 0.94     | 11.85**  |
| MTU-1001 X NDR-359           | 42.97         | 0.43   | -0.23  | 1.26  | 4.12   | -0.23  | 23.47           | 13.20**  | -1.81    | 12.46**  | 10.69**  | 22.65**  |
| MTU-1001X BM-71              | 44.30         | 9.56** | 2.86   | 4.40  | 7.35** | 2.86   | 16.80           | -17.04** | -29.71** | -19.49** | -20.75** | -12.20** |
| MTU-1001X SHIATS Dhan 1      | 43.13         | 0.39   | 0.15   | 1.65  | 4.52   | 0.15   | 22.00           | 6.67**   | -7.95**  | 5.43*    | 3.77     | 14.98**  |
| Sahabagi dhanX NDR-359       | 43.03         | 1.73   | 1.25   | 1.41  | 4.28   | -0.08  | 22.40           | 13.48**  | 2.21     | 7.35**   | 5.66*    | 17.07**  |
| Sahabagi dhanX BM-71         | 43.07         | 7.80** | 2.29   | 1.49  | 4.36   | 0.00   | 21.77           | 13.02**  | -0.68    | 4.31     | 2.67     | 13.76**  |
| Sahabagi dhan XSHIATS Dhan 1 | 42.73         | 0.58   | -0.31  | 0.71  | 3.55   | -0.77  | 21.43           | 9.17**   | -2.21    | 2.72     | 1.10     | 12.02**  |
| BPT-5204X NDR-359            | 44.03         | 3.97   | 3.61   | 3.77  | 6.70*  | 2.24   | 17.90           | 2.95     | 1.94     | -14.22** | -15.57** | -6.45*   |
| BPT-5204XBM-71               | 41.47         | 3.67   | -1.74  | -2.28 | 0.48   | -3.72  | 20.53           | 21.45**  | 19.29**  | -1.60    | -3.14    | 7.32**   |
| BPT-5204XSHIATS Dhan 1       | 44.10         | 3.68   | 2.88   | 3.93  | 6.87*  | 2.40   | 18.90           | 9.36**   | 8.93**   | -9.42**  | -10.85** | -1.22    |
| BPT-2411XNDR-359             | 43.77         | 4.21   | 2.98   | 3.14  | 6.06*  | 1.63   | 19.23           | 6.13*    | 2.94     | -7.83**  | -9.28**  | 0.52     |
| BPT-2411XBM-71               | 43.07         | 8.62** | 3.78   | 1.49  | 4.36   | 0.00   | 21.60           | 22.44**  | 15.61**  | 3.51     | 1.89     | 12.89**  |
| BPT-2411XSHIATS Dhan 1       | 42.47         | 0.67   | -0.93  | 0.08  | 2.91   | -1.39  | 18.63           | 3.42     | -0.27    | -10.70** | -12.11** | -2.61    |
| BPT-2615XNDR-359             | 45.20         | 8.92** | 6.35*  | 6.52* | 9.53** | 4.95   | 18.67           | 14.95**  | 6.30*    | -10.54** | -11.95** | -2.44    |
| BPT-2615XBM-71               | 41.73         | 6.60** | 3.05   | -1.65 | 1.13   | -3.10  | 19.03           | 20.78**  | 14.66**  | -8.79**  | -10.22** | -0.52    |
| BPT-2615XSHIATS Dhan 1       | 43.40         | 4.12   | 1.24   | 2.28  | 5.17   | 0.77   | 20.83           | 29.13**  | 20.08    | -0.16    | -1.73    | 8.89**   |
| NLR-34449XNDR-359            | 42.77         | 1.21   | 0.63   | 0.79  | 3.63   | -0.70  | 18.27           | 6.21*    | 4.02     | -12.46** | -13.84   | -4.53    |
| NLR-34449X BM-71             | 42.60         | 6.76** | 1.41   | 0.39  | 3.23   | -1.08  | 21.57           | 29.00**  | 28.09    | 3.35     | 1.73     | 12.72**  |
| NLR-34449X SHIATS Dhan 1     | 44.63         | 5.18*  | 4.12   | 5.18  | 8.16** | 3.64   | 19.57           | 14.47**  | 12.78    | -6.23*   | -7.70**  | 2.26     |

**Table: 4.12 Estimates of heterosis, heterobeltiosis and standard heterosis for Grain Yield/ Plant (g)**

| <b>Cross</b>                  | <b>Mean</b> | <b>Mid</b> | <b>Better</b> | <b>Jaya</b> | <b>IR 64</b> | <b>Anjali</b> |
|-------------------------------|-------------|------------|---------------|-------------|--------------|---------------|
| MTU-1010 X NDR-359            | 32.73       | 5.93       | 5.36          | 5.36        | -0.61        | 1.55          |
| MTU-1010 XBM-71               | 35.30       | 38.34**    | 14.86**       | 13.63**     | 7.19         | 9.51*         |
| MTU-1010 X SHIATS Dhan 1      | 32.73       | 5.82       | 5.14          | 5.36        | -0.61        | 1.55          |
| MTU-1001 X NDR-359            | 35.43       | 22.89**    | 14.06**       | 14.06**     | 7.59         | 9.93*         |
| MTU-1001X BM-71               | 29.33       | 25.09**    | 10.28*        | -5.58       | -10.93**     | -9.00*        |
| MTU-1001X SHIATS Dhan 1       | 33.60       | 16.40**    | 7.92          | 8.15        | 2.02         | 4.24          |
| Sahabhagi dhanX NDR-359       | 35.37       | 16.91**    | 13.84**       | 13.84**     | 7.39         | 9.72*         |
| Sahabhagi dhanX BM-71         | 31.37       | 26.14**    | 6.57          | 0.97        | -4.76        | -2.69         |
| Sahabhagi dhan XSHIATS Dhan 1 | 36.17       | 19.43**    | 16.17**       | 16.42**     | 9.82*        | 12.20**       |
| BPT-5204X NDR-359             | 32.33       | 0.57       | -2.71         | 4.08        | -1.82        | 0.31          |
| BPT-5204XBM-71                | 29.87       | 11.58**    | -10.13*       | -3.86       | -9.31*       | -7.34         |
| BPT-5204XSHIATS Dhan 1        | 33.90       | 5.33       | 2.01          | 9.12*       | 2.94         | 5.17          |
| BPT-2411XNDR-359              | 32.90       | 6.65       | 5.90          | 5.90        | -0.10        | 2.07          |
| BPT-2411XBM-71                | 32.23       | 26.57**    | 5.22          | 3.76        | -2.13        | 0.00          |
| BPT-2411XSHIATS Dhan 1        | 34.17       | 10.63**    | 9.74*         | 9.98*       | 3.74         | 6.00          |
| BPT-2615XNDR-359              | 35.60       | 15.08**    | 14.58**       | 14.58**     | 8.09*        | 10.43*        |
| BPT-2615XBM-71                | 30.27       | 18.46**    | -1.73         | -2.58       | -8.10*       | -6.10         |
| BPT-2615XSHIATS Dhan 1        | 34.87       | 12.59**    | 11.99**       | 12.23**     | 5.87         | 8.17*         |
| NLR-34449XNDR-359             | 30.67       | 1.88       | -1.29         | -1.29       | -6.88        | -4.86         |
| NLR-34449X BM-71              | 32.43       | 31.22**    | 11.33*        | 4.40        | -1.52        | 0.62          |
| NLR-34449X SHIATS Dhan 1      | 37.46       | 24.31**    | 20.32**       | 20.58**     | 13.74**      | 16.22**       |

On the basis of *per se* performance and economic heterosis for important quantitative traits five best rice hybrids identified over the best check given in (table 4.13).

**Table4.13 Five best hybrids based on *per se* and economic heterosis (Hc) for quantitative characters in Rice**

| S.N. | Crosses                   | Characters                    | MEAN   | Hc        |
|------|---------------------------|-------------------------------|--------|-----------|
| 1.   | Days to 50% Flowering     | Sahabhagi dhan x SHIATS Dhan1 | 79.67  | -20.86**  |
|      |                           | MTU1010 x BM71                | 86.00  | -14.57 ** |
|      |                           | MTU1001 x BM71                | 90.00  | -10.60 ** |
|      |                           | NLR34449 x NDR359             | 89.00  | -11.59 ** |
|      |                           | Sahahabhagi dhan x NDR359     | 89.00  | -11.59**  |
| 2.   | Plant height(cm)          | BPT2411 x NDR359              | 100.13 | -8.53**   |
|      |                           | BPT2615 x NDR359              | 100.97 | -7.76**   |
|      |                           | MTU1010 x SHIATS Dhan1        | 106.57 | -10.60**  |
|      |                           | BPT-5204XBM71                 | 109.71 | -7.97**   |
|      |                           | MTU1001 x SHIATS Dhan1        | 109.53 | -8.11**   |
| 3.   | Test weight(g)            | MTU1010 x NDR359              | 24.93  | 19.49 **  |
|      |                           | NLR34449 x BM71               | 21.57  | 12.72 **  |
|      |                           | BPT2615 x SHIATS Dhan1        | 20.83  | 8.89**    |
|      |                           | BPT2411 x BM71                | 21.60  | 12.89**   |
|      |                           | BPT5204 x BM71                | 20.53  | 7.32      |
| 5    | Grain yield/plant         | NLR-34449 x SHIATS Dhan 1     | 37.46  | 13.74**   |
|      |                           | Sahabhagi dhanxSHIATS Dhan 1  | 36.17  | 9.82*     |
|      |                           | BPT-2615 x NDR-359            | 35.6   | 8.09*     |
|      |                           | MTU-1001 x NDR-359            | 35.43  | 7.59      |
|      |                           | Sahabhagi dhan x NDR-359      | 35.37  | 7.39      |
| 6.   | Number of Grains/ panicle | BPT-5204 x SHIATS Dhan 1      | 223.33 | 29.92**   |
|      |                           | BPT-5204 x NDR-359            | 208.5  | 21.29**   |
|      |                           | BPT-2411 x SHIATS Dhan 1      | 207.87 | 20.92**   |
|      |                           | NLR-34449 x SHIATS Dhan 1     | 206.27 | 19.99**   |
|      |                           | MTU-1010 x BM-71              | 205.2  | 19.37**   |

## 4.6 Combining ability analysis

The analysis of variance showed highly significant differences among the genotypes for all the yield and yield contributing characters. The mean sum of square due to genotypes, GCA, SCA, lines and testers were significant for all the characters presented in (table no 4.14) So all the characters were subjected to combining ability analysis of line x tester design proposed by Kempthorne (1957).

### 4.6.1 Estimation of general and specific combining ability effects

The character wise estimates of general combining ability (*gca*) effects (seven lines and three testers) and specific combining ability (*sca*) effects of (21 hybrids) for different characters and analysis are presented in character-wise below. (Table 4.15 and 4.16)

#### 4.6.1 Days to 50% flowering

General combining ability effects for days to 50% flowering showed wide range of variation only five parents viz., Sahabhagi dhan (-8.51\*\*), MTU 1010 (-4.24\*\*), NLR 34449 (-1.16\*\*) SHIATS Dhan1 (-0.93) and MTU 1001 (-0.91\*) showed negative *gca* effect for days to 50% flowering Among the lines showed significant negative *gca* effects for days to 50% flowering these parents considered as good combiners for earliness.

Promising hybrids which scored significant negative *sca* effects are MTU 1010 x BM 71 (-7.25\*\*) MTU 1001 x BM 71(-6.58\*\*), Sahabhagi dhan x SHIATS Dhan1 (-7.25\*\*), BPT 2411 x SHIATS Dhan1 (-4.96\*\*), BPT 2615 x NDR 359 (-2.57) and NLR 34449 x NDR 359. -5.99\*\*) were recorded as a good specific combiners to days to 50% flowering.

#### 4.6.2 Plant height (cm)

*Gca* effects for plant height showed wide range of variation Among the lines MTU 1010 (-4.06\*\*) and MTU-1001(-2.45\*\*) exhibited significant negative *gca* effects, Among the testers, *gca* effects of NDR-359(-3.77\*\*) were significant and negative.

Evaluation of 21 crosses for *sca* effects for the trait plant height revealed that 7 crosses were good with significant negative *sca* values. Desirable cross combinations with significant negative *sca* effects were, MTU-1010 x SHIATS Dhan1(-6.03\*\*), MTU-1001 x SHIATS Dhan1( -4.68\*\*), Sahabhagi dhan x SHIATS Dhan1 (-5.89\*\*), BPT-5204 x BM-71 (-7.96\*\*), BPT-2411 x NDR-359 (-10.08\*\*), BPT 2615 x NDR 359 (-9.85\*\*) and NLR 34449 x NDR359 (-3.79\*) were recorded as good specific combiners for plant height.

#### 4.6.3 Number of tillers / plant

Among the lines BPT-5204 (1.4\*\*) recorded significant positive *gca* effects and in testers SHIATS Dhan1 (0.75\*\*) showed significant positive *gca* effects which indicates that these parents are good combiners for number of tillers/plant.

Evaluation of the hybrids for *sca* effects for number of tillers per plant revealed that one cross was good with significant positive *gca* effects. The cross MTU 1001 x BM 71 (1.86\*\*) found good combiner for number of tillers/plant.

#### 4.6.4 Number of panicles/plant

Among the lines BPT 5204 (1.4\*\*) recorded significant positive *gca* effects and in testers SHIATS Dhan1 (1.08\*\*) recorded significant positive effects were found to be good general combiners for number of panicles/plant.

Evaluation of the hybrids for *sca* effects for number of number of panicle/plant revealed that 1 cross was good with significant positive *gca* effects. The cross MTU 1001 x BM 71 (1.94\*\*) was the desirable specific combiner.

#### 4.6.5 Panicle length (cm)

For panicle length none of the line or testers showed significant positive *gca* effects. For panicle length, 3 hybrids exhibited significant positive *sca* effects BPT-5204 x SHIATS Dhan1, (1.68) BPT-2411 x BM-71(1.64), Sahabhagi dhan x NDR-359 (0.67) were non significant but positive had been said as good combiners for panicle length.

#### 4.6.6 Flag leaf length (cm)

The *gca* effect for flag leaf length among the lines MTU 1010 (0.28), BPT 2615 (0.49) and BPT 2411 (0.37) showed positive *gca* effects but non significant. The tester NDR-359(0.49) and SHIATS Dhan1 (0.09) recorded positive *gca* effect. Thus this parents were considered as average combiners for flag leaf length.

The one hybrid NLR 34449 x NDR 359 (2.54\*\*) registered significant positive *sca* effects has been said as a good combination for this trait.

#### 4.6.7 Flag leaf width (cm)

Among the lines, MTU-1010 (0.09\*\*), BPT 2615 (0.04) recorded significant positive *gca* effects. Among the testers, NDR 359 (0.01) and BM 71 (0.01) exhibited positive *gca* effects but not significant were considered as average general combiners for flag leaf width.

For the character flag leaf width, 5 crosses exhibited significant positive *sca* effects, while 5 crosses recorded significant negative *sca* effects five hybrids MTU 1001 x SHIATS Dhan1, (0.17\*\*) Sahabhagi dhan x BM 71 (0.11\*\*) BPT 5204 x BM 71 (0.11\*\*), BPT 2411 x SHIATS Dhan1 (0.11\*) and NLR 34449 x NDR 359 (0.9\*) were superior with significant positive *sca* effects thus this hybrids was recorded as best specific combiners for flag leaf width.

#### **4.6.8 Number of grains / panicle**

For the character number of grains/panicle, three lines BPT-5204 (12.41), BPT-2411 (10.88\*\*) and MTU-1010 (7.73\*\*) showed significant positive *gca* effects. The testers SHIATS Dhan1 (7.47\*\*) exhibited significant positive *gca* effects and *Sca* effects were identified as a good general combiners for number of grains/panicle.

The maximum *sca* effects was recorded in five hybrids viz., NLR 34449 x SHIATS Dhan1 (20.09\*\*), Sahabhagi dhan x BM 71 (19.05\*\*), MTU 1010 x BM 71 (17.08\*\*), BPT 5204 x SHIATS Dhan 1 (14.27\*\*) and MTU 1001 x NDR 359 (11.39\*\*) recorded high *sca* effects which were significant and positive high *sca* effects were identified as best specific combiner for number of grains/panicle.

#### **4.6 .9 Days to Maturity**

General combining ability effects for days to maturity showed wide range of variation only three lines viz., Sahabhagi dhan (-583\*\*), MTU 1010 (-5.08\*\*) showed negative significant *gca* effect for days to maturity among the testers NDR359 (-0.33) and BM 71 (-0.12) showed non significant negative *gca* effects for days to maturity these parents considered as good combiners for maturity.

Out of the 21 crosses studied significant negative specific combining ability effects exhibited by 6 crosses, which are desirable. Promising hybrids which scored significant negative *sca* effects are BPT 2411 x SHIATS Dhan1 (7.29\*\*), MTU 1010 x BM 71 (-6.73), MTU-1001 x BM 71 (-3.71\*\*), Sahabhagi dhan x NDR 359 (-3.61\*\*), BPT 2615 x NDR 359 (-2.96\*\*) and BPT-5204 x NDR 359 (-1.52) were recorded as best specific combiners for early maturity.

#### **4.6.10 Spikelet fertility (%)**

For the trait spikelet fertility %, the *gca* effects of one lines MTU 1010 (1.27) and NLR 34449 (0.12) were positive and non significant . The testers SHIATS Dhan1 (1.47\*) was positive and showed significant *gca* effects. Lines MTU 1010 and NLR 34449 were

considered as average general combiners and tester SHIATS Dhan1 was considered as good general combiner.

Evaluation of the cross combinations for spikelet fertility per cent revealed that 2 crosses exhibited significant positive *sca* effects, whereas .The cross Sahabhagi dhan x NDR 359 (3.44\*) and BPT 2615 x BM 71 (3.04\*) exhibited significant positive *sca* effects were identified as good specific combiners for spikelet fertility %.

#### **4.6.11 Spikelet sterility (%)**

For the trait spikelet sterility %, the *gca* effects of one lines MTU-1001 (3.53\*\*) were positive and significant .The testers BM-71 (1.98\*) was positive significant *gca* effects were identified as good general combiners.

Evaluation of the cross combinations for spikelet sterility per cent revealed that 2 crosses Sahabhagi dhan x NDR 359 and BPT 2615 x BM 71 exhibited significant negative *sca* effects. The cross BPT 2615 x NDR-359 and Sahabhagi dhan x BM 71 exhibited positive *sca* effects but not significant.

#### **4.6.12 Biological yield (g)**

For Biological yield, the lines Sahabhagi dhan (2.21) followed by NLR 34449 (0.87) registered positive *gca* effects but not significant. Among the testers SHIATS Dhan1 (3.33\*\*) exhibited significant positive *gca* effects .The lines Sahabhagi dhan and NLR 3449 were identified as average combiners and tester SHIATS Dhan1 was identified as good general combiner.

For Biological yield, 2 crosses recorded significant positive *sca* effects MTU 1001 x NDR-359 (6.55\*\*) and MTU 1010 x BM 71 (6.24\*\*) exhibited significant positive *sca* effects were identified as good specific combiners for biological yield.

#### **4.6.13 Harvest index**

For harvest index MTU 1010 (0.62), MTU 1001 (0.12) and BPT 2615 (0.09) registered positive *gca* effects but not significant. Four lines Sahabhagi dhan, BPT-2411, BPT-5204 and NLR 34449 negative *gca* effects but not significant. Among the testers NDR 359 (0.23) positive *gca* effects and negative *gca* effects were registered by BM 71. MTU 1010, MTU 1001, BPT 2615 and NDR 359 were identified as average general combiner for harvest index.

For Harvest index, one cross BPT 2615 x NDR 359 (1.53\*) recorded significant positive *sca* effects considered as best specific combiner for harvest index.

#### 4.6.14 Test weight (g)

Among the lines, Sahabhagi dhan (1.56\*\*), MTU-1010 (0.95\*\*) and, MTU 1001 (0.45\*) analysis were good for test weight with positive significant *gca* effects. Among the testers, NDR-359 (0.09\*) were found to be good general combiners with significant positive *gca* effect were identified as average general combiners.

Positive significant *sac* effects for test weight were found for 6 crosses manifested significant positive *sca* effects, whereas 7 crosses exhibited significant negative *sca* effects. Some of the cross combinations with significant positive *sca* effects are MTU 1010 x NDR 359 (3.29\*\*), MTU 1001 x NDR 359 (2.32\*\*), BPT 5204 x BM 71 (1.91\*\*) and BPT 2411 x BM 71 (2.26\*\*) were identified as good specific combiners for test weight.

#### 4.6.15 Grain yield / plant

The positive significant *gca* effect for grain yield/plant were exhibited by Sahabhagi dhan (1.03) and MTU-1010 (0.32) manifested positive *gca* effects. Among the testers, SHIATS Dhan1 (1.43\*\*) recorded significant positive *gca* effects which indicated these parents to be good general combiners for grain yield per plant.

Promising parental lines identified of rice on the basis of *per se* and GCA effects for important yield related traits are presented in (table 4.17).

For grain yield per plant, 3 crosses recorded significant positive *sca* effects. Among twenty one hybrids, three hybrids MTU 1010 x BM 71(3.44\*\*), MTU 1001 x NDR 359 (2.34), and NLR 34449 x SHIATS Dhan 1 (2.51\*\*) registered significant positive *sca* effects were identified as good specific combiners for grain yield/plant.

Promising hybrids identified on the basis of *Per se*, combining ability effects and economic heterosis in for yield related traits presented in (table 4.18).

**Table 4.14 Analysis of variance for combining ability for 15 quantitative characters in rice.**

|                         |    | Days to<br>50%<br>Flowering | Plant<br>Height<br>(cm) | Number<br>of<br>Tillers/<br>Plant | Number<br>of<br>panicles<br>/plant | Panicle<br>Length<br>(cm) | Flag<br>Leaf<br>Length<br>(cm) | Flag<br>Leaf<br>Width<br>(cm) | Number of<br>Grains /<br>panicle | Days to<br>Maturity | Spikelet<br>Fertility<br>(%) | Spikelet<br>Sterility<br>(%) | Biological<br>Yield (g) | Harvest<br>Index<br>(%) | Test<br>Weight<br>(g) | Grain<br>Yield/<br>Plant (g) |
|-------------------------|----|-----------------------------|-------------------------|-----------------------------------|------------------------------------|---------------------------|--------------------------------|-------------------------------|----------------------------------|---------------------|------------------------------|------------------------------|-------------------------|-------------------------|-----------------------|------------------------------|
| Replicates              | 2  | 0.45                        | 5.21                    | 1.31                              | 1.83                               | 1.76                      | 0.18                           | 0.01                          | 35.36                            | 0.51                | 1.96                         | 2.43                         | 10.42                   | 1.24                    | 0.22                  | 3.69                         |
| Crosses                 | 20 | 139.7**                     | 147.97**                | 4.36**                            | 5.82**                             | 4.44*                     | 5.66**                         | 0.04**                        | 849.59**                         | 92.98**             | 19.03**                      | 31.27**                      | 61.15**                 | 2.66                    | 13.22*<br>*           | 14.74**                      |
| Line Effect             | 6  | 288.94*                     | 84.11                   | 5.49                              | 5.59                               | 6.14                      | 2.87                           | 0.04                          | 1029.81                          | 201.02*             | 13.95                        | 29.27                        | 19.92                   | 0.98                    | 9.13                  | 4.66                         |
| Tester Effect           | 2  | 23.14                       | 223.8                   | 8.9                               | 24.11**                            | 2.68                      | 6.2                            | 0.01                          | 1414.88                          | 3.4                 | 43.12                        | 105.28*                      | 208.31                  | 2.63                    | 4.16                  | 53.75*                       |
| Line * Tester<br>Effect | 12 | 84.51**                     | 167.27**                | 3.05**                            | 2.89*                              | 3.89                      | 6.96**                         | 0.05**                        | 665.26**                         | 53.88**             | 17.55**                      | 19.94*                       | 57.24**                 | 3.51*                   | 16.77*<br>*           | 13.28**                      |
| Error                   | 40 | 0.7                         | 7.71                    | 1.06                              | 1.3                                | 1.99                      | 1.9                            | 0.01                          | 83.38                            | 1.55                | 6.25                         | 8.54                         | 15.19                   | 1.59                    | 0.43                  | 2.14                         |
| Total                   | 62 | 45.53                       | 52.88                   | 2.13                              | 2.78                               | 2.77                      | 3.05                           | 0.02                          | 329                              | 31.01               | 10.24                        | 15.68                        | 29.86                   | 1.92                    | 4.55                  | 6.25                         |
| Var.gca                 |    | 10.33                       | 9.82                    | 0.41                              | 0.91                               | 0.09                      | 0.16                           | 0.008                         | 77                               | 6.73                | 1.5                          | 4                            | 6.47                    | 0.01                    | 0.42                  | 1.79                         |
| Var.sca                 |    | 27.83                       | 53.56                   | 0.69                              | 0.57                               | 0.28                      | 1.63                           | 0.01                          | 199.29                           | 17.52               | 3.84                         | 4.24                         | 13.4                    | 0.61                    | 5.46                  | 3.64                         |
| gca/ca                  |    | 0.37                        | 0.18                    | 0.59                              | 1.60                               | 0.32                      | 0.10                           | 0.70                          | 0.39                             | 0.38                | 0.39                         | 0.94                         | 0.48                    | 0.02                    | 0.08                  | 0.49                         |

\*Significance at 5% level, \*\*significance at 1% level

**Table 4.15 General Combining ability effects of parent for 15 quantitative characters in rice**

| Character          | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles/ plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant (g) |
|--------------------|-----------------------|-------------------|--------------------------|---------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|------------------------|
| MTU-1010           | -4.24**               | -4.06**           | 0.24                     | 0.28                      | 0.28                | 0.72                  | 0.09**               | 7.73**                     | -5.08**          | 1.27                   | -2.08*                 | 0                    | 0.62              | 0.95**          | 0.32                   |
| MTU-1001           | -0.91*                | -2.45**           | 0.29                     | 0.47                      | -0.08               | 0.12                  | 0.03                 | -7.89**                    | -1.1**           | -2.47**                | 3.53**                 | -1.23                | 0.12              | 0.45*           | -0.48                  |
| Shahabagi dhan     | -8.51**               | 5.49**            | -0.29                    | -0.33                     | -1.21*              | -0.7                  | 0                    | -13.48**                   | -5.83**          | 0.9                    | -1.43                  | 2.21                 | -0.41             | 1.56**          | 1.03                   |
| BPT-5204           | 6.53**                | 0.83              | 1.4**                    | 1.32**                    | 1.06                | -0.42                 | -0.11**              | 12.41**                    | 5.91**           | -0.58                  | 0.05                   | -2.32                | -0.15             | -1.19**         | -1.24*                 |
| BPT-2411           | 7.53**                | -0.89             | -0.79*                   | -0.08                     | 0.57                | 0.37                  | -0.04                | 10.88**                    | 6.15**           | 0.16                   | 0.65                   | -0.32                | -0.25             | -0.48*          | -0.17                  |
| BPT-2615           | 0.76*                 | -0.27             | -0.92**                  | -1.14**                   | -0.98               | 0.49                  | 0.04                 | 0.83                       | 0.36             | 0.6                    | -0.33                  | 0.79                 | 0.09              | -0.79***        | 0.3                    |
| NLR-34449          | -1.16**               | 1.36              | 0.06                     | -0.53                     | 0.36                | -0.58                 | -0.01                | -10.47**                   | -0.41            | 0.12                   | -0.39                  | 0.87                 | -0.02             | -0.5*           | 0.25                   |
| NDR-359            | -0.21                 | -3.77**           | -0.41                    | -1.06**                   | 0.35                | 0.49                  | 0.01                 | 1.32                       | -0.33            | -0.09                  | 0.45                   | -0.39                | 0.23              | 0.39**          | 0.3                    |
| BM-71              | 1.14**                | 1.97**            | -0.34                    | -0.02                     | -0.36               | -0.58                 | 0.01                 | -8.79**                    | -0.12            | -1.39*                 | 1.98**                 | -2.94**              | -0.41             | -0.48**         | -1.73**                |
| SHIATS Dhan 1      | -0.93**               | 1.8**             | 0.75**                   | 1.08**                    | 0.01                | 0.09                  | -0.02                | 7.47**                     | 0.45             | 1.47**                 | -2.43**                | 3.33**               | 0.18              | 0.09            | 1.43**                 |
| CD 95% GCA(Line)   | 0.68                  | 1.73              | 0.66                     | 0.73                      | 1.17                | 0.97                  | 0.05                 | 5.53                       | 0.77             | 1.65                   | 1.81                   | 2.78                 | 0.87              | 0.42            | 1.04                   |
| CD 95% GCA(Tester) | 0.45                  | 1.13              | 0.44                     | 0.48                      | 0.77                | 0.64                  | 0.03                 | 3.62                       | 0.51             | 1.08                   | 1.19                   | 1.82                 | 0.57              | 0.28            | 0.68                   |

\*Significance at 5% level, \*\*significance at 1% level

**Table 4.16 Specific Combining ability effects of hybrids for 15 quantitative characters in rice**

| <b>F1 crosses (Hybrids)</b>  | <b>Days to 50% Flowering</b> | <b>Plant Height (cm)</b> | <b>Number of Tillers/ Plant</b> | <b>Number of panicles/ plant</b> | <b>Panicle Length (cm)</b> | <b>Flag Leaf Length (cm)</b> | <b>Flag Leaf Width (cm)</b> | <b>Number of Grains / panicle</b> | <b>Days to Maturity</b> | <b>Spikelet Fertility (%)</b> | <b>Spikelet Sterility (%)</b> | <b>Biological Yield (g)</b> | <b>Harvest Index (%)</b> | <b>Test Weight (g)</b> | <b>Grain Yield/ Plant (g)</b> |
|------------------------------|------------------------------|--------------------------|---------------------------------|----------------------------------|----------------------------|------------------------------|-----------------------------|-----------------------------------|-------------------------|-------------------------------|-------------------------------|-----------------------------|--------------------------|------------------------|-------------------------------|
| MTU-1010 X NDR-359           | 3.43**                       | 7.97**                   | -0.43                           | 0.01                             | 0.45                       | 0.14                         | -0.06                       | -7.23                             | 4.04**                  | -0.52                         | 0.08                          | -0.39                       | -0.93                    | 3.29**                 | -1.16                         |
| MTU-1010 XBM-71              | -7.25**                      | -1.94                    | 0.04                            | -0.9                             | 0.23                       | -1.18                        | 0.06                        | 17.08**                           | -6.73**                 | 1.81                          | -1.95                         | 6.24*                       | 0.81                     | -3.34**                | 3.44**                        |
| MTU-1010 X SHIATS Dhan 1     | 3.82**                       | -6.03**                  | 0.38                            | 0.9                              | -0.67                      | 1.04                         | 0.01                        | -9.85*                            | 2.7**                   | -1.29                         | 1.86                          | -5.85*                      | 0.12                     | 0.05                   | -2.28*                        |
| MTU-1001 X NDR-359           | 3.1**                        | 5.39**                   | -1.72**                         | -1.12                            | 0.51                       | -0.43                        | -0.11*                      | 11.39*                            | 2.33**                  | 2.85                          | -2.1                          | 6.55**                      | -0.73                    | 2.32**                 | 2.34*                         |
| MTU-1001X BM-71              | -6.58**                      | -0.71                    | 1.86**                          | 1.94**                           | 0.19                       | -0.22                        | -0.06                       | 2.47                              | -3.71**                 | -1.48                         | 1.94                          | -6*                         | 1.24                     | -3.47**                | -1.73                         |
| MTU-1001X SHIATS Dhan 1      | 3.48**                       | -4.68**                  | -0.14                           | -0.83                            | -0.71                      | 0.64                         | 0.17**                      | -13.86**                          | 1.38*                   | -1.37                         | 0.15                          | -0.55                       | -0.52                    | 1.15**                 | -0.62                         |
| Sahabagi dhanX NDR-359       | 1.37*                        | 5.98**                   | 0.6                             | -0.35                            | 0.67                       | -0.07                        | 0                           | -6.45                             | -3.61**                 | 3.44*                         | -4.04*                        | 0.19                        | -0.14                    | 0.14                   | 0.76                          |
| Sahabagi dhanX BM-71         | 5.88**                       | -0.09                    | 0.07                            | 0.57                             | -0.12                      | 0.2                          | 0.11**                      | 19.05**                           | 1.69*                   | -3.12*                        | 2.6                           | -2.85                       | 0.53                     | 0.38                   | -1.2                          |
| Sahabagi dhan XSHIATS Dhan 1 | -7.25**                      | -5.89**                  | -0.66                           | -0.23                            | -0.55                      | -0.13                        | -0.12**                     | -12.6*                            | 1.92**                  | -0.32                         | 1.44                          | 2.67                        | -0.39                    | -0.53                  | 0.44                          |
| BPT-5204X NDR-359            | -0.68                        | 4.38**                   | 0.14                            | 1.14                             | -0.97                      | 1.82*                        | 0.03                        | 5.59                              | -1.52*                  | -1.93                         | 2.75                          | -0.29                       | 0.61                     | -1.6**                 | 0                             |
| BPT-5204XBM-71               | -0.03                        | -7.96**                  | 0.24                            | -1                               | -0.72                      | 0.33                         | 0.11*                       | -19.87**                          | 0.28                    | -0.7                          | 0.19                          | 0.84                        | -1.33                    | 1.91**                 | -0.44                         |
| BPT-5204XSHIATS Dhan 1       | 0.7                          | 3.58*                    | -0.38                           | -0.14                            | 1.68                       | 1.49                         | -0.14**                     | 14.27**                           | 1.24                    | 2.64                          | -2.94                         | -0.55                       | 0.72                     | -0.3                   | 0.44                          |
| BPT-2411XNDR-359             | 1.32*                        | -10.08**                 | 0.36                            | 0.24                             | -1.84                      | -0.44                        | 0.07                        | 0.15                              | 2.92**                  | -1.88                         | 1.35                          | -2.82                       | 0.44                     | -0.98**                | -0.5                          |
| BPT-2411XBM-71               | 3.64**                       | 7.55**                   | -0.3                            | 0.23                             | 1.64                       | -0.56                        | -0.18**                     | -0.48                             | 4.38**                  | 0.69                          | 0.15                          | 1.71                        | 0.37                     | 2.26**                 | 0.86                          |
| BPT-2411XSHIATS Dhan 1       | -4.96**                      | 2.52                     | -0.06                           | -0.47                            | 0.2                        | 1                            | 0.11*                       | 0.33                              | -7.29**                 | 1.19                          | -1.5                          | 1.11                        | -0.82                    | -1.28**                | -0.36                         |
| BPT-2615XNDR-359             | -2.57**                      | -9.85**                  | 0.26                            | 0.43                             | 0.88                       | 0.07                         | -0.03                       | -0.06                             | -2.96**                 | -1.59                         | 2.33                          | 1.94                        | 1.53*                    | -1.24**                | 1.72                          |
| BPT-2615XBM-71               | 1.75**                       | 2.27                     | -0.27                           | -0.61                            | -0.21                      | 1.05                         | 0.06                        | -1.56                             | 3.17**                  | 3.04*                         | -3.43*                        | -1.76                       | -1.3                     | 0.01                   | -1.58                         |
| BPT-2615XSHIATS Dhan 1       | 0.82                         | 7.58**                   | 0                               | 0.19                             | -0.67                      | -1.12                        | -0.03                       | 1.62                              | -0.2                    | -1.45                         | 1.11                          | -0.18                       | -0.23                    | 1.23**                 | -0.14                         |
| NLR-34449XNDR-359            | -5.99**                      | -3.79*                   | 0.78                            | -0.35                            | 0.3                        | 2.54*                        | 0.09*                       | -3.4                              | -1.2                    | -0.37                         | -0.37                         | -5.16*                      | -0.79                    | -1.93**                | -3.16**                       |
| NLR-34449X BM-71             | 2.59**                       | 0.87                     | -1.64                           | -0.23                            | -1.02                      | 0.38                         | -0.1*                       | -16.69**                          | 0.93                    | -0.23                         | 0.5                           | 1.82                        | -0.33                    | 2.25**                 | 0.64                          |
| NLR-34449X SHIATS Dhan 1     | 3.39**                       | 2.91                     | 0.86                            | 0.57                             | 0.72                       | 2.92*                        | 0                           | 20.09**                           | 0.26                    | 0.6                           | -0.13                         | 3.35                        | 1.12                     | -0.33                  | 2.51**                        |
| CD 95% SCA                   | 1.18                         | 3                        | 1.15                            | 1.27                             | 2.03                       | 1.68                         | 0.08                        | 9.58                              | 1.34                    | 2.87                          | 3.14                          | 4.82                        | 1.51                     | 0.73                   | 1.8                           |

\*Significance at 5% level, \*\*significance at 1% level

**Table 4.17 Promising parental lines of rice on the basis of perse and GCA effects for important yield related traits**

| Characters                       | Parent         | <i>Perse</i> | GCA     |
|----------------------------------|----------------|--------------|---------|
| Grain Yield/ Plant               | BPT-5204       | 33.23        | -1.24*  |
|                                  | SHIATS Dhan 1  | 31.13        | 1.43**  |
|                                  | BM 71          | 20.3         | -1.73** |
|                                  | MTU 1010       | 30.73        | 0.32    |
| Days to 50% Flowering            | BPT-5204       | 105.33       | 6.53**  |
|                                  | BPT-2411       | 102          | 7.53**  |
|                                  | BM 71          | 102.33       | 1.14**  |
| Plant Height (cm)                | Sahabhagi dhan | 127.6        | 5.49**  |
|                                  | SHIATS Dhan 1  | 120.33       | 1.8**   |
|                                  | BM-71          | 125          | 1.97**  |
| Number of panicles/plant         | BPT-5204       | 14.77        | 1.32**  |
|                                  | SHIATS Dhan 1  | 14.6         | 1.08**  |
| Total number of Grains / panicle | BPT-5204       | 172.67       | 12.41** |
|                                  | BPT-2411       | 185          | 10.88** |
|                                  | SHIATS Dhan 1  | 206.97       | 7.47**  |
|                                  | MTU 1010       | 145          | 7.73**  |

**Table 4.18 Promising hybrids identified on the basis of *Per se*, combining ability effects and economic heterosis for yield related traits.**

| S.N | Hybrids                   | Per se | SCA effect | Hc<br>(Economic<br>heterosis) | Parents        |               |               |               |
|-----|---------------------------|--------|------------|-------------------------------|----------------|---------------|---------------|---------------|
|     |                           |        |            |                               | Female         | GCA<br>effect | Male          | GCA<br>effect |
| 1.  | Days to 50% flowering     |        |            |                               |                |               |               |               |
|     | NLR344449 X BM71          | 98.93  | 3.44**     | -1.72*                        | NLR34449       | -1.16*        | BM 71         | 1.14**        |
|     | MTU1001 X NDR359          | 98.33  | 3.1**      | -2.32*                        | MTU1001        | -0.91*        | NDR359        | -0.21         |
|     | MTU1001 X SHIATS Dhan1    | 98.0   | 3.48**     | -2.65*                        | MTU 1001       | -0.91*        | SHIATS Dhan1  | -0.93**       |
|     | BPT-2615 X SHIATS Dhan1   | 97     | 0.82       | -2.65*                        | BPT 2615       | 0.76*         | SHIATS Dhan1  | -0.93**       |
|     | JAYA ( Check)             | 100.6  | -          | -                             | -              | -             | -             | -             |
| 2.  | Plant height              |        |            |                               |                |               |               |               |
|     | MTU-1001X BM-71           | 113.67 | -0.71      | -7.02**                       | MTU 1001       | -2.45**       | BM 71         | 1.97**        |
|     | BPT-5204X NDR-359         | 116.30 | 4.38**     | -2.43                         | BPT 5204       | 0.83          | NDR 359       | -3.57**       |
|     | MTU-1010 X SHIATS Dhan 1  | 106.57 | -6.03**    | -10.60**                      | MTU 1010       | -4.06**       | SHIATSdhan-1  | 1.8**         |
|     | BPT2615 X NDR359          | 100.97 | -9.58**    | -15.30**                      | BPT2615        | -0.27         | NDR359        | -3.57**       |
|     | JAYA ( Check)             | 119.2  |            |                               |                |               |               |               |
| 3.  | Test weight               |        |            |                               |                |               |               |               |
|     | MTU1010XNDR359            | 24.93  | 20.09**    | 3.29**                        | MTU1010        | -0.95**       | NDR359        | 0.39**        |
|     | MTIU1001XNDR359           | 23.47  | 19.05**    | 2.32**                        | MTU1001        | 0.45**        | NDR359        | 0.39**        |
|     | SAHABHAGIDHANXNDR359      | 22.40  | 17.08**    | 0.14                          | SAHABHAGIDHAN  | 1.56**        | NDR359        | 0.39**        |
|     | MTU1001XSHIATSDHAN1       | 22.00  | 14.27**    | 1.15**                        | MTU1001        | 0.45*         | SHIATSDHAN1   | 0.09          |
|     | JAYA CHECK                | 20.87  |            |                               |                |               |               |               |
| 4   | Grain yield/plant         |        |            |                               |                |               |               |               |
|     | MTU-1010 XBM-71           | 35.30  | 3.44**     | 7.19                          | MTU 1010       | 0.32          | BM 71         | -1.73         |
|     | NLR-34449X SHIATS Dhan 1  | 37.46  | 2.51**     | 13.74**                       | NLR 34449      | 0.25          | SHIATSdhan-1  | 1.43**        |
|     | MTU-1001 X NDR-359        | 35.43  | 2.34*      | 7.59                          | MTU 1001       | -0.48         | NDR 359       | 0.3           |
|     | BPT-2615XNDR-359          | 35.60  | 1.72       | 8.09*                         | BPT 2615       | 0.3           | NDR 359       | 0.3           |
|     | IR 64 ( Check)            | 32.93  | -          | -                             | -              | -             | -             | -             |
| 5.  | Number of panicles/plant  |        |            |                               |                |               |               |               |
|     | MTU-1001X BM-71           | 15.67  | 1.94**     | 32.02**                       | MTU 1001       | 0.47          | BM 71         | -0.02         |
|     | BPT-5204X NDR-359         | 14.67  | 1.14       | 5.34                          | BPT 5204       | 1.32**        | NDR 359       | -1.06**       |
|     | MTU-1010 X SHIATS Dhan 1  | 15.53  | 0.9        | 28.02**                       | MTU 1010       | 0.28          | SHIATSdhan-1  | 1.08**        |
|     | NLR-34449X SHIATS Dhan 1  | 14.4   | 0.57       | 18.68**                       | NLR 34449      | -0.53         | SHIATSdhan-1  | 1.08**        |
|     | IR 64 ( Check)            | 11.87  |            |                               |                |               |               |               |
| 6.  | Number of grains /panicle |        |            |                               |                |               |               |               |
|     | NLR-34449X SHIATS Dhan 1  | 206.27 | 20.09**    | 19.99**                       | NLR 34449      | -10.47**      | SHIATS dhan-1 | 7.47**        |
|     | Shahabagi dhanX BM-71     | 185.97 | 19.05**    | 8.18*                         | Shahabhagidhan | -13.48**      | BM 71         | -8.79**       |
|     | MTU-1010 XBM-71           | 205.20 | 17.08**    | 19.37**                       | MTU 1010       | 7.73**        | BM 71         | -8.79**       |
|     | BPT-5204XSHIATS Dhan 1    | 223.33 | 14.27**    | 29.92**                       | BPT 5204       | 12.41**       | SHIATS dhan-1 | 7.47**        |
|     | IR 64 (Check)             | 171.90 | -          | -                             | -              | -             | -             | -             |

### **Percent contribution of parents and crosses**

The percent contribution of parents, crosses and their interactions have been tabulated in (table 4.19). The highest proportional contribution of female parent was observed for days to maturity (64.86), days to 50% flowering (62.04), panicle length (41.42), number of tillers/plant (37.71) and number of grains /panicle.

The proportional contribution of male parent also studied. The highest proportional contribution was shown by number of panicles/plant (41.40), grain yield/plant (36.45), biological yield (34.06) and spikelet fertility % (22.66). The contribution of interaction of line x tester was exhibited through harvest index (79.07), test weight (76.12), plant height (67.02), flag leaf length (73.82) and grain yield/plant (54.05).

**Table 4.19 Proportional contribution of lines, testers and interactions to total variance in rice**

| Source of variation | df | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles/ plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains/panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological yield ( g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant (g) |
|---------------------|----|-----------------------|-------------------|--------------------------|---------------------------|---------------------|-----------------------|----------------------|--------------------------|------------------|------------------------|------------------------|-----------------------|-------------------|-----------------|------------------------|
| Lines               | 6  | 62.47                 | 17.53             | 37.79                    | 28.79                     | 41.40               | 15.20                 | 28.57                | 36.36                    | 64.86            | 21.98                  | 28.07                  | 9.77                  | 11.03             | 20.72           | 9.48                   |
| Testers             | 2  | 1.65                  | 15.12             | 20.39                    | 41.40                     | 6.02                | 10.96                 | 1.51                 | 16.65                    | 0.36             | 22.66                  | 33.66                  | 34.06                 | 9.88              | 3.15            | 36.45                  |
| line x tester       | 12 | 36.29                 | 67.82             | 41.88                    | 29.80                     | 52.55               | 73.82                 | 69.91                | 46.98                    | 34.77            | 55.34                  | 38.25                  | 56.16                 | 79.07             | 76.12           | 54.05                  |

#### **4.7 Genetic parameters**

Coefficient of variance is the percentage ratio of standard deviation of a sample to its mean. Analysis of variance provides estimates of phenotypic, genotypic and environmental variance, which are used for the estimation of respective coefficient of variance (**Burton, 1952**).

##### **Phenotypic coefficient of variance**

A wide range of phenotypic coefficient of variation (PCV) was observed for different traits, it's ranged from 3.98 (harvest index) to 23.13 (spikelet sterility %). The moderate PCV was recorded for number of grains/panicles (15.54) followed by number of panicles/plant(14.43), number of tillers/plant (12.75), test weight (12.10), panicle length (11.05) and grain yield/plant (10.55) whereas low estimates of PCV were recorded for characters like biological yield (9.19), flag leaf width (8.61), days to 50% flowering (7.96), flag leaf length (7.16), plant height (6.88), spikelet fertility % (6.12) days to maturity (5.47) and harvest index (3.98) and high pcv was recorded for spikelet sterility % (23.13) presented in ( table 4.20).

##### **Genotypic coefficient of variance**

A wide range of Genotypic coefficient of variation (GCV) was observed for different traits, it's ranged from (2.66) harvest index to (20.02) spikelet sterility %. The moderate GCV was recorded for number of grains/panicles (14.87) followed by test weight (11.69) number of panicles/plant (11.91), and number of tillers/plant (11.03), whereas low estimates of PCV were recorded for characters like grain yield/plant (9.36 ). panicle length (8.87), days to 50% flowering (7.89), biological yield (7.38), flag leaf width (7.13), plant height (6.48), days to maturity (5.40) spikelet fertility % (5.27), flag leaf length (5.04), and harvest index (2.66) and high GCV was recorded for spikelet sterility percent (20.02).

##### **Heritability (broad sense)**

The estimates of heritability in broad sense for 15 yield traits as given table 4.3. The estimates heritability ranged from 45 (harvest index) to 98 (days to 50% flowering). High heritability was recorded for days to 50% flowering (98), days to maturity (97), Test weight (93) no. of grains /panicle (92), plant height (89), grain yield/plant (79), number of tillers/plant(75) spikelet sterility% (75), spikelet fertility % (74), flag leaf width (69), number

of panicles/plant (68), biological yield (65) and panicle length (64), and medium heritability was observed for flag leaf length (50) and harvest index (45).

### Genetic advance

A perusal of genetic advance for different traits revealed that it varied from 3.68 (harvest index) to (35.68) spikelet sterility % (35.68), number of grains/panicle (29.31), test weight (23.26), and number of panicles/plant (20.27) recorded highest estimates of genetic advance, whereas moderate estimate of genetic advance were recorded for characters like no. of number of tillers/ plant (19.64), grain yield/plant (17.12), days to 50% flowering (16.12) panicle length (14.68), plant height (12.57), Biological yield (12.22), flag leaf width (12.17) and days to maturity (10.97) and low estimate of genetic advance were recorded for characters like spikelet fertility % (9.37), flag leaf length (7.32) and harvest index (3.68).

**Table- 4. 20 Estimates of genetic parameters for 15 quantitative traits in rice**

| Parameters               | PCV   | GCV   | $h^2$<br>(Broad Sense)% | Genetic<br>Advancement<br>5% | Gen. Adv<br>as % of<br>Mean 5% |
|--------------------------|-------|-------|-------------------------|------------------------------|--------------------------------|
| Days to 50% Flowering    | 7.96  | 7.89  | 98                      | 15.51                        | 16.12                          |
| Plant Height (cm)        | 6.88  | 6.48  | 89                      | 14.51                        | 12.57                          |
| Number of Tillers/ Plant | 12.75 | 11.03 | 75                      | 2.96                         | 19.64                          |
| Number of panicles/plant | 14.43 | 11.91 | 68                      | 2.61                         | 20.27                          |
| Panicle Length (cm)      | 11.05 | 8.87  | 64                      | 3.82                         | 14.68                          |
| Flag Leaf Length (cm)    | 7.16  | 5.04  | 50                      | 2.19                         | 7.32                           |
| Flag Leaf Width (cm)     | 8.61  | 7.13  | 69                      | 0.18                         | 12.17                          |
| Nubero of Grains/panicle | 15.54 | 14.87 | 92                      | 52.54                        | 29.31                          |
| Days to Maturity         | 5.47  | 5.40  | 97                      | 13.93                        | 10.97                          |
| Spikelet Fertility (%)   | 6.12  | 5.27  | 74                      | 7.29                         | 9.37                           |
| Spikelet Sterility (%)   | 23.13 | 20.02 | 75                      | 7.98                         | 35.68                          |
| Biological yield (g)     | 9.19  | 7.38  | 65                      | 9.11                         | 12.22                          |
| Harvest Index (%)        | 3.98  | 2.66  | 45                      | 1.57                         | 3.68                           |
| Test Weight (g)          | 12.10 | 11.69 | 93                      | 4.61                         | 23.26                          |
| Grain Yield/ Plant (g)   | 10.55 | 9.36  | 79                      | 5.48                         | 17.12                          |

## 4.8 Morphological Diversity

Genetic diversity present in the available germplasm has immense value on crop improvement for a character of interest. From the point of selecting parents for hybridization, which are divergent enough for the character of interest, estimation of the genetic distance is most important for a successful breeding programme. The multivariate analysis using Mahalanobis'  $D^2$  statistic provides a useful statistical tool for measuring the genetic diversity in germplasm collections with respect to the characters considered together. The quantitative and quality assessment of genetic divergence was made by adopting Mahalanobis  $D^2$  statistic for yield and its contributing characters. Genetic divergence was estimated and the results obtained from the study are discussed below.

### 4.8.1 Clustering procedure

The genetic diversity among 34 genotypes was measured by employing  $D^2$  statistics to the data of 15 quantitative characters in the present study. Distribution of 34 genotypes into six clusters was at random with maximum number of 17 genotypes in cluster I. Cluster IV is the second largest with 9 genotypes followed by cluster III with 5 genotypes. The cluster II, V and VI were solitary clusters. The parents and hybrids in clusters II, V and VI are divergent to other parents and hybrids. presented in (table no 4.8.1).

### 4.8.2 Intra and inter cluster average distances

The intra and inter cluster average distances among six clusters were variable (table 4.8.2). The maximum intra cluster distance ( $D^2$ ) was recorded for cluster IV (73.407) followed by cluster I (42.859), cluster III (32.488) and minimum intra cluster distance was recorded for cluster II (0.000), cluster IV (0.000) and cluster VI (0.000) as it comprised single genotypes. Presented in (table no 4.8.2).

Inter cluster distances ( $D^2$ ) was found maximum between cluster VI and V (695.974) followed by V and IV (614.066), clusters V and II (557.295), cluster VI and III (421.414), cluster I and V (353.333), and cluster IV and III (353.333). Minimum inter cluster was (40.022) between cluster III and II, followed by cluster II and I (70.710), cluster I and III (90.954) and between cluster IV and I (133.153).

### **4.8.3 Cluster means**

A comparison of the mean values of fifteen characters of six different clusters is presented in (table 4.8.3) and considerable differences in cluster means were evident for all the characters.

#### **Cluster I**

Cluster I comprised of 17 genotypes and identified with maximum panicle length (26.472), spikelet fertility % (78.768) and test weight (20.879). It showed minimum for flag leaf length (29.180cm) and moderate days to 50% flowering (98.341), harvest index (42.97) and grain yield/plant (32.594).

#### **Cluster II**

Cluster II comprised of single genotype and identified with maximum flag leaf length (1.557), biological yield (72.927), grain yield/plant(32.900) and grains/panicle (201.533) and minimum for plant height (100.133) and moderate for days to maturity (135.667).

#### **Cluster III**

Cluster III comprised of five genotype and identified with maximum days to 50% flowering (105.333) and tillers/plant (15.727) and moderate performance for grain yield per plant (32.31), test weight (18.525) and grains/panicle (192.987).

#### **Cluster IV**

Cluster IV comprised of nine genotypes and identified with moderate performance for grain yield per plant (32.041), test weight (19.437), and grains/panicle (167.222).

#### **Cluster V**

Cluster V comprised of single genotype and identified with maximum flag leaf length (31.650) and minimum for days to 50% flowering (78.667) and test weight (14.917) and moderate performance for grain yield per plant (330.800). And number of grains/panicle (168.0).

#### **Cluster VI**

Cluster VI comprised of single genotype and identified with maximum plant height (125.00) and days to maturity (137.00) and minimum for grain yield/plant (20.300), harvest index

(37.800), biological yield (54.00) and panicle length (17.600) and moderate performance for fertility % (75.443).

#### **4.8.4 Relative contribution of individual characters towards divergence**

The per cent contribution towards genetic divergence by all the 15 characters is presented in (table 4.8.4). The trait days to maturity (30.11) showed maximum contribution towards genetic divergence followed by days to 50% flowering (21.03), test weight (16.22), grains per panicle (11.23), grain yield/plant (10.01) and plant height (6.60) while spikelet fertility % , flag leaf length, number of tillers/plat , biological yield, harvest index, panicle length, flag leaf width and number of tillers/plant reported negligible contribution towards divergence.

**Table 4.8.1 Distrubution of 34 rice genotypes into different clusters based on morphological characters**

| <b>S. No</b> | <b>Cluster</b> | <b>Number of genotypes</b> | <b>Name of the Genotypes</b>                                                                                                                                                                                                                                                                                              |
|--------------|----------------|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.           | I              | 17                         | BPT-2615 x SHIATS dhan1, NLR-34449 x SHIATS Dhan1, BPT-2411 x SHIATS Dhan1, BPT-5204 x NDR-359, BPT-2615 x BM-71,Jaya, BPT-2411, NLR-34449 x BM-71, MTU-1001 x SHIATS Dhan1, MTU-1001 x NDR-359, BPT 5204 x BM-71, MTU-1010 x SHIATS Dhan1, Sahabhagi dhan x BM-71, MTU-1010 x NDR-359, IR-64,MTU1001, BPT-2615 x NDR-359 |
| 2.           | II             | 1                          | BPT-2411 x NDR-359,                                                                                                                                                                                                                                                                                                       |
| 3.           | III            | 5                          | BPT-5204, NDR-359,SHIATS Dhan1,BPT-2411 x BM-71, BPT-5204X x SHIATS Dhan1                                                                                                                                                                                                                                                 |
| 4.           | IV             | 9                          | MTU-1001 x BM-71, NLR-34449 x NDR-359,NLR-34449, MTU1010, Sahabhagi dhan x NDR-359,MTU-1010 x BM-71, Anjali, Sahabhagi dhan x SHIATS Dhan1, Sahabhagi dhan                                                                                                                                                                |
| 5.           | V              | 1                          | BPT-2615                                                                                                                                                                                                                                                                                                                  |
| 6            | VI             | 1                          | BM-71                                                                                                                                                                                                                                                                                                                     |

**Table 4.8.2 Intra (diagnol) and Inter- Cluster Distances in rice**

|           | <b>1 Cluster</b> | <b>2 Cluster</b> | <b>3 Cluster</b> | <b>4 Cluster</b> | <b>5 Cluster</b> | <b>6 Cluster</b> |
|-----------|------------------|------------------|------------------|------------------|------------------|------------------|
| 1 Cluster | <b>42.859</b>    | 70.710           | 91.954           | 133.153          | 353.333          | 259.860          |
| 2 Cluster |                  | <b>0.000</b>     | 44.022           | 256.266          | 557.295          | 209.749          |
| 3 Cluster |                  |                  | <b>32.488</b>    | 302.191          | 614.066          | 194.972          |
| 4 Cluster |                  |                  |                  | <b>73.407</b>    | 134.436          | 421.414          |
| 5 Cluster |                  |                  |                  |                  | <b>0.000</b>     | 695.974          |
| 6 Cluster |                  |                  |                  |                  |                  | <b>0.000</b>     |

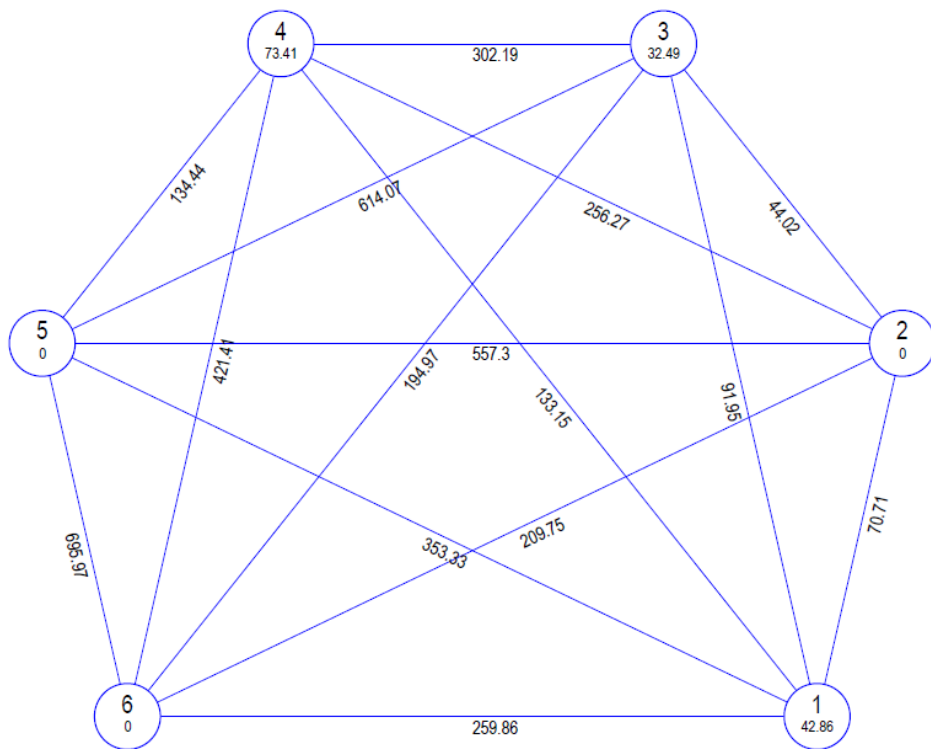
**Table 4.8.3 Mean performance of rice genotypes included in six clusters for fifteen characters.**

|           | Days to<br>50%<br>Flowering | Plant<br>Height<br>(cm) | Number<br>of<br>Tillers/<br>Plant | Number<br>of<br>panicles/<br>plant | Panicle<br>Length<br>(cm) | Flag<br>Leaf<br>Length<br>(cm) | Flag<br>Leaf<br>Width<br>(cm) | Number<br>of<br>Grains /<br>panicle | Days to<br>Maturity | Spikelet<br>Fertility<br>(%) | Spikelet<br>Sterility<br>(%) | Biological<br>Yield (g) | Harvest<br>Index<br>(%) | Test<br>Weight<br>(g) | Grain<br>Yield/<br>Plant(g) |
|-----------|-----------------------------|-------------------------|-----------------------------------|------------------------------------|---------------------------|--------------------------------|-------------------------------|-------------------------------------|---------------------|------------------------------|------------------------------|-------------------------|-------------------------|-----------------------|-----------------------------|
| 1 Cluster | 98.341                      | 115.273                 | 15.302                            | 13.014                             | 26.472                    | 29.810                         | 1.532                         | 186.665                             | 127.878             | 78.768                       | 21.258                       | 75.790                  | 42.971                  | 20.879                | 32.594                      |
| 2 Cluster | 105.000                     | 100.133                 | 14.900                            | 12.367                             | 26.367                    | 30.267                         | 1.577                         | 201.533                             | 135.667             | 78.000                       | 22.667                       | 72.927                  | 43.767                  | 19.233                | 32.900                      |
| 3 Cluster | 105.333                     | 120.747                 | 15.727                            | 14.147                             | 26.105                    | 29.877                         | 1.414                         | 192.987                             | 136.240             | 77.147                       | 23.093                       | 75.264                  | 42.947                  | 18.525                | 32.313                      |
| 4 Cluster | 87.481                      | 113.178                 | 15.074                            | 12.644                             | 26.146                    | 29.867                         | 1.491                         | 167.622                             | 120.030             | 77.210                       | 23.213                       | 74.050                  | 43.064                  | 19.437                | 32.041                      |
| 5 Cluster | 78.667                      | 118.000                 | 13.100                            | 10.833                             | 26.033                    | 31.650                         | 1.533                         | 168.000                             | 111.667             | 73.167                       | 26.500                       | 76.017                  | 40.500                  | 14.917                | 30.800                      |
| 6 Cluster | 102.333                     | 125.000                 | 9.700                             | 7.967                              | 17.600                    | 30.800                         | 1.373                         | 78.833                              | 137.000             | 75.443                       | 25.680                       | 54.000                  | 37.800                  | 16.600                | 20.300                      |

**Table.4.8.4.** Percent Contribution of morphological characters to genetic divergence among 34 genotypes of rice (*Oryza sativa* L.)

| Sl. No | Source                    | Contribution % |
|--------|---------------------------|----------------|
| 1      | Days to 50% Flowering     | 21.03          |
| 2      | Plant Height (cm)         | 6.60           |
| 3      | Number Tillers/ Plant     | 0.53           |
| 4      | Number of panicles/plant  | 0.36           |
| 5      | Panicle Length (cm)       | 0.36           |
| 6      | Flag Leaf Length (cm)     | 0.18           |
| 7      | Flag Leaf Width (cm)      | 1.25           |
| 8      | Number of grains /panicle | 11.23          |
| 9      | Days to Maturity          | 30.11          |
| 10     | Spikelet Fertility (%)    | 1.07           |
| 11     | Spikelet Sterility (%)    | 0.01           |
| 12     | Biological yield(g)       | 0.36           |
| 13     | Harvest Index (%)         | 0.71           |
| 14     | Test Weight(g)            | 16.22          |
| 15     | Grain Yield/ Plant(g)     | 10.01          |

# Tocher Method



Mahalanobis Euclidean Distance (Not to the Scale)

(Fig.1) Cluster diagram based on morphological characters in rice

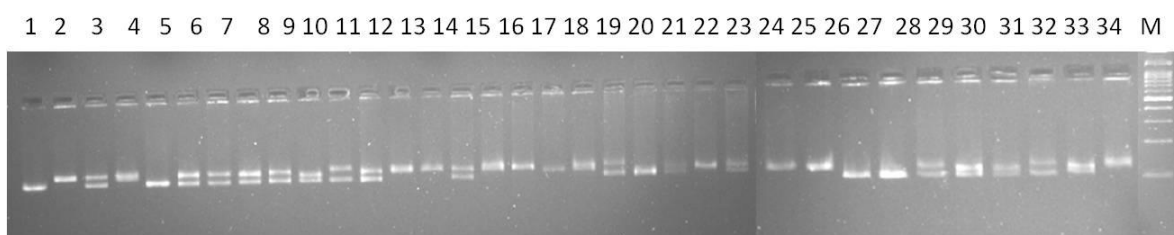
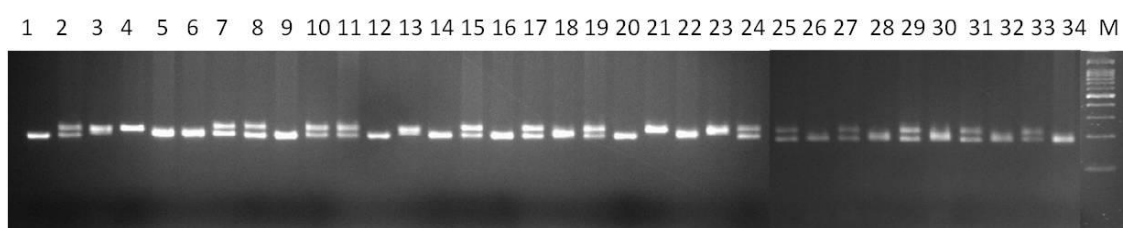
#### 4.9 Molecular diversity

A total of thirty SSR markers were used to assess the extent of polymorphism and genetic diversity across the 34 rice genotypes. The list of primers along with their sequences given in (table.3.8)

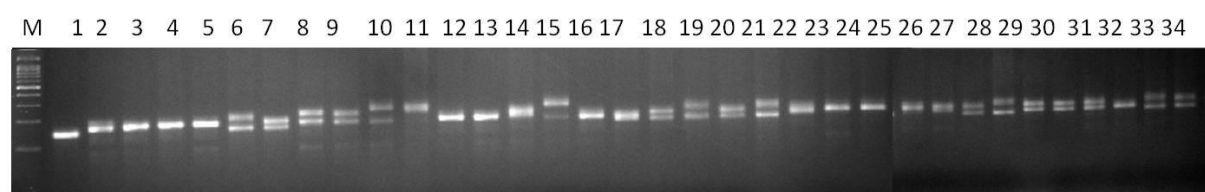
Out of the 30 SSRs, 25 markers were found to be polymorphic, whereas remaining were monomorphic. The level of polymorphism among the 34 rice genotypes was evaluated by allele number and PIC values for all the SSR loci. A total 86 alleles were detected from 25 SSR markers with an average of 4.12, which ranged from 2 (RM 10123, RM 20354 and RM 223) to 7 (RM 232 and RM 18571).The banding pattern of SSR markers among the 34 rice genotypes given in plate 7.

The details of the SSR markers with their number of alleles, and PIC values are given in (table 4.9.1) Polymorphism information content (PIC) denotes the polymorphic informativeness of a marker. Among the set of 34 rice genotypes, six rare alleles were found. The PIC values, which are a reflection of allele diversity and frequency among the genotypes, were not uniformly high for all the SSR loci tested. The average PIC value was 0.50 at a range from 0.11 (RM 10123) to a maximum of 0.75 (RM 232). This high amount of PIC values was an indication that SSR markers are more polymorphic and of more diversity existed among the genotypes. The primers which showed more number of alleles were also found to contain high amount of PIC also. These results showed that the significant correlation existed between the PIC values and the number of alleles. Sufficient polymorphism revealed by the 25 SSR markers among the 34 rice genotypes in the present study justifies their use in genetic improvement programme, which depends on the extent of genetic variation.

The SSR profiling of the 34 rice genotypes using the primer RM572.



The SSR profiling of the 34 rice genotypes using the primer RM22321



The SSR profiling of the 34 rice genotypes using the primer RM11184

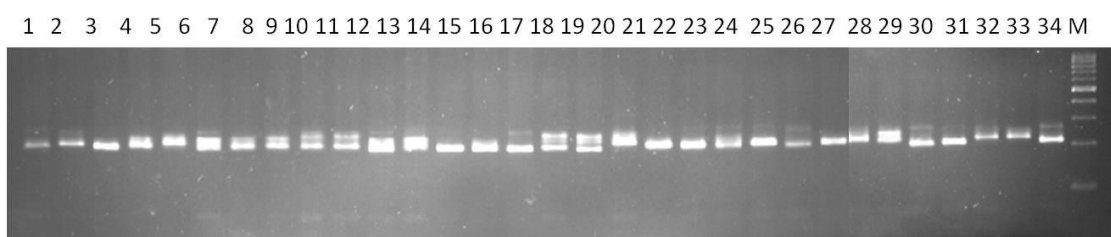


Plate 7 The SSR profiling of the 34 rice genotypes using the primer RM23181

**Table 4.9.1 Parameters for genetic analysis of 25 SSR loci across the 34 rice accessions**

| S. No. | SSR loci | Chromosome | Alleles | PIC  |
|--------|----------|------------|---------|------|
| 1      | RM 10123 | 1          | 2       | 0.11 |
| 2      | RM550    | 2          | 4       | 0.28 |
| 3      | RM21918  | 7          | 6       | 0.60 |
| 4      | RM24152  | 9          | 3       | 0.31 |
| 5      | RM19456  | 6          | 5       | 0.61 |
| 6      | RM232    | 12         | 7       | 0.75 |
| 7      | RM20773  | 6          | 4       | 0.54 |
| 8      | RM22321  | 8          | 4       | 0.62 |
| 9      | RM572    | 1          | 3       | 0.37 |
| 10     | RM28521  | 8          | 3       | 0.39 |
| 11     | RM20354  | 6          | 2       | 0.32 |
| 12     | RM223    | 12         | 2       | 0.45 |
| 13     | RM27644  | 11         | 5       | 0.65 |
| 14     | RM18571  | 5          | 7       | 0.72 |
| 15     | RM21478  | 7          | 6       | 0.64 |
| 16     | RM23181  | 8          | 3       | 0.45 |
| 17     | RM 18434 | 5          | 3       | 0.38 |
| 18     | RM24240  | 9          | 4       | 0.57 |
| 19     | RM11361  | 1          | 3       | 0.34 |
| 20     | RM12119  | 2          | 4       | 0.60 |
| 21     | RM22283  | 9          | 5       | 0.65 |
| 22     | RM18337  | 5          | 6       | 0.61 |
| 23     | RM11184  | 1          | 4       | 0.52 |
| 24     | RM26118  | 10         | 4       | 0.49 |
| 25     | RM22881  | 8          | 4       | 0.50 |
|        | Mean     |            | 4.12    | 0.50 |

Genetic distances were estimated for pairs of varieties with their hybrids according to Jaccard's coefficient (Jaccard, 1908) and these values were presented in (table 4.9.6) The hybrid MTU 1010 x NDR 359 showed 48% dissimilarity from the parent mtu1010, whereas 59% dissimilarity from the NDR 359 parent. Likewise the F1 hybrid MTU 1010 x SHIATS Dhan 1 showed 72% dissimilarity with MTU1010 and 61% dissimilarity with the parent SHIATS Dhan 1. (table 4.9.2).

**Table 4.9.2 Genetic diversity of hybrids with parents based on SSR markers**

| Hybrids               | Parents                  | Dissimilarity percentage |
|-----------------------|--------------------------|--------------------------|
| MTU1010 xNDR359       | MTU1010<br>NDR359        | 48%<br>59%               |
| MTU1010 xBM 71        | MTU1010<br>BM71          | 71%<br>47%               |
| BPT2615 xBM 71        | BPT2615<br>BM71          | 59%<br>61%               |
| MTU1010xSHIATS Dhan 1 | MTU1010<br>SHIATS Dhan 1 | 72%<br>61%               |

Jaccard's coefficient results showed that high amount of diversity existed between BPT 2411 x NDR 359 and MTU 1001 (81%), followed by the IR64 with BPT 5204 and BPT 2411 x NDR 359. The hybrid BPT 2411 x NDR 359 showed 79% dissimilarity with IR 64 at molecular level using SSR markers presented (table 4.9.3)

**Table 4.9.3 Highly diverse genotypes based on SSR profiling**

| Hybrid/ genotype  | Dissimilarity percentage | With hybrid/ genotypes |
|-------------------|--------------------------|------------------------|
| BPT2411 x NDR359  | 81%                      | MTU1001                |
| BPT2411 x NDR359  | 74%                      | MTU1001 x NDR359       |
| IR64              | 79%                      | BPT5204                |
| IR64              | 77%                      | BPT2411                |
| IR64              | 79%                      | BPT2411 x NDR359       |
| NLR34449 x NDR359 | 78%                      | BPT2411 xNDR359        |
| BPT5204 x NDR359  | 85%                      | ANJALI                 |
| BPT5204 x BM71    | 82%                      | ANJALI                 |

In otherwise the Jaccard's coefficient of similarity (table 4.9.5) ranged from 0.15 (BPT 5204 x BM 71 and Shabagi dhan x Shiats Dhan1) to 0.81 (MTU 1010 x NDR 359, and MTU 1001) with an average of 0.42, suggesting nature of the genotypes under study. These results highlighted the presence of diversity at genomic level among the 34 rice genotypes. It is however suggested to increase the number of markers for efficiency in further characterization of the genotypes into distinct groups.

The dendrogram based on the UPGMA analysis of NTSYS software grouped the studied rice genotypes into five major clusters (table 4.9.4). The cluster I comprised of 11 genotypes, cluster II comprised of nine genotypes, whereas cluster III comprised of four genotypes. The cluster IV and V comprised of seven and three genotypes respectively. The cluster I comprised of MTU 1010 x NDR 359, MTU 1001, MTU 1010 x BM 71, MTU 1001 x NDR 359, MTU 1001 x SHIATS Dhan 1, Sahabhazi dhan x BM71, MTU 1010 x SHIATS Dhan 1, BPT 2615, Anjali, Sahabhazi dhan x SHIATS Dhan 1, Sahabhazi dhan. The cluster III consisted of three varieties and one hybrid viz., NDR 359, SHIATS Dhan 1, BM 71, BPT 2411 x BM 71. The cluster II consisted of hybrids except the variety Jaya. The details of the genotypes to their respective clusters given in (fig 2). The cluster IV comprised of seven including varieties and hybrids viz., MTU 1001 x BM 71, MTU 1010, IR 64, Sahabhazi dhan x NDR 359, NLR 34449, NLR 34449 x NDR 359, and BPT 2615 x NDR 359.

**Table 4.9.4 List of genotypes categorised into different clusters based on SSR profiling**

| <b>Cluster</b> | <b>Total number</b> | <b>Genotypes/ hybrids</b>                                                                                                                                                                                                    |
|----------------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cluster I      | 11                  | MTU 1010 xNDR 359<br>MTU 1001, MTU 1010 x BM 71<br>MTU 1001 x NDR 359, MTU 1001 x SHIATS Dhan 1, Sahabhagi dhan x BM 71, MTU 1010 x SHIATS Dhan 1,<br>BPT 2615, Anjali,<br>Sahabhagi dhan x SHIATS Dhan 1,<br>Sahabhagi dhan |
| Cluster II     | 9                   | BPT 2615 x SHIATS Dhan 1,<br>BPT 2411x SHIATS Dhan 1,<br>BPT 5204, BPT 2411,<br>BPT 2411 x NDR 359,<br>Jaya, NLR 34449 x SHIATS Dhan 1, NLR 34449 x BM 71,<br>BPT 2615 x BM 71                                               |
| Cluster III    | 4                   | NDR 359, SHIATS Dhan 1, BM 71, BPT 2411 x BM 71                                                                                                                                                                              |
| Cluster IV     | 7                   | MTU 1001 x BM 71,<br>MTU 1010, IR 64,<br>Sahabhagi dhan x NDR 359<br>NLR 34449, NLR 34449 x NDR 359,<br>BPT 2615 x NDR 359                                                                                                   |
| Cluster V      | 3                   | BPT 5204 x NDR 359<br>BPT 5204 x BM 71<br>BPT 5204x SHIATS Dhan 1                                                                                                                                                            |

**Table 4.9.5 Jaccard's similarity coefficient of the 34 rice genotypes**

|     | G1   | G2   | G3   | G4   | G5   | G6   | G7   | G8   | G9   | G10  | G11  | G12  | G13  | G14  | G15  |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| G1  | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G2  | 0.73 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G3  | 0.67 | 0.50 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |
| G4  | 0.72 | 0.69 | 0.53 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |
| G5  | 0.71 | 0.47 | 0.50 | 0.58 | 1.00 |      |      |      |      |      |      |      |      |      |      |
| G6  | 0.65 | 0.45 | 0.47 | 0.62 | 0.45 | 1.00 |      |      |      |      |      |      |      |      |      |
| G7  | 0.43 | 0.30 | 0.32 | 0.35 | 0.26 | 0.65 | 1.00 |      |      |      |      |      |      |      |      |
| G8  | 0.55 | 0.36 | 0.38 | 0.52 | 0.38 | 0.76 | 0.55 | 1.00 |      |      |      |      |      |      |      |
| G9  | 0.50 | 0.30 | 0.32 | 0.35 | 0.32 | 0.57 | 0.67 | 0.42 | 1.00 |      |      |      |      |      |      |
| G10 | 0.45 | 0.33 | 0.35 | 0.43 | 0.35 | 0.67 | 0.45 | 0.71 | 0.39 | 1.00 |      |      |      |      |      |
| G11 | 0.52 | 0.33 | 0.42 | 0.38 | 0.35 | 0.67 | 0.78 | 0.57 | 0.78 | 0.48 | 1.00 |      |      |      |      |
| G12 | 0.45 | 0.40 | 0.35 | 0.43 | 0.35 | 0.67 | 0.52 | 0.50 | 0.52 | 0.55 | 0.62 | 1.00 |      |      |      |
| G13 | 0.81 | 0.67 | 0.60 | 0.58 | 0.56 | 0.68 | 0.45 | 0.50 | 0.53 | 0.48 | 0.55 | 0.55 | 1.00 |      |      |
| G14 | 0.44 | 0.29 | 0.38 | 0.37 | 0.39 | 0.45 | 0.25 | 0.43 | 0.32 | 0.38 | 0.35 | 0.35 | 0.39 | 1.00 |      |
| G15 | 0.33 | 0.33 | 0.26 | 0.38 | 0.27 | 0.41 | 0.23 | 0.39 | 0.35 | 0.41 | 0.38 | 0.38 | 0.35 | 0.67 | 1.00 |
| G16 | 0.32 | 0.19 | 0.32 | 0.26 | 0.27 | 0.39 | 0.32 | 0.43 | 0.32 | 0.39 | 0.41 | 0.35 | 0.33 | 0.69 | 0.47 |

| G16 | G17  | G18  | G19  | G20  | G21  | G22  | G23  | G24  | G25  | G26  | G27  | G28  | G29  | G30  | G31  | G32  | G33  | G34  |      |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| G17 | 0.43 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G18 | 0.48 | 0.58 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G19 | 0.32 | 0.48 | 0.63 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G20 | 0.27 | 0.42 | 0.50 | 0.81 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G21 | 0.48 | 0.48 | 0.57 | 0.59 | 0.46 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |      |
| G22 | 0.39 | 0.52 | 0.54 | 0.71 | 0.64 | 0.65 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |      |
| G23 | 0.23 | 0.35 | 0.43 | 0.39 | 0.39 | 0.26 | 0.36 | 1.00 |      |      |      |      |      |      |      |      |      |      |      |
| G24 | 0.24 | 0.35 | 0.42 | 0.38 | 0.38 | 0.27 | 0.36 | 0.67 | 1.00 |      |      |      |      |      |      |      |      |      |      |
| G25 | 0.41 | 0.40 | 0.54 | 0.50 | 0.50 | 0.38 | 0.42 | 0.67 | 0.48 | 1.00 |      |      |      |      |      |      |      |      |      |
| G26 | 0.15 | 0.30 | 0.32 | 0.38 | 0.38 | 0.22 | 0.31 | 0.58 | 0.70 | 0.42 | 1.00 |      |      |      |      |      |      |      |      |
| G27 | 0.23 | 0.32 | 0.39 | 0.41 | 0.41 | 0.35 | 0.38 | 0.60 | 0.64 | 0.57 | 0.64 | 1.00 |      |      |      |      |      |      |      |
| G28 | 0.32 | 0.50 | 0.41 | 0.37 | 0.37 | 0.31 | 0.40 | 0.55 | 0.46 | 0.59 | 0.46 | 0.54 | 1.00 |      |      |      |      |      |      |
| G29 | 0.29 | 0.42 | 0.38 | 0.46 | 0.46 | 0.33 | 0.50 | 0.53 | 0.43 | 0.50 | 0.38 | 0.52 | 0.62 | 1.00 |      |      |      |      |      |
| G30 | 0.23 | 0.40 | 0.32 | 0.29 | 0.33 | 0.38 | 0.26 | 0.43 | 0.36 | 0.42 | 0.36 | 0.57 | 0.59 | 0.57 | 1.00 |      |      |      |      |
| G31 | 0.36 | 0.41 | 0.43 | 0.30 | 0.34 | 0.24 | 0.37 | 0.38 | 0.42 | 0.42 | 0.37 | 0.44 | 0.58 | 0.44 | 0.37 | 1.00 |      |      |      |
| G32 | 0.35 | 0.42 | 0.24 | 0.21 | 0.30 | 0.23 | 0.32 | 0.32 | 0.32 | 0.38 | 0.32 | 0.40 | 0.62 | 0.45 | 0.50 | 0.50 | 1.00 |      |      |
| G33 | 0.35 | 0.42 | 0.33 | 0.25 | 0.30 | 0.19 | 0.27 | 0.32 | 0.38 | 0.38 | 0.32 | 0.40 | 0.62 | 0.52 | 0.50 | 0.57 | 0.68 | 1.00 |      |
| G34 | 0.39 | 0.64 | 0.41 | 0.37 | 0.32 | 0.31 | 0.40 | 0.48 | 0.46 | 0.40 | 0.46 | 0.42 | 0.64 | 0.48 | 0.40 | 0.52 | 0.55 | 0.48 | 1.00 |

Note: G1 – G34 rice varieties and genotypes

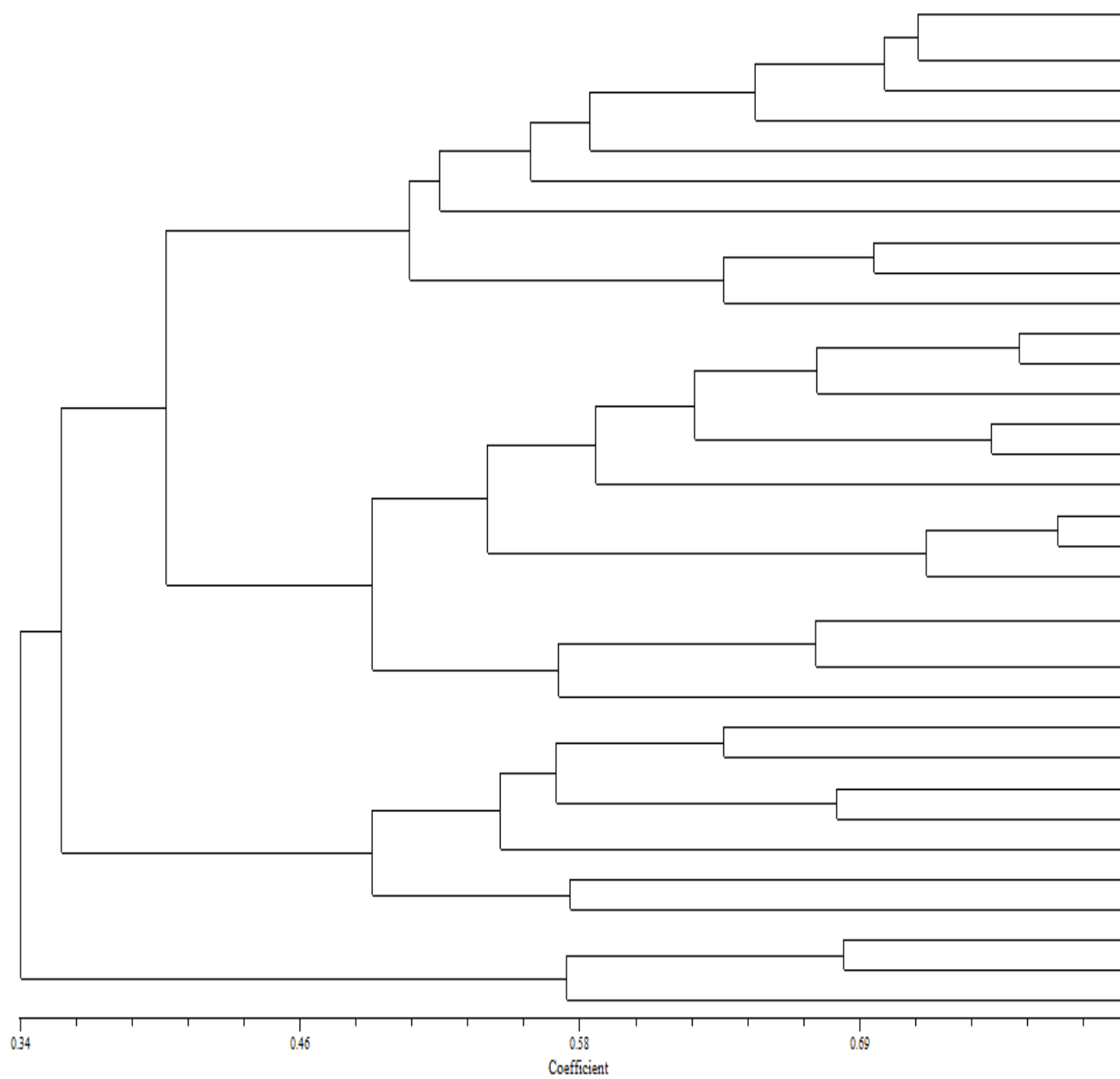


Fig. 2 SSR based UPGMA

## DISCUSSION

Rice is one of the world's most important staple cereal food crops growing in at least 114 countries under diverse conditions. Rice is the staple food crop of India. Among the rice producing countries, India ranks first in the world in area of rice cultivation with 44.2 million ha and second in production with 104.32 million tons and productivity of 3.08 t/ ha-1 (**Directorate of Economics and Statistics (D & ES 2016-17)**).

Introduction of semi dwarf varieties possessing improved harvest index, non- lodging, and erect plant type with high responsiveness to fertilizers in mid-sixties boosted the rice production of India subsequently. However, the productivity has come to stagnation since the last two decades and all efforts have failed to give tangible results to break the present genetic yield barrier in rice. Since land is shrinking resource, increasing food production by expanding the area under cultivation is impossible. So the only way out is to enhance marginal land productivity.

There is need for a paradigm shift in rice research to meet the challenges of the future decades for ensuring food security. To make India self sufficient in rice, it is needed to improve the productivity to a greater extent (**Hossain, 1996**). The task is quite challenging and the options available are very limited. True to the strategy of converting constraints into opportunities, existence of wide yield gaps found across ecologies and zones should be regarded as potential opportunities for raising the yield level and achieving thereby the future targets.

It was observed that successful demonstration of substantial yield increase through exploitation of heterosis through hybridization of genetically diverse parents which are having high variability in rice is of utmost important. Exploitation of heterosis for yield increase in rice through hybrid varieties becomes a practical option. It has encouraged scientists in other rice growing countries including India to adopt hybrid technology as a practical option to enhance the productivity of rice.

In this direction the present study “**Heterosis and Combining ability estimates using L × T analysis and Genetic divergence using SSR markers in Rice** “ was carried out by using 10 genotypes (7 lines and 3 testers) which were selected based on perse performance for grain yield/plant in *kharif* 2014. These were mated in Line x Tester fashion in *kharif* 2015. The resulting 21 hybrids along with ten parents and three checks a total of 34 genotypes were evaluated in *Rabi* 2015-16 at National Rice Research Institute , (formerly Central Rice

Research Institute) Cuttack. Based on the analysis of heterosis, combining ability and genetic divergence best parents and hybrids were identified for yield and yield attributing traits. The results of the present investigation are discussed here under.

## **5.1 ANALYSIS OF VARIANCE**

The analysis of variance for fifteen quantitative characters the treatments, parents and hybrids showed significant differences among all genotypes for all the characters studied. The differences among the parents were observed to be significant for all the characters studied while parents vs. crosses were observed to be significant for all the characters except flag leaf length and crosses were observed to be significant for all the characters except panicle length and Harvest Index. The interaction due to lines x testers were significant for all the traits studied except panicle length. Interaction effects of Parents vs. crosses were significant for all the characters, except flag leaf length.

## **5.2 HETEROSIS**

Heterosis is an universal phenomenon and exploitation of heterosis is a quick and convenient way of combining desirable characters and hence assumes greater significance in the development of hybrids. Hybrids have become an integral part of agriculture to boost productivity as they would respond very well to higher fertilizer levels.

The commercial exploitation of heterosis in rice has been a recent development. So that the crosses with high heterotic potential could be isolated for further evaluation and commercial cultivation. Magnitude of heterosis as such does not assure its commercial exploitation unless it is significantly superior over the standard check varieties. The success of developing commercial hybrid depends upon choice of superior parents coupled with cross potentiality as evident from economic heterosis. Therefore, it is prerequisite to know the basic information on the nature and magnitude of heterosis present in the crosses. Therefore, in present investigation, the performance of all the 21F<sub>1</sub> hybrids were compared with three standard checks, namely, Jaya, IR64 and Anjali. Revealed marked differences in the nature and magnitude of heterosis among F<sub>1</sub>hybrids for all the traits. The negative heterotic values for days to 50% flowering and plant height indicate earliness and short stature, respectively, which are desirable. For the other characters positive estimates were considered as desirable.

For days to 50 % flowering, negative value of heterosis is desirable as early flowering is usually associated with early maturity. It enhances the productivity per day per unit area. Among the 21 hybrids, Eleven hybrids exhibited significant negative heterosis over mid parent. Eighteen hybrids were with significantly superior negative for heterobeltiosis. Only 15 hybrids manifested significant superiority for earliness over Jaya. The hybrids those recorded significant standard negative heterosis are viz., Sahabhazi dhan x SHIATS Dhan1, MTU 1010 x BM 71, Sahabhazi dhan x NDR 359 , MTU 1001 x BM 71 exhibited highest negative heterosis for days to 50 % flowering. These findings of was observed by Shankar *et al.* (2010), Subbaiah *et al.* (2013). Jain *et al.* (2014) Veerasha *et al.* (2015 and Sahu *et al.* (2017)

The negative significant heterosis for plant height is desirable because dwarf plant stature is essential to develop semi-dwarf high yielding varieties which are believed to be lodging resistant. 16 hybrids were shorter than their better parents by exhibiting significant negative heterobeltiosis. Nine hybrids showed negative heterosis over best checks over check Jaya and IR-64, respectively. Among them top three hybrids exhibiting highest magnitude of heterosis viz., BPT 2411 x NDR 359, BPT 2615 x NDR 359 and MTU 1010 x SHIATS Dhan1. These results were also reported by, Sankar *et al.* (2010), Babu *et al.* (2010), and Subbaiah *et al.* (2013) Jain *et al.* (2014) and Veerasha *et al.* (2015) and Huang *et al.* (2016) and Sahu *et al.* (2017)

Number of panicles/ plant contributes to higher grain yield/plant ,six hybrids recorded positive significant average heterosis, while two hybrids recorded positive significant heterobeltiosis. When compared to Jaya. Eight hybrids registered significant positive standard heterosis with a range varying from Standard heterosis overcheck IR-64 the crosses MTU1010 x BM71, MTU1010 x SHIATS Dhan1, BPT5204 x SHIATS Dhan1 and BPT 5204 x NDR 359 were the heterotic hybrids for number of panicles /plant. The similar results were also reported by Rosamma and Vijayakumar (2005), Sankar *et al.* (2010), Babu *et al.* (2010b), and Subbaiah *et al.* (2013) Jain *et al.* (2014) Veerasha *et al.* (2015) and Huang *et al.* (2016) and Sahu *et al.* (2017)

Panicle length with positive and significant heterosis may contribute to enhance the number of spikelets / panicle, subsequently boost the grain yield / plant. Out of 21 hybrids 17 hybrids showed the significant positive heterosis over mid parent and as many as 7 hybrids registered positive superior heterosis over better parents. The heterotic hybrids namely BPT 5204 x

SHIATS Dhan1 BPT 5204 x SHIATS Dhan1 were the best hybrids for panicle length. Manifested significant positive heterosis over both the standard checks. The similar results were also reported by Sankar *et al.* (2010), Babu *et al.* (2010b) and Veeresha *et al.* (2015)

Number of grains/panicle is the major yield attributing character, hence significant positive heterobeltiosis and standard heterosis is desirable. Sixteen hybrids recorded significant positive mid parental heterosis for total number of grains per panicle. As many as eight hybrids registered significant positive heterobeltiosis over the better parents. Seven hybrids showed significant increase in number of grains/ panicle over Jaya and IR64. Hybrids manifested significant positive standard heterosis NLR 34449 x SHIATS Dhan1, Sahabthagidhan x SHIATS Dhan1, BPT2615 x NDR359 and MTU1001 x NDR 359. These findings were also reported by Sharma *et al.* (2013) and Singh *et al.* (2013) and Veeresha *et al.* (2015) and Huang *et al.* (2016).

Spikelet fertility % is one of the important traits which contribute directly to the yield enhancement. The hybrids with positive heterosis are desirable for this vital trait. Out of 21 hybrids, six hybrids viz., registered significant positive standard heterosis over Jaya. The heterotic hybrids namely (BPT 2615 x BM 71). The similar results were also reported by Sharma *et al.* (2013) and Singh *et al.* (2013) and Veeresha *et al.* (2015).

Test weight is one of the important yield related traits. The hybrids with positive heterosis are desirable for this trait. Out of 21 hybrids eighteen hybrids were found to be superior to their mid parental values with significant positive average heterosis. While 9 hybrids recorded significantly higher grain weight over their better parents three hybrids showed higher grain weight than standard checks Jaya and IR 64, respectively MTU1010 x NDR359, NLR 34449 x BM 71 and BPT 2615 x SHIATS Dhan1. Superiority of this character was reported by Subbaiah *et al.* (2013), Jain *et al.* (2014), Veeresha *et al.* (2015) and Huang *et al.* (2016).

Heterosis for grain yield in positive direction is desirable as higher grain yield is the main objective for almost all the breeding programme. Fourteen hybrids expressed significant positive average heterosis. 10 hybrids manifested significant positive heterobeltiosis. High heterosis over Jaya and IR-64 was shown by the four hybrids NLR 34449 x SHIATS Dhan1 followed by Sahabthagi dhan X SHIATS Dhan1, BPT 2615 X NDR 359 and MTU 1010 x BM 71.

Negative to positive heterosis over standard check reported by Shankar *et al.* (2010), Babu *et al.* (2010b) and Subbaiah *et al.* (2013). Heterosis and heterobeltiosis of both positive and negative nature was reported by Vanaja and Babu (2004), Verma *et al.* (2004) and Neelam *et al.* (2013) and Veerasha *et al.* (2015) and Huang *et al.* (2016) and Sahu *et al.* (2017).

### 5.3 COMBINING ABILITY

Knowledge of genetic system controlling yield and its components is useful in understanding the prepotency of the parents and thus help to select parents possessing an inbuilt genetic potential. Ever since **Sprague and Tatum (1942)** had given the current concept of combining ability in crop breeding, it has attained a paramount importance in breeding experiments for isolating potential parental lines and superior hybrids, the concept provides the means of understanding the nature of gene action which ultimately helps the breeder in formulating suitable breeding programme in exploiting the heterosis and developing high yielding hybrids and varieties.

General combining ability (gca) refers to average performance of a line in a series of cross combinations and is mainly attributable to additive and additive x additive gene effects which is mainly an interallelic interaction and indicate part of intra allelic interaction also. Whereas Specific combining ability (sca) refers to the performance of a line in specific cross combination and is mainly attributed dominant, overdominance and epistatic effects of genes i.e., non-additive part additive component of genetic variance is fixable through normal selection procedures, whereas non-additive component is not fixable, and its presence for controlling traits necessitates exploitation of hybrid vigour through heterosis breeding.

In the present investigation combining ability analysis revealed significant mean sum of squares due to general and specific combining ability effects indicates that both additive and non-additive gene actions involved in the inheritance of all the characters. Whereas the relative importance of general and specific combining ability variances is quite useful in understanding of relative components for the expression of a character. It is expressed as ratio between GCA to SCA. If GCA is greater it implies preponderance of additive gene action and if SCA is greater, it denotes preponderance of non-additive gene action.

In present study, the analysis of GCA and SCA variances showed that all the yield and yield contributing characters were controlled preponderantly by non-additive gene actions since,

specific combining ability variance (SCA) was greater than general combining ability variance (GCA). The existence of both additive and non additive type of gene action for various yield traits has also been reported by Kumar *et al.* (2006), Kumar Babu *et al.* (2010a), and Veerasha *et al.* (2015). For formulations of sound breeding program it is essential to assess the nature of inheritance of yield contributing characters and the potentialities of parents in hybrid combinations. Combining ability estimates must be considered for parental choice. In a self pollinated crop like rice, combining ability analysis is of special importance, since it leads to the identification of potential lines that can be used to develop hybrids and varieties.

### **General combining ability effects**

The information regarding general combining ability (gca) effects of the parents is of prime importance, as it helps in successful prediction of genetic potentiality of crosses, which yield desirable individuals in segregating populations of self pollinated crops. Estimates of gca effects showed that it was difficult to choose a good combiner for all the traits, as the combining ability effects were not consistent for all the yield and yield attributing traits simultaneously. It might be possible due to low negative association of different traits. The data fairly showed that none of the parent was good general combiner for all the characters presented in (Table 5.1). However, it was noted that lines (female) MTU 1010 and MTU 1001 proved to be the best general combiners for days to 50% flowering, plant height, total number of grains /panicle and for grain yield/plant. Whereas tester (male) SHIATS Dhan1 was best general combiner for grain yield/plant, biological yield, spikelet fertility %, number of panicles/plant, number of tillers/ plant, and days to 50% flowering. These findings are in agreement with those reported Singh and Kumar (2004), Singh *et al.* (2005), Narasiman *et al.* (2007), Sahu *et al.* (2013) Santha *et al.* (2016) and Bhati *et al.* (2017). The gca effects together with relative per se performance is useful for selecting desirable parent with favourable genes for different component of yield and quality. The per se performance of the parent and their gca effects for all the characters were almost in close correspondence, which indicated that the per se performance of the parent for these traits could possibly be taken as a criterion for selection of parent.

### Specific combining ability effects

In general, specific combining ability is associated with interaction effects, which may be due to dominance and epistatic component of variation that are non-fixable in nature.

Hence, it can be utilized in  $F_1$  generation only for development of hybrid varieties. In the present investigation, none of the cross combination showed high SCA effect for all the characters. Ghosh (1993) and Dwivedi *et al.* (1999) also observed that none of the cross exhibited significant sca effect for all the traits. The present finding revealed that cross combination MTU 1010 x BM 71, NLR 34449 x SHIATS Dhan 1, MTU 1001 x NDR 359 and BPT 2615 x NDR 359 exhibited high sca effects for grain yield / plant. The desirable sca effect MTU 1010 x BM 71 was found to relate with number of grains / panicle , grain yield / plant was accompanied by desirable sca effects for test weight, days to 50% flowering, days to maturity , biological yield. Desirable sca effect of NLR 34449 x SHIATS Dhan 1 for grain yield/plant and number of grains / panicle. Desirable sca effect of MTU 1001 x NDR 359 for number of grains / panicle, biological yield, test weight and grain yield/plant. Desirable sca effect of BPT 2615 x NDR 359 days to 50% flowering, plant height, days to maturity, harvest index and grain yield/plant.

Similar pattern of association between sca effects for grain yield / plant with other yield attributing traits were reported by Thakar *et.al.* (2012), Sahu *et. al.* (2013), Patil *et.al.*(2014) and Veeresha *et al.* (2015), Santha *etal.* (2016) and Bhati *etal.* (2017).

Three hybrids MTU 1010 x BM 71 (high x low), MTU 1001 x NDR 359 (low x high) and NLR 34449 x SHIATS Dhan1(high x high) were identified as good specific cross combinations based on positive sca effects and *per se* performance. The crosses involving High  $\times$  Low gca effects resulted in superior combinations which may be due to complementary gene action and the crosses between two low combiners producing crosses with significant sca effect indicating the presence of non-additive interallelic interaction. Gene interactions of parents and hybrids are presented in (table5.2 and 5.3)

The estimates of SCA variances were much higher for all the characters as compared to their respective GCA variances suggesting the preponderance of non-additive gene action. Several workers have reported preponderance of non-additive gene effects for number of tillers /

plant, number of grains/panicle and spikelet fertility% (Vaithiyalingan & Nadarajan, 2005), panicle length and test weight (Punitha *et al.*, 2004) and for number of tiller/plant, plant height, days to 50% flowering, panicle length, number of grains/ panicle, spikelet fertility % and grain yield/plant (Bagheri, 2010). Similar results were also observed by Siddique *et al.* (1992), Satyanarayana *et al.* (2000), Bisne and Motiramani (2005) and Veeresha *et al.* (2013b). Hence, heterosis breeding is an appropriate and suitable approach for yield improvement in these materials. The contributions of line x tester interaction sum of squares were higher than that of lines or testers for all the characters resulting in higher estimates of SCA variances for interactions. These results are in confirmation with the findings of Sarker *et al.* (2002), Bagheri (2010) and Veeresha *et al.* (2015).

### **Promising hybrids based on *per se* performance, sca effect and Standard heterosis**

Based on *per se* performance, significant sca effects and heterosis for yield in the crosses NLR-34449 x SHIATS Dhan1, Sahabhazi dhan x SHIATS Dhan1, BPT-2615 x NDR-359 and MTU 1010 x BM 71 recorded high *per se* performance (37.46, 36.17, 35.60 and 35.30), sca effects ( 2.51, 0.44, 1.72 and 3.44 ) and standard heterosis (13.74%, 9.82%, 8.09% and 7.19 %) and recorded high *per se* performance over the best check IR-64 for grain yield/plant were identified as promising heterotic hybrids. (Panicles view in plate no 8)

### **5.4 Heritability and Genetic advance**

Coefficient of variance is the percentage ratio of standard deviation of a sample to its mean. Analysis of variance provides estimates of phenotypic, genotypic and environmental variance which are used for the estimation of respective coefficient of variation. A wide range of coefficient of variation was observed for different traits,

Phenotypic coefficient of variation (PCV) ranged from 3.98 (harvest index) to 23.13 (spikelet sterility %) and Genotypic coefficient of variation (GCV) was ranged from 2.66 (harvest index) to 20.02 (spikelet sterility %). The moderate PCV and GCV was recorded for number of grains / panicles, number of panicles/plant, number of tillers/ plant, test weight. where as moderate PCV and Low GCV observed for panicle length and grain yield /plant. Low estimates of PCV and GCV were recorded for characters like biological yield, flag leaf width,

days to 50% flowering, flag leaf length, plant height, spikelet fertility % , days to maturity and harvest index and high PCV and GCV was recorded for sterility percent.

There was a good correspondence between genotypic and phenotypic coefficient of variation for all the characters studied. The magnitude of phenotypic coefficient of variation was higher than the genotypic coefficient of variation for all the characters.

These findings are in agreement with Ghosh and Sharma (2012), Chandramohan singh *et al.* (2013), Sanghera *et al.* (2013) Rajput *et al.* (2014), Nirmala devi (2015) Kumar *et al.* (2015) and Umesh *et al.* (2015).

Heritability and genetic advance are important parameters that directly affect the response to selection. Heritability is a measure of genetic relationship between parent and progeny and has been widely used to assess the degree to which a character may be transmitted from parent to off spring. It also indicated that relative importance of heritability and environment in the expression of characters. High heritability alone is not enough to make sufficient improvement through selection in advance generation unless accompanied by substantial amount of genetic advance. The heritability is combination with intensity of selection and amount of variability present i.e. the population influence the grain to be obtained from selection. If heritability of a character is very high, selection would be fairly easy and effective.

The estimates heritability ranged from 45(harvest index) to 98 (days to 50% flowering). A perusal of genetic advance for different traits revealed that it varied from 3.68(harvest index) to 35.68(spikelet sterility %).

The high heritability along with high genetic advance (GA) was recorded for spikelet sterility %, number of grains / panicle, test weight and number of panicles/ plant where as high heritability along with moderate GA observed for number of tillers/ plant, grain yield / plant, days to 50% flowering, panicle length, plant height, Biological yield, flag leaf width and days to maturity. High heritability and low GA recorded for spikelet fertility %where asmedium heritability and low GA was observed for flag leaf length and harvest index.

The high heritability with high genetic advance estimates indicates preponderance of additive gene action for expression of these traits. These findings of heritability and genetic advance

are in agreement with earlier reported on rice by Dhurai *et al.* (2014a) Islam *et al.* (2015), Mohan *et al.* (2015), Kumar *et al.* (2015), Umesh *et al.* (2015) and Bitew *et al.* (2016).

### **5.5 Quality characters of hybrids and parents**

The success of any genotype is not only depends on its yield, but also depends on the grain quality which is mostly acceptable by the consumer. Quality traits are complex in nature, which is influenced by the environment. Understanding the relationship between yield and its components is of paramount importance for making the best use of the relationships in selection.

In the present study, relative performance for various quality traits over the respective checks (Jaya, IR64 and Anjali) were estimated for all the 21 cross combinations and parents. Hulling recovery is an important factor deciding the amount of marketable produce. Its positive value is desirable. Out of 21 hybrids, 11 were good over best check (Jaya). The hybrids (BPT5204 x NDR359) considered as best genotype for hulling followed by MTU1010 x SHIATS Dhan1 and NLR34449 x SHIATS Dhan1.

The similar type of results has been reported by Sharma *et al.* (2013), Singh *et al.* (2013) and Nirmala devi (2015)

Assessment of physico-chemical properties of grain is an important aspect in rice crop, as it is directly related to the price differentials. Kernel length, kernel breadth, kernel length breadth ratio (L/B), kernel length after cooking (KLAC), kernel breadth after cooking (KBAC), and kernel elongation ratio are the important physical quality characters which determine the appearance and market value of the rice grain.

Medium slender type is more preferred by the consumers. Hence, the negative heterosis for kernel length is desirable from quality point of view. In the present study, out of 21 crosses, 9 hybrids showed the superiority over the best check Jaya. The hybrids MTU-1001 x BM-71 and BPT2411 x NDR359 were the best hybrids for this trait. Reddy *et al.* (2012), and Singh *et al.* (2013) and Nirmala devi (2015) also reported significant positive results for kernel length.

## 5.6 Morphological diversity

For a successful breeding programme, the diverse parents are of utmost importance. Since hybridization between divergent parents is likely to produce wide variability and transgressive segregations. Crosses between unrelated lines tend to exhibit heterosis. Thus, diverse lines from different clusters should be chosen for crossing in a hybrid rice breeding programme.

The multivariate analysis using Mahalanobis'  $D^2$  statistic provides a useful statistical tool for measuring the genetic diversity in germplasm collections with respect to the characters considered together. The quantitative and quality assessment of genetic divergence was made by adopting Mahalanobis'  $D^2$  statistic for yield and its contributing characters. Genetic divergence was estimated and the results obtained from the study are discussed below.

Wilk's 'V' (statistic) criterion was used to test the significant differences between the groups based on the pooled effects of all the characters. The significance of 34 genotypes (10 parents, 21 hybrids and 3 checks) in the analysis of variance of dispersion clearly indicated the significant pooled effect of all the characters studied between different genotypes. Hence, further analysis was made to estimate  $D^2$  analysis.

In order to assess the genetic diversity among 34 genotypes (10 parents, 21 hybrids and 3 checks),  $D^2$  statistic was used following the procedure given by **Rao (1952)**. Since the entire 15 yield component characters were correlated, they were transformed into uncorrelated linear combination through pivotal condensation method.

The 34 genotypes were grouped into six clusters. The distribution of 34 genotypes into clusters was at random with maximum number of 17 genotypes in cluster I. Cluster IV is the second largest with 9 genotypes followed by cluster III with 5 genotypes. The cluster II, V and VI were solitary clusters. Distribution of genotypes into different clusters, suggested the presence of substantial genetic divergence among the germplasm lines screened in the present investigation and further indicated that this material may serve as good source for selecting the diverse parents for hybridization programme, aimed at isolating desirable recombinants for seed yield as well as for other yield contributing characters. The formation of solitary clusters may be due to total isolation preventing the gene flow or due to intense natural or human selection for diverse adaptive. The parents and hybrids in clusters II, V and VI are divergent to other parents and hybrids. Genotypes from the same centre of origin were distributed in different clusters which may be due to differential adaptation to varied agro-

ecosystems as explained by Sabesan *et al.* (2010), Banumathy *et al.* (2010) Kar *et al.* (2013), Monohara *et al.* (2013), Karuppaiyan *et al.* (2013) and Dhutmal *et al.* (2017).

The intra and inter cluster average distances among six clusters were variable. The maximum intra cluster distance ( $D^2$ ) was recorded for cluster IV followed by cluster I, cluster III and minimum intra cluster distance was recorded for cluster II, cluster IV and cluster VI as it comprised single genotypes.

Inter cluster distances ( $D^2$ ) was found maximum between cluster VI and V followed by V and IV clusters V and II, cluster VI and III, cluster I and V, and cluster IV and III. Which indicates these clusters are highly divergent and it is desirable to select the genotypes from these divergent clusters in breeding programme for obtaining desirable segregants.

Minimum inter -cluster was between cluster III and II, followed by cluster II and I, cluster I and III and between cluster IV and I suggests that these clusters are closely related and the hybridization using the genotypes does not yield variable segregants. Similar findings were also revealed by Chand *et al.* (2005), Devi *et al.* (2015) and Dhutmal *et al.* (2017).

Among the fifteen quantitative characters studied the most important character contributing to the divergence was days to maturity showed maximum contribution towards genetic divergence followed by days to 50% flowering, test weight, number of grains / panicle, grain yield / plant and plant height while spikelet fertility%, flag leaf length, number of panicles/plant, biological yield, harvest index, panicle length, flag leaf width and number of tillers / plant reported negligible contribution towards divergence. Similar results were reported by Dhutmal *et al.* (2017)

Mean performance of different clusters revealed wide range of differences Cluster I comprised of 17 genotypes and identified with maximum panicle length, spikelet fertility %, and test weight showed minimum for flag leaf length, Cluster II comprised of single genotype and identified with maximum flag leaf length, biological yield, grain yield/plant and number of grains/panicle and minimum for plant height. Cluster III comprised of five genotype and identified with maximum days to 50% flowering. Cluster IV comprised of nine genotypes and identified with moderate performance for grain yield / plant (32.041), Cluster V comprised of single genotype and identified with maximum flag leaf length (31.650) and minimum for days to 50% flowering. Cluster VI comprised of single genotype and identified with maximum plant height. Cluster with mean values indicate the presence of most

promising genotypes in them and can be extremely used for further breeding programme to generate new breeding material. These findings are in agreement with the results of Nayak *et al.* (2004) and Dushyantha and Kantri (2010) and Sandhya *et al.* (2014) and Bharathi *et al.* (2016)

### 5.8 Molecular diversity

The level of polymorphism among the 34 rice genotypes was evaluated by allele number and PIC values for all the SSR loci. In the present study, 25 markers were found to be polymorphic, whereas remaining five were monomorphic. A total 86 alleles were detected from 25 SSR markers with an average of four, which ranged from 2 to 7. Rathi and Sarma (2012) obtained 181 alleles from 37 SSR markers ranging from 2 to 13 with an average of 4.90 alleles per marker while studying genetic diversity of 106 glutinous rice land races of Assam. Ram *et al.* (2007) obtained 3 to 8 alleles with an average of 4.86 alleles per marker. In other studies, Pachauri *et al.* (2013) assessed 41 rice collected from different part of India using 24 SSR markers and detected 2 to 4 alleles per locus with an average of 2.79 alleles per SSR locus. Similarly, recent reports on the genetic diversity among Indian and exotic rice genotypes using 39 SSRs found 183 scorable alleles at an average of 4.8 allele per locus (Babu *et al.* 2014). The population structure and genetic diversity also estimated by few reports where they estimated diversity among North Western Himalayas of India (Salgotra *et al.* 2015). Becerra *et al.* (2017) assessed the genetic diversity in temperate japonica rice germplasm using SSR markers among 1200 accessions, mainly temperate japonica rice accessions, well adapted to the local conditions. Total number of alleles scored across 249 genotypes was 183 with an overall mean of 6.1 alleles per locus, ranging 2-14. Jayamaniet *al.* (2007) studied 176 rice accessions originating from 19 countries in Portuguese working germplasm using 24 SSR markers and found 3 to 16 alleles per locus with an average of 7.7 alleles. These reports are similar to the present study on allelic diversity in the 34 rice genotypes using 30 SSR markers. However, the high number of alleles per marker could probably be a result of large number of accessions used (Jayamani *et al.*, 2007 and Choudhary *et al.*, 2013).

In the present study, average PIC value was 0.51 at a range from 0.23 to a maximum of 0.75. Low PIC values for some other primers were earlier reported by Juneja *et al.*, (2006). The average PIC value of 0.51 indicated that SSR markers used in this study were highly informative because markers with PIC values of 0.5 or higher are highly informative for

genetic studies and are extremely useful in distinguishing the polymorphism rate of a marker at a specific locus (DeWoody *et al.*, 1995). The PIC of an SSR marker, which is also defined as its capacity to discriminate genotypes depends on the allelic diversity (Ribeiro-Carvalho *et al.*, 2004). A strong positive correlation between gene diversity of an SSR locus and the number of alleles detected is also reported by Yu *et al.* (2003) and Onaga *et al.* (2013). Thus SSR analysis has considerable potential for studying the genetic diversity of rice (Bligh *et al.*, 1999. Jeung *et al.*, 2005, Xu *et al.*, 2004).

Diversity analysis using molecular markers determines the degree of relatedness and helps in accurate grouping of genotypes, identification of parents for exploitation of heterosis and detection of duplicate genotypes. It has potential for assessing changes in genetic diversity over time and space the grouping pattern showed that the clustering was done mostly according the parentage involved. Also there is a wide diversity existed between the parents and F<sub>1</sub> progeny. The F<sub>1</sub> line MTU1010 x NDR359 was clustered in A1, whereas their parents are in different clusters. The parent MTU1010 was in cluster B, whereas NDR359 under cluster A2. The results showed that high amount of heterosis and diversity existed. Likewise BPT5204 existed in cluster A2, whereas its progeny was in B cluster. The results showed that the F<sub>1</sub> progeny obtained from different crosses are highly divergent with the parents.

It is commonly observed that genetic variation determined by various molecular marker systems produce different results; this is due to analyzing different regions in the genome captured by the respective markers. Therefore, differences could be expected in the compilation of molecular and morphological data. Morphological traits are associated with a relatively small number of loci, thus the potential difference could be lost in the analysis of large amounts of molecular data (Diederichsen, 2009).

In order to determine the degree of correlation of the morphological and molecular data Mantel test was performed. The Mantel matrix correspondence test was used to compare the similarity matrices. The test indicated that clusters produced based on morphological and SSR markers were correlated as the value indicated as 0.45. similar results were also reported by Autrique *et al.* (1996) in their genetic diversity study in durum wheat using RFLP and agronomic traits calculated a moderate correlation (0.47) which was a result of using wide range of genotypes representing more than one ecotype, where it was reverse in other reports in rice (Taran *et al.*, 2005; Rahman *et al.*, 2011) and other crops (Moghaddam *et al.*, 2005; Rana *et al.*, 2005; Garcia *et al.*, 2007). Correspondence between molecular and agronomic

diversity might be improved by analyzing more morphological and DNA markers (Martinez *et al.*, 2005). The clustering pattern was observed to be similar broadly. The genotypes MTU 1010 x NDR 359, MTU 1001 x NDR 359, MTU 1001 x SHIATS Dhan1 were grouped together by both morphological and molecular dendrogram methods. Swain *et al* (2017) studied the genetic diversity of Wild Rice of Eastern India Using SSR Markers on 26 accessions of *Oryza rufipogon* and *Oryza nivara* collected from different districts of Orissa, West Bengal and Tripura. They concluded that concluded that the SSR markers used were found to be equally informative for the genetic diversity study between and among the accessions of two wild species such as *Oryza rufipogon* and *Oryza nivara* collected from different locations of Orissa, West Bengal & Tripura.

Combination of morphological and molecular markers is useful in studying genetic diversity of rice for conservation, breeding and other crop improvement activities (Rahman *et al.*, 2011). The best measure to analyze genetic diversity among genotypes would be with the use of all information, both from morphological characters and DNA based markers. Molecular marker data and morphological data subjected to various numerical and taxonomical techniques measures the relationship among the genotypes (Kumar *et al.*, 2003). The genotypes which are found to be diverse based on both morphological and molecular diversity could be used for further breeding programme.

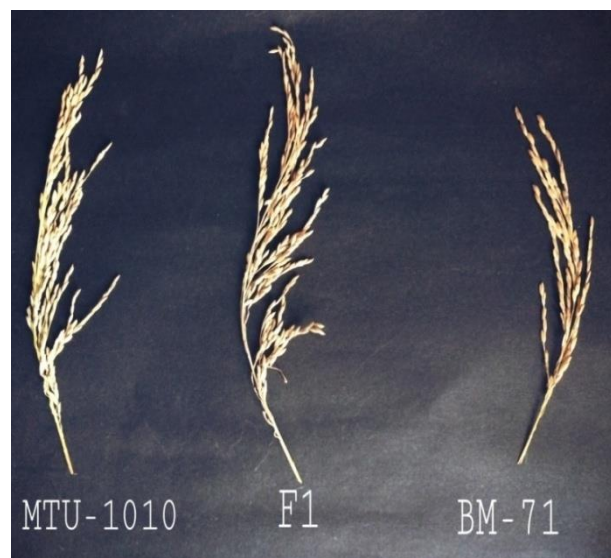


Plate 8 Panicle view of best Parents and Hybrids

**Table 5.1 Classification of parents based on general combining ability**

| Character     | Days to<br>50%<br>Flowering | Plant<br>Height (cm) | Number<br>of<br>Tillers/<br>Plant | Number of<br>panicles/plant | Panicle<br>Length<br>(cm) | Flag Leaf<br>Length<br>(cm) | Flag Leaf<br>Width (cm) | Number<br>ofGrains /<br>panicle | Days to<br>Maturity | Spikelet<br>Fertility<br>(%) | Spikelet<br>Sterility<br>(%) | Biological<br>Yield (g) | Harvest<br>Index<br>(%) | Test<br>Weight<br>(g) | Grain<br>Yield/<br>Plant(g) |
|---------------|-----------------------------|----------------------|-----------------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------|---------------------------------|---------------------|------------------------------|------------------------------|-------------------------|-------------------------|-----------------------|-----------------------------|
| MTU-1010      | G                           | G                    | A                                 | A                           | A                         | A                           | A                       | G                               | G                   | A                            | P                            | A                       | A                       | A                     | A                           |
| MTU-1001      | G                           | G                    | A                                 | A                           | P                         | A                           | A                       | P                               | G                   | P                            | G                            | P                       | A                       | A                     | P                           |
| Sahabdagidhan | G                           | P                    | P                                 | P                           | P                         | P                           | A                       | P                               | G                   | A                            | P                            | A                       | P                       | G                     | A                           |
| BPT-5204      | P                           | P                    | G                                 | G                           | P                         | P                           | P                       | G                               | P                   | P                            | A                            | P                       | P                       | P                     | P                           |
| BPT-2411      | P                           | A                    | P                                 | P                           | A                         | A                           | P                       | G                               | P                   | A                            | A                            | P                       | P                       | P                     | P                           |
| BPT-2615      | A                           | A                    | P                                 | P                           | P                         | A                           | A                       | A                               | A                   | A                            | P                            | A                       | A                       | P                     | A                           |
| NLR-34449     | G                           | P                    | A                                 | P                           | A                         | P                           | P                       | P                               | A                   | A                            | P                            | A                       | P                       | P                     | A                           |
| NDR-359       | G                           | G                    | P                                 | P                           | A                         | A                           | A                       | A                               | P                   | P                            | A                            | P                       | A                       | A                     | A                           |
| BM-71         | P                           | P                    | P                                 | P                           | P                         | P                           | A                       | P                               | P                   | P                            | G                            | A                       | P                       | P                     | P                           |
| SHIATS Dhan 1 | G                           | P                    | G                                 | G                           | A                         | A                           | P                       | G                               | A                   | G                            | P                            | G                       | A                       | A                     | G                           |

**Table 5.2 Gene interactions in hybrids**

| F1                            | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/Plant | Number of panicles/plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/Plant(g) |
|-------------------------------|-----------------------|-------------------|-------------------------|--------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|----------------------|
| MTU-1010 X NDR-359            | Lxl                   | lxl               | hxl                     | hxl                      | Hxh                 | hxx                   | hxx                  | hxx                        | lxl              | hxl                    | lxx                    | hxl                  | hxx               | hxx             | hxx                  |
| MTU-1010 XBM-71               | Lx h                  | lxx               | hxl                     | hxl                      | Hxl                 | hxl                   | hxx                  | hxl                        | lxl              | hxl                    | lxx                    | hxl                  | hxl               | hxl             | hxl                  |
| MTU-1010 X SHIATS Dhan 1      | Lxl                   | lxx               | hxx                     | hxx                      | Hxx                 | hxx                   | hxl                  | hxx                        | lxx              | hxx                    | lxl                    | hxx                  | hxx               | hxx             | hxx                  |
| MTU-1001 X NDR-359            | Lxl                   | lxl               | hxl                     | hxl                      | Lxx                 | hxx                   | hxx                  | lxx                        | lxl              | lxl                    | hxx                    | lxl                  | hxx               | hxx             | lxx                  |
| MTU-1001X BM-71               | Lxx                   | lxx               | hxl                     | hxl                      | lxl                 | hxl                   | hxx                  | lxl                        | lxl              | lxl                    | hxx                    | lxl                  | hxl               | hxl             | lxl                  |
| MTU-1001X SHIATS Dhan 1       | Lxl                   | lxx               | hxx                     | hxx                      | lxx                 | hxx                   | hxl                  | lxx                        | lxx              | lxx                    | hxl                    | lxx                  | hxx               | hxx             | lxx                  |
| SahabdagidhanX NDR-359        | Lxl                   | hxl               | lxl                     | lxl                      | lxx                 | hxx                   | hxx                  | lxx                        | lxl              | hxl                    | lxx                    | hxl                  | lxx               | hxx             | hxx                  |
| SahabdagidhanX BM-71          | Lxx                   | hxx               | lxl                     | lxl                      | lxl                 | hxl                   | hxx                  | lxl                        | lxl              | hxl                    | lxx                    | hxl                  | lxl               | hxl             | hxl                  |
| Sahabdagidhan x SHIATS Dhan 1 | LxL                   | hxx               | lxx                     | lxx                      | lxx                 | hxx                   | hxl                  | lxx                        | lxx              | hxx                    | lxl                    | hxx                  | lxx               | hxx             | hxx                  |
| BPT-5204X NDR-359             | hxl                   | hxl               | hxl                     | hxl                      | hxx                 | lxx                   | lxx                  | hxx                        | hxl              | lxl                    | hxx                    | lxl                  | lxx               | lxx             | lxx                  |
| BPT-5204XBM-71                | hxx                   | hxx               | hxl                     | hxl                      | hxl                 | lxl                   | lxx                  | hxl                        | hxl              | lxl                    | hxx                    | lxl                  | lxl               | lxl             | lxl                  |
| BPT-5204XSHIATS Dhan 1        | hxl                   | hxx               | hxx                     | hxx                      | hxx                 | lxx                   | lxl                  | hxx                        | hxx              | lxx                    | hxl                    | lxx                  | lxx               | lxx             | lxx                  |
| BPT-2411XNDR-359              | hxl                   | lxl               | lxl                     | lxl                      | hxx                 | lxx                   | lxx                  | hxx                        | hxl              | hxl                    | hxx                    | lxl                  | lxx               | lxx             | lxx                  |
| BPT-2411XBM-71                | hxx                   | lxx               | lxl                     | lxl                      | hxl                 | lxl                   | lxx                  | hxl                        | hxl              | hxl                    | hxx                    | lxl                  | lxl               | lxl             | lxl                  |
| BPT-2411XSHIATS Dhan 1        | hxl                   | lxx               | lxx                     | lxx                      | hxx                 | lxx                   | lxl                  | hxx                        | hxx              | hxx                    | hxl                    | lxx                  | lxx               | lxx             | lxx                  |
| BPT-2615XNDR-359              | hxl                   | lxl               | lxl                     | lxl                      | lxx                 | hxx                   | hxx                  | hxx                        | hxl              | hxl                    | lxx                    | hxl                  | hxx               | lxx             | hxx                  |
| BPT-2615XBM-71                | hxx                   | lxx               | lxl                     | lxl                      | lxl                 | hxl                   | hxx                  | hxl                        | hxl              | hxl                    | lxx                    | hxl                  | hxl               | lxl             | hxl                  |
| BPT-2615XSHIATS Dhan 1        | hxl                   | lxx               | lxx                     | lxx                      | lxx                 | hxx                   | hxl                  | hxx                        | hxx              | hxx                    | lxl                    | hxx                  | hxx               | lxx             | hxx                  |
| NLR-34449XNDR-359             | Lxl                   | hxl               | hxl                     | lxl                      | hxx                 | lxx                   | lxx                  | lxx                        | lxl              | hxl                    | lxx                    | hxl                  | lxx               | lxx             | hxx                  |
| NLR-34449X BM-71              | Lxx                   | hxx               | hxl                     | lxl                      | hxl                 | lxl                   | lxx                  | lxl                        | lxl              | hxl                    | lxx                    | hxl                  | lxl               | lxl             | hxl                  |
| NLR-34449X SHIATS Dhan 1      | Lxl                   | hxx               | hxx                     | lxx                      | hxx                 | lxx                   | lxl                  | lxx                        | lxx              | hxx                    | lxl                    | hxx                  | lxx               | lxx             | hxx                  |

**Table 5.3 Gene interactions in hybrids**

| F1                           | Days to 50% Flowering | Plant Height (cm) | Number of Tillers/ Plant | Number of panicles /plant | Panicle Length (cm) | Flag Leaf Length (cm) | Flag Leaf Width (cm) | Number of Grains / panicle | Days to Maturity | Spikelet Fertility (%) | Spikelet Sterility (%) | Biological Yield (g) | Harvest Index (%) | Test Weight (g) | Grain Yield/ Plant (g) |
|------------------------------|-----------------------|-------------------|--------------------------|---------------------------|---------------------|-----------------------|----------------------|----------------------------|------------------|------------------------|------------------------|----------------------|-------------------|-----------------|------------------------|
| MTU-1010 X NDR-359           | DxD                   | DxD               | AxD                      | AxD                       | AxA                 | AxA                   | AxA                  | AxA                        | DxD              | AxD                    | DxA                    | AxD                  | AxA               | AxA             | AxA                    |
| MTU-1010 XBM-71              | DxA                   | DxA               | AxD                      | AxD                       | AxD                 | AxD                   | AxA                  | AxD                        | DxD              | AxD                    | DxA                    | AxD                  | AxD               | AxD             | AxD                    |
| MTU-1010 X SHIATS Dhan 1     | DxD                   | DxA               | AxA                      | AxA                       | AxA                 | AxA                   | AxD                  | AxA                        | DxA              | AxA                    | DxD                    | AxA                  | AxA               | AxA             | AxA                    |
| MTU-1001 X NDR-359           | DxD                   | DxD               | AxD                      | AxD                       | DxA                 | AxA                   | AxA                  | DxA                        | DxD              | DxD                    | AxA                    | DxD                  | AxA               | AxA             | DxA                    |
| MTU-1001X BM-71              | DxA                   | DxA               | AxD                      | AxD                       | DxD                 | AxD                   | AxA                  | DxD                        | DxD              | DxD                    | AxA                    | DxD                  | AxD               | AxD             | DxD                    |
| MTU-1001X SHIATS Dhan 1      | DxD                   | DxA               | AxA                      | AxA                       | DxA                 | AxA                   | AxD                  | DxA                        | DxA              | DxA                    | AxD                    | DxA                  | AxA               | AxA             | DxA                    |
| Shahabgag idhanX NDR-359     | DxD                   | AxD               | DxD                      | DxD                       | DxA                 | AxA                   | AxA                  | DxA                        | DxD              | AxD                    | DxA                    | AxD                  | DxA               | AxA             | AxA                    |
| SahabgagidhanX BM-71         | DxA                   | AxA               | DxD                      | DxD                       | DxD                 | AxD                   | AxA                  | DxD                        | DxD              | AxD                    | DxA                    | AxD                  | DxD               | AxD             | AxD                    |
| Sahabgagidhan XSHIATS Dhan 1 | DxD                   | AxA               | DxA                      | DxA                       | DxA                 | AxA                   | AxD                  | DxA                        | DxA              | AxA                    | DxD                    | AxA                  | DxA               | AxA             | AxA                    |
| BPT-5204X NDR-359            | AxD                   | AxD               | AxD                      | AxD                       | AxA                 | DxA                   | DxA                  | AxA                        | AxD              | DxD                    | AxA                    | DxD                  | DxA               | DxA             | DxA                    |
| BPT-5204XBM-71               | AxA                   | AxA               | AxD                      | AxD                       | AxD                 | DxD                   | DxA                  | AxD                        | AxD              | DxD                    | AxA                    | DxD                  | DxD               | DxD             | DxD                    |
| BPT-5204XSHIATS Dhan 1       | AxD                   | AxA               | AxA                      | AxA                       | AxA                 | DxA                   | DxD                  | AxA                        | AxA              | DxA                    | AxD                    | DxA                  | DxA               | DxA             | DxA                    |
| BPT-2411XNDR-359             | AxD                   | DxD               | DxD                      | DxD                       | AxA                 | DxA                   | DxA                  | AxA                        | AxD              | AxD                    | AxA                    | DxD                  | DxA               | DxA             | DxA                    |
| BPT-2411XBM-71               | AxA                   | DxA               | DxD                      | DxD                       | AxD                 | DxD                   | DxA                  | AxD                        | AxD              | AxD                    | AxA                    | DxD                  | DxD               | DxD             | DxD                    |
| BPT-2411XSHIATS Dhan 1       | AxD                   | DxA               | DxA                      | DxA                       | AxA                 | DxA                   | DxD                  | AxA                        | AxA              | AxA                    | AxD                    | DxA                  | DxA               | DxA             | DxA                    |
| BPT-2615XNDR-359             | AxD                   | DxD               | DxD                      | DxD                       | DxA                 | AxA                   | AxA                  | AxA                        | AxD              | AxD                    | DxA                    | AxD                  | AxA               | DxA             | AxA                    |
| BPT-2615XBM-71               | AxD                   | DxA               | DxD                      | DxD                       | DxD                 | AxD                   | AxA                  | AxD                        | AxD              | AxD                    | DxA                    | AxD                  | AxD               | DxD             | AxD                    |
| BPT-2615XSHIATS Dhan 1       | AxD                   | DxA               | DxA                      | DxA                       | DxA                 | AxA                   | AxD                  | AxA                        | AxA              | AxA                    | DxD                    | AxA                  | AxA               | DxA             | AxA                    |
| NLR-34449XNDR-359            | DxD                   | AxD               | AxD                      | DxD                       | AxA                 | DxA                   | DxA                  | DxA                        | DxD              | AxD                    | DxA                    | AxD                  | DxA               | DxA             | AxA                    |
| NLR-34449X BM-71             | DxA                   | AxA               | AxD                      | DxD                       | AxD                 | DxD                   | DxA                  | DxD                        | DxD              | AxD                    | DxA                    | AxD                  | DxD               | DxD             | AxD                    |
| NLR-34449X SHIATS Dhan 1     | DxD                   | AxA               | AxA                      | DxA                       | AxA                 | DxA                   | DxD                  | DxA                        | DxA              | AxA                    | DxD                    | AxA                  | DxA               | DxA             | AxA                    |

## SUMMARY AND CONCLUSION

The present investigation was carried out with the objective to collect the basic information on heterosis, combining ability and genetic divergence at morphological and molecular level by using SSR markers. Ten genotypes (7 lines and 3 testers) were selected based on *per se* performance for grain yield/plant after evaluating 100 genotypes during *kharif*, 2014. Selected lines and testers used for further experimentation and crossing programme initiated by using line x tester mating design in *kharif*, 2015 to generate 21 hybrids at Field Experimentation Centre, Department of Genetics and Plant Breeding, Naini Agricultural Institute, SHUATS, Allahabad. Twenty one hybrids along with ten parents and three checks, a total of 34 genotypes evaluated during *Rabi* 2015-16 at National Rice Research Institute, (formerly Central Rice Research Institute), Cuttack. Data recorded on different yield and yield attributing traits.

The salient findings from the study and conclusion drawn from the results are summarized here as under.

- The analysis of variance for heterosis revealed significant differences for all the characters studied. The differences among the parents were observed to be significant for all the characters studied while parents vs. crosses were observed to be significant for all the characters except flag leaf length and crosses were observed to be significant for all the characters except panicle length and Harvest Index.
- The interaction due to lines x testers were significant for all the traits studied except panicle length. Interaction effects of Parents vs. crosses were significant for all the characters, except flag leaf length.
- . High heterosis over Jaya and IR 64 was shown by the four hybrids NLR 34449 x SHIATS Dhan1 (20.58% and 13.74%) followed by Sahabhagi dhan x SHIATS Dhan1 (16.62% and 9.82%), BPT 2615 x NDR 359 (14.58% and 8.09 %) and MTU 1010 x BM 71 ( 13.63% and 7.19 %).
- The analysis of variance for combining ability showed high significance of crosses for all the traits studied. The variance due to lines and testers were significant for all the characters studied. All the traits were observed significant for line × tester interaction.

The SCA variances were higher than GCA variances for all the characters indicating the predominance of non-additive gene action.

- The lines Sahabhagi dhan (1.03) and MTU 1010 (0.32) and the tester SHIATS Dhan1 (1.43) possessed significant positive gca effects implying that they are good general combiners and may serve as useful source for improvement hybridization programmes.
- Three hybrids MTU 1010 x BM 71 (high x low), MTU 1001 x NDR 359 (low x high) and NLR 34449 x SHIATS dhan1 (low x high) were identified as good specific cross combinations based on positive sca effects and per se performance.
- Based on per se performance, significant sca effects and standard heterosis for yield in the crosses NLR 34449 x SHIATS Dhan1, Sahabhagi dhan x SHIATS Dhan1, BPT 2615 x NDR 359 and MTU 1010 x BM 71 recorded high per se performance (37.46, 36.17, 35.60 and 35.30), sca effects ( 2.51, 0.44, 1.72 and 3.44 ) and standard heterosis (13.74%, 9.82%, 8.09% and 7.19 %) and recorded high per se performance over the best check IR-64 for grain yield/ plant were identified as promising heterotic hybrids.
- The estimates of heritability in broad sense for 15 yield traits ranged from 45 (harvest index) to 98 (days to 50% flowering). High heritability was recorded for days to 50% flowering (98), days to maturity (97), Test weight (93) no. of grains/ panicle (92), plant height (89), grain yield /plant (79), number of tillers/plant(75) spikelet sterility % (75), spikelet fertility % (74), flag leaf width (69), number of panicles /plant (68), biological yield (65)and panicle length (64),) and medium heritability was observed for flag leaf length (50) and harvest index (45).
- A perusal of genetic advance for different traits varied from 3.68(harvest index) to (35.68spikelet sterility % (35.68), number of grains/ panicle(29.31), test weight (23.26), and number of panicles/ plant (20.27) recorded highest estimates of genetic advance, whereas moderate estimate of genetic advance were recorded for characters like no of tillers / plant (19.64)), grain yield / plant (17.12.), days to 50% flowering (16.12), panicle length (14.68), plant height (12.57), Biological yield (12.22), flag leaf width (12.17) and days to maturity (10.97) and low estimate of genetic advance were recorded for characters like spikelet fertility % (9.37),flag leaf length (7.32) and harvest index (3.68).

- The hybrids BPT5204 x NDR359 considered as best genotype for hulling followed by MTU1010 x SHIATS Dhan1 and NLR34449 x SHIATS Dhan1.
- The 34 genotypes (10 parents, 21 hybrids and 3 checks) were grouped into six clusters using the Tocher's method of clustering; the distribution of 34 genotypes into clusters was at random with maximum number of 17 genotypes in cluster I. Cluster IV is the second largest with 9 genotypes followed by cluster III with 5 genotypes. The cluster II, V and VI were solitary clusters. The parents and hybrids in clusters II, V and VI are divergent to other parents and hybrids.
- Inter cluster distances ( $D^2$ ) was found maximum between cluster VI and V followed by V and IV clusters V and II, cluster VI and III, cluster I and V, and cluster IV and III which indicates these clusters are highly divergent and it is desirable to select the genotypes from these divergent clusters in breeding programme for obtaining desirable segregants.
- Among the fifteen quantitative characters studied the most important character contributing to the divergence was days to maturity showed maximum contribution towards genetic divergence followed by days to 50% flowering, test weight, number of grains /panicle, grain yield / plant and plant height while spikelet fertility %, flag leaf length, number of panicles/plant, biological yield, harvest index, panicle length, flag leaf width and number of tiller/ plant reported negligible contribution towards divergence.
- A total of thirty SSR markers were used to assess the extent of genetic diversity across the 34 rice genotypes. Out of the 30 SSRs, 25 markers were found to be polymorphic, whereas remaining 5 were monomorphic. The level of polymorphism among the 34 rice genotypes was evaluated by allele number and PIC values for all the SSR loci.
- A total 86 alleles were detected from 25 SSR markers with an average of 4.12, which ranged from 2 (RM 10123, RM 20354 and RM 223) to 7 (RM 232 and RM 18571). Polymorphism information content (PIC) denotes the polymorphic informative ness of a marker.
- Among the set of 34 rice genotypes, six rare alleles were found. The PIC values, which are a reflection of allele diversity and frequency among the genotypes, were not

uniformly high for all the SSR loci tested. The average PIC value was 0.50 at a range from 0.11 (RM 10123) to a maximum of 0.75 (RM 232). This high amount of PIC values was an indication that SSR markers are more polymorphic and of more diversity existed among the genotypes

- The primers which showed more number of alleles were also found to contain high amount of PIC also. These results showed that the significant correlation existed between the PIC values and the number of alleles. Sufficient polymorphism revealed by the 25 SSR markers among the 34 rice genotypes in the present study justifies their use in genetic improvement programme, which depends on the extent of genetic variation.
- The dendrogram based on the UPGMA analysis of NTSYS software grouped the studied rice genotypes into five major clusters. The cluster I comprised of 11 genotypes, cluster II comprised of nine genotypes, whereas cluster III comprised of four genotypes. The cluster IV and V comprised of seven and three genotypes respectively
- Also there is a wide diversity existed between the parents and F<sub>1</sub> progeny. The hybrid MTU 1010 x NDR 359 was clustered in A1, where as their parents are in different clusters. The parent MTU 1010 was in cluster B, where as NDR 359 under cluster A2. The results showed that high amount of heterosis and diversity existed. Likewise BPT5204 existed in cluster A2, whereas its progeny was in B cluster. The results showed that the F<sub>1</sub> progeny obtained from different crosses are highly divergent with the parents.
- The Jaccard's coefficient of similarity ranged from 0.15 (BPT 5204 x BM71 and Sahabhazi dhan x SHIATS Dhan1) to 0.81 (MTU 1010 x NDR 359, and MTU 1001) with an average of 0.42, suggesting diverse nature of the genotypes under study. These results highlighted the presence of diversity at genomic level among the 34 rice genotypes. It is however suggested to increase the number of markers for efficiency in further characterization of the genotypes into distinct groups.
- The hybrids MTU 1010x NDR 359, MTU 1001 x NDR 359, MTU 1001 x SHIATS Dhan1 were grouped together by both morphological and molecular dendrogram methods.

## **CONCLUSION**

The experimental results concluded that four hybrids namely NLR 34449 x SHIATS Dhan1, Sahabhagi dhan x SHIATS Dhan1, BPT 2615 x NDR 359 and MTU 1010 x BM 71 shown high grain yield/plant (13.74%, 9.82%, 8.09% and 7.19 %) than the check variety IR 64. Parents Sahabhagi dhan, MTU 1010 and SHIATS Dhan1 possessed significant gca effects as good general combiners for yield and yield contributing characters and three hybrids namely MTU 1010 x BM 71, MTU 1001 x NDR 359 and NLR 34449 x SHIATS Dhan1 recorded significant sca effects for number of grains/panicle and grain yield/plant. Hybrids MTU 1010 x NDR 359, MTU 1001 x NDR 359 and MTU 1001 x SHIATS Dhan1 were grouped together by both morphological and molecular dendrogram methods.

## **BIBLIOGRAPHY**

- Agriculture Statistics at glance (2016).** Directorate of Economic and Statistic Agricultural Government of India.
- Ahmed, M.S., Aktar, K., Rashid, E.S.M.H. and Bashar, M.K. (2010).** Diversity analysis in Boro rice (*Oryza sativa* L.) accessions. *Bangladesh Journal of Agriculture Research*, 35(1): 29-36.
- Akter, Hasan, M.J., Begum, H., Kulsum, M.U. and Hossain, M.K. (2010).** Combining Ability Analysis in Rice (*Oryza Sativa* L.). *Bangladesh Journal of Plant Breeding and Genetics*, 23(2): 07-13.
- Allam, C.R., Jaiswal, H.K., Qamar, A., Venkateshwarlu, C. and Reddy, Y.S. (2015).** Variability, heritability and genetic advance studies in some indigenous genotypes of basmati rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 6(2): 506-511.
- Allard, R.W. (1960).** Principles of plant breeding. *John Wiley & Sons*, New York.
- Anonymous, 2013:**<http://www.irri.org>.
- Ashfaq, Khan, M., Salam, A., Khan, U., Habib, S., Ahmad, Rashid. (2012).** Association of Various Morphological Traits with Yield and Genetic Divergence in Rice (*Oryza sativa* L.). *International Journal of Agriculture & Biology*, 14(1): 55-62.
- Ashok,K., Sarial, Sindhu, S., Sarial and Singh, V.P. (2007).** Combining ability of new Basmati fertility restorers for grain yield and its components in rice. *Indian Journal of Genetics and Plant Breeding*, 67(2): 156-160.
- Ashvani, P., Dhaka, R. P. S. and Kumar, V. (2007).** Genetic variability and heritability studies in Rice (*Oryza sativa* L.). *Advances in Plant Science*, 20(1): 47-49.
- Asish, B.K., Kalaiyarasi, R. and Thiyagarajan, K. (2010).** Genetic divergence of rice varieties and hybrids for quality traits. *Oryza- An International Journal on Rice*, 47(2): 91-95.

- Autrique, E., Nachit, M.M., Monneveux, P., Tanksley, S.D. and Sorrells, B. (1996).** Genetic diversity in durum wheat based on RFLPs, morphological traits, and coefficient of parentage. *Crop Science*, 36(8): 735-742.
- Awasthi, L.P., Misra, C.H. and Pandey, V.K. (2005).** Genetic divergence in aromatic rice (*Oryza sativa* L.). *SABRAO Journal of Breeding & Genetics*, 44(2): 356-359.
- Babu, G., Satyanarayana, P.V., Rao, C.P. and Rao, V.S. (2010).** Combining ability for yield, components and quality traits in hybrid rice (*Oryza sativa* L.). *The Andhra Agricultural Journal*, 57(2): 143-147.
- Babu, G.K., Satyanarayana, P.V., Rao, C.P. and Rao, V.S. (2010).** Heterosis for yield, components and quality traits in rice (*Oryza sativa* L.). *The Andhra Agricultural Journal*, 57(3): 226-229.
- Babu, K., Meena, V., Agarwal, V., Agrawal, P.K. (2014).** Population structure and genetic diversity analysis of Indian and exotic rice (*Oryza sativa* L.) accessions using SSR markers. *Molecular Biology Reports*, 41(7): 4329-4339.
- Bagheri, N. (2010).** Heterosis and combining ability analysis for yield and related-yield traits in hybrid rice. *International Journal of Biology*, 2(2): 222-231.
- Banumathy, S., Manimaran, R., Sheeba, A., Manivannan, N., Ramya, B., Kumar, D. and. Ramasubramanian, G.V. (2010).** Genetic diversity analysis of rice germplasm lines for yield attributing traits. *Electronic Journal of Plant Breeding*, 1(4): 500-504.
- Banumathy, S., Thiyagarajan, K. and Vaidyanathan, P. (2003).** Combining ability for yield and yield components in three line hybrid rice. *Oryza* 40(3&4): 75-77.
- Becerra, Viviana, Paredes, Mario, Ferreira, Marcio, E., Gutiérrez, Eduardo, Diaz, Lucy, M. (2017).** Assessment of genetic diversity and population structure in temperate japonica rice germplasm used in breeding in Chile with SSR markers. *Chilean Journal of Agricultural Research*, 77(1): 15-26.
- Beer, S.C., Siripoonwiwat, W., Donoughue, L.S., Souza, E., Matthews, D. and Sorrells, M. E. (1997).** Association between molecular markers and quantitative traits in an oat germplasm pool. *Journal of Agriculture*, 97(3): 997-1001.

- Bhadru, D., Rao, V.T., Mohan, Y.C. and Bharathi, D. (2012).** Genetic variability and diversity studies in yield and its component traits in rice (*Oryza sativa* L.). *SABRAO Journal of Breeding & Genetics*, 44(1): 129-137.
- Bharathi, G.B., Krishna Veni, M., Lal, A. and Lalitha, K.J. (2016).** Studies on Genetic Divergence in High Yielding Rice (*Oryza sativa* L.). *Journal of Rice Research*, 9(2): 382-386.
- Bhati, P.K., Singh, S.K., Singh, R. and Upadhyay, D. (2017).** Combining ability for yield and yield traits using 'wa' cytoplasm in rice (*Oryza sativa* L.). *Bangladesh Journal of Botany*, 46(1): 53-59.
- Bhorali, P. (2004).** Combining ability of restorer lines over environments and inheritance of fertility restoration in rice (*Oryza sativa* L.). Ph.D. Thesis, Assam Agricultural University, Jorhat-13.
- Bhutia, K.S., Sarkar, K.K. and Roy, S.K. (2005).** Genetic divergence for yield and quality traits in some high yielding and local genotypes of rice (*Oryza sativa* L.). *Journal of Environmental and Ecology*, 23(1): 1-3.
- Bidhan, R., Hossain, M., Hossain, F. and Roy, B. (2001).** Genetic variability in yield components of rice (*Oryza sativa* L.). *Environment and Ecology*, 19(1): 186-189.
- Bisht, V., Singh, B., Rao, K.S., Maikhuri, R.K. and Nautiyal, A.R. (2007).** Genetic divergence of paddy landraces in Nanakosi micro-watershed of Uttarakhand and Himalaya. *Journal of Tropical Agriculture*, 45(1-2): 48-50.
- Bisne, R. and Motiramani, N.K. (2005).** Identification of maintainers and restorers using WA source cytoplasmic male sterile lines in rice. *International Rice Research. Notes*, 30(1): 14-15.
- Bitew, J.M. (2016).** Estimation of Genetic Parameters, Heritability and Genetic Advance for Yield Related Traits in Upland Rice (*Oryza sativa* L.) and *Oryza glaberrima* Steud Genotypes in North western Ethiopia. *World Scientific News*, 47(2): 340-350.

- Bligh, H.F.J., Blackhall, N.W., Edwards, K.J. and McClung, A.M. (1999).** Using amplified length polymorphisms and simple sequence length polymorphisms to identify cultivars of brown and white milled rice. *Crop Science*, 39(18): 1715-1721.
- Bora, A., Choudhary, P.R., Pande, V. (2016).** Assessment of genetic purity in rice (*Oryza sativa* L.) hybrids using microsatellite markers. *3Biotech*, 22(5): 44-48.
- Bose, L.K., Pradhan, S.K. (2005).** Genetic divergence in deep water rice genotypes. *Journal of Control, European. Agriculture*, 6(4): 635-640.
- Burton, G.W. (1952).** Quantitative inheritance of grasses. *Production 6<sup>th</sup> international Grassland congress*, 1(6): 277-283.
- Burton, G.W. and Devane. (1953).** Estimation of heritability in tall fescue. *Festulaarundnacea from replicated clonal material Agronomy*, 45(6): 478-481.
- Chakma, S.P., Huq, H., Mahmud, F. and Husna, A. (2012).** Genetic Diversity Analysis in Rice (*Oryza sativa* L.). *Bangladesh Journal of plant Breeding & Genetics*, 25(1): 31-39.
- Chakraborty, R., Chakraborty, S., Dutta, B.K. and Paul, S.B. (2009).** Combining ability analysis for grain yield and yield components in bold grained rice (*Oryza sativa* L.). *Agricultural Agronomy*, 58(1): 79-82.
- Chakraborty, S. and Chaturvedi, H.P. (2014).** Genetic Variability in Upland Rice (*Oryza sativa* L.) Genotypes of Nagaland. *Indian Research Journal Genetics & Biotechnology*, 6(2): 374-378.
- Chakravarthi, B.K. and Naravaneni, R. (2006).** SSR marker based DNA fingerprinting and diversity study in rice (*Oryza sativa* L.). *African Journal of Biotechnology*, 5(9): 684-688.
- Chakravorty, A. and Ghosh, P.D. (2012).** Genetic divergence in landraces of rice (*Oryza sativa* L.) of West Bengal. *Indian Journal of Crop and Weed*, 8(2): 23-28.

- Chambers, M. and Avoy M. (2000).** Comparison of microsatellites and amplified fragment length polymorphism markers for parentage analysis. *Molecular Ecology*, 9(11): 1037-1048.
- Chamundeswari, N., Satyanarayana, P.V. and Reddy, K.R. (2012).** Genetic assessment of physical quality traits in rice (*Oryza sativa* L.) by generation means analysis. *Research on crop*, 13(3): 1078-1083.
- Chanbeni, B., Ovung, Y., Lal, G.M. and Rai, P.K. (2012).** Studies on genetic diversity in Rice (*Oryza sativa* L.). *Journal of Agricultural Technology*, 8(3): 1059-1065.
- Chand, S.P., Roy, S.K. and Senapati, B.K. (2005).** Genetic divergence in Aman rice under semi-deepwater condition. *Crop Research*, 30(1): 46-49.
- Chaudhary, M. and Motiramani, N.K. (2003).** Variability and association among yield attributes and grain quality in traditional aromatic rice accessions. *Crop Improvement, India*, 30(1): 84-90.
- Cheema, A.A., Rashid., Ashraf., Ziaul Qamar. (2004).** Genetic divergence in rice collection. *Pakistan Journal of Botany*, 36(3): 557-565.
- Choudhary, G., Ranjit, K.N., Surapaneni, M., Deborah, D.A., Vipparla, A., et al. (2013).** Molecular Genetic Diversity of Major Indian Rice Cultivars over Decadal Periods. *Plos one*, 8(6): 1169-1245.
- Directorate of Economics and Statistics, (2016-17).**
- Darwin, C. (1859).** The origin of species by means of natural selection or the preservation of favoured races in the struggle for life. *Philosophical Library*, New York.
- Das, P., Kundu, A., Mandal, N. and Indrani, D. (2004).** Genetic divergence in land race collections of rice (*Oryza sativa* L.). *Journal of International academy*, 8(4): 488-494.
- Devi, K.R., Parimala, K., Venkanna, V., Lingaiah, N., Hari, Y. and Chandra, B.S. (2016).** Estimation of Variability for Grain Yield and Quality Traits in Rice (*Oryza sativa* L.). *International Journal Pure Applied Bioscience*, 4(2): 250-255.

- Devi, N.G., Babu, R.V., Padmavathi, G. and Sunitha, T. (2015).** Genetic Diversity in Grain Quality Traits of Rice Genotypes. *Journal of Rice Research*, 8(1): 109-118.
- DeWoody, J.A., Honeycutt, R.L. and Skow, L.C. (1995).** Microsatellite markers in white tailed deer. *Journal of Heredity*, 86(2): 317-319.
- Dhurai, S.Y., Bhati, P.K. and Saroj, S.K. (2014).** Studies on genetic variability for yield and quality characters in rice (*Oryza sativa* L.) under integrated fertilizer management. *An International quarterly Journal of Life Sciences*, 9(2): 845-848.
- Dhutmal, R.R. and Kalpande, H.V. (2017).** Genetic Divergence and Principle Component Analysis in Upland Rainfed Rice (*Oryza sativa* L.). *Bangladesh Journal of Botany*, 46(1): 125-132.
- Diederichsen, A. (2009).** Duplication assessments in Nordic *Avena sativa* accessions at the Canadian national gene bank. *Genetic Resource Crop Evolution*, 56(12): 587–597.
- Dutta, P., Nath, P., Barua, P.K. (2013).** Morphological Traits as Selection Indices in Rice, A Statistical View. *Universal Journal Agriculture Research*, 1(3): 85-96.
- Dwivedi, D.K. and Pandey, M.P. (2012).** Gene action and heterosis for yield and associated traits in Indica and Tropical Japonica crosses of rice (*Oryza sativa* L.) involving wide compatibility gene(s). *International Journal plant Breeding and Genetics*, 6(9): 140-150.
- Dwivedi, D.K., Pandey, M.P., Pandey, S.K. and Rongbai, L.I. (1999).** Combining ability over environments in rice involving Indica and tropical Japonica lines. *Oryza*, 36(2): 101–107.
- Dwivedi, R., Srivastava, K., Devi, A., Kumari, P. and Dwivedi, D.K. (2015).** Genetic Variability in Rice Under Saline Condition. *Trends in Biosciences*, 8(15): 3881-3887.
- Elayaraja, K., Prakash, M., Saravanan, K., Kumar, B.S and Ganesan, J. (2005).** Effect of physical and chemical mutagens on certain quantitative characters in rice (*Oryza sativa* L.). *Crop Research*, 30(2): 309-312.

- El-Namaky, R.A. (2012).** Heterosis and combining ability of some agronomic and physiological characters in rice. *Journal of Agriculture Research Kafer El-Sheikh University*, 38(2): 266.
- FAO (2016).** Food and Agriculture Organisation.
- Farohmandfor, R., Farahmandjar, E., Varnoamkhasti, M.G. and Zarei, M. (2010).** Millet Rice Quality Assessment. *International Journal of Food Engineering*, 6(2): 7-9.
- Fisher, R.A. (1918).** The correlation between relative on supposition of mendelian inheritance. *Tans Royal Social Edinburgah*, 52(6): 399-433.
- Fisher, R.A. and Yates, A.H. (1938).** Statistical tables for biological, Agricultural and medical research. *Olivar and Boyd Edinburgh*, 22-26.
- Fisher, R.A. and Yates, F. (1967).** Statistical tables for biological, agricultural and medical research. *Longman Group Limited*, London.
- Gangashetty, P.I., Salimath, P.M., Hanamaratti, N.G. (2013).** Genetic Variability Studies in Genetically Diverse non-basmati Local Aromatic Genotypes of Rice (*Oryza sativa* L.). *Rice Genomics and Genetics*, 4(2): 4-8.
- Garcia, M.V., Balatti, P.A. and Arturi, M.J. (2007).** Genetic variability in natural population of *Paspalum dilatatum* Poir analyzed by means of morphological traits and molecular markers. *Gene Resources Crop Evolution*, 54(2): 935-946.
- Gholizadeh, F., Navabpour, S., Sabouri, H. and Ramezapour, S. (2007).** Estimation of genetic diversity in rice (*Oryza sativa* L.) genotypes using SSR markers and morph physiological characters. *Crop and Pasture Science*, 6(2): 312-316.
- Ghorbanipour, A. and Rabiei, B. (2011).** Genetic analysis of physical and chemical characteristic association with grain quality in rice. *Iranian Journal of field crop Science*, 4(2): 339-347.
- Ghosh, A. (1993).** Combining ability for yield and its related traits in upland rice. *Oryza*, 30(2): 275-279.

- Ghosh, S.C. and Sharma, K., Deepak, P. (2012).** Genetic parameters of agro-morpho-physiological traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 3(1): 711-714.
- Ghosh, S.C., Chandrakar, P.K., Rastogi, N.K., Sharma, D. and Sarawgi, A.K. (2012).** Combining ability analysis using cms breeding system for developing hybrids in rice (*Oryza sativa* L.). *Bangladesh Journal of Agricultural Research*, 37(4): 583-592.
- Gokula, K.J., Kumar, B.S. and Prakash, M. (2014).** Variability Studies for some Yield and Quality Traits in Rice (*Oryza sativa* L.). *Plant Archives*, 14(2): 64-68.
- Gracia, A.A.F., Benchimol, L.L., Anotonica, M.M., Geraldi, I.O. and Deuza, A.P. (2004).** Comparision of RAPD, RFLP, AFLP and SSR marker for diversity studies in tropical maize inbred line. *Euphytica*, 108(2): 53-63.
- Griffing, B. (1956).** Concept of general and specific combining ability in relation to diallel crossing system. *Australian Journal Biological Science*, 9(1): 463-493.
- Haque, S., Pradhan, S.K. and Singh. (2014).** Genetic diversity analysis of direct seeded rice genotypes under drought situation. *Oryza*, 51(2): 121-124.
- Hari, P.K., Zaman, F.U., Singh, A.K. and Tomar S.M.S. (2006).** Analysis of combining ability status among parents and hybrids in rice (*Oryza sativa* L.). *Indian Journal of Genetics*, 66(1): 28-30.
- Hasan, M.J., Kulsum, M.U., Akter, A., Masuduzzaman, A.S.M. and Ramesha, M.S. (2014).** Genetic variability and character association for agronomic traits in hybrid rice (*Oryza sativa* L.). *Bangladesh Journal of Plant Breeding and Genetics*, 24(1): 45-51.
- Hossain, M. (1996).** Economic prosperity in Asia-Implications for rice research. Khush, G.S. (ed) *Rice Genetics III*, IRRI, Manila, Philippines, 3-16.

- Huang, X., Yang, S., Gong, J., Zhao, Q., Feng, Q., Zhan, Q. (2016).** Genomic architecture of heterosis for yield traits in rice. *Nature*, 537(8): 629–633.
- Huxley, J.S. (1955).** Mormonism in birds. *Proc XI International Organization Congress, Bale*.
- Ilieva, V., Markova, N., Andov, D. and Andreevska, D. (2013).** Combining ability analysis of some yield components in rice (*Oryza sativa* L.). *Food science, Engineering and Technology*, 110(4): 1005-1009.
- Ishwar, I. and Ananda, C.R. (2007).** Combining ability studies for yield and yield associated traits in rice (*Oryza sativa* L.) involving Assam rice cultures. *International Journal Agriculture Sciences*, 3(2): 234-236.
- Islam, M.A., Raffi, S.A., Hossain, M.A., Hasan, A.K. (2015).** Analysis of genetic variability, heritability and genetic advance for yield and yield associated traits in some promising advanced lines of rice. *Progressive Agriculture*, 2(6): 26-31.
- Jain, A., Payasi, D., Reddy, K. and Shenoy, V. (2014).** Heterosis Manifestation in Rice (*Oryza sativa* L.) Hybrids under Water Limited Rainfed Condition. *International Journal of Bio-resource and Stress Management*, 5(4): 480-485.
- Jalaluddin, M., Nakai, H. and Yamamoto, T. (2007).** Genetic diversity and DNA fingerprinting of some modern indica and japonica rice. *SABRAO Journal of Breeding & Genetics*, 39(1): 43-52.
- Jarwar, A.D., Cruz, Q.D. and Junejo, G.S. (2013).** Heterosis of some yield and its related characters in aromatic rice (*Oryza sativa* L.) varieties and their  $f_1$  hybrids under lowland and upland environments. *Pakistan Journal of Agriculture, Engineering & Veterinary Sciences*, 29(1): 13-23.
- Jayamani, P., Negrao, S., Martins, M., Macas, B. and Oliveira, M.M. (2007).** Genetic Relatedness of Portuguese Rice Accessions from Diverse Origins as Assessed by Microsatellite Markers. *Crop Science*, 47(4): 879-884.

- Jeung, J.U., Hwang, H.G., Moon, H.P. and Jena, K.K. (2005).** Fingerprinting temperate *japonica* and tropical *indica* rice genotypes by comparative analysis of DNA markers. *Euphytica*, 146(2): 239-251.
- Johnson, H.W., Robison, H.F. and Comstock, R.E. (1955).** Estimates of genetic and environmental variability in soyabean. *Agronomy Journal*, 47(8): 314-318.
- Jones, E.S., Sullivan, H., Bhatramakki, D. and Smith, J.S.C. (2007).** A comparison of simple sequence repeat and single nucleotide polymorphism marker technologies for the genotypic analysis of maize (*Zea mays* L.). *Theoretical Applied Genetics*, 115(2): 361-371.
- Jones, J. W. (1926).** Hybrid vigour in rice. *Journal of American Society Agronomy*, 18(1): 423-428.
- Juneja, H., Inagaki, Y.A. and Fujimura, T. (2006).** Highly polymorphic microsatellites of rice consist of AT repeats and a classification of closely related cultivars with these microsatellite loci. *Theoretical Applied Genetics*, 94(1): 61-67.
- Kanawapee, N., Sanitchon, J., Srihaban, P. and Theerakulpisut, P. (2011).** Genetic diversity analysis of rice cultivars (*Oryza sativa* L.) differing in salinity tolerance based on RAPD and SSR markers. *Electronic Journal of Biotechnology*, 14(6): 342-346.
- Kar, A.K., Das, S.R and Bastia, D. (2013).** Genetic divergence in selected indigenous aromatic rice of Odisha. *Oryza*, 50(2): 185-188.
- Karim, D., Sarkar, U., Siddique, M.N.A., Miah, M.A.K. and Hasnat, M.Z. (2007).** Variability and genetic parameter analysis in aromatic rice. *International Journal of Sustainable Crop Production*, 2(5): 15-18.
- Karuppaiyan, R., Kapoor, C. and Gopi, R. (2013).** Variability, heritability and genetic divergence in lowland rice genotypes under the mid-hills of Sikkim. *Oryza*, 50: 81-84.
- Kemphorne, O. (1957).** Introduction to genetic statistics. *John Wiley and Sons*, New York, 453-471.

- Ketan, R. and Sarkar, G. (2014).** Studies on variability, heritability, genetic advance and path analysis in some indigenous Aman rice (*Oryza sativa* L.). *Journal of Crop and Weed*, 10(2):308-315.
- Khalid,A., Ahmed, O., Mustafa, M., Ali, F., Yonglain, Z. and Fazhan, Q. (2012).** Genetic variability for yield and related attributes of upland rice genotypes in semi arid zone (Sudan). *African Journal of Agricultural Research*, 7(33): 4613-4619.
- Khriedinuo, P., Fukrei, Kumar, A., Wricha,T., Myank, R.A., Patnayak. (2011).** Genetic Variability in Yield and its Components in Upland Rice Grown in Acid Soils of North East India. *Journal of Rice Research*, 4(2): 1-2.
- Khute, I.K., Singh, S., Sahu, P. and Sharma, D. (2015).** Gene action and combining ability analysis to develop NPT based rice hybrids in Chhattisgarh plains. *Electronic journal of plant breeding*, 6(2): 366-372.
- Kumar, A., Rangare, N.R. and Vidyakar, V. (2013).** Study of genetic variability of Indian and exotic rice germplasm in Allahabad agroclimate. *The Bioscan*, 8(4): 1445-1451.
- Kumar, A., Singh, N.K. and Sharma, V.K. (2006).** Combining ability analysis for identifying elite parents for heterotic rice hybrids. *Oryza* 43(2): 82-86.
- Kumar, D.B.M. (2008).** Genetic divergence in red rice. *Karnataka Journal of Agricultural Science*, 21(3): 346-348.
- Kumar, R., Suresh, B.G., Rai, K.S. and Sandhya. (2015).** Genetic variability and divergence studies in elite rice genotypes for biometrical traits. *The ecoscan*, 9(1&2): 209-212.
- Kumar, S., Singh, D., Sirohi, A. and Satyendra. (2008).** Genetic diversity in rice (*Oryza sativa* L.) under aerobic conditions. *Environment. and Ecology*, 26(2): 606-608.
- Kumar, S.T., Marasimmon, R., Eswaran, R., Kumar, C.P.S., anandan, A. (2007).** Studies on genetic variability, heritability and genetic advance in segregating

generations of rice (*Oryza sativa* L.). *International Journal of Plant Science*, 2 (1): 48-51.

**Kunkerkar, R.L., Sawant, D.S., Shetye, V.N. and Vanave, P.B. (2012).** Heterosis studies in rice hybrids involving diverse cytotosteriles. *Oryza*, 49(1): 60-61).

**Latha, S., Deepak, D., Gulzar, S., Sanghera. (2013).** Combining Ability and Heterosis for Grain Yield and its Component Traits in Rice (*Oryza sativa* L.). *Electronic Journal of Agriculture*, 102(5): 2067-3205.

**Latha, S., Sharma, D. and Sanghera, G.S. (2013).** Combining ability and heterosis for grain yield and its component traits in rice (*Oryza sativa* L.). *Not Science and Biology*, 5(1): 90-97

**Lavanya, C. (2000).** Combining ability for yield and its components in hybrid rice. *Oryza*, 37(1): 11-14.

**Liang, G.H., Reddy, C.R. and Dayton, A.D. (1971).** Heterosis, inbreeding depression and heritability estimates in a systematic series of grain sorghum genotypes. *Crop Science*, 12(15): 400-411.

**Lingaiah, N., Venkanna, V. and Cheralu, C. (2014).** Genetic Variability Analysis in Rice (*Oryza sativa* L.). *International journal of Pure Application Bioscience*, 2(5): 203-204.

**Lokaprakash, R., Shivashankar, G., Mahadevappa, M., Shankaregowda, B.T. and Kulkarni, R.S. (1991).** Combining ability for yield and its components in rice. *Oryza*, 28(6): 319-322.

**Lush, J.L. (1940).** Intra-sire correlation on regression of off-spring on dams as a method of estimating heritability of characters. *Proceedings of American Society of Animal Production*, 33(9): 292-301.

**Mahalanobis, P.C. (1936).** On the generalized distance in statistics. *Proceedings National Institute Science, India*, 3(2): 12-49.

- Majumder, D.A.N., Shamsuddin, A.K.M., Kabir, M.A. and Hassan, L. (2008).** Genetic variability, correlated response and path analysis of yield and yield contributing traits of spring wheat. *Journal of Bangladesh Agricultural University*, 6(2): 227-234.
- Mall, A.K., Babu, J.D.P. and Babu, G.S. (2005).** Estimation of genetic variability in rice. *Journal of Maharashtra Agriculture University*, 30(2): 166-168.
- Manohara, K.K., Singh, N.P. (2013).** Genetic divergence among rice landraces of Goa. *Oryza*, 50(4): 100-104.
- Manonmani, S. and Ranganathan, T.B. (1998).** Genetic analysis in early lines of *indica* rice. *Oryza*, 35(4): 358-360.
- Manuel, W.W. and Prasad, M.N. (1992).** Combining ability and heterosis in rice. *Oryza*, 29(4): 15-18.
- Martinez, L., Cavagnaro, P. and Masuelli, R. (2005).** Evaluation of diversity among Argentine grapevine (*Vitis vinifera* L.) varieties using morphological data and AFLP markers. *Electronic Journal Biotechnology*, 6(2): 37-45.
- Meena, A.K., Suresh, J., Mahanthesha, M., Meena, H.P. (2015).** Genetic variability, heritability and genetic advance for yield and yield components in rice (*Oryza sativa* L.). *The Bioscan*, 9(3&4): 1053-1056.
- Mishra, L.K., Sarawgi, A.K. and Mishra, R.K. (2003).** Genetic diversity for morphological and quality traits in rice (*Oryza sativa* L.). *Advances in Plant Sciences*, 16(1): 287-293.
- Moghaddam, M.E., Trethowan, R.M., William, H.M., Rezai, A., Arzani, A. and Mirlohi, A.F. (2005).** Assessment of genetic diversity in bread wheat genotypes for tolerance to drought using AFLPs and agronomic traits. *Euphytica*, 141(8): 147-156.
- Mohammad, T., Dera, W. and Ahmad, Z. (2002).** Genetic variability of different plant and yield characters in rice. *Sarhad Journal Agriculture*, 18(2): 207-210.

- Mohan, Y.C., Thippeswamy, K., Bhoomeshwar, Madhavalatha, B. and Samreen, J., Monohara, K.K. and Singh, N.P. (2013).** Genetic divergence among rice landraces of Goa. *Oryza*, 50(6): 100-104.
- Munisonnappa, S. and Vidya, C.B. (2007).** Standard Heterosis in Newly Developed Rice Hybrids. *Karnataka Journal Agricultural Science*, 20(2): 379-380.
- Nagaraju, C., Reddi, M.S., Kumar, T.S., Hariprasad, R.K. and Sudhakar, P. (2015).** Gene action and combining ability analysis for grain yield and quality components in rice (*Oryza sativa* L.). *Progressive Agriculture*, 15(1): 35-40.
- Narasimman, R., Kumar, T.S., Eswarn, R., Praveen, C., Kumar, S. and Anandan, A. (2007).** Combining ability and heterosis for grain yield and its component characters in rice (*Oryza sativa* L.). *Crop Improvement*, 34(1): 16-18.
- Navin, K., Tiwari, B., Lal, G.M., Miahra, S.P., Katiyar, A. and Khuntay, Y. (2015).** Evaluation of rice hybrids (*Oryza sativa* L.) for yield and its component characters. *Indian Research Journal Genetics and Biotechnology*, 7(1): 41-43.
- Nayak, A.R., Chaudhary, D. and Reddy, J.N. (2002).** Genetic variability, heritability and genetic advance in scented rice. *Indian Agriculture*, 46(12): 45-47.
- Nayak, A.R., Chaudhary, D. and Reddy, J.N. (2004).** Genetic divergence in scented rice. *Oryza*, 384(42): 79-82.
- Neelam, S., Ramesha, M.S., Reddy, T.D. and Sankar, S.A. (2013).** Study of heterosis by utilizing male sterility-restoration system in rice (*Oryza sativa* L.). *Journal Rice Research*, 2(2): 24-28.
- Nirmala, D.G., Padmavathi, G.,kota, S. and Babu, V.R. (2015).** Genetic variability, heritability and correlation coefficients of grain quality characters in rice (*Oryza sativa* L.). *Sabao Journal of Breeding and Genetics*, 47(4): 424- 433.

- Nuruzzaman, M., Alam, M.F., Ahmed, M.G., Shohael, A.M., Biswas, M.K., Amin, M.R. and Hossain, M.M. (2002).** Studies on parental variability and heterosis in rice. *Pakistan Journal Biological Science*, 5(10): 1006-1009.
- Ogunbayo, S.A., Sie, M., Toulou, B., Daniel, I.O. and Gregorio, G.B. (2014).** Genetic variation and heritability of yield and related traits in promising rice genotypes (*Oryza sativa* L.). *Journal of Plant Breeding and Crop Sciences*, 6(11): 153-159.
- Oladi, M., Nematzadeh, G., Ghara, A.G., Ghadi, A.A. and Rezaei, M. (2014).** Analysis of the physicochemical properties and grain yield of some rice promising lines from multiple Crosses. *International journals of Advanced Biological and Biomedical Research*, 2(3): 769-774.
- Onaga, G., Egdane, J., Edema, R. and Abdelbagi, I. (2013).** Morphological and genetic diversity analysis of rice. *Journal Crop Science Biotechnology*, 16 (1): 53-62.
- Pachauri, V., Taneja, N., Vikram, P., Singhand, N.K. and Singh, S. (2013).** Molecular and morphological characterization of Indian farmers rice varieties (*Oryza sativa* L.). *AJCS*, 7(7): 923-932.
- Padmaja, D., Radhika, K., Subba Rao, L.V and Padma, V. (2008).** Studies on variability, heritability and genetic advance for quantitative characters in rice (*Oryza sativa* L.). *Journal of Plant Genetic Resources*, 21(3): 196-198.
- Pandey, P. and Anurag, P.J. (2010).** Estimation of genetic parameters in indigenous rice. *AAB Bioflux*, 2(1): 79- 84.
- Pandey, P., Anurag,P.J., Tiwari, D.K., Yadav, S.K., Kumar, B. (2009).** Genetic Variability, Diversity and Association of Quantitative Traits with Grain Yield in Rice (*Oryza sativa* L.). *Journal of bioscience*, 17(2): 77-82.
- Pankaj, K., Singh, Murali, N., Mishra, Dipak, K. and Verma, R. (2006).** Genetic divergence in lowland rice of north eastern region of India. *Communications in Biometry and Crop Science*, 1(1):35–40.

- Panse, V.G. and Sukhatme, P.V. (1967).** Statistical methods for agricultural workers. *Indian Council of Agricultural Research, New Delhi*, 2(1): 381-384.
- Patil, A.B., Mehta, H.D. (2014).** Combining ability analysis for yield in rice hybrid (*Oryza sativa* L.). *Electric journal of plant breeding*, 5(4): 626-631.
- Prabakaran, A., Paramasivam, K., Rajesh, T. and Rajarajan, D. (2010).** Molecular characterization of rice land races using SSR markers. *Electronic Journal Plant Breeding*, 1(4): 512-516.
- Prasad, G., Rao, S.L.V., Sujatha, M. and Chaitanya, U. (2013).** Heterosis and combining ability analysis for few cold tolerant rice germplasm lines at their seedling stage. *International Journal Developed Research*, 3(8): 010-012.
- Pratap, N., Singh, P.K., Shekhar, R., Soni, S.K. and Mall, A.K. (2012).** Genetic variability, character association and diversity analyses for economic traits in rice (*Oryza sativa* L.). *SAARC Journal of Agriculture*, 10(2): 83-94.
- Pulin, B., Sarma, D. and Hazarika, G.N. (2017).** Magnitude of heterosis for yield and its components in hybrid rice (*Oryza sativa* L.). *International Journal of Agricultural Science and Research*, 7(2): 209-216.
- Punitha, D., Joel, A.J., Manomani, S. and Thiyagarajan, K. (2004).** Combining ability for yield and its components. *Advances in Plant Sciences*, 17(1): 345-348.
- Rafii, M.Y., Zakiah, M.Z., Asfaliza, R., Iffah, H.M.D., Latif, M.A. and Malek, M.A. (2014).** Grain Quality Performance and Heritability Estimation in Selected F1 Rice Genotypes Sains Malaysian. *Rice Research Series*, 46(18): 192-196.
- Rahimi, M., Rabiei, B., Samizadeh, H. and Ghasemi, A.K. (2010).** Combining Ability and Heterosis in Rice (*Oryza sativa* L.) Cultivars. *Journal Agriculture Science and Technology*, 12(1): 223-231.

- Rahman, M.M., Rahman, M.A., Hossain, A. and Rasul, G. (2011).** Comparative study on morphological, physiological and molecular genetic diversity analysis in rice (*Oryza sativa* L.). *Libyan Agriculture Research Center of International Journal*, 2(2): 85-93.
- Rahman, M.M., Syed, M.A., Akter, A., Meskatul, A.M.D. and Monjurul, A.M.D. (2014).** Genetic Variability, Correlation and Path Coefficient Analysis of Morphological Traits in Transplanted Aman Rice (*Oryza sativa* L.). *American-Eurasian Journal Agriculture and Environment Science*, 14 (5): 387-391.
- Rajguru, S.N., Burgos, N.R., Gealy, D.R., Sneller, C.H. and Stewart, J.M. (2002).** Genetic diversity of Red Rice in Arkansas. *Rice Research Series*, 2(1): 99-104.
- Rajput, A.S., Suresh, B.G. and Bhatii, M. (2014).** Genetic diversity of irrigated medium duration of rice genotypes suited for eastern plain zone of U.P. *Journal of Agriculture and Veterinary Science*, 7(7): 42-45.
- Raju, S., Rao, M.V.B. and Sudarshanam, A. (2006).** Heterosis and genetic studies on yield and associated physiological traits in rice (*Oryza sativa* L.). *Oryza*, 43(1): 264-273.
- Ram, S.G., Thiruvengadam, V. and Vinod, K.K. (2007).** Genetic diversity among cultivars, land races and wild relatives of rice as revealed by microsatellite markers. *Journal of Applied Genetics*, 48(4): 337-345.
- Ramadan, E.A., Elmoghazy, A.M., Mowafi, H.F. (2015).** Molecular Markers based Genetic Diversity Analysis for Drought Tolerance in Rice (*Oryza Sativa*, L.) using SSR Markers. *International Journal of Scientific Research in Agricultural Sciences*, 2(6): 137-146.
- Rana, M.K., Singh, V.P. and Bhat, K.V. (2005).** Assessment of genetic diversity in upland cotton (*Gossypium hirsutum* L.) breeding lines by using amplified fragment length polymorphism (AFLP) markers and morphological characteristics. *Genetic Resources Crop Evolution*, 52(1): 989-997.
- Rao, C.R. (1952).** Advance Statistical Method for Biometrical Research. *John Wiley and Sons*, New York, 2(1): 390-398.

- Rathi, S. and Sarma, R.N. (2012).** Microsatellite diversity in indigenous glutinous rice land races of Assam. *Indian Journal of Biotechnology*, 11(4): 23-29.
- Ravi, M., Geethanjali, S., Sameeya, F. and Maheswaran, M. (2003).** Molecular Marker based Genetic Diversity Analysis in Rice (*Oryza sativa* L.) using RAPD and SSR markers. *Euphytica*, 133(12): 243–252.
- Ravindra, B.V., Shreya, K., Singh, K.D., Usharani, G. and Nagesh, P. (2013).** Evaluation of Popular Rice (*Oryza sativa* L.) Hybrids for Quantitative, Qualitative and Nutritional Aspects. *International Journal of Scientific and Research Publications*, 2(6): 2250-3153.
- Reddy, M., Rajendar, T., Raju, C., Surendar, R., Sravani, D., Reddy, T., Dayakar. and Reddy, G., Narasimha, N. (2012).** Heterosis for yield and kernel size in aromatic rice (*Oryza Sativa*. L). *Annals of Biological Research*, 3(6): 0976-1233.
- Ribeiro, C.R., Guedes, H., Igrejas, G., Stephenson, P., Schwarzacher, T. and Heslop, J.S. (2004).** High levels of genetic diversity throughout the range of the Portuguese wheat landrace Barbela. *Annals of Botany*, 94(8): 699-705.
- Rogbell, J.E., Subbaraman, N. and Karthikeyan, C. (1998).** Heterosis in rice under saline conditions. *Crop Research Hisar*, 15(4): 68-72.
- Rohlf, H.J. (2002).** NTSYS-PC, Numerical taxonomy and multivariate system. *Setauket, New York*, 2(1): 12-18.
- Rosalin, S., Mohapatra, S., Roy, D.P., Swain., Singh, O.N., Meher, J., Dash, S.K., Rao, G.J.N., Subudhi, H.N. (2017).** Assessment of Genetic Diversity in Wild Rice of Eastern India Using SSR Markers. *Journal of Agricultural Science*, 9(6): 6-12.
- Rosamma, C.A. and Vijay, K.N.K. (2005).** Heterosis and combining ability in rice (*Oryza sativa* L.) hybrids developed for Kerala State. *Indian Journal of Genetics and Plant Breeding*, 65(2): 119-120.

- Roy, S., Islam, M.A., Sarker, A., Malek, M.A., Rafii, Y.M. and Ismail, M.R. (2013).** Determination of genetic diversity in lentil germplasm based on quantitative traits. *Australian Journal of Crop Science*, 7(1): 67-74.
- Russell, J., Fuller, J., Young, G., Thomas, B., Taramin, G., Macaulay, M., Waugh, M. and Powell, M. (1997).** Discriminating between barley genotypes using microsatellite markers. *Genome*, 40(1): 442-450.
- Sabesan, T., Saravanan, K. and Anandan, A. (2010).** Genetic Divergence analysis for certain yield and quality traits in rice (*Oryza sativa* L.) grown in irrigated saline low land of Annamalaiagar, South India. *Journal of Central European Agriculture*, 10(4): 28-42.
- Sahu, R., Singh, S.K., Singh, D.K., Vennela, N., Prudhvi, R., Reddy, S., Kumar, S., Rathan, ND. (2017).** Heterosis studies for yield and yield traits in rice (*Oryza Sativa* L.) under rainfed condition. *International Journal of Agriculture, Environment and Biotechnology*, 10(1): 1-10.
- Sahu, V., Singh, S.K., Sharma, A. and Bhati, P.K. (2013).** Combining ability analysis for yield and yield traits using 'WA' cytoplasm in rice (*Oryza sativa* L.). *The Bioscan*, 8(3): 871-874.
- Saidaiiah, P., Kumar, S. and Ramesha, M.S. (2010).** Variability for yield and yield component attributes in rice. *Crop Research*, 39(1, 2 & 3): 91-93.
- Salgotra R.K., Gupta, B.B. and Singh, P. (2009).** Combining ability studies for yield and yield components in Basmati rice. *Oryza*, 46(8): 12-18.
- Salgotra, R.K., Gupta B.B., Bhat, J.A., Sharma, S. (2015).** Genetic Diversity and Population Structure of Basmati Rice (*Oryza sativa* L.) Germplasm Collected from North Western Himalayas Using Trait Linked SSR Markers. *PLOS ONE*, 10(2): 68-76.
- Samrath, B. and Sharma, D. (2014).** Study of combining ability to develop hybrids in rice (*Oryza sativa* L.). *Advance research journal of Improvement*, 2(1): 2231-640.

- Sandhya, G., Suresh, B.G. and Kumar, R. (2014).** Genetic Variability, Interrelationship and Path Analysis for Yield Improvement of Rice Genotypes. *Bioscan* , 9(3): 1161-1164.
- Sanghera, G.S. and Hussain, W. (2013).** Gene Action and Combining Ability Studies Using CMS System for Developments of Hybrid Rice under Temperate Conditions. *American Journal of Agriculture Science and Technology*, 1(2): 27-44.
- Sanjeev, K., Singh, H.B. and Sharma. J.K. (2007).** Combining ability analysis for grain yield and other associated traits in rice. *Oryza*, 44(2): 108-114.
- Santha, V. and Karthikeyan. (2016).** Combining Ability Studies for Yield and Yield Components in Rice (*Oryza Sativa* L.). *Research Article, Vegetos*, 29(4): 63-68.
- Sarawgi, A.K. and Bisne, R. (2007).** Studies on genetic divergence of aromatic rice germplasm for agromorphological and quality characters. *Oryza*, 44(1): 74-76.
- Sarkar C.K.G., Fu, Z. and Singh, A.K. (2002).** Genetics of fertility restoration of WA based cytoplasmic male sterility system in rice (*Oryza sativa* L.) using basmati restorer lines. *Indian Journal of Genetics*, 62(4): 305-308.
- Sarker, U., Biswas, P.S., Prasad, B. and Khaleque, M.A. (2002).** Heterosis and genetic analysis in rice hybrids. *Pakistan Journal of Biological Science*, 5(1): 1-5.
- Sarma, M.K., Sharma, A.K., Agrawal, R.K. and Richharia, A.K. (2007).** Combining ability and gene action for yield and quality traits in Ahu rices of Assam. *Indian Journal of Genetics and Plant Breeding*, 67(3): 278-280.
- Satish, Y., Seetharam, K.V., Reddy, N.S. and Naidu, T.C.M. (2003).** Genetic variability, heritability and genetic advance in scented rice. *Andhra Agricultural Journal*, 50(182): 24-26.
- Satyanarayana, P.V., Reddy, M.S., Kumar, S. and Madhuri, J. (2000).** Combining ability studies on yield components in rice. *Oryza*, 37(6): 22-25.

- Savita, B., Pandey, D.P. and Singh, D. (2015).** Combining ability and heterosis for yield and its component traits in rice (*Oryza sativa* L.). *Electronic Journal of Plant Breeding*, 6(1): 12-18.
- Seetharam, K., Thirumeni, S. and Paramasivam, K. (2009).** Estimation of genetic diversity in rice (*Oryza sativa* L.) genotypes using SSR markers and morphological characters. *African Journal of Biotechnology*, 18(10): 2050-2059.
- Selvaraj, I., Nagarajan, P., Thiyagarajan, K. and Bharathi, M. (2010).** Predicting the relationship components in hulled x hull less crosses of barley. *Haryana agricultural University Journal Research*, 19(2): 230-234.
- Semagn, K., Bjornstad, A., Ndjiondjp, M.N. (2006).** Progress and prospects of marker assisted backcrossing as a tool in crop breeding programs. *African. Journal. Biotechnology*, 5(25): 2588-2603.
- Senapati, B.K. and Sarkar, G. (2005).** Genetic divergence in tall indica rice (*Oryza sativa* L.) under rainfed saline soil of Sundarban. *Oryza*, 42(1): 70-72.
- Shahidhullah, S.M., Hanafi, M.M., Ismail, M.R. and Khair, A. (2008).** Genetic diversity in grain quality and duration of aromatic rice. *Tropical Agriculture Research and Extension*, 11(8): 60- 64.
- Shahidullah, S.M., Hanafi, M. M., Ashrafuzzaman, M., Razi, I.M. and Khair, A. (2009).** Genetic diversity in grain quality and nutrition of aromatic rices. *African Journal of Biotechnology*, 8(7): 1238-1246.
- Shahriar, M.H., Robin, A.H.K., Begum, S.N. and Hoque, A. (2014).** Diversity analysis of some selected rice genotypes through SSR- based molecular markers. *Journal Bangladesh Agriculture University*, 12(2): 307–311.
- Shankar, V.G., Ansari, N.A., Ahamed, M.I. and Rao, P.V.R. (2010).** Heterosis studies using thermo-sensitive genetic male sterile lines in rice. *Oryza*, 47(2): 100-105.

- Sharifi, P., Dehghani, H., Moumeni, A. and Moghaddam, M. (2010).** Estimation of genetic parameters for some cooking quality related traits in rice using diallel crosses analysis. *Indian Journal of Crop Science*, 12(2): 152- 169.
- Sharma, S.K., Singh, S.K., Nandan, R., Sharma, A., Kumar, R., Kumar, M.K. and Singh, V. (2013).** Estimation of heterosis and inbreeding depression for yield and yield related traits in rice (*Oryza sativa* L.). *Molecular Plant Breeding*, 4(1): 29-36.
- Sharma, A. and Koutu, G.K. (2011).** Genetic divergence in exotic rice genotypes. *Journal Crop and Weed*, 7(12): 24-33.
- Sharma, A.K. and Sharma, R.N. (2007).** Genetic variability and character association in early maturing rice. *Oryza*, 44(4): 300-303.
- Sharma, A.K. and Sharma, R.N. (2007).** Genetic variability in early maturing rice. *Journal of Applied Biology*, 15(2): 13-19.
- Sheethal, Y., Poonam, R., Navinder, S., Sunita, J. and Rajinder, J.K. (2008).** Assessment of genetic diversity among rice genotypes with differential adaptations to salinity using physio-morphological and molecular markers. *Journal Plant Biochemistry and Biotechnology*, 17(1): 287-302.
- Shull, G.H. (1914).** Duplicate gene for capsule form in *Bursabursa pastoris* of heterosis. *Ziestchrifture inductive Abstammungs and Verebungletrie*, 12(8):11-14.
- Siddiq, E.A., Jachuck, P.J., Mahadevappa, K., Zaman, F.U., Kumar, R., Vidya, B., Sidhu, G., Kumar, S., Prasad, M.N., Rangaswamy, M., Pandey, M.P., Panwar, D.V.S. and Ahmad, I. (1992).** Hybrid Rice Research in India. *International Rice Research Conference, IRRI*, 6(2): 04-12.
- Singh, C.M., Suresh, B.G., Kumar, B. and Mehandi, S. (2013).** Analysis of quantitative variation and selection criteria for yield improvement in exotic germplasm of upland rice (*Oryza sativa* L.). *The Bioscan*, 8(2): 485-492.

- Singh, N., Choudhury, D.R., Tiwari, G., Singh, A.K., Kumar, S., Srinivasan, K., Tyagi, R.K., Sharma, A.D., Singh, N.K. and Singh, R. (2016).** Genetic diversity trend in Indian rice varieties and analysis using SSR markers. *Indian Journal of Agriculture*, 17(1): 127.
- Singh, P.K., Dhakad, B.K., Singh, H.B. and Singh, A.K. (2012).** Genetic variability and association analysis in rice (*Oryza sativa* L.) treated with *Trichoderma harzianum*. *Crop Research*, 44(6): 141-145.
- Singh, P.K., Mishra, M.N., Hore, D.K. and Panwar, A S. (2002).** Genetic variability in some indigenous low land rice genotypes of North East India. *Indian Journal Hill Farming*, 15(1): 113-115.
- Singh, P.K., Thakur, R., Chaudhary, C.K. and Singh, N.B. (1995).** Combining ability and heterosis for yield and panicle traits in rice (*Oryza sativa* L.). *Crop Research*, 19(2): 6-12.
- Singh, R.K. and Singh, O. (2005).** Genetic variation for quality characters in mutants of aromatic rice. *Annals of agriculture Research*, 26(93): 406-410.
- Singh, S.K., Singh, C.M. and Lal, G.M. (2011).** Assessment of genetic variability for yield and its component characters in rice (*Oryza sativa* L.). *Research in Plant Biology*, 1(4): 73-76.
- Singhara, G.S., Ahmad, N., Zargar, M.A., Singh, S.P. (2003).** Variability and association studies for panicle and grain characters in rice (*Oryza sativa* L.) under temperate conditions. *Agriculture and Biology Research*, 19 (2) : 91-96.
- Sinha, S., Tripathi, A.K. and Bisen, U.K. (2004).** Study of genetic variability and correlation coefficient analysis in midland landraces of rice. *Annals of Agriculture Reserach*, 25(1): 1-3.
- Smith, S. and Helentjaris, T. (1996).** DNA fingerprinting and plant variety protection in Genome Mapping in Plants. *Landes Company, Texas*, 2(1): 95-110.

- Sneath, P.H.A. and Sokal, R.R. (1973).** Numerical taxonomy. *Freeman and Company, San Francisco*, 2(6): 28-34.
- Sohrabi, M.,Rafii, M.Y.,Hanafi, M.M., Kumar, A. and Latif, M.A. (2012).** Genetic diversity of upland rice germplasm in Malaysia based on quantitative traits. *The Scientific World Journal*, 20(4): 112-116.
- Sprague, G.F. and Tatum, L.A. (1942).** General Vs. specific combining ability in single crosses of corn. *Journal of American Society of Agronomy*, 3(2): 923-932.
- Sreedhar, S., Dayakar Reddy, T. and Ramesha, M.S. (2012).** Expression of heterosis in rice hybrids over three environments. *Oryza*, 49(1): 19-17.
- Sreeramachandra,M.B., Satyanarayana, P.V., Madhuri, R. (2000).** Combining ability analysis for identifying elite parents for heterotic rice hybrids. *Oryza*, 37(4): 19-22.
- Subbaiah, P.V., Sekhar, M.R., Reddy, K.H.P., Reddy, N.P.E. (2013).** Heterosis for yield and yield components in CMS based hybrids in rice (*Oryza sativa* L.). *The Andhra agriculture journal*, 60(2): 292-296.
- Subudhi, H.N., Swain, D., Das, S., Sharma, S.G. and Singh, O.N. (2012).** Studies on Grain Yield, Physico-Chemical and Cooking Characters of Elite Rice Varieties (*Oryza sativa* L.). *Eastern India Journal of Agricultural Science*, 4(12): 92-104.
- Sudhakar, T. (2015).** Heterosis and combining ability in rice as influenced by introgressions from wild species *Oryza rufipogon* including sub-QTL into the restorer line KMR3. *Euphytica*, 202(5): 81–95.
- Sujeet, P.H., Gowda, R. (2016).** Estimation of heterosis and combining ability in tomato for fruit shelf life and yield component traits using line x tester method. *International Journal of Agronomy and Agricultural Research*, 9(3): 10-19.
- Swain, B., Acharya, B. and Pande, K. (2003).** Combining ability analysis for yield and yield components in low land rice. *Oryza*, 40 (3&4): 70-72.

- Swamy, M.H., Gururajao, M.R. and Vidyachandra, B. (2003).** Studies on combining ability in rice hybrids involving new CMS lines. *Karnataka Journal of Agricultural Sciences*, 16(2): 228-233.
- Taran, B., Zhang, C., Warkentin, T., Tullu, A. and Vandenberg, A. (2005).** Genetic diversity among varieties and wild species accessions of pea (*Pisum sativum* L.) based on molecular markers and morphological and physiological characters. *Genome*, 48(6): 257-272.
- Temnykh, S., Park, W.D., Ayres, N., Cartinhour, S., Hauck, N., Lipovich, L., Cho, Y.G., Ishii, T. and McCouch, S.R. (2000).** Mapping and genome organization of microsatellite sequences in rice (*Oryza sativa* (L.)). *Theoritical Applied Genetics*, 100(2): 697-712.
- Thakare, I.S., Mehta, A.M., Patel, J.S. and Takle, S.R. (2012).** Combining Ability Analysis for Yield and Grain Quality Traits in Rice Hybrids. *Journal of Rice Research*, 3(1): 1-5.
- Tiwari, V.N. and Sarathe, M.L. (2000).** Heterosis and inbreeding depression in direct seeded rain fed rice. *Oryza*, 37(4): 37-38.
- Torres, E.A., Geraldi, I.O. (2011).** Partial diallel analysis of agronomic characters in rice (*Oryza sativa* L.). *Genetic Molecular Biology*, 30(3): 20-26.
- Tu, S. Shuijin, Z., Ruixia, D., Yang, D., Xie, H. and Jiatuan, Z. (2008).** Analysis of combining ability and heritability of the major agronomic characters in some parents of three-line *indica* hybrid rice. *Journal of Fujian Agriculture and Forestry University*, 37(3): 230-234.
- Tushara, M., Rao, V.S., Lal, A.M., Krishna, V.B. and Narasimha, K.L. (2013).** Correlation of quantitative and qualitative characters with yield in medium and long duration genotypes of rice (*oryza sativa* L.). *The Andhra Agricultural journal*, 60(1): 29-35.
- Umadevi, M., Veerabadhiran, P. (2012).** Genetic Variability and Association for Floral Quantitative and Quality Traits in Rice (*Oryza sativa* L.). *Journal of Genetics and Evolution*, 3(2): 41-45.

- Umesh, H.K., Sravan, T., Showkat, A.W. and Bhardwaj, R. (2015).** Estimation of genetic variability, heritability and genetic advance for yield and quality traits in some indigenous Basmati rice (*Oryza sativa* L.) genotypes. *International Journal of Farm Sciences*, 5(4): 32-40.
- Vaithiyalingan, M. and Nadarajan, N. (2005).** Combining ability studies in inter racial crosses of rice (*Oryza sativa* L.). *Research Crops*, 6(2): 281-286.
- Vanaja, T. and Babu, C.L. (2006).** Variability in grain quality attributes of high yielding rice varieties (*Oryza sativa* L.) of diverse origin. *Journal of Tropical Agriculture*, 44(2): 61-63.
- Vanaja, T. and Babu, L.C. (2004).** Heterosis for yield and yield components in rice (*Oryza sativa* L.). *Journal Tropical Agriculture*, 42(1-2): 43-44.
- Vanniarajan, C., Vinod, K.K. and Pereira, A. (2012).** Molecular evaluation of genetic diversity and association studies in rice (*Oryza sativa* L.). *Journal of Genetics*, 91(9): 9-19.
- Vavilov, N.I. (1957).** Origin variation immunity and breeding of cultivated plants chronicalbotanica, an international collection of studies in the method and history of biology and agriculture. *Fransver Doom*, 11(6): 13-18.
- Veeresha, B.A., Hanamaratti, N.G. and Salimath, P.M. (2015).** Heterosis and Combining Ability Studies for yield and Productivity Traits in Rice. *International journal of Current Agricultural Research*, 4(5): 120-126.
- Veeresha, B.A., Salimath, P.M., Hanamaratti, N.G., Chetti, M.B., Nadaf, H.L. and Merwade, M.N. (2013).** Combining ability analysis for yield and yield contributing traits in hybrid rice. *Karnataka Journal of Agriculture Sciences*, 26(4) : 494-496.
- Vennila, S., Anbuselvam, Y. and Palaniraja, K. (2011).** Heterosis studies for yield and its components in rice (*Oryza sativa* L.). *International Journal Recent Scientific Research*, 2 (9): 261-262.

- Verma, R.S., Yadav, R.D.S., Singh, R.S., Giri, S.P. and Dwivedi, J.L. (2004).** Studies on heterosis and inbreeding depression in rice (*Oryza sativa* L.). *Oryza*, 41(3&4): 131-132.
- Vijayakumar, S.B., Kulkarni, R.S. and Murthy, N. (1994).** Line x tester analysis for combining ability in ratooned F<sub>1</sub> rice. *Oryza*, 31(2): 8-11.
- Virmani, S.S. and Edwards, I.B. (1983).** Current status and future prospectus for breeding rice and wheat. *Advanced Agronomy*, 36(2): 145-214.
- Vivek, S., Singh, S., Singh, S.K. and Singh, H. (2005).** Estimation of genetic variability, heritability and genetic advance in rice (*Oryza sativa* L.). *Agriculture Science Digest*, 25(3): 207-209.
- Wilfred, M.W. and Prasad, M.N. (1992).** Combining ability and heterosis in rice (*Oryzasativa* L.). *Oryza*, 29: 15-18.
- Xu, X.H., Wang, G.C., Zheng, X.B. and Wang, H.X. (1974).** A report on the vertical distribution of the rice varieties in Simao, Yunnan. *Acta Botanica Sinica*, 16(2): 208-222.
- Xu, Y., Beachell, H., McCouch, S.R. (2004).** A marker-based approach to broadening the genetic base of rice in USA. *Crop Science*, 44(2): 1947-1959.
- Yadav, A.K. (2000).** Studies on genetic variability and genetic advance in scented rice. *Indian Agriculture*, 46(12): 45-47.
- Yu, S.B., Xu, W. J., Kumar, H.M., Ali, J., Fu, B.Y. (2003).** Molecular diversity and multilocus organization of the parental lines used in the International Rice Molecular Breeding Program. *Theoretical Applied Genetics*, 108(12): 131-140.
- Zafar, N., Aziz, S. and Masood, S. (2004).** Phenotypic divergence for agro-morphological traits among landrace genotypes of rice (*Oryza sativa* L.). *Pakistan International Journal of Agriculture and Biology*, 6(2): 335-339.

- Zeng, L., Kwon, T.R., Liu, X., Wilson, C., Grieve, M.C. and Gragorio, G.B. (2004).** Genetic diversity analyzed by microsatellite markers among rice (*Oryza sativa* L.) genotypes with different adaptations to saline soils. *Plant Science*, 166(12): 1275-1285.
- Zheng, K.L., Shen, B. and Qian, H.R. (1991).** DNA polymorphism generated by arbitrary primed PCR in rice (*Oryza sativa* L.). *Rice Genetics Newsletter*, 8(6): 134-136.