

**IDENTIFICATION OF NOVEL QTLs  
FOR BPH TOLERANCE IN RICE  
(*Oryza sativa* L.) USING RESISTANT  
DONOR BM 71 (MTU ITJ 206-7-4-1)**

**GANTA SUNEEL KUMAR**

**B.Sc. (Ag.)**

**MASTER OF SCIENCE IN AGRICULTURE  
(GENETICS AND PLANT BREEDING)**



**2019**

**IDENTIFICATION OF NOVEL QTLs FOR  
BPH TOLERANCE IN RICE (*Oryza sativa* L.)  
USING RESISTANT DONOR BM 71  
(MTU ITJ 206-7-4-1)**

**BY**  
**GANTA SUNEEL KUMAR**  
B.Sc. (Ag.)

**THESIS SUBMITTED TO THE  
ACHARYA N.G.RANGA AGRICULTURAL UNIVERSITY  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF SCIENCE IN AGRICULTURE  
(GENETICS AND PLANT BREEDING)**

**CHAIRPERSON: Dr. B. N. V. S. R. RAVI KUMAR**



**DEPARTMENT OF GENETICS AND PLANT BREEDING  
AGRICULTURAL COLLEGE, BAPATLA  
ACHARYA N. G. RANGA AGRICULTURAL UNIVERSITY  
GUNTUR – 522 034. A. P.**

**2019**

# DECLARATION

I, **Mr. GANTA SUNEEL KUMAR**, hereby declare that the thesis entitled **“IDENTIFICATION OF NOVEL QTLs FOR BPH TOLERANCE IN RICE (*Oryza sativa* L.) USING RESISTANT DONOR BM 71 (MTU ITJ 206-7-4-1)”** submitted to **Acharya N. G. Ranga Agricultural University** for the degree of **Master of Science in Agriculture** in the major field of **Genetics and Plant Breeding** is the result of original research work done by me. I also declare that any material in the thesis has not been published earlier.

Place :

Date :

**(GANTA SUNEEL KUMAR)**

**(ID.No. BAM-17-19)**

## **CERTIFICATE**

**Mr. GANTA SUNEEL KUMAR** has satisfactorily prosecuted the course of research and that thesis entitled “**IDENTIFICATION OF NOVEL QTLs FOR BPH TOLERANCE IN RICE (*Oryza sativa* L.) USING RESISTANT DONOR BM 71 (MTU ITJ 206-7-4-1)**” submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any university.

Date:

**(B. N. V. S. R. RAVI KUMAR)**  
**Chairperson**  
Senior Scientist (Plant Breeding)  
RARS, Maruteru

# CERTIFICATE

This is to certify that thesis entitled “**IDENTIFICATION OF NOVEL QTLs FOR BPH TOLERANCE IN RICE (*Oryza sativa* L.) USING RESISTANT DONOR BM 71 (MTU ITJ 206-7-4-1)**” submitted in partial fulfillment of the requirements for the degree of ‘Master of Science in Agriculture’ in the major field of **Genetics and Plant Breeding** of the Acharya N. G. Ranga Agricultural University, Lam, Guntur is a record of the bonafide original research work carried out by **Mr. GANTA SUNEEL KUMAR** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

## Thesis approved by the Student Advisory Committee

Chairperson : **Dr. B. N. V. S. R. RAVI KUMAR**  
Senior Scientist (Plant Breeding)  
Regional Agricultural Research Station  
Maruteru – 534 122

---

Member : **Dr. B. VIJAYA LAKSHMI**  
Associate Professor  
Department of Genetics and Plant breeding  
Agricultural College  
Bapatla – 522 101

---

Member : **Dr. M. NANDA KISHORE**  
Senior Scientist (Entomology)  
Regional Agricultural Research Station  
Maruteru – 534 122

---

**Date of final viva-voce:**

## ACKNOWLEDGEMENTS

*I take this opportunity to express my deep sense of gratitude and heartfelt regards to Chairperson of my advisory committee, **Dr. B. N. V. S. R. Ravi Kumar**, Senior Scientist, Genetics and Plant Breeding, RARS, Maruteru for his constructive suggestions, boundless help and indefatigable guidance which provided me commendable encouragement and shaped my efforts into a successful research work,*

*I wish to express my esteem gratitude, my deepest admiration and heartfelt thanks to member of my advisory committee, **Dr. B. Vijaya Lakshmi**, Associate Professor, Department of Genetics and Plant Breeding, Agricultural College, Bapatla for her keen interest, timely suggestions, boundless help, unforgettable guidance and motivation which provided me constant encouragement and shaped my efforts into a successful research work,*

*I extend my respect and profound sense of gratitude to the esteemed Chairman of my advisory committee, **Dr. M. Nanda Kishore**, Senior Scientist (Entomology), RARS, Maruteru for his constant critical supervision, sustained interest, caring nature, immense help, constant inspiration and fruitful advice, during the course of investigation.*

*I accord my sincere thanks to **Dr. T. Srinivas**, Professor & Head, Department of Genetics and Plant Breeding, Agricultural College, Bapatla, and **Dr. V. Satyanarayana Rao**, Associate Director of Research, Lam, Guntur, **Dr. P. Muniratnam**, Associate Director of Research, RARS, Maruteru, West Godavari, **Dr. P.V. Satyanarayana**, Principal Scientist (Rice), RARS, Maruteru for their constant support and generous help rendered during my course work and research work,*

*I sincerely extend my profound gratitude to **Dr. P.V. Ramana Rao**, Senior Scientist (Plant Breeding), **Dr. M. Girija Rani**, Senior Scientist (Plant Breeding), **A. Anand Kumar** Scientist (Entomology), **Dr. N. Chamundeeswari**, Senior Scientist (Plant Breeding), RARS, Maruteru and **Dr. N. Raj Kumar** (Plant Pathology) and **Dayamadhuri** for their sustained encouragement, constant support and valuable suggestions offered during my P.G. programme.*

*I accord my sincere thanks to teaching staff of Department of Genetics and Plant Breeding, Agricultural College, Bapatla, Dr. Prasanna Rajesh, Dr. V. Roja, Dr. T. Haritha, Smt. M. Thushara, Sri. G. Vinay Kumar for their constant support and generous help rendered during my course work and research work.*

*I am very much thankful to SRFs in Biotechnology lab of RARS, Maruteru, Uma, Kalpana and Kasturi for their crucial assistance during my research work.*

*I am very much thankful to Prasanna Lakshmi (AEO), R. Durga Sai Kumar (TA), and Sarojini, Satyaveni, Srilaxmi, Laxmiparvathi and Hymavathi (field workers) for their crucial assistance during my research work.*

*I would like to convey my heartfelt thanks to all my Seniors Janardhan, Sudeepthi, Vijaya Durga, Sharath Raju, Mounika and classmates of M.Sc (Ag) Srikanth, Sandeep, Mallikarjun, Durgarao, Pavani, Bala, Kranthi, Anuhya, Sunil, Kishore and Maruthi for their support in odd times, affection and memories.*

*From my mere existence on earth to present situation, my every step of life is moulded by father Sri G. Eswara Rao, my mother Smt. G. Pydi Raju, my brother G. Durga Prasad, my uncle D. Rambabu and D. Srinivas I will forever remain indebted to them.*

*I am thankful to Acharya N. G. Ranga Agricultural University for providing financial assistance in the form of stipend during my course of study.*

Place:

*(Ganta Suneel Kumar)*

Date:

# CONTENTS

| <b>Chapter No.</b> | <b>Title</b>            | <b>Page No.</b> |
|--------------------|-------------------------|-----------------|
| I                  | INTRODUCTION            | 1-3             |
| II                 | REVIEW OF LITERATURE    | 4-21            |
| III                | MATERIAL AND METHODS    | 22-42           |
| IV                 | RESULTS AND DISCUSSION  | 43-76           |
| V                  | SUMMARY AND CONCLUSIONS | 77-78           |
|                    | LITERATURE CITED        | 79-90           |
|                    | APPENDICES              | 91-97           |

## LIST OF TABLES

| S. No. | Title   | Page No. |
|--------|---|----------|
| 2.1    | Genetic variability for yield characters in rice  | 7-8      |
| 2.2    | Scientific studies made by several workers on heritability and genetic advance in rice  | 11-13    |
| 3.1    | List of RILs and checks used in the study   | 24-25    |
| 3.2    | List of SSR markers used for parental polymorphism study between MTU3626 and BM71   | 27-28    |
| 3.3    | Scoring criteria of BPH screening   | 30       |
| 4.1    | Analysis of variance (mean sum of squares) for yield and yield contributing characters in RILs and checks during <i>kharif</i> , 2018       | 44       |
| 4.2    | Estimates of genetic variability parameters for evaluation of yield and yield contributing characters rice RILs during <i>kharif</i> , 2018 | 46       |
| 4.3    | BPH scores of RILs under lab conditions at seedling stage   | 51-52    |
| 4.4    | BPH scores of RILs under field conditions at crop maturity stage  | 53-54    |
| 4.5    | SSR Markers used for parental polymorphic survey between MTU 3626 and BM 71   | 57       |
| 4.6    | Polymorphic markers between MTU 3626 and BM 71 with their physical positions (Mbp) on respective chromosomes                                | 59       |
| 4.7    | QTLs identified for tolerant to BPH in the RIL population derived from the cross MTU 3626 and BM 71   | 61       |
| 4.8    | Names of RILs used in genotyping with two parents MTU 3626 and BM 71  | 70       |
| 4.9    | Respective flanking markers of five QTLs identified with their positions and sequence   | 74       |
| 4.10   | Performance of RILs for yield and yield attributing traits  | 76       |

## LIST OF FIGURES

| S. No. | Title   | Page No. |
|--------|---|----------|
| 3.1    | Field layout for evaluation of RILs for yield and yield attributed traits   | 26       |
| 3.2    | Field layout for BPH field screening  | 31       |
| 4.1    | Variability parameters for five characters studied in 142 RILs and two checks   | 47       |
| 4.2    | Graphical representation of SSR markers across 12 chromosomes and percentage of polymorphism between MTU 3626 and BM 71 | 58       |
| 4.3a   | Linkage map construction for chromosomes 1, 2, 3 and 4  | 62       |
| 4.3b   | Linkage map construction for chromosomes 5, 6, 7 and 8  | 63       |
| 4.3c   | Linkage map construction for chromosomes 9, 10, 11 and 12   | 64       |
| 4.4a   | LOD curve of composite interval mapping of ch.2 for BPH tolerance QTL <i>qmbph2.1</i>                                   | 71       |
| 4.4b   | LOD curve of composite interval mapping of ch.4 for BPH tolerance QTL <i>qmbph4.1</i>                                   | 71       |
| 4.4c   | LOD curve of composite interval mapping of ch.12 for BPH tolerance QTL <i>qmbph12.1</i>                                 | 71       |
| 4.5    | Linkage map and LOD curve for chromosomes 2, 4 and 12 using composite interval mapping                                  | 72       |

## LIST OF PLATES

| <b>S. No.</b> | <b>Title</b>   | <b>Page No.</b> |
|---------------|--|-----------------|
| 4.1           | Seedling screening of RILs against BPH tolerance in lab conditions             | 50              |
| 4.2           | Field screening of RILs against brown plant hopper in natural field conditions | 50              |
| 4.3a          | Gel image showed parental polymorphism studies on chromosome 1                 | 56              |
| 4.3b          | Gel image showed parental polymorphism studies on chromosome 11                | 56              |
| 4.4a          | Representative gel image for left flanking marker RM263 ( <i>qmbph2.1</i> )    | 66              |
| 4.4b          | Representative gel image for right flanking marker RM13893 ( <i>qmbph2.1</i> ) | 67              |
| 4.5a          | Representative gel image for left flanking marker RM4552 ( <i>qmbph12.1</i> )  | 68              |
| 4.5b          | Representative gel image for right flanking marker RM1226 ( <i>qmbph12.1</i> ) | 69              |

## LIST OF APPENDICES

| <b>S.<br/>No.</b> | <b>Title</b>  | <b>Page<br/>No.</b> |
|-------------------|---|---------------------|
| 1                 | Mean performance of rice RILs and checks for yield contributing traits during <i>kharif</i> , 2018. | 91-97               |

## LIST OF SYMBOLS AND ABBREVIATIONS

|               |   |  |
|---------------|---|--|
| %             | : | Per cent   |
| @             | : | at the rate of                                   |
| °C            | : | Degree centigrade                                |
| µl            | : | Micro litre                                      |
| a.i.          | : | active ingredient                                |
| ANOVA         | : | Analysis of variance                             |
| BPH           | : | Brown plant hopper                               |
| CD            | : | Critical Difference                              |
| CH            | : | Chromosome                                       |
| CIMMYT        | : | International Maize and Wheat Improvement Center |
| cM            | : | Centi morgan                                     |
| cm            | : | Centi meter                                      |
| CRD           | : | Completely Randomized Design                     |
| CTAB          | : | Cetyl Tri Methyl Ammonium Bromide                |
| CV            | : | Coefficient of Variation                         |
| df            | : | Degrees of Freedom                               |
| DNA           | : | Deoxyribo Nucleic Acid                           |
| EC            | : | Emulsifiable Concentrate                         |
| <i>et al.</i> | : | and coworkers                                    |
| g             | : | Grams  |
| GA            | : | Genetic Advance                                  |
| GAM           | : | Genetic Advance as per cent of Mean              |
| GCV           | : | Genotypic Coefficient of Variation               |
| h             | : | Hour   |
| $h^2b$        | : | Heritability in Broad sense                      |
| ha            | : | Hectare  |
| HPR           | : | Host Plant Resistance                            |
| ICIM          | : | Inclusive Composite Interval Mapping             |
| IIRR          | : | Indian Institute of Rice Research                |
| IPM           | : | Integrated Pest Management                       |
| IRRI          | : | International Rice Research Institute            |
| kbp           | : | Kilo base pair                                   |
| LOD           | : | Logarithm Of Odd                                 |
| MAS           | : | Marker Aided Selection                           |

|              |   |  |
|--------------|---|--|
| Mbp          | : | Mega base pair                           |
| mg           | : | milligram                                |
| mha          | : | Million hectare                          |
| ml           | : | millilitre                               |
| mm           | : | millimeter                               |
| mt           | : | Million tonnes                           |
| MSL          | : | Mean Sea Level                           |
| nm           | : | Nanometer                                |
| OD           | : | Optical Density                          |
| PCR          | : | Polymerase Chain Reaction                |
| PCV          | : | Phenotypic Coefficient of Variation      |
| PVE          | : | Phenotypic Variance                      |
| PVP          | : | Poly Vinyl Pyrrolidone                   |
| QTL          | : | Quantitative Trait Loci                  |
| QIC          | : | Composite Interval Mapping               |
| QIM          | : | Simple Interval Mapping                  |
| <i>qmbph</i> | : | QTL Maruteru BPH                         |
| RARS         | : | Regional Agricultural Research Station   |
| RBD          | : | Randomised Block Design                  |
| RIL          | : | Recombinant Inbred Line                  |
| RNA          | : | Ribo Nucleic Acid                        |
| rpm          | : | Revolutions per minute                   |
| SES          | : | Standard Evaluation System               |
| SSR          | : | Simple Sequence Repeat (Microsatellites) |
| SSST         | : | Standard Seed Box Screening Technique    |
| <i>viz.,</i> | : | namely                                   |

---

## ABSTRACT

|                     |   |  |
|---------------------|---|--|
| Name of the Author  | : | <b>GANTA SUNEEL KUMAR</b>  |
| Title of the Thesis | : | <b>Identification of Novel QTLs for BPH Tolerance in Rice (<i>Oryza sativa</i> L.) Using Resistant Donor BM 71 (MTU ITJ 206-7-4-1)</b> |
| Degree              | : | Master of Science  |
| Faculty             | : | Agriculture  |
| Department          | : | <b>Genetics and Plant Breeding</b>   |
| Chairperson         | : | <b>Dr. B. N. V. S. R. Ravi Kumar</b>   |
| University          | : | Acharya N.G. Ranga Agricultural University   |
| Year of Submission  | : | 2019   |

---

The current research study was carried out during *kharif*, 2018 at Regional Agricultural Research Station, Maruteru, Andhra Pradesh with one hundred and forty two RILs and two checks to study the variability, heritability and genetic advance for yield and yield contributing traits and to identify QTLs for BPH tolerance.

The ANOVA explained significant differences among the RILs for all traits *viz.* days to fifty percent flowering, plant height (cm), number of ear bearing tillers per plant, panicle length (cm) and grain yield per plant (g) indicating sufficient genetic variability among the RILs. Both GCV and PCV were higher for grain yield (g) per plant and high heritability accompanied with high genetic advance as percent of mean was observed indicating presence of additive gene action in inheritance of this trait and therefore direct selection is effective. Moderate heritability and genetic advance as percent of mean was recorded for plant height (cm) and ear bearing tillers per plant indicating presence of both additive and non additive gene actions. Moderate heritability with low genetic advance as percent of mean was observed for days to 50% flowering and panicle length (cm) indicating non additive gene action and selection may not be effective for the above traits.

Evaluation of one hundred and forty two RILs for BPH tolerance was done in both lab and filed conditions. The results revealed that in lab screening forty four RILs were resistant, sixty two were moderately resistant, thirty were moderately susceptible and six were susceptible, whereas in field screening sixty seven RILs were resistant, thirty four were moderately resistant, twenty one were moderately susceptible, twenty were susceptible.

Construction of linkage map and QTL analysis, using seventy seven polymorphic markers, revealed that composite interval mapping and interval mapping has identified three QTLs for BPH tolerance *viz.*, *qmbph2.1*, *qmbph4.1* and *qmbph12.1* on chromosomes 2, 4 and 12 respectively. In addition to above three QTLs, two more QTLs, *qmbph5.1* and *qmbph7.1* were identified by interval mapping on chromosomes 5 and 7 respectively. Fine mapping of the above QTLs and identification of putative genes will be the future line of the present study.

## Chapter – I

---

### *Introduction*

## Chapter I

# INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crops in the world. Rice crop is cultivated in an area of 162.76 million hectares across the globe with average production of 495.87 million tonnes of milled rice and productivity of 4.55 t/ha. Rice is grown in 44.5 million hectares of area in India with a production of 115.63 million tonnes of milled rice and an average yield of 3.94 t/ha (United States Department of Agriculture, 2018-2019). Andhra Pradesh has 22.18 lakh hectares of rice area, 126.91 lakh tonnes of production and a productivity of 5.72 t/ha of paddy (Directorate of Economics and Statistics, 2017-18).

Rice crop is a host to large number of insects and plant hoppers are major among them. Of the six kinds of plant hoppers, brown plant hopper (BPH; *Nilaparvata lugens* Stal) is the most destructive monophagous insect pest of rice (Park *et al.*, 2008) in Asia. Appearance of BPH is reported in countries like China, Vietnam, Philippines, Indonesia, Thailand, Japan, Korea, India, Bangladesh and Malaysia and caused devastating BPH outbreaks (Heong *et al.*, 2009). An estimated economic yield loss of more than 2.7 million tonnes of rice was reported in China due to BPH outbreaks in 2005 and 2006. The economic yield loss in grain yield due to brown plant hopper ranges from 10% (moderately affected fields) to 70% (severely affected fields) and damage to the standing crop sometimes reaches 100% (Kar *et al.*, 2011). Out breaks of BPH in 1972, 1973 and 1974 in Asian countries and several parts of India had created unprecedented yield losses in rice (Kulshreshtha *et al.*, 1974).

Development and use of resistant varieties is an efficient and most economical method to control brown plant hopper, therefore it is essential to identify brown plant hopper resistant genes and incorporate them into rice cultivars by using modern molecular tools (Alam *et al.*, 1998 and Renganayaki *et al.*, 2002). But, the resistant varieties are specific to a biotype and they are vulnerable to other types of biotypes (Gallagher *et al.*, 1994). In Southeast Asia biotypes 1 and 2 were distributed widely, biotype 3 is laboratory specific and it was identified in Philippines, and biotype 4 is mostly seen in the Indian conditions (Khush and Brar., 1991).

To solve this problem development of quantitative resistance to brown plant hopper is a most appropriate suggestion (Bosque *et al.*, 1992). With the availability of new genomic tools, ideal mapping populations and more reliable phenotyping techniques, genes involved in complex traits like BPH resistance can be searched easily (Mohanty *et al.*, 2017).

Recently, the advent of molecular marker technology has made it easy to identify and locate genes which were controlling simple and complex traits in crop plants. Quantitative trait loci (QTL) analysis using molecular markers has now emerged as a powerful tool to study genetics of quantitative resistance to insect pests in crop plants. The main objective of the QTL mapping is to understand the genetic basis of quantitative trait which was specific by determining the number, location and gene actions of particular loci involved. QTL mapping helps in identification of DNA markers which are diagnostic for specific gene of interest (phenotype interest). Thus marker assisted selection is an effective tool used to manipulate off springs carrying alleles for target traits grown under non target environments (Park *et al.*, 2008). For successful QTL mapping, it was essential to select a suitable mapping population *viz.*, F<sub>2</sub> populations, double haploids, back cross populations, RILs and NILs to identify QTLs (Collard *et al.*, 2005).

Different sources for resistance to BPH biotypes were identified firstly in 1967 (Pathak *et al.*, 1969). Most of the QTLs which had BPH resistance were discovered in landraces and wild rices and are mapped to different chromosomes 1, 2, 3, 4, 6, 7, 8, 10 and 12 (Alam *et al.*, 1998).

Till date 30 genes were identified for BPH resistance (Deen *et al.*, 2017) and they were mapped to six chromosomes among 12 chromosomes of rice (Cheng *et al.*, 2013). Fourteen genes identified had resistance to BPH, they obtained from six wild rice species, *O. officinalis*, *O. australiensis*, *O. rufipogon*, *O. eichingeri*, *O. latifolia* and *O. minuta*, however remaining sixteen genes resistance to BPH were identified from cultivated rice (Jena and Kim, 2010). Among the 30 genes 10 genes were finely mapped, eight genes (*BPH14*, *BPH17*, *BPH18*, *BPH26*, *BPH29*, *BPH9* and *BPH32*) were cloned successfully and they were located on chromosomes 2, 3,4,6,8 and 12 (Hu *et al.*, 2013 and Pan *et al.*, 2019).

Microsatellites (1-10 nucleotides) are sub categories of tandem repeats (Gemayel *et al.*, 2012). They are co-dominant, multi allelic and highly polymorphic in nature for particular trait, thus they are widely used in analysis of closely related genotypes (McCouch *et al.*, 2002). The distribution of SSRs was highly non-random and vary a greater deal in various regions of genes of rice (Lawson and Zhong., 2006). SSR primers give simple assays using agarose gel electrophoresis (Singh *et al.*, 2010) and they are extensively used for rice germplasm evaluation and genetic dissection of QTLs for various important traits (Akkayya *et al.*, 1992).

BM 71 (MTU ITJ 206-7-4-1) was a strong plant hopper resistant donor developed during *rabi*, 1993 at Regional Agricultural Research Station, Maruteru. It has also exhibited resistance for plant hoppers under both lab and field conditions across several locations in co-ordinated testing. The present investigation was taken up in this context to identify the QTLs responsible for BPH resistance in BM 71 with the following objectives:

1. To evaluate RIL population (MTU 3626/BM 71) for BPH tolerance in F<sub>5</sub> generation and Yield traits.
2. To identify novel BPH tolerance QTLs in RIL (MTU 3626/BM 71) population of rice.

## Chapter – II

---

## *Review of Literature*

## Chapter II

# REVIEW OF LITERATURE

Rice is a major food crop grown in south India and cultivated year round. The present study in rice was taken to evaluate the RIL (MTU 3626/BM 71) population of F<sub>5</sub> generation in both field and glass house conditions against BPH resistance and also evaluate for yield and yield attributing characters and finally to identify the novel QTL/QTL's for BPH tolerance. The literature available on the main objectives of the present study has been comprehensively reviewed under the following headings.

2.1 Genetic variability

2.2 Heritability and genetic advance

2.3 Evaluation of RILs for brown plant hopper resistance

2.4 Identification of QTL's for BPH tolerance

## 2.1 GENETIC VARIABILITY

The difference between PCV and GCV estimates is an indication of relative influence of environment on the trait. If the difference is low, influence of environment is less indicating high heritability of the trait. Reverse is the case when the difference between PCV and GCV is high (Allard., 1960).

Longjam *et al.* (2019) studied variability studies on forty six rice genotypes and reported low PCV and GCV for days to 50% flowering, plant height (cm) and panicle length (cm), high PCV with moderate GCV for ear bearing tillers per plant and grain yield per plant (g).

Kurmanchali *et al.* (2019) studied variability for twenty four genotypes and resulted as moderate GCV and PCV for days to 50% flowering and plant height (cm), moderate PCV and low GCV for panicle length (cm), high GCV and PCV for ear bearing tillers, high PCV and moderate GCV for grain yield per plant (g).

Maurya *et al.* (2018) studied thirty eight rice germplasm cultures for variability and they revealed high PCV and GCV for ear bearing tillers and grain yield per plant (g), moderate PCV and GCV for days to 50% flowering and plant height (cm), low PCV and GCV for panicle length (cm).

Rahul *et al.* (2018) studied twenty eight rice genotypes for variability and they finally reported low PCV and GCV for days to 50% flowering, high PCV and GCV for plant height (cm), moderate PCV and GCV for ear bearing tillers per plant, low GCV and PCV for panicle length (cm) and high PCV and moderate GCV for grain yield per plant (g).

Kumar *et al.* (2018) studied ninety four BC<sub>4</sub>F<sub>4</sub> plants for variability and reported low PCV and GCV for days to 50% flowering, moderate PCV and low GCV for plant height (cm), low GCV and moderate PCV for panicle length (cm).

Kusuma *et al.* (2018) studied one hundred and nineteen F<sub>6</sub> rice breeding lines of rice and reported low PCV and GCV for days to 50% flowering, low PCV and GCV for plant height (cm), moderate PCV and low GCV for ear bearing tillers per plant, low GCV and PCV for panicle length (cm) and high PCV and GCV for grain yield per plant (g).

Sumanth *et al.* (2017) studied twenty three rice genotypes for variability and reported low PCV and GCV for days to 50% flowering and panicle length (cm), moderate PCV and GCV for plant height (cm) and ear bearing tillers, high GCV and PCV for grain yield per plant (g).

Devi *et al.* (2017) studied on variability for twenty seven rice genotypes and reported low PCV and GCV for days to 50% flowering, low PCV and moderate GCV for ear bearing tillers, moderate PCV and low GCV for panicle length (cm), moderate GCV and PCV for plant height (cm), both high GCV and PCV were recorded for grain yield per plant (g).

Sameera *et al.* (2016) studied twenty five rice genotypes and reported lower PCV and GCV values for days to 50% flowering, plant height (cm) and panicle length (cm) and higher estimates of both PCV and GCV for number of grains per panicle also moderate values for grain yield per plant per plant (g).

Rashmi *et al.* (2016) studied moderate PCV and GCV for days to 50% flowering and panicle length (cm), high PCV and moderate GCV for ear bearing tillers, high PCV and GCV for plant height (cm) and grain yield.

Tejaswini *et al.* (2016a) studied one hundred and fourteen F<sub>5</sub> generation families of rice belonging to six crosses and reported high PCV and GCV for grain yield per plant (g).

Tejaswini *et al.* (2016b) studied forty two F<sub>5</sub> families belonging to four crosses and reported high GCV and PCV for grain yield per plant (g).

The character wise chronological report of available literature on phenotypic and genotypic coefficient of variability is presented in the Table 2.1.

**Table 2.1 Genetic variability for yield characters in rice**

| S. No. | Character                               | Variability            | Reference  |
|--------|---|------------------------|--|
| 1      | Days to 50% flowering                   | High PCV and GCV       | Dutta <i>et al.</i> (2013)<br>Nayak <i>et al.</i> (2016)   |
|        |   | Moderate PCV, GCV      | Kishore <i>et al.</i> (2015)<br>Sathisha <i>et al.</i> (2015)<br>Girma <i>et al.</i> (2018)  |
|        |   | Moderate PCV, Low GCV  | Vanisree <i>et al.</i> (2013)<br>Bornare <i>et al.</i> (2014)  |
|        |   | Low PCV, GCV           | Habiba <i>et al.</i> (2015)<br>Hossain <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Konate <i>et al.</i> (2016)<br>Adhikari <i>et al.</i> (2018) |
| 2      | Plant height (cm)                       | High PCV and GCV       | Dutta <i>et al.</i> (2013)<br>Tuwar <i>et al.</i> (2013)<br>Vanisree <i>et al.</i> (2013)<br>Nayak <i>et al.</i> (2016)<br>Girma <i>et al.</i> (2018)  |
|        |   | High PCV, Moderate GCV | Singh <i>et al.</i> (2014)   |
|        |   | Moderate PCV, GCV      | Habiba <i>et al.</i> (2015)<br>Sathisha <i>et al.</i> (2015)   |
|        |   | Moderate PCV, Low GCV  | Ramanjaneyulu <i>et al.</i> (2014)<br>Hasan <i>et al.</i> (2015)   |
|        |   | Low PCV, GCV           | Shahriar <i>et al.</i> (2014)<br>Hossain <i>et al.</i> (2015)<br>Kishore <i>et al.</i> (2015)<br>Anis <i>et al.</i> (2016)<br>Konate <i>et al.</i> (2016)<br>Adhikari <i>et al.</i> (2018)   |
| 3      | Number of ear bearing tillers per plant | High PCV and GCV       | Bornare <i>et al.</i> (2014)<br>Hossain <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)                                  |
|        |   | High PCV, Moderate GCV | Ramanjaneyulu <i>et al.</i> (2014)<br>Hasan <i>et al.</i> (2015)   |
|        |   | Moderate PCV, GCV      | Shahriar <i>et al.</i> (2014)<br>Habiba <i>et al.</i> (2015)<br>Girma <i>et al.</i> (2018)   |

Table 2.1 (cont.)

| S. No. | Character                 | Variability            | Reference   |
|--------|---------------------------|------------------------|---|
|        |                           | Moderate PCV, Low GCV  | Fentie <i>et al.</i> (2014)<br>Lingaiah <i>et al.</i> (2014)<br>Rai <i>et al.</i> (2014)<br>Adhikari <i>et al.</i> (2018)                               |
|        |                           | Low PCV, GCV           | Vanisree <i>et al.</i> (2013)<br>Kishore <i>et al.</i> (2015)<br>Konate <i>et al.</i> (2016)  |
| 4      | Panicle length (cm)       | High PCV and GCV       | Nayak <i>et al.</i> (2016)  |
|        |                           | High PCV, Moderate GCV | Hasan <i>et al.</i> (2015)  |
|        |                           | Moderate PCV, GCV      | Dutta <i>et al.</i> (2013)<br>Rai <i>et al.</i> (2014)<br>Reddy <i>et al.</i> (2014)  |
|        |                           | Moderate PCV, Low GCV  | Sathisha <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Anis <i>et al.</i> (2016)  |
|        |                           | Low PCV, GCV           | Habiba <i>et al.</i> (2015)<br>Kishore <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Adhikari <i>et al.</i> (2018)<br>Girma <i>et al.</i> (2018) |
| 5      | Grain yield per plant (g) | High PCV and GCV       | Rai <i>et al.</i> (2014)<br>Hossain <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)                                     |
|        |                           | High PCV, Moderate GCV | Vanisree <i>et al.</i> (2013)<br>Ramanjaneyulu <i>et al.</i> (2014)<br>Adhikari <i>et al.</i> (2018)  |
|        |                           | Moderate PCV, GCV      | Pandey <i>et al.</i> (2012)<br>Hasan <i>et al.</i> (2015)<br>Girma <i>et al.</i> (2018)   |
|        |                           | Moderate PCV, Low GCV  | Ahmeda <i>et al.</i> (2016)<br>Chandramohan <i>et al.</i> (2016)<br>Anis <i>et al.</i> (2016)<br>Konate <i>et al.</i> (2016)                            |
|        |                           | Low PCV, GCV           | Vijaya and Shailaja (2016)  |

## 2.2 HERITABILITY AND GENETIC ADVANCE

Kurmanchali *et al.* (2019) studied twenty four rice genotypes for heritability and genetic advance. The results revealed that high heritability coupled with moderate genetic advance for days to 50% flowering and plant height (cm), high heritability with low genetic advance for ear bearing tillers per plant, panicle length (cm) and grain yield per plant (g).

Rahul *et al.* (2018) studied twenty eight rice genotypes for heritability and genetic advance. The results show high level of heritability combined with moderate level of genetic advance estimates for days to 50 % flowering and panicle length (cm) while high level of heritability coupled with high genetic advance for plant height (cm) and grain yield per plant (g), whereas number of ear bearing tillers had moderate level heritability with moderate genetic advance.

Adhikari *et al.* (2018) evaluated twenty six rice genotypes for heritability and genetic advance studies, results revealed that high heritability combined with moderate genetic advance for days to 50% flowering, high heritability attained with low genetic advance for plant height (cm), moderate heritability and genetic advance for grain yield (g), moderate heritability fused with low genetic advance for panicle length (cm) and low heritability attained with low genetic advance for ear bearing tillers.

Girma *et al.* (2018) evaluated sixty four rice genotypes for heritability and genetic advance, the results obtained that high heritability combined with high genetic advance for days to 50% flowering, plant height (cm), ear bearing tillers per plant, grain yield (g) and moderate heritability fused with low genetic advance for panicle length (cm).

Kusuma *et al.* (2018) evaluated one hundred and nineteen rice breeding lines for heritability and genetic advance as percent of mean. High heritability coupled with high GAM was recorded for grain yield per plant (g).

Sumanth *et al.* (2017) screened twenty three rice genotypes for heritability studies, the results were interpreted as high heritability accompanied with high genetic advance for plant height (cm), ear bearing tillers per plant and grain yield per plant (g), high heritability coupled with moderate genetic advance for panicle length (cm) and high heritability fused with low genetic advance for days to 50% flowering.

Konate *et al.* (2016) screened seventeen RILs for heritability and genetic advance and results revealed that high heritability accompanied with moderate genetic advance for days to 50% flowering and grain yield per plant (g), high heritability with low genetic advance for plant height (cm), high heritability united with moderate genetic advance for ear bearing tillers and panicle length (cm).

Anis *et al.* (2016) screened promising rice lines and reported high heritability accompanied with moderate genetic advance for plant height (cm), panicle length (cm) and grain yield per plant (g).

Chandramohan *et al.* (2016) screened forty four rice genotypes to study the heritability and genetic advance for yield contributing traits. Days to 50 % flowering and plant height (cm) exhibited high level of heritability along with low estimates of genetic advance and effective bearing tillers per plant showed low values of both. High heritability coupled with moderate genetic advance values was recorded for panicle length (cm) and grain yield per plant (g).

Tejaswini *et al.* (2016a) screened one hundred and fourteen F<sub>5</sub> families from six crosses to study heritability and genetic advance. High heritability coupled with high genetic advance recorded for grain yield per plant (g).

Tejaswini *et al.* (2016b) evaluated forty two F<sub>5</sub> rice families belongs to four crosses and recorded high heritability accompanied with high genetic advance as percent of mean for grain yield per plant (g).

The character wise chronological report of available literature on heritability and genetic advance as percent of mean is presented in the Table 2.2.

**Table 2.2 Scientific studies made by several workers on heritability and genetic advance in rice**

| S. No | Character             | Heritability | Genetic advance as % of mean | Reference   |
|-------|-----------------------|--------------|------------------------------|---|
| 1     | Days to 50% flowering | High         | High                         | Kishore <i>et al.</i> (2015)<br>Sathisha <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)<br>Rashmi <i>et al.</i> (2016)<br>Maurya <i>et al.</i> (2018)   |
|       |                       | High         | Moderate                     | Lingaiah <i>et al.</i> (2014)<br>Reddy <i>et al.</i> (2014)<br>Habiba <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Devi <i>et al.</i> (2017)  |
|       |                       | High         | Low                          | Hossain <i>et al.</i> (2015)<br>Vijaya and Shailaja (2016)<br>Sameera <i>et al.</i> (2016)<br>Sumanth <i>et al.</i> (2017)<br>Kumar <i>et al.</i> (2018)<br>Longjam <i>et al.</i> (2019)  |
|       |                       | Low          | Low                          | Bornare <i>et al.</i> (2014)  |
| 2     | Plant height(cm)      | High         | High                         | Reddy <i>et al.</i> (2014)<br>Habiba <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)<br>Rashmi <i>et al.</i> (2016)<br>Devi <i>et al.</i> (2017)<br>Sumanth <i>et al.</i> (2017)<br>Kumar <i>et al.</i> (2018)<br>Maurya <i>et al.</i> (2018) |
|       |                       | High         | Moderate                     | Shahriar <i>et al.</i> (2014)<br>Hasan <i>et al.</i> (2015)<br>Hossain <i>et al.</i> (2015)<br>Kishore <i>et al.</i> (2015)<br>Sathisha <i>et al.</i> (2015)<br>Longjam <i>et al.</i> (2019)  |
|       |                       | High         | Low                          | Sameera <i>et al.</i> (2016)  |
|       |                       | Moderate     | Moderate                     | Fentie <i>et al.</i> (2014)   |
|       |                       | Low          | High                         | Idris and Mohamed (2013)<br>Ramanjaneyulu <i>et al.</i> (2014)  |
|       |                       |              |                              |   |

Table 2.2 (cont.)

| S. No | Character                               | Heritability | Genetic advance as % of mean | Reference   |
|-------|---|--------------|------------------------------|---|
| 3     | Number of ear bearing tillers per plant | High         | High                         | Hossain <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Shrivastava <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)<br>Sameera <i>et al.</i> (2016)<br>Sumanth <i>et al.</i> (2017)<br>Maurya <i>et al.</i> (2018)  |
|       |   | High         | Low                          | Habiba <i>et al.</i> (2015)   |
|       |   | Moderate     | High                         | Ketan and Sarkar (2014)<br>Rashmi <i>et al.</i> (2016)<br>Longjam <i>et al.</i> (2019)  |
|       |   | Moderate     | Moderate                     | Rai <i>et al.</i> (2014)<br>Ramanjaneyulu <i>et al.</i> (2014)<br>Shahriar <i>et al.</i> (2014)   |
|       |   | Moderate     | Low                          | Kishore <i>et al.</i> (2015)  |
|       |   | Low          | Moderate                     | Toshimenla <i>et al.</i> (2013)   |
|       |   | Low          | Low                          | Fentie <i>et al.</i> (2014)<br>Lingaiah <i>et al.</i> (2014)  |
| 4     | Panicle length (cm)                     | High         | High                         | Reddy <i>et al.</i> (2014)<br>Hasan <i>et al.</i> (2015)<br>Rashmi <i>et al.</i> (2016)<br>Kumar <i>et al.</i> (2018)   |
|       |   | High         | Moderate                     | Lingaiah <i>et al.</i> (2014)<br>Habiba <i>et al.</i> (2015)<br>Hossain <i>et al.</i> (2015)<br>Sahu <i>et al.</i> (2015)<br>Sathisha <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)<br>Sameera <i>et al.</i> (2016)<br>Sumanth <i>et al.</i> (2017)<br>Maurya <i>et al.</i> (2018) |
|       |   | High         | Low                          | Kishore <i>et al.</i> (2015)<br>Longjam <i>et al.</i> (2019)  |
|       |   | Moderate     | Moderate                     | Toshimenla <i>et al.</i> (2013)<br>Shrivastava <i>et al.</i> (2015)   |
|       |   | Moderate     | Low                          | Idris and Mohamed (2013)<br>Shahriar <i>et al.</i> (2014)   |
|       |   | Low          | Low                          | Fentie <i>et al.</i> (2014)   |

Table 2.2 (cont.)

| <b>S. No</b> | <b>Character</b>          | <b>Heritability</b> | <b>Genetic advance as % of mean</b> | <b>Reference</b>  |
|--------------|---------------------------|---------------------|-------------------------------------|---|
| 5            | Grain yield per plant (g) | High                | High                                | Bornare <i>et al.</i> (2014)<br>Ketan and Sarkar (2014)<br>Khare <i>et al.</i> (2014)<br>Rai <i>et al.</i> (2014)<br>Sahu <i>et al.</i> (2015)<br>Nayak <i>et al.</i> (2016)<br>Rashmi <i>et al.</i> (2016)<br>Sameera <i>et al.</i> (2016)<br>Sumanth <i>et al.</i> (2017) |
|              |                           | Moderate            | High                                | Tuwar <i>et al.</i> (2013)<br>Maurya <i>et al.</i> (2018)<br>Longjam <i>et al.</i> (2019)   |
|              |                           | Low                 | Low                                 | Vijaya and Shailaja (2016)  |

## 2.3 EVALUATION OF RILS FOR BROWN PLANT HOPPER RESISTANCE

Kusuma *et al.* (2018) evaluated one hundred and nineteen F<sub>6</sub> rice breeding lines under field and lab conditions for BPH resistance. The results revealed that out of one hundred and nineteen lines, thirty two lines showed resistance in lab screening (Standard Seed box Screening Test) and sixty two lines exhibited resistance in field screening.

Jiang *et al.* (2018) used standard seed box method for screening at the seedling stage. The results showed the resistance score for Jin 23B harbouring Bph14 and Bph15, designated as Jin 23B (14/15), account damage score of 2.28, which conferred highest resistance rating among all the selected lines. Seven plants from central row of each plot were subjected to agronomic trait measurements in the field screening including days to heading (DTH) and plant height (PH). After the maturity of rice, the seven plants from central row were harvested individually for panicle number (PN), number of grains per panicle (NGP), spikelet fertility (SF), weight of 1000 grains (GW) and yield per plant (YD) measurement. These results predict that Jin 23B performs similar to the control under field conditions.

Kumar *et al.* (2018) used standard screen box method for evaluating F<sub>2</sub> and F<sub>2:3</sub> populations. Out of four hundred and sixty three F<sub>2</sub> plants, three hundred and thirty one plants showed resistance to BPH and one hundred and thirty two plants were found to be susceptible. Screening of one hundred and ninety three F<sub>2:3</sub> progenies showed segregation ratio of 42 resistant: 99 segregating: 52 susceptible.

Mohanty *et al.* (2017) screened three hundred F<sub>8</sub> RILs obtained from a cross between TN1 and Salkathi. A total of one hundred and twenty two RILs were found to be resistant whereas one hundred and seventy eight RILs were susceptible. Twenty RILs showed mean resistance score of 0.0-1.0 like resistant parent Salkathi while one hundred and four RILs showed mean resistance score of 8.1-9.0 like susceptible parent TN 1.

Thamarai *et al.*, (2017) conducted screening of twenty six selected rice genotypes along with resistant and susceptible checks *viz.*, PTB-33 and TN-1 using standard seed box screening technique (SSST) to evaluate the BPH resistance against the local population (Coimbatore, India) of BPH (*Nilaparvata lugens*) in glass house

condition. Among the 26 rice genotypes screened none of the entry was observed as highly resistant. In SSST method, RP 2068-18-3-5 and ASD-7 were found to be resistant with the mean score between 2.25 and 2.85 respectively. PTB-41, T-12, Rathuheenathi, Swarnalatha, PTB-19, Pokkali, Chinsaba, Mudgo and Vellaikudavazhai were found to be moderately resistant.

Shabanimofrad *et al.* (2017) developed one hundred and fifty F<sub>3</sub> lines from a cross between MR276 and Rathu Heenati. Rathu Heenati was resistant, whereas MR276 was moderately susceptible to BPH. One hundred and fifty of the MR276/RathuHeenati F<sub>3</sub> population showed transgressive segregation for resistance to BPH, and the resistance scores exhibited a continuous distribution with a range from 1.5 to 9.0, indicating polygenic control of the resistance to BPH under controlled conditions.

Bhogadi *et al.* (2015) screened twenty six rice genotypes at APRRI, Maruteru under field conditions during wet seasons of 2012 and 2013. The results of screening trials showed that the genotype *viz.*, PTB 33, BM 71 and Rathu heenathi were rated as resistant (R) with an average damage score of 2, 2.5 and 3.0, respectively. Eleven genotypes *viz.*, ACC5098, Deepthi (MTU 4870), Bhavapuri Sannalu (BPT 1768), Akshaya (BPT 2231), Vijetha (MTU 1001), Cottondora Sannalu (MTU 1010), ACC 2398, Swarnalatha, IR 65482, Prabhath (MTU 3626) and MTU 1064 showed moderate level of resistance with an average damage score ranging between 3.5 and 6.0.

Tetarwal *et al.* (2014) studied a total of one hundred and seventy eight rice genotypes from various station and national trials were evaluated for resistance against brown plant hopper (BPH) under natural infestation condition during *kharif* 2011 at CCS HAU, Rice Research Station, Kaul, Kaithal. The results revealed that only five genotypes *viz.*, CN 1724-9-4-5, MAUB-181, ACC-451 and IR 79584-38-2-1-9 were resistant, twenty eight were moderately resistant, one hundred and two were moderately susceptible and the rest were susceptible (43) to brown plant hopper.

Wu *et al.* (2014) conducted the seedling screening of F<sub>2:3</sub> populations of DV 85 and Balamawee against BPH resistance by following standard screen box method. They concluded that Balamawee showed a higher level of antibiosis than DV85, where as DV 85 showed moderate level resistance to BPH population.

Prithnsha *et al.* (2014) screened twenty rice varieties through seed box testing by using standard evaluation system. The genotypes PTB 33, Rathuheenathi and RP 2068-18-3-5 had shown least plant damage score (0-0.68) and were categorized as highly resistant (HR). Maximum average plant damage score (9) was observed in genotypes Milyang 63, Chinsaba, Pokkali, TN 1 and IR 36. Three rice genotypes Rathu Heenati (ACC 11730), RP 2068-18-3-5 and PTB 33 were categorized as highly resistant (HR), while five genotypes Babawee, Swarnalatha, T 12 and IR 64 are resistant (R).

Harini *et al.* (2013) used standard screen box method for evaluating twenty eight rice genotypes against BPH resistance, PTB33 widely used as donor parent for BPH by rice breeders consisting of Bph2 and Bph3 genes (Khush, 1979) and Pokkali reported to have Bph9 gene (Murata *et al.*, 2001), scored as 1 and 3 respectively, and TN1 showed a score of 9.

Wang *et al.* (2013) screened three hundred and twelve accessions with resistant check Rathu Heenathi and susceptible check Wuyujing3. Among the three hundred and twelve accessions, sixty eight were highly resistant to SBPH, twenty five were resistant, ninety three were susceptible and one hundred and twenty eight were highly susceptible.

Hu *et al.* (2013) evaluated the lines containing two Bph genes, 9311 (14/15), 9311 (15/18) and 9311 (14/18) were resistant (R), moderately resistant (MR) and MR, with scores of 2.1, 3.4 and 4.1 respectively. They also evaluated the agronomic traits of improved lines with all seven genotype combinations and the control 9311 under natural field conditions. All the improved lines showed a significant increase in PN (Panicle number) and NG (Number of grains) compared with the control 9311. Overall, the yields of improved lines were higher than or similar to that of the control (9311) under natural field conditions.

Kumari *et al.* (2010) screened two hundred and sixty eight F<sub>7</sub> RILs infested with the BPH biotype 4 and the results showed thirty four resistant lines (score 1.0-3.9), four moderately resistant lines (score 4.0-4.9), one hundred and fifty one moderately susceptible (score 6 5.0-8.9) and thirty seven susceptible lines (score 9).

Santhanalaxmi *et al.* (2010) used a population of one hundred and six F<sub>3</sub> families along with parents resistant (PTB 33) and susceptible check (TN 1) for evaluating BPH resistance at seedling stage using standard seed box method. The results revealed the presence of dominance gene which is controlling resistance and 60%-70% F<sub>3</sub> progenies are resistance.

Liu *et al.* (2009) conducted BPH screening in both greenhouse and field conditions. Among one hundred and eighty F<sub>2,3</sub> lines, none of the lines was highly resistant to BPH (score 0), twenty three were resistant (score 1 or 3) and thirty two were moderately resistant (score 5). The resistant and moderately resistant type occurred at a frequency of 18.0% and 18.4%, respectively.

Sun *et al.* (2007) evaluated one hundred and forty seven F<sub>3</sub> families, derived from cross between Col.5 T and 02428, against BPH resistance while ASD7 and Taichung Native-1 were used as resistance and susceptible checks respectively. The final results showed that Col.5 Thailand average score 1.4 and 02428 average score 8.2, where as F<sub>1</sub> scores 5.8, resistant check ASD 7 scored 1.1 and susceptible check Taichung Native 1 scored 9.0.

Su *et al.* (2005) conducted the screening of eighty one RILs against BPH resistance. The resistance scores of eighty one RILs infested with biotype 2 showed a bimodal distribution. If RILs with a resistance score lower than five were considered as resistant while those above five were considered as susceptible, forty two RILs were resistant and thirty nine RILs were susceptible.

Soundararajan *et al.* (2004) used a mapping population of ninety four DH lines from cross between IR64 and Azucena for evaluating BPH resistance using standard seed box screening method. The results showed average scores of resistant and susceptible checks PTB33 and TN 1 was 2.4 and 7.1 respectively. Whereas the average damage scores of DHLs, IR 64 and Azucena were 4.2, 4.3 and 6.8 respectively.

## **2.4 IDENTIFICATION OF QTLS FOR BPH TOLERANCE**

Brown plant hopper (*Nilaparvata lugens* Stal) is one of the most destructive insect pests in rice-growing areas of Asia and Southeast Asia. Both adults and nymphs of the insect feed on rice sheaths by sucking sap from phloem. All the growth stages of rice plant in the field are vulnerable to BPH. Mild infestations by the insects lead to

yellowing of leaves, reduction in plant height, growth, vigour, number of productive tillers and grain filling. Heavy infestations cause complete drying and death of plants, this phenomenon known as “hopper burn” (Mohanty *et al.*, 2017). Chemical pesticide application was expensive in terms of environment pollution and cost, thus it was not a ideal strategy to control BPH. Therefore breeding for BPH resistance is most economic to control. Hence it is essential to identify new resistant genes cloned and develop varieties of rice (Qiu *et al.*, 2013).

Pan *et al.* (2019) mapped novel brown plant hopper resistant gene on short arm of chromosome 4 which is flanked by InDel markers S13 and X48 by an interval of 38kb and mapped another gene on long arm of chromosome 4 flanked by SSR markers RM16766 and RM17033 which was similar to Bph27.

Naik *et al.* (2018) identified a new R gene (bph33 (t)) which was resistant to BPH by using advanced generation population of two hundred and sixty RILs (TN1/RP2068). They phenotyped the RIL's at two locations and linkage analysis was done with ninety nine polymorphic SSR markers. QTL analysis was done through Ici Mapping and they identified loci on chromosome number 1 delimited by markers RM488 and RM11522.

Kumar *et al.* (2018) identified a qtl resistant to BPH, which was designated as Bph34 on long arm of rice chromosome 4 using an inter specific F<sub>2</sub> population derived from a cross between susceptible indica cultivar PR 122 and BPH resistant wild species, *O. nivara* acc. IRGC104646. QTL mapping identified single major locus at 28.8 LOD score between SNP markers, AX-95952039 and AX-95921548.

Wang *et al.* (2018) used F<sub>2</sub> population derived from a cross between AC-1613 and 9311 for mapping the BPH resistance gene. They located the gene on the short arm of chromosome 4 between RM16278 and RM16425, named as Bph30 which was explained 42.7% of the phenotypic variance of BPH resistance.

Mohanty *et al.* (2017) identified two QTLs and designated as qBph4.3 and qBph4.4. qBph4.3 with phenotype variance of 37.02% is located between the markers RM551 and RM335 and it seems to be a novel QTL associated with BPH resistance, other QTL with phenotype variance of 7.1% is located between markers RM335 and RM5633. They used a total of six hundred and ninety eight microsatellite primers to

find polymorphism between resistant parent, Salkathi and susceptible parent, TN1. Out of which ninety-two (13.18%) primers generated polymorphic markers between TN1 and Salkathi.

Prahalada *et al.* (2017) identified a new resistant gene which was designed as BPH 31. They develop this gene for improving rice cultivars against BPH resistance in Indian sub continent. BPH 31 gene was located on long arm of chromosome 3 within the interval of 475kb between the flanking markers PA26 and RM2334.

Shabanimofrad *et al.* (2017) used mapping population of one hundred and fifty F<sub>3</sub> lines derived from a cross between MR 276 and Rathu Heenati for detecting qtl associated with BPH resistance. In total 10 QTLs controlling BPH resistance were mapped on chromosomes 1, 3, 6, 7, 9, 10 and 12. Four QTLs, qBph.1.1, qBph.3.1, qBph.6.1, and qBph.7.1 were mapped on chromosomes 1, 3, 6, and 7 base on standard seed box screening test score, they all together explaining 41% of the phenotypic variance.

Ren *et al.* (2016) identified a novel gene which was designated as Bph32 resistance to brown plant hopper. Bph32 gene located on chromosome 6 and it was flanked by the simple sequence repeat (SSR) markers RM19291 and RM8072.

Wu *et al.* (2014) mapped a brown plant hopper resistance gene, which was named as Bph28(t) and it was placed on chromosome 11, flanked by the SSR markers RM202 and RM5961 with distance of 25.9cM.

Qiu *et al.* (2013) mapped the Qbph8 locus to a 7.3cM region on chromosome 8 by using F<sub>2</sub> population derived from a cross between the Indica cultivars 93-11 and Swarnalata, flanked by the SSR markers RM339 and RM515.

Wang *et al.* (2013) mapped three QTLs for SBPH resistance, which were designated as qSBPH2, qSBPH3 and qSBPH7.1. They mapped on chromosomes 2, 3 and 7 by composite interval mapping. The LOD values for qSBPH2, qSBPH3 and qSBPH7.1 was 2.33, 2.54 and 3.42 respectively, whereas these three QTLs explained phenotypic variance of 10.0%, 7.7% and 17.4%, respectively.

Liu *et al.* (2009) used an F<sub>2</sub> mapping population from the cross between a BPH resistant Vietnamese landrace Yagyaw and the susceptible cultivar Cpslo17. Four QTLs contributing to BPH resistance were mapped on chromosomes 2, 4, 7 and 9

respectively. Qbph-2 was flanked by RM5529 and RM1358, and located on the telomere of chromosome 2, explaining 9.18% of the phenotypic variation. Qbph-4 was flanked by RM401 and RM335, and located on the telomere of chromosome 4, explaining 12.77% of the phenotypic variation. Qbph-7 was flanked by RM542 and RM500, and located on chromosome 7, explaining 6.30% of the phenotypic variation. Qbph-9 was flanked by RM3533 and RM242, and located on chromosome 9, explaining 5.64% of the phenotypic variation. Qbph-4 explains the largest phenotypic variation.

Rahman *et al.* (2009) conducted an experiment using one hundred and ninety F<sub>2</sub> population derived from a cross between an introgression line, 'IR71033-121-15', from *Oryza minuta* and a susceptible Korean *japonica* variety, 'Junambyeo' to identify new QTLs for BPH. They identified two major QTLs on the short arm of chromosome 4, and on the long arm of chromosome 12. They were designated as Bph20 (t) and Bph21 (t) respectively.

Sun *et al.* (2007) identified new QTL's, Qbph 2 and Qbph 6 on chromosome 2 and chromosome 6 respectively for BPH resistance. The Qbph2 was detected with a LOD score of 3.40, located between RM6843 and RM 3355 on the long arm of chromosome 2. Whereas Qbph6 was detected with a LOD score of 18.30, located between RM510 and RM 314 on the short arm of chromosome 6. They used 551 SSR primers for surveying polymorphism between Col.5 T and 02428, of which 185 markers showed parental polymorphism between parents.

Jairin *et al.* (2007) finely mapped the locus between two flanking micro satellite markers, RM589 and RM588, on the short arm of chromosome 6 and designated as Bph3 within 0.9 and 1.4 cM, respectively. They also confirmed both the location of Bph3 and the allelic relationship between Bph3 and bph4 on chromosome 6.

Chen *et al.* (2006) identified a brown plant hopper resistance gene named bph19 (t). It was mapped finely on short arm of chromosome 3, flanked between the SSR markers RM6308 and RM3134 with a distance about 1.0cM.

Hong *et al.* (2006) mapped the resistant gene flanked between RM7102 and RM463 SSR markers which were named as bph2 in ASD7 on the long arm of chromosome 12, with distances of 7.6cM and 7.2cM respectively.

Jena *et al.* (2006) identified a new resistance gene in an introgression line (IR65482-7-216-1-2) and named as Bph18 (t). The new gene was flanked by the SSR marker RM463 and the STS marker S15552 on long arm of chromosome 12.

Su *et al.* (2005) identified a new QTL on chromosome 11 and it was designated as a Qbph1 using a population of eighty one recombinant inbred lines derived from a cross between a susceptible rice Kinmaze and DV85. Composite interval mapping revealed that one quantitative trait locus (QTL) with a LOD score of 10.1 was detected between XNpb202 and C1172 (RFLP Markers) on chromosome 11.

Ren *et al.* (2004) used one hundred and eighty seven RILs derived from resistant parent B5 and susceptible parent Minghui 63 and they identified a new QTL on chromosome 2 which was named as Qbp3 with LOD of 3.4 and explaining phenotypic variance up to 3.4%.

Huang *et al.* (2001) using two hundred and fifty F<sub>3</sub> families from a cross between 'B5' and 'Minghui 63' and the QTL analysis using Mapmaker/QTL 1.1 detected two QTLs for BPH resistance. The first, designated Qbp1, detected with a LOD score of 12.89, was located in the 14.3-cM length interval between R1925 and R2443 on the long arm of chromosome 3. This QTL explained 26.4% of the phenotypic variance of BPH resistance in this population. The second QTL, Qbp2, was resolved with a LOD score of 7.69 to a 0.4-cM interval between C820 and R288 on the short arm of chromosome 4. This QTL accounted for 14.3% of the phenotypic variance of BPH resistance in this population. Both the QTLs jointly explained 41.1% of the phenotypic variance of BPH resistance in this population.

Liu *et al.* (2001) identified a new QTL which was named as *BPH 13(t)* between the flanking markers RM240 and RM250 on chromosome 2 using mapping population derived from cross between resistant parent *Oryza eichingeri* and susceptible parent 02428.

## Chapter – III

---

### *Material and Methods*

## Chapter III

# MATERIAL AND METHODS

The present research work on “Identification of novel QTLs for BPH tolerance using donor BM 71 (MTU ITJ 206-7-4-1)” was taken up during *kharif*, 2018 at Regional Agricultural Research Station, Maruteru, West Godavari district of Andhra Pradesh. Maruteru is located at 81.44<sup>0</sup> E longitude, 26.38<sup>0</sup> N latitude and 5 m above MSL. The soils are characterized as black alluvial clay soils, neutral to slightly alkaline in reaction with medium levels of phosphorus and potassium. Annual rainfall of the location is 1150 mm.

The material and methods used for research work are described below.

### 3.1 EXPERIMENTAL MATERIAL AND DESIGN

#### 3.1.1 Development of RILs

The experimental material consists of one hundred and forty two RILs derived from the cross MTU 3626/BM 71 (Table 3.1) in F<sub>5</sub> generation, resistant check BM 71 and susceptible check TN 1. MTU 3626 (Prabhat) is a semi dwarf, medium duration, coarse grain, high yielding variety, susceptible to brown plant hopper, was used as the female parent and BM 71, a medium duration, high yield potential, and donor of BPH resistance was used for male parent. Crossing programme was done for MTU 3626 and BM 71 to produce F<sub>1</sub> plant, then seed of F<sub>1</sub> generation utilized for selfing to produce F<sub>2</sub> generation. Single seed descent method was used for advanced generations up to F<sub>5</sub> generation.

#### 3.1.2 Material used for yield attributing characters

The experimental material consisting of one hundred and forty two RILs in F<sub>5</sub> generation and two high yielding checks MTU 7029 and MTU 1075 were sown in simple lattice design with two replications with the spacing of 20 cm X 15 cm in 1.2 m<sup>2</sup> plot size (Figure 3.1).

### **3.1.3 Material used for screening**

One hundred and forty two RILs, along with resistant check BM 71 and susceptible check TN 1 were sown in trays for seedling screening and transplanted in field for field screening.

### **3.1.4 Markers used for parental polymorphism study**

Three hundred and fifteen SSR markers were used for parental polymorphism study between MTU 3626 and BM 71 across 12 chromosomes (Table 3.2). Among three hundred and fifteen SSR markers used, seventy seven polymorphic SSR markers were used for genotyping.

### **3.1.5 Identification of QTLs**

Out of one hundred and forty two RILs in F<sub>5</sub> generation, DNA was extracted from one hundred and thirty six RILs, two parents BM 71 and MTU 3626 used during PCR amplification, remaining six RILs were discarded due to their phenotypic inferiority in screening.

### **3.1.6 Mass rearing of BPH**

Rearing of BPH was done by collecting different instar nymphs of BPH and growing them in controlled conditions. Taichung Native -1 (TN 1) is highly susceptible to BPH. For maintaining and rearing of BPH, TN-1 plants were grown in special pots up to 4-6 weeks age. Adult gravid females of BPH obtained from the maintenance cage were released to the potted TN 1 plants for oviposition and exposed for 3 days. Then the oviposited plants were placed in maintenance cage for hatching the eggs. The host plants in insect rearing cages were changed twice a week and replaced them with fresh potted plants for active survival of nymphs (Heinrichs *et al.*, 1985).

**Table 3.1 List of RILs and checks used in the study**

| <b>S. No.</b> | <b>RIL Name</b> | <b>S. No.</b> | <b>RIL Name</b> |
|---------------|-----------------|---------------|-----------------|
| 1             | 2711-1          | 38            | 2711-41         |
| 2             | 2711-2          | 39            | 2711-43         |
| 3             | 2711-3          | 40            | 2711-44         |
| 4             | 2711-4          | 41            | 2711-45         |
| 5             | 2711-5          | 42            | 2711-46         |
| 6             | 2711-6          | 43            | 2711-47         |
| 7             | 2711-7          | 44            | 2711-49         |
| 8             | 2711-8          | 45            | 2711-50         |
| 9             | 2711-9          | 46            | 2711-52         |
| 10            | 2711-11         | 47            | 2711-53         |
| 11            | 2711-13         | 48            | 2711-54         |
| 12            | 2711-14         | 49            | 2711-55         |
| 13            | 2711-15         | 50            | 2711-56         |
| 14            | 2711-16         | 51            | 2711-57         |
| 15            | 2711-17         | 52            | 2711-58         |
| 16            | 2711-18         | 53            | 2711-59         |
| 17            | 2711-19         | 54            | 2711-60         |
| 18            | 2711-20         | 55            | 2711-61         |
| 19            | 2711-22         | 56            | 2711-62         |
| 20            | 2711-23         | 57            | 2711-63         |
| 21            | 2711-24         | 58            | 2711-64         |
| 22            | 2711-25         | 59            | 2711-65         |
| 23            | 2711-26         | 60            | 2711-66         |
| 24            | 2711-27         | 61            | 2711-67         |
| 25            | 2711-28         | 62            | 2711-68         |
| 26            | 2711-29         | 63            | 2711-69         |
| 27            | 2711-30         | 64            | 2711-71         |
| 28            | 2711-31         | 65            | 2711-72         |
| 29            | 2711-32         | 66            | 2711-73         |
| 30            | 2711-33         | 67            | 2711-74         |
| 31            | 2711-34         | 68            | 2711-75         |
| 32            | 2711-35         | 69            | 2711-76         |
| 33            | 2711-36         | 70            | 2711-77         |
| 34            | 2711-37         | 71            | 2711-78         |
| 35            | 2711-38         | 72            | 2711-79         |
| 36            | 2711-39         | 73            | 2711-80         |
| 37            | 2711-40         | 74            | 2711-83         |

| <b>S. No.</b> | <b>RIL Name</b> |
|---------------|-----------------|
| 75            | 2711-84         |
| 76            | 2711-86         |
| 77            | 2711-87         |
| 78            | 2711-88         |
| 79            | 2711-89         |
| 80            | 2711-92         |
| 81            | 2711-93         |
| 82            | 2711-94         |
| 83            | 2711-100        |
| 84            | 2711-101        |
| 85            | 2711-102        |
| 86            | 2711-103        |
| 87            | 2711-104        |
| 88            | 2711-105        |
| 89            | 2711-106        |
| 90            | 2711-107        |
| 91            | 2711-108        |
| 92            | 2711-110        |
| 93            | 2711-111        |
| 94            | 2711-112        |
| 95            | 2711-113        |
| 96            | 2711-115        |
| 97            | 2711-116        |
| 98            | 2711-117        |
| 99            | 2711-119        |
| 100           | 2711-120        |
| 101           | 2711-122        |
| 102           | 2711-123        |
| 103           | 2711-125        |
| 104           | 2711-127        |
| 105           | 2711-129        |
| 106           | 2711-130        |
| 107           | 2711-131        |
| 108           | 2711-133        |
| 109           | 2711-137        |
| 110           | 2711-140        |

| <b>S. No.</b> | <b>RIL Name</b> |
|---------------|-----------------|
| 111           | 2711-143        |
| 112           | 2711-147        |
| 113           | 2711-149        |
| 114           | 2711-150        |
| 115           | 2711-151        |
| 116           | 2711-162        |
| 117           | 2711-164        |
| 118           | 2711-167        |
| 119           | 2711-168        |
| 120           | 2711-169        |
| 121           | 2711-170        |
| 122           | 2711-172        |
| 123           | 2711-175        |
| 124           | 2711-176        |
| 125           | 2711-177        |
| 126           | 2711-178        |
| 127           | 2711-179        |
| 128           | 2711-182        |
| 129           | 2711-184        |
| 130           | 2711-185        |
| 131           | 2711-186        |
| 132           | 2711-187        |
| 133           | 2711-188        |
| 134           | 2711-189        |
| 135           | 2711-191        |
| 136           | 2711-192        |
| 137           | 2711-193        |
| 138           | 2711-195        |
| 139           | 2711-196        |
| 140           | 2711-197        |
| 141           | 2711-198        |
| 142           | 2711-199        |
| 143           | MTU 7029 Check  |
| 144           | MTU 1075 Check  |
| 145           | BM 71           |
| 146           | MTU 3626        |



|                |          | — 2m —             |     |     |     |     |     |     |     |     |     |     |     |  |  |
|----------------|----------|--------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|--|
|                |          | ROAD               |     |     |     |     |     |     |     |     |     |     |     |  |  |
| R <sub>1</sub> | Block 1  | 1                  | 13  | 25  | 37  | 49  | 61  | 73  | 85  | 97  | 109 | 121 | 133 |  |  |
|                | Block 2  | 2                  | 14  | 26  | 38  | 50  | 62  | 74  | 86  | 98  | 110 | 122 | 134 |  |  |
|                | Block 3  | 3                  | 15  | 27  | 39  | 51  | 63  | 75  | 87  | 99  | 111 | 123 | 135 |  |  |
|                | Block 4  | 4                  | 16  | 28  | 40  | 52  | 64  | 76  | 88  | 100 | 112 | 124 | 136 |  |  |
|                | Block 5  | 5                  | 17  | 29  | 41  | 53  | 65  | 77  | 89  | 101 | 113 | 125 | 137 |  |  |
|                | Block 6  | 6                  | 18  | 30  | 42  | 54  | 66  | 78  | 90  | 102 | 114 | 126 | 138 |  |  |
|                | Block 7  | 7                  | 19  | 31  | 43  | 55  | 67  | 79  | 91  | 103 | 115 | 127 | 139 |  |  |
|                | Block 8  | 8                  | 20  | 32  | 44  | 56  | 68  | 80  | 92  | 104 | 116 | 128 | 140 |  |  |
|                | Block 9  | 9                  | 21  | 33  | 45  | 57  | 69  | 81  | 93  | 105 | 117 | 129 | 141 |  |  |
|                | Block 10 | 10                 | 22  | 34  | 46  | 58  | 70  | 82  | 94  | 106 | 118 | 130 | 142 |  |  |
|                | Block 11 | 11                 | 23  | 35  | 47  | 59  | 71  | 83  | 95  | 107 | 119 | 131 | 143 |  |  |
|                | Block 12 | 12                 | 24  | 36  | 48  | 60  | 72  | 84  | 96  | 108 | 120 | 132 | 144 |  |  |
|                |          | IRRIGATION CHANNEL |     |     |     |     |     |     |     |     |     |     |     |  |  |
| R <sub>2</sub> | Block 1  | 1                  | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  |  |  |
|                | Block 2  | 13                 | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  |  |  |
|                | Block 3  | 25                 | 26  | 27  | 28  | 29  | 30  | 31  | 32  | 33  | 34  | 35  | 36  |  |  |
|                | Block 4  | 37                 | 38  | 39  | 40  | 41  | 42  | 43  | 44  | 45  | 46  | 47  | 48  |  |  |
|                | Block 5  | 49                 | 50  | 51  | 52  | 53  | 54  | 55  | 56  | 57  | 58  | 59  | 60  |  |  |
|                | Block 6  | 61                 | 62  | 63  | 64  | 65  | 66  | 67  | 68  | 69  | 70  | 71  | 72  |  |  |
|                | Block 7  | 73                 | 74  | 75  | 76  | 77  | 78  | 79  | 80  | 81  | 82  | 83  | 84  |  |  |
|                | Block 8  | 85                 | 86  | 87  | 88  | 89  | 90  | 91  | 92  | 93  | 94  | 95  | 96  |  |  |
|                | Block 9  | 97                 | 98  | 99  | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 |  |  |
|                | Block 10 | 109                | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 |  |  |
|                | Block 11 | 121                | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 |  |  |
| Block 12       | 133      | 134                | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 |     |  |  |
|                |          | BUND               |     |     |     |     |     |     |     |     |     |     |     |  |  |

Figure 3.1 Field layout for evaluation of RILs for yield and yield attributing traits

**Table 3.2 List of SSR markers used for parental polymorphism studies between MTU 3626 and BM 71**

| S. No. | CH 1    | CH 2    | CH 3    | CH 4    | CH 5    | CH 6    |
|--------|---------|---------|---------|---------|---------|---------|
| 1      | RM 472  | RM250   | RM6881  | RM280   | RM161   | RM564   |
| 2      | RM490   | RM251   | RM426   | RM185   | RM162   | RM510   |
| 3      | RM8278  | RM138   | RM15524 | RM252   | RM163   | RM400   |
| 4      | RM8368  | RM240   | RM15539 | RM348   | RM421   | RM5330  |
| 5      | RM9     | RM324   | RM15528 | RM335   | RM5     | RM225   |
| 6      | RM11841 | RM211   | RM15488 | RM281   | RM17990 | RM253   |
| 7      | RM11312 | RM263   | RM15466 | RM282   | RM18471 | RM340   |
| 8      | RM11069 | RM13893 | RM520   | RM283   | RM4674  | RM589   |
| 9      | RM6887  | RM7288  | RM231   | RM284   | RM5844  | RM3476  |
| 10     | RM10655 | RM12569 | RM203   | RM16569 | RM289   | RM2229  |
| 11     | RM10864 | RM6933  | RM251   | RM261   | RM548   | RM8101  |
| 12     | RM84    | RM3865  | RM7     | RM551   | RM5454  | RM412   |
| 13     | RM128   | RM5430  | RM338   | RM8213  | RM2585  | RM20634 |
| 14     | RM10000 | RM8017  | RM5924  | RM252   | RM1182  | RM5509  |
| 15     | RM6464  | RM3501  | RM489   | RM124   | RM5592  | RM190   |
| 16     | RM12184 | RM5578  | RM14434 | RM2530  | RM18204 |         |
| 17     | RM104   | RM13584 | RM15583 | RM6006  | RM3777  |         |
| 18     | RM8135  |         | RM15554 | RM5047  | RM3853  |         |
| 19     | RM10344 |         | RM15441 | RM16433 | RM169   |         |
| 20     | RM495   |         | RM15561 | RM518   | RM2010  |         |
| 21     | RM259   |         | RM15848 | RM16266 | RM3351  |         |
| 22     | RM237   |         | RM5924  | RM17492 | RM6024  |         |
| 23     | RM3412  |         |         | RM3423  | RM18384 |         |
| 24     | RM8094  |         |         | RM3335  | RM18004 |         |
| 25     | RM10694 |         |         | RM7313  | RM18608 |         |
| 26     | RM10793 |         |         | RM3892  | RM17780 |         |
| 27     |         |         |         | RM17483 | RM18215 |         |
| 28     |         |         |         | RM1667  | RM3160  |         |
| 29     |         |         |         |         | RM18939 |         |
| 30     |         |         |         |         | RM3529  |         |
| 31     |         |         |         |         | RM437   |         |
| 32     |         |         |         |         | RM19199 |         |
| 33     |         |         |         |         | RM6320  |         |
| 34     |         |         |         |         | RM3068  |         |
| 35     |         |         |         |         | RM2998  |         |
| 36     |         |         |         |         | RM5693  |         |
| 37     |         |         |         |         | RM18941 |         |
| 38     |         |         |         |         | RM18919 |         |
| 39     |         |         |         |         | RM18959 |         |

Table 3.2 (cont.)

| S. No. | CH 7    | CH 8    | CH 9    | CH 10   | CH 11   | CH 12   |
|--------|---------|---------|---------|---------|---------|---------|
| 1      | RM336   | RM210   | RM122   | RM258   | RM7443  | RM247   |
| 2      | RM234   | RM8271  | RM3909  | RM222   | RM286   | RM3455  |
| 3      | RM2     | RM8040  | RM5122  | RM1240  | RM254   | RM2972  |
| 4      | RM6697  | RM5485  | RM257   | RM25648 | RM229   | RM2844  |
| 5      | RM4986  | RM6032  | RM278   | RM216   | RM4844  | RM5338  |
| 6      | RM5426  | RM23099 | RM2855  | RM5373  | RM187   | RM6953  |
| 7      | RM22168 | RM8058  | RM23877 | RM496   | RM27186 | RM6052  |
| 8      | RM8033  | RM23645 | RM524   | RM25643 | RM6334  | RM6037  |
| 9      | RM320   | RM22506 | RM3912  | RM244   | RM26870 | RM7018  |
| 10     | RM7161  | RM4153  | RM3209  | RM484   | RM6499  | RM3331  |
| 11     | RM21950 | RM23310 | RM105   | RM6364  | RM26459 | RM28130 |
| 12     | RM2191  | RM23251 | RM23865 | RM25809 | RM26190 | RM1584  |
| 13     | RM21661 | RM44    | RM219   |         | RM6440  | RM5746  |
| 14     | RM8044  | RM42    | RM1099  |         | RM3721  | RM313   |
| 15     | RM21320 | RM8019  | RM23854 |         | RM26860 | RM28731 |
| 16     | RM134   | RM3496  | RM23915 |         | RM26616 | RM1226  |
| 17     | RM125   | RM502   | RM1553  |         | RM6094  | RM558   |
| 18     | RM295   | RM344   | RM464   |         | RM1233  | RM1246  |
| 19     | RM182   | RM404   | RM23668 |         | RM5766  | RM1296  |
| 20     | RM8006  | RM152   | RM23869 |         | RM332   | RM28073 |
| 21     | RM1335  | RM8266  | RM23788 |         | RM4069  | RM28759 |
| 22     | RM418   | RM1235  | RM5515  |         | RM6293  | RM17    |
| 23     | RM455   | RM3215  | RM24336 |         | RM26182 | RM28102 |
| 24     | RM1048  | RM2910  | RM23800 |         | RM26440 | RM27520 |
| 25     | RM500   | RM264   | RM5899  |         | RM25982 | RM6296  |
| 26     |         | RM23146 | RM24791 |         | RM27373 | RM101   |
| 27     |         | RM22891 | RM23916 |         | RM3701  | RM2854  |
| 28     |         | RM5485  | RM23998 |         | RM26187 | RM6265  |
| 29     |         | RM22230 | RM553   |         | RM202   | RM3483  |
| 30     |         |         |         |         | RM27369 | RM6396  |
| 31     |         |         |         |         | RM552   | RM4552  |
| 32     |         |         |         |         | RM224   | RM2529  |
| 33     |         |         |         |         | RM5926  |         |
| 34     |         |         |         |         | RM26658 |         |
| 35     |         |         |         |         | RM144   |         |
| 36     |         |         |         |         | RM3701  |         |
| 37     |         |         |         |         | RM26187 |         |

## **3.2 PHENOTYPIC EVALUATION**

### **3.2.1 Seedling Screening for BPH**

The pre germinated seeds of the RILs were sown 3 cm apart in a galvanized iron tray and filled with soil. Resistant check was sown in the middle column along the length of the seed box and each RIL was sown in a row across half the width of the seed box separated with susceptible check with at least 20 plants per row and a susceptible check was sown in four border rows. At nine days after sowing, the second and third instar nymphs of BPH were released on seedlings for infestation at the rate of 8-10 nymphs per each seedling. After release of nymphs, wired mesh cages were used to cover the box to prevent the escape of nymphs and prevent natural enemies entry into boxes (Heinrichs *et al.*, 1985). RILs sown in trays were exposed to BPH up to 90% of the seedlings of susceptible check (TN 1) showed specific symptom of BPH attack *i.e* hopper burn. The RILs were categorized by using scale (0-9) of SES, IRRI (2014) in Table 3.3.

### **3.2.2 Field screening for BPH tolerance**

The RILs selected for screening were raised in nursery beds and were transplanted at 21 days after sowing along with resistant and susceptible checks. Twenty hills of each RIL were transplanted in two rows of 10 hills each. Five rows of test variety were transplanted alternating with one row of susceptible check (TN 1) and resistant check (BM 71). In addition TN 1 seedlings were transplanted as border rows of the field to serve as bombardment rows for infestation of test seedlings with BPH (Figure 3.2). Foliar spray of Lambda cyhalothrin 5% EC @ 12.5 g *a.i.*/ha was applied once at 20 days after transplanting and repeated twice at ten days interval to induce the BPH resurgence (Heinrichs *et al.*, 1985). The RILs were scored when 90% of plants in the susceptible check (TN-1) were wilted as per the standard evaluation system (SES) on 0 to 9 scale as described in Table 3.3 (IRRI, 2014).

**Table 3.3 Scoring Criteria of BPH screening**

| <b>Score</b> | <b>Criteria</b>  | <b>Reaction</b>             |
|--------------|--|-----------------------------|
| 0            | No injury  | Immune (I)                  |
| 1            | Very slight injury   | Highly resistant (HR)       |
| 3            | First and 2 <sup>nd</sup> leaves of most plants partially yellowing  | Resistant (R)               |
| 5            | Pronounced yellowing and stunting or about 10-25% of the plants wilting or dead and remaining plants severely stunted or dying | Moderately resistant (MR)   |
| 7            | More than half of the plants wilting or drying   | Moderately susceptible (MS) |
| 9            | All plants dead  | Susceptible (S)             |



|       |                    |       |                    |       |                    |       |                    |       |                    |       |                    |      |                    |      |
|-------|--------------------|-------|--------------------|-------|--------------------|-------|--------------------|-------|--------------------|-------|--------------------|------|--------------------|------|
| TN 1  | Irrigation channel | TN 1  | Irrigation channel | TN 1  | Irrigation channel | TN 1  | Irrigation channel | TN 1  | Irrigation channel | TN 1  | Irrigation channel | TN 1 | Irrigation channel | TN 1 |
|       |                    | 1     |                    | 26    |                    | 51    |                    | 74    |                    | 99    |                    | 124  |                    |      |
|       |                    | 2     |                    | 27    |                    | 52    |                    | 75    |                    | 100   |                    | 125  |                    |      |
|       |                    | 3     |                    | 28    |                    | 53    |                    | 76    |                    | 101   |                    | 126  |                    |      |
|       |                    | 4     |                    | 29    |                    | 54    |                    | 77    |                    | 102   |                    | 127  |                    |      |
|       |                    | 5     |                    | 30    |                    | 55    |                    | 78    |                    | 103   |                    | 128  |                    |      |
|       |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1 |                    |      |
|       |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM71 |                    |      |
|       |                    | 6     |                    | 31    |                    | 56    |                    | 79    |                    | 104   |                    | 129  |                    |      |
|       |                    | 7     |                    | 32    |                    | 57    |                    | 80    |                    | 105   |                    | 130  |                    |      |
|       |                    | 8     |                    | 33    |                    | 58    |                    | 81    |                    | 106   |                    | 131  |                    |      |
|       |                    | 9     |                    | 34    |                    | 59    |                    | 82    |                    | 107   |                    | 132  |                    |      |
|       |                    | 10    |                    | 35    |                    | 60    |                    | 83    |                    | 108   |                    | 133  |                    |      |
|       |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1 |                    |      |
|       |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM71 |                    |      |
|       |                    | 11    |                    | 36    |                    | 61    |                    | 84    |                    | 109   |                    | 134  |                    |      |
|       |                    | 12    |                    | 37    |                    | 62    |                    | 85    |                    | 110   |                    | 135  |                    |      |
|       |                    | 13    |                    | 38    |                    | 63    |                    | 86    |                    | 111   |                    | 136  |                    |      |
|       |                    | 14    |                    | 39    |                    | 64    |                    | 87    |                    | 112   |                    | 137  |                    |      |
|       |                    | 15    |                    | 40    |                    | 65    |                    | 88    |                    | 113   |                    | 138  |                    |      |
|       |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1 |                    |      |
|       |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM 71 |                    | BM71 |                    |      |
|       |                    | 16    |                    | 41    |                    | 66    |                    | 89    |                    | 114   |                    | 139  |                    |      |
|       |                    | 17    |                    | 42    |                    | 67    |                    | 90    |                    | 115   |                    | 140  |                    |      |
|       |                    | 18    |                    | 43    |                    | 68    |                    | 91    |                    | 116   |                    | 141  |                    |      |
|       |                    | 19    |                    | 44    |                    | 69    |                    | 92    |                    | 117   |                    | 142  |                    |      |
|       |                    | 20    |                    | 45    |                    | 70    |                    | 93    |                    | 118   |                    | TN-1 |                    |      |
|       |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1  |                    | TN 1 |                    |      |
| BM 71 | BM 71              | BM 71 | BM 71              | BM 71 | BM71               |       |                    |       |                    |       |                    |      |                    |      |
| 21    | 46                 | 71    | 94                 | 119   | TN-1               |       |                    |       |                    |       |                    |      |                    |      |
| 22    | 47                 | 72    | 95                 | 120   | 143                |       |                    |       |                    |       |                    |      |                    |      |
| 23    | 48                 | 73    | 96                 | 121   | 144                |       |                    |       |                    |       |                    |      |                    |      |
| 24    | 49                 | 72    | 97                 | 122   | TN-1               |       |                    |       |                    |       |                    |      |                    |      |
| 25    | 50                 | 73    | 98                 | 123   | BM71               |       |                    |       |                    |       |                    |      |                    |      |
| TN 1  | TN 1               | TN 1  | TN 1               | TN 1  | TN 1               |       |                    |       |                    |       |                    |      |                    |      |

**Figure 3.2 Field layout for BPH field screening**

### 3.3 IDENTIFICATION OF NOVEL QTL's FOR BPH TOLERANCE

#### 3.3.1 Collection and Preservation of Leaf Material

The leaf material was collected from one hundred and thirty six RILs in F<sub>5</sub> generation, parents MTU 3626 and BM 71 from nursery and are stored in labelled plastic cover at -20°C.

#### 3.3.2 DNA extraction

DNA was extracted from the leaf tissue of all the RILs and parental lines using the modified Cetyl Tri Methyl Ammonium Bromide (CTAB) method of Dellaporta *et al.* (1983) as described below:

##### Reagents

- CTAB extraction buffer. Chemicals with their concentrations of CTAB extraction buffer is presented below.

| S. No. | Chemical Name                             | Concentration |             | Volume for 500 ml |
|--------|---|---------------|-------------|-------------------|
|        |   | For stock     | For working |                   |
| 1      | Tris HCL                                  | 1 M           | 200 mM      | 100 ml            |
| 2      | Ethylene diamine tetra acetic acid (EDTA) | 0.5 M         | 20 mM       | 20 ml             |
| 3      | Sodium chloride (NaCl)                    | 5 M           | 1.4 mM      | 140 ml            |
| 4      | Cetyl trimethyl ammonium bromide (CTAB)   | 2%            | 2 g         | 10 g              |
| 5      | PVP                                       | 2%            | 2 g         | 10 g              |

- RNase-10 mg/ml
- Absolute ethanol

## Methodology

- The leaf tissue collected was cut into 0.5 cm long pieces and preserved.
- 400 µl DNA extraction buffer was added using micropipette and the tissue was grinded until the buffer turns dark green.
- The dark green colour solution obtained was transferred into a micro centrifuge tube labelled with the plant number.
- To this tube 200 µl of Tris saturated phenol and 200 µl of chloroform: isoamyl alcohol mixture (24:1) was added and centrifuged at 10,000 rpm for about 10 minutes in a cooling centrifuge.
- The supernatant thus obtained was transferred into another labelled tube using a micropipette.
- To the aqueous supernatant, 10 µl of RNase was added and incubated at 37<sup>0</sup>C for about 30 to 45 minutes.
- After incubation, 400 µl of chloroform: isoamyl alcohol mixture (24:1) was added and mixed gently and centrifuged at 10,000 rpm for 10 minutes.
- The top aqueous phase *i.e.*, supernatant was transferred to another labelled tube.
- To this solution, equal volume of chilled isopropanol was added, mixed well and centrifuged at 10,000 rpm for 10 minutes.
- After centrifugation the supernatant was discarded and the DNA pellet will be settled at the bottom of the tube. 200 µl of 70% ethanol was added and centrifuged at 10,000 rpm for 10 minutes.
- The supernatant was discarded and the tubes containing DNA pellet was air dried at room temperature for about 1 to 2 hours till the smell of ethanol completely goes off.
- After the pellet was completely dried with no smell of alcohol, the DNA pellet was suspended in 100-200 µl of T<sub>10</sub>E<sub>1</sub> Buffer and stored at -20<sup>0</sup>C.

The DNA thus obtained was subjected to quantification.

### 3.3.3 Estimation of the Quality and Quantity of Genomic DNA

The purity and concentration of DNA was estimated by spectrophotometric technique using eight channel spectrophotometer (Thermo scientific Nano drop 8000). The measurement of absorbance recorded at 260 nm. DNA has maximum absorbance at 260 nm, one optical density (OD) corresponded approximately to 50 µl/ml of double stranded DNA.

$$\text{Concentration of DNA } (\mu\text{g/ml}) = \text{Dilution factor} \times \text{standard (30 } \mu\text{l/ml)} \times \text{OD at 260 nm.}$$

The purity of the DNA was estimated as the ratio of OD 260 to OD 280.

1. If the ratio is 1.8 to 2.0 the sample of DNA is relatively pure.
2. If the ratio is more than 1.8 the sample of the DNA is contaminated with RNA.
3. If the ratio is less than 1.8 the sample of the DNA is either contaminated with phenol or protein.

### 3.3.4 Polymerase Chain Reaction

The in vitro amplification of DNA by repeated cycles of strand separation and polymerization, by DNA polymerase activity is called polymerase chain reaction (PCR). This technique was developed by Kary. B. Mullis at Cites Corporation, California in 1985 and he was awarded with the noble prize in chemistry in 1993. PCR is now considered as a basic tool for molecular biology. The polymerase chain reaction technique is used for generating large quantities of a specified DNA segment of interest. The PCR components are presented below.

| PCR Components                          | 1X           |
|---|--------------|
| Taq buffer (10X) with MgCl <sub>2</sub> | 1 µl         |
| dNTPs mix (2.5 mM each)                 | 1 µl         |
| Forward primer (5 pM)                   | 1 µl         |
| Reverse primer(5 pM)                    | 1 µl         |
| Template (50 ng/µl)                     | 3 µl         |
| Taq polymerase (1u/µl)                  | 1 µl         |
| Sterile distilled Water                 | 2 µl         |
| <b>Total</b>                            | <b>10 µl</b> |

### 3.3.4.1 Procedure of PCR

SSR markers are very powerful tools in Marker Assisted Selection (MAS) due to their hyper polymorphism, abundance in the genome, co-dominant inheritance, simplicity of assay, most important being already mapped both physically and genetically in the rice genome. Amplification of single SSR involves two different primers- F (Forward) and R (Reverse) primers. SSR primers are usually in the size range of 18 to 25 bases. *Taq* DNA polymerase is the most vital ingredient of a PCR reaction. *Taq* DNA polymerase is a special category of DNA polymerase, which is obtained from a thermophilic bacterium, *Thermus aquaticus* and is highly thermo stable.

The steps involved in PCR are given below:

- Master mix consisting of PCR buffer, dNTPs, forward primer, reverse primer, Milli Q water, *Taq* DNA polymerase was prepared.
- In order to avoid minor pipetting errors, a little extra quantity of master mix was prepared to ensure that adequate quantity was available for the samples. Empirically, for every 10 reactions, one extra reaction was taken.
- The tube containing master mix was spun for about 10 to 15 seconds and kept in ice until added to PCR tubes.
- Master mix was added equally to all the wells in the PCR plate, given a spin and kept inside the thermocycler (Applied Biosystem's Veriti PCR machine).

The actual technique of PCR involves repeated cycles for amplification of target DNA. Each cycle has 3 stages. 1. Denaturation 2. Annealing 3. Extension

On raising the temperature to 94°C for about 0.5 min, the DNA gets denatured and the two strands are separated. When the temperature of mixture is slowly cooled to about 58°C for 0.5 min the primers base pair with the complementary regions flanking the target DNA segments. The initiation of DNA synthesis occurs at 3-hydroxyl end of each primer by the enzyme *Taq* DNA polymerase. The primers are extended by joining the bases complementary to DNA strands. However the temperature has to be kept optimal as required by the enzyme *Taq* DNA polymerase, the optimum temperature is around 72°C for 1 min. It is estimated that the end of 35 cycles of PCR, about a million fold target DNA is synthesized. The thermo profile for PCR is given below.

| Activity             | Temperature (°C) | Duration (min) | Number of cycles |
|----------------------|------------------|----------------|------------------|
| Initial Denaturation | 94               | 5.0            | 1                |
| Denaturation         | 94               | 0.5            | 35               |
| Annealing            | 58               | 0.5            | 35               |
| Extension            | 72               | 1              | 35               |
| Final Extension      | 72               | 7.0            | 1                |

After completion of 35 cycles PCR plate was taken out and stored at 4°C.

### 3.3.5 Agarose Gel Electrophoresis

The migration of charged particles under the influence of direct electric field is known as electrophoresis. The electrophoresis technique was first developed in 1930s by A. Tiselius of Sweden. Many important biological molecules such as amino acids, peptides, proteins, nucleic acids and nucleotides possess ionizable groups. When they are subjected to electric field the charged molecules migrate towards either cathode or anode under the influence of electric field. Agarose gel electrophoresis is useful in identification and separation of DNA molecules.

#### 3.3.5.1 Gel preparation

- Prepare 1X TAE buffer by diluting 50X TAE buffer.
- Agarose gel was prepared by adding 15 g agarose to 500 ml of 1X TAE buffer (3%) and boiled till agarose dissolves completely and a clear solution is formed.
- The electrophoresis apparatus and the combs were washed with distilled water and the combs were placed approximately 2 cm away from the cathode.
- When the temperature of molten agarose was around 50°C, ethidium bromide was added at a concentration of 15 µl / 500 ml mixed and poured into the central part of the tank without any air bubbles.
- The gel casting set was kept undisturbed till the agarose solidifies.
- Upon solidification, 1X TAE buffer was poured in to the gel tank till the level reached 0.6-0.8 cms above the gel surface.
- The combs were lifted gently ensuring that the wells remained intact.

### 3.3.5.2 Loading DNA

PCR plate was taken out from the refrigerator and tracking dye, bromophenol blue (0.25% bromophenol blue and 40% sucrose mixed in water) was added and given one spin for uniform mixing of bromophenol blue. The samples were then loaded carefully into the wells.

### 3.3.5.3 Electrophoresis

- After loading all DNA samples in to the wells electrophoresis unit was made air tight with a lid and power supply was switched on.
- DNA molecules with in an agarose gel matrix are subjected to steady electric field; it will migrate through the gel towards the positive electrode, anode since DNA has a strong negative charge at neutral p<sup>H</sup>. The pores in the gel separate the linear fragments of DNA according to their size.
- The gel was run at 80 to 120V till the dye front reached 3/4<sup>th</sup> of the gel.

### 3.3.5.4 Gel documentation

The resolved PCR bands were documented using Syngene gel doc system.

### 3.3.6 Scoring of the gels

The Polymorphic markers which differentiates recurrent and donor parent were identified. All the entries were analysed using all polymorphic markers and scored. **2** was used to indicate the homozygous allele of recurring parent, **0** was used to indicate the homozygous allele of donor parent and **1** was used to indicate the heterozygous alleles. **-1** was used to indicate the missing alleles.

## 3.4 BIOMETRICAL OBSERVATIONS RECORDED

Observations were recorded on ten randomly selected plants per each entry per replication for plant height at maturity (cm), number of ear bearing tillers per plant, panicle length (cm) and grain yield per plant (g). Days to 50% flowering was recorded on plot basis. BPH damage score was recorded as per 0-9 scale of Standard Evaluation System (SES) for rice (IRRI, 2014).

The details of the observations recorded and methods followed are presented here under character wise.

### **3.4.1 Days to 50% Flowering**

The total number of days taken for 50 per cent flowering from the date of sowing was recorded.

### **3.4.2 Plant Height (cm)**

It was measured at maturity from bottom of the plant to the tip of the panicle and expressed in cm.

### **3.4.3 Number of Ear Bearing Tillers per Plant**

Total number of panicle bearing tillers were counted in each of the 10 randomly selected plants at maturity.

### **3.4.4 Panicle Length (cm)**

The length from base of the panicle to the tip was measured in cm.

### **3.4.5 Grain Yield per Plant (g)**

The matured panicles were harvested, threshed, cleaned and seed dried to 12 percent moisture level. The grain yield per plant was recorded in grams.

### **3.4.6 Scoring of Test Plants for BPH Damage**

The scoring was done as per 0-9 scale of Standard Evaluation System (SES) for rice (IRRI, 2014). (Table 3.3).

## **3.5 STATISTICAL PROCEDURE**

### **3.5.1 Analysis of Variance for Simple Lattice Design**

For each quantitative trait, ANOVA was computed as per the standard statistical procedure given by Rao (2007).

$$Y_{ij(m)} = \mu + \beta_i + \tau_m + e_{ij(m)}$$

Where,

- $Y_{ij(m)}$  = Performance of the  $m^{\text{th}}$  genotype in  $j^{\text{th}}$  plot and  $i^{\text{th}}$  block  
 $\mu$  = general mean  
 $\beta_i$  = effect of  $i^{\text{th}}$  block  
 $\tau_m$  = effect of  $m^{\text{th}}$  genotype  
 $e_{ij(m)}$  = random error associates with  $j^{\text{th}}$  plot,  $i^{\text{th}}$  block and  $m^{\text{th}}$  genotype

### ANOVA for Simple Lattice Design

| Source of variation                   | d.f                  | SS   | MSS   | Expected MSS              | F calculated |
|---------------------------------------|----------------------|------|-------|---------------------------|--------------|
| Replications                          | r-1                  | RSS  | $M_r$ | $\sigma^2_e + \sigma^2_r$ | $M_r/M_e$    |
| Blocks within replications (adjusted) | r(k-1)               | BSS  | $M_b$ | $\sigma^2_e + \sigma^2_b$ | $M_b/M_e$    |
| Treatments unadjusted                 | t-1                  | TrSS | $M_t$ | $\sigma^2_e + \sigma^2_g$ | $M_t/M_e$    |
| Intrablock Error                      | (k-1)<br>(rk-k-1)    | ESS  | $M_e$ | $\sigma^2_e$              |              |
| Total                                 | (rk <sup>2</sup> -1) | TSS  |       |                           |              |

The analysis of variance (ANOVA) for each character was carried out as indicated below:

Where,

- $r$  = Number of replications  
 $k$  = Number of blocks  
 $t$  = Number of treatments =  $k^2$   
 $\sigma^2_e$  = Error variance  
 $\sigma^2_g$  = Variance due to treatments  
 $\sigma^2_b$  = Variance due to blocks  
 $\sigma^2_r$  = Variance due to replications  
 $M_r$  = Mean sum of squares due to replications  
 $M_b$  = Mean sum of squares due to blocks  
 $M_t$  = Mean sum of squares due to treatments  
 $M_e$  = Mean sum of squares due to error

Test of significance for each character was carried out against the corresponding error degrees of freedom using 'F' table values given by Fisher and Yates (1963).

## 3.5.2 Estimation of Genetic Parameters

### 3.5.2.1 Variance

The genotypic and phenotypic variance was calculated as per the formula given by Burton and Devane (1953).

$$\text{Genotypic variance } (\sigma^2_g) = \frac{(\text{MSS due to treatments} - \text{MSS due to error})}{\text{Number of replications}}$$

$$\text{Phenotypic variance } (\sigma^2_p) = (\sigma^2_g) + (\sigma^2_e)$$

Where,  $(\sigma^2_e)$  = error variance

### 3.5.2.2 Genotypic and phenotypic coefficients of variation

Phenotypic and genotypic coefficients of variation (PCV and GCV) were computed according to the formula given by Falconer (1964).

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\text{Genotypic standard deviation } (\sigma_g)}{\text{Mean } (\bar{X})} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\text{Phenotypic standard deviation } (\sigma_p)}{\text{Mean } (\bar{X})} \times 100$$

Categorization of the range of variation was done as proposed by Sivasubramanian and Madhavamenon (1973).

|          |   |         |
|----------|---|---------|
| Low      | = | <10%    |
| Moderate | = | 10-20 % |
| High     | = | >20 %   |

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

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

$$h^2 \text{ (b)} = \frac{\text{Genotypic variance } (\sigma^2_g)}{\text{Phenotypic variance } (\sigma^2_p)} \times 100$$

Sivasubramanian and Madhavamenon (1973) suggested this,  $h^2$  (b) estimates were categorized into below range

|          |   |                |
|----------|---|----------------|
| Low      | = | 0 - 30 %       |
| Moderate | = | 31 - 60 %      |
| High     | = | more than 60 % |

#### 3.5.2.4 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).

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

Where,

K = Selection differential at 5% selection intensity (2.06).

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

$\sigma_p^2$  = Phenotypic standard deviation.

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

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% |

#### 3.5.3 QTL analysis

The linkage groups and the marker order were determined using integrated QTL software, IciMapping, Version 4.1 (<http://www.isbreeding.net>) developed by Quantitative Genetics Group collaboration of CIMMYT (Wang *et al.*, 2016). Kosambi mapping function was used to convert the recombination frequency to genetic distance in centi-Morgan (cM). The inclusive composite interval additive mapping (ICIM-ADD) program in integrated QTL software, IciMapping, Version 4.1 was used to identify QTLs associated with BPH resistance. SSR marker data of 136 RILs were used for

development of linkage map using IciMapping, Version4.1 Software. SSR marker data of 136 RILs and their corresponding phenotypic values of RILs were used to establish marker-phenotype association through IciMapping, Version4.1 Software. The LOD values of more than 2.0 were used as empirical threshold value to claim association of SSR marker with putative genetic locus for BPH resistance through interval mapping.

## Chapter – IV

---

# *Results and Discussion*

## Chapter IV

# RESULTS AND DISCUSSION

Plant hoppers are the major pests in tropical and temperate Asia. BPH resistant sources were initially identified in 1967 by Pathak *et al.* (1969), and as on date more than thirty genes were reported for BPH resistance. Some genes were used in development of BPH resistant cultivars, but emergence of new brown plant hopper biotypes threatened the viability of such genes. These circumstances demanded the need for progressive research work on host plant resistance to map or identify new sources and genes for resistance to brown plant hopper. In the current study, an attempt was made to identify QTLs governing resistance to brown plant hopper in RIL (MTU 3626/BM 71) population in F<sub>5</sub> generation. The results obtained are furnished here under

4.1 Analysis of variance (ANOVA)

4.2 Genetic variability, heritability and genetic advance as per cent of mean

4.3 Evaluation of RILs for brown plant hopper resistance

4.4 Identification of novel QTLs for BPH tolerance

### 4.1 ANALYSIS OF VARIANCE

The data obtained in the present investigation on one hundred and forty two F<sub>5</sub> RILs along with two checks *viz.*, MTU 1075 (Pushyami) and MTU 7029 (Swarna) for five characters *viz.*, days to 50% flowering, plant height (cm), number of ear bearing tillers per plant, panicle length (cm) and grain yield per plant (g) were subjected to statistical analysis. The ANOVA indicated presence of significant differences among the genotypes for five characters *viz.*, days to 50% flowering, plant height (cm), panicle length (cm), number of ear bearing tillers per plant and grain yield per plant (g) at 1% level of significance indicating considerable variation in the material under study (Table 4.1).

**Table 4.1 Analysis of variance (mean sum of squares) for yield and yield contributing characters in RILs and checks during *kharif*, 2018**

| Source of variation                  | Degrees of freedom | Days to 50% flowering | Plant height (cm) | No of ear bearing tillers | Panicle length (cm) | Grain yield per plant (g) |
|--------------------------------------|--------------------|-----------------------|-------------------|---------------------------|---------------------|---------------------------|
| Replications                         | 1                  | 32.00                 | 5.95              | 9.28                      | 3.42                | 8.35                      |
| Blocks within replication (adjusted) | 22                 | 9.91                  | 59.92             | 1.46                      | 4.04                | 2.06                      |
| Treatments (unadjusted)              | 143                | 39.77**               | 413.08**          | 2.83**                    | 10.67**             | 12.21**                   |
| Intra block Error                    | 121                | 4.16                  | 46.10             | 0.85                      | 3.85                | 1.26                      |
| Total                                | 287                | 22.44                 | 229.87            | 1.91                      | 7.26                | 6.80                      |

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

## **4.2 GENETIC VARIABILITY, HERITABILITY AND GENETIC ADVANCE AS PER CENT OF MEAN**

Nature and magnitude of variability present in the crop is key to success of crop improvement. If the variation is more, there is a greater possibility of developing desired variety. Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) estimation will provide information regarding non heritable and heritable portion of variation existing in the material under study.

Heritability and genetic advance are important selection parameters. Heritability is the heritable portion of phenotypic variance and it is a good index of the transmission of characters from parents to their off spring (Falconer, 1964). High heritability coupled with high genetic advance results more reliable index of selection value.

The mean performance of one hundred and forty two F<sub>5</sub> RILs along with two high yielding checks evaluated during *kharif*, 2018 for five characters were presented in Appendix-1 while estimates of mean, PCV, GCV, heritability in broad sense and GAM for different traits under study were computed and presented in the Table 4.2 and variability performance for five characters was shown in Figure 4.1.

### **4.1.1 Days to 50% flowering**

The mean number of days to 50% flowering was 97 days and it was minimum for 2711-20, 2711-188 and 2711-197 (91 days) and maximum for 2711-172 (107 days).

Low PCV (6.51) and GCV (4.36) were observed for this trait indicating occurrence of less variability among these RILs for this trait. Narrow differences between them suggest that this trait is less influenced by environment.

Moderate heritability (44.77%) coupled with low GAM (6.03) was recorded for this trait which revealed the presence of both non additive and additive gene actions and exploitation of heterosis for such traits will be effective.

The results were accompanied with the findings of Longjam *et al.* (2019), Konate *et al.* (2016), Adhikari *et al.* (2018), Sumanth *et al.* (2017) and Devi *et al.* (2017).

### **4.1.2 Plant height (cm)**

Average plant height recorded was 133.00 cm with a range of 101.00 cm (2711-31) to 172.00 cm (2711-61).

Both PCV (15.57) and GCV (8.59) were moderately observed for this trait indicating moderate variation among RILs for this trait.

Both heritability (44.42%) and GAM (14.00) were moderate for this trait indicating the operation of both additive and non-additive gene actions and heterosis breeding based on this trait may be effective.

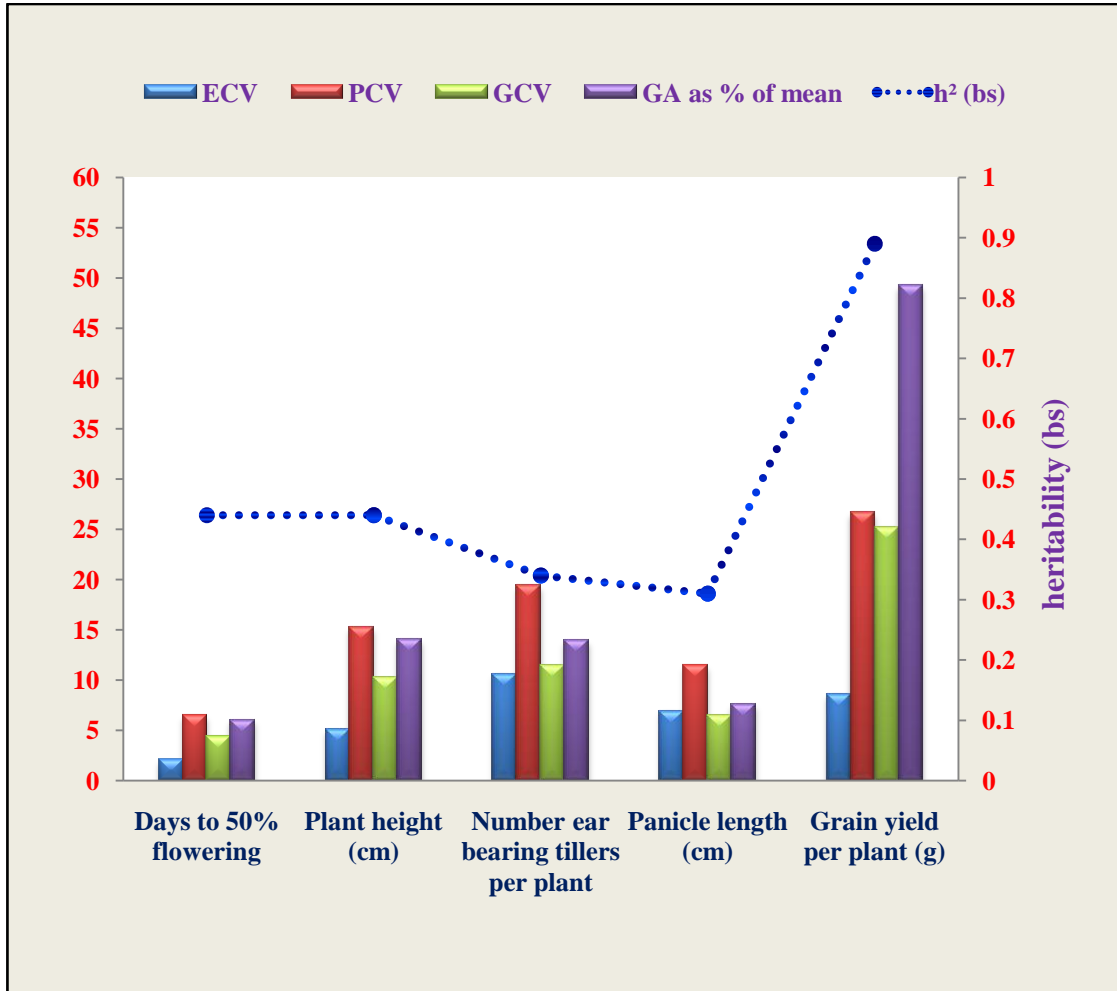
The results for plant height were in harmony with the earlier findings of Habiba *et al.* (2015), Sathisha *et al.* (2015) and Fentie *et al.* (2014).

### **4.1.3 Number of Ear Bearing Tillers per Plant**

The maximum number of productive tillers per plant observed were 14.00 (2711-177) and minimum was 7.00 (2711-30). The mean number of productive tillers per plant was 8.70.

**Table 4.2 Estimates of genetic variability parameters for evaluation of yield and yield contributing characters in RILs during *kharif*, 2018**

| Character                               | Mean   | Range   |         | PCV   | GCV   | h <sup>2</sup> (bs) | GA    | GA as % of mean |
|---|--------|---------|---------|-------|-------|---------------------|-------|-----------------|
|   |        | Minimum | Maximum |       |       |                     |       |                 |
| Days to 50% flowering                   | 96.00  | 91.00   | 107.00  | 6.51  | 4.36  | 44.77               | 5.83  | 6.03            |
| Plant height (cm)                       | 133.05 | 100.60  | 172.00  | 15.27 | 10.18 | 44.42               | 18.62 | 14.00           |
| Number of ear bearing tillers per plant | 8.70   | 7.00    | 14.30   | 19.36 | 11.44 | 34.90               | 1.22  | 13.94           |
| Panicle length (cm)                     | 28.49  | 12.00   | 32.15   | 11.47 | 6.49  | 31.93               | 2.16  | 7.56            |
| Grain yield per plant (g)               | 13.13  | 4.05    | 20.36   | 26.63 | 25.21 | 89.68               | 6.47  | 49.25           |



**Figure 4.1** Variability parameters for five characters studied in 142 RILs and two checks

Both PCV (19.36) and GCV (11.44) were moderately observed for number of ear bearing tillers per plant indicating the presence of heritable variation among the RILs studied. Moderate heritability (34.90%) accompanied with moderate GAM (13.94) was observed for this trait indicating the operation of both additive and non-additive gene actions and heterosis breeding based on this trait may be effective.

The results for number of ear bearing tillers per plant was similar with Girma *et al.* (2018), Habiba *et al.* (2015), Rai *et al.* (2014), Ramanjaneyulu *et al.* (2014), Sahirar *et al.* (2014).

#### **4.1.4 Panicle Length (cm)**

The average panicle length recorded was 28.48 cm ranging from 12.00 cm (2711-83) to 32.15 cm (2711-86).

Moderate PCV (11.47) and low GCV (6.49) estimates for this trait indicating less amount of heritable variation among RILs studied. The difference between PCV and GCV was low indicating less environmental influence.

Panicle length exhibited moderate heritability (31.93%) with low GAM (7.56) indicating the performance of both non-additive and additive gene actions and results may not be acquired desirably by simple selection but may be attained through heterosis breeding.

These findings are in accordance with earlier reports of Anis *et al.* (2016), Sathisha *et al.* (2015) and Srivasthava *et al.* (2015), Idris *et al.* (2013).

#### **4.1.5 Grain yield per Plant (g)**

Grain yield per plant in the material under study ranged from 4.05 g (2711-33) to 20.36 g (2711-37) and the mean grain yield per plant was 13.13 g.

Both high PCV (26.63) and GCV (25.21) were observed for grain yield per plant (g) indicating greater variation among the RILs studied. High heritability (89.68%) with high GAM (49.25) was observed indicating the prevalence of additive gene affects controlling this trait. Higher estimates of heritability with less difference between PCV and GCV for this character indicates that the character is mainly controlled by the genetic factor and direct selection will be effective.

The results are similar with the reports of Nayak *et al.* (2016), Sahu *et al.* (2015), Hossain *et al.* (2015), Rai *et al.* (2014), Sumanth *et al.* (2017), Rashmi *et al.* (2016).

Hence, 2711-37 (20.36g) RIL was statistically significant over the better check MTU 1075 and nine RILs *viz.*, 2711-31, 2711-50, 2711-69, 2711-84, 2711-88, 2711-94, 2711-100, 2711-168 and 2711-198 were on par with two checks MTU 7029 and MTU 1075.

### **4.3 EVALUATION OF RILS FOR BROWN PLANT HOPPER RESISTANCE**

One hundred and forty two RILs with two checks *i.e.* susceptible check (Taichung Native 1) and resistant check (BM 71) were screened under lab conditions (Plate: 4.1) and natural field conditions (Plate: 4.2) at Regional Agricultural Research Station, Maruteru, during *kharif*, 2018. Resistant check (BM 71) showed damage score 3 in both field and seedling screening whereas susceptible check (TN 1) showed damage score of 9. The damage score of RILs ranged from 1 to 9 with an average of 3.91.

One hundred and forty two RILs response to BPH tolerance was categorized into resistant (score between 1-3), moderately resistant (score between 3-5), moderately susceptible (score between 5-7) and susceptible (score between 7-9).

Screening results under standard seed box technique showed forty four RILs had a score of 1-3, sixty two RILs showed score of 3-5, thirty RILs showed score between 5-7 and six RILs showed susceptible score of 7-9. Whereas in field conditions as sixty seven RILs showed 1-3 score, thirty four RILs showed score of 3-5, twenty RILs showed 5-7 score and twenty one RILs showed 7-9 score. BPH scores for lab screening was given Table 4.3 and field screening was given in Table 4.4.



**Layout for standard seed box method**



**Hopper burn in seed box**

**Plate 4.1 Seedling Screening of RILs against BPH tolerance in lab conditions at RARS, Maruteru**



**Layout for field screening**



**Burning of RILs**

**TN 1 as a Border**

**Plate 4.2 Field screening of RILs against brown plant hopper in natural field conditions, during *Kharif*, 2018**

**Table 4.3 BPH scores of RILs under lab conditions at seedling stage**

| <b>S. No.</b> | <b>RIL name</b> | <b>Score</b> | <b>S. No.</b> | <b>RIL name</b> | <b>Score</b> |
|---------------|-----------------|--------------|---------------|-----------------|--------------|
| 1             | 2711-1          | 9.00         | 40            | 2711-44         | 3.62         |
| 2             | 2711-2          | 2.90         | 41            | 2711-45         | 1.52         |
| 3             | 2711-3          | 5.85         | 42            | 2711-46         | 4.32         |
| 4             | 2711-4          | 5.00         | 43            | 2711-47         | 1.00         |
| 5             | 2711-5          | 3.50         | 44            | 2711-49         | 4.95         |
| 6             | 2711-6          | 7.20         | 45            | 2711-50         | 2.96         |
| 7             | 2711-7          | 7.00         | 46            | 2711-52         | 5.11         |
| 8             | 2711-8          | 3.42         | 47            | 2711-53         | 5.22         |
| 9             | 2711-9          | 5.22         | 48            | 2711-54         | 7.00         |
| 10            | 2711-11         | 3.35         | 49            | 2711-55         | 5.12         |
| 11            | 2711-13         | 3.50         | 50            | 2711-56         | 2.85         |
| 12            | 2711-14         | 5.00         | 51            | 2711-57         | 2.92         |
| 13            | 2711-15         | 5.23         | 52            | 2711-58         | 2.23         |
| 14            | 2711-16         | 3.45         | 53            | 2711-59         | 1.15         |
| 15            | 2711-17         | 6.52         | 54            | 2711-60         | 4.90         |
| 16            | 2711-18         | 5.30         | 55            | 2711-61         | 3.60         |
| 17            | 2711-19         | 3.60         | 56            | 2711-62         | 2.56         |
| 18            | 2711-20         | 8.23         | 57            | 2711-63         | 4.53         |
| 19            | 2711-22         | 4.90         | 58            | 2711-64         | 6.90         |
| 20            | 2711-23         | 5.00         | 59            | 2711-65         | 4.95         |
| 21            | 2711-24         | 3.65         | 60            | 2711-66         | 7.23         |
| 22            | 2711-25         | 1.52         | 61            | 2711-67         | 5.50         |
| 23            | 2711-26         | 3.60         | 62            | 2711-68         | 5.92         |
| 24            | 2711-27         | 3.21         | 63            | 2711-69         | 3.23         |
| 25            | 2711-28         | 2.56         | 64            | 2711-71         | 3.20         |
| 26            | 2711-29         | 5.60         | 65            | 2711-72         | 3.63         |
| 27            | 2711-30         | 4.67         | 66            | 2711-73         | 6.82         |
| 28            | 2711-31         | 3.52         | 67            | 2711-74         | 3.20         |
| 29            | 2711-32         | 2.92         | 68            | 2711-75         | 2.85         |
| 30            | 2711-33         | 5.00         | 69            | 2711-76         | 3.60         |
| 31            | 2711-34         | 4.56         | 70            | 2711-77         | 4.26         |
| 32            | 2711-35         | 3.45         | 71            | 2711-78         | 2.46         |
| 33            | 2711-36         | 5.65         | 72            | 2711-79         | 6.90         |
| 34            | 2711-37         | 4.20         | 73            | 2711-80         | 4.80         |
| 35            | 2711-38         | 3.56         | 74            | 2711-83         | 3.56         |
| 36            | 2711-39         | 5.65         | 75            | 2711-84         | 2.30         |
| 37            | 2711-40         | 5.23         | 76            | 2711-86         | 3.80         |
| 38            | 2711-41         | 7.80         | 77            | 2711-87         | 5.20         |
| 39            | 2711-43         | 3.52         | 78            | 2711-88         | 4.95         |

Table 4.3 (cont.)

| S. No. | RIL name | Score | S. No. | RIL name | Score |
|--------|----------|-------|--------|----------|-------|
| 79     | 2711-89  | 2.95  | 116    | 2711-162 | 7.00  |
| 80     | 2711-92  | 5.63  | 117    | 2711-164 | 5.00  |
| 81     | 2711-93  | 4.95  | 118    | 2711-167 | 3.26  |
| 82     | 2711-94  | 4.12  | 119    | 2711-168 | 3.85  |
| 83     | 2711-100 | 2.50  | 120    | 2711-169 | 5.26  |
| 84     | 2711-101 | 1.90  | 121    | 2711-170 | 5.00  |
| 85     | 2711-102 | 3.76  | 122    | 2711-172 | 4.86  |
| 86     | 2711-103 | 4.20  | 123    | 2711-175 | 2.95  |
| 87     | 2711-104 | 1.29  | 124    | 2711-176 | 3.00  |
| 88     | 2711-105 | 2.96  | 125    | 2711-177 | 4.96  |
| 89     | 2711-106 | 1.92  | 126    | 2711-178 | 5.00  |
| 90     | 2711-107 | 4.28  | 127    | 2711-179 | 7.00  |
| 91     | 2711-108 | 2.56  | 128    | 2711-182 | 2.87  |
| 92     | 2711-110 | 4.75  | 129    | 2711-184 | 3.00  |
| 93     | 2711-111 | 3.00  | 130    | 2711-185 | 7.00  |
| 94     | 2711-112 | 2.95  | 131    | 2711-186 | 4.85  |
| 95     | 2711-113 | 1.86  | 132    | 2711-187 | 1.58  |
| 96     | 2711-115 | 6.53  | 133    | 2711-188 | 1.22  |
| 97     | 2711-116 | 6.93  | 134    | 2711-189 | 4.95  |
| 98     | 2711-117 | 6.40  | 135    | 2711-191 | 1.45  |
| 99     | 2711-119 | 5.13  | 136    | 2711-192 | 2.92  |
| 100    | 2711-120 | 2.96  | 137    | 2711-193 | 1.00  |
| 101    | 2711-122 | 2.85  | 138    | 2711-195 | 1.00  |
| 102    | 2711-123 | 1.00  | 139    | 2711-196 | 5.56  |
| 103    | 2711-125 | 4.95  | 140    | 2711-197 | 1.00  |
| 104    | 2711-127 | 3.27  | 141    | 2711-198 | 2.98  |
| 105    | 2711-129 | 1.00  | 142    | 2711-199 | 5.00  |
| 106    | 2711-130 | 5.00  | 143    | BM71     | 3.00  |
| 107    | 2711-131 | 6.95  | 144    | TN-1     | 9.00  |
| 108    | 2711-133 | 2.98  |        |          |       |
| 109    | 2711-137 | 5.00  |        |          |       |
| 110    | 2711-140 | 4.92  |        |          |       |
| 111    | 2711-143 | 4.92  |        |          |       |
| 112    | 2711-147 | 1.56  |        |          |       |
| 113    | 2711-149 | 1.60  |        |          |       |
| 114    | 2711-150 | 4.82  |        |          |       |
| 115    | 2711-151 | 3.56  |        |          |       |

**Table 4.4 BPH scores of RILs under field conditions at crop maturity stage**

| S. No. | RIL name | Score | S. No. | RIL name | Score |
|--------|----------|-------|--------|----------|-------|
| 1      | 2711-1   | 1.70  | 40     | 2711-44  | 6.10  |
| 2      | 2711-2   | 1.50  | 41     | 2711-45  | 4.15  |
| 3      | 2711-3   | 7.80  | 42     | 2711-46  | 2.50  |
| 4      | 2711-4   | 3.10  | 43     | 2711-47  | 4.20  |
| 5      | 2711-5   | 5.23  | 44     | 2711-49  | 3.65  |
| 6      | 2711-6   | 5.35  | 45     | 2711-50  | 2.75  |
| 7      | 2711-7   | 2.50  | 46     | 2711-52  | 2.30  |
| 8      | 2711-8   | 4.82  | 47     | 2711-53  | 1.50  |
| 9      | 2711-9   | 4.15  | 48     | 2711-54  | 1.70  |
| 10     | 2711-11  | 9.00  | 49     | 2711-55  | 1.24  |
| 11     | 2711-13  | 9.00  | 50     | 2711-56  | 1.33  |
| 12     | 2711-14  | 5.10  | 51     | 2711-57  | 1.80  |
| 13     | 2711-15  | 4.20  | 52     | 2711-58  | 1.08  |
| 14     | 2711-16  | 9.00  | 53     | 2711-59  | 2.30  |
| 15     | 2711-17  | 4.72  | 54     | 2711-60  | 2.90  |
| 16     | 2711-18  | 6.80  | 55     | 2711-61  | 7.30  |
| 17     | 2711-19  | 3.40  | 56     | 2711-62  | 2.02  |
| 18     | 2711-20  | 3.20  | 57     | 2711-63  | 1.50  |
| 19     | 2711-22  | 2.60  | 58     | 2711-64  | 5.80  |
| 20     | 2711-23  | 9.00  | 59     | 2711-65  | 3.40  |
| 21     | 2711-24  | 2.20  | 60     | 2711-66  | 8.82  |
| 22     | 2711-25  | 2.40  | 61     | 2711-67  | 9.00  |
| 23     | 2711-26  | 4.40  | 62     | 2711-68  | 8.30  |
| 24     | 2711-27  | 2.45  | 63     | 2711-69  | 4.95  |
| 25     | 2711-28  | 1.90  | 64     | 2711-71  | 8.40  |
| 26     | 2711-29  | 9.00  | 65     | 2711-72  | 7.90  |
| 27     | 2711-30  | 1.70  | 66     | 2711-73  | 3.25  |
| 28     | 2711-31  | 3.70  | 67     | 2711-74  | 2.95  |
| 29     | 2711-32  | 1.60  | 68     | 2711-75  | 1.10  |
| 30     | 2711-33  | 9.00  | 69     | 2711-76  | 7.10  |
| 31     | 2711-34  | 1.50  | 70     | 2711-77  | 1.23  |
| 32     | 2711-35  | 6.90  | 71     | 2711-78  | 1.14  |
| 33     | 2711-36  | 7.80  | 72     | 2711-79  | 1.20  |
| 34     | 2711-37  | 3.90  | 73     | 2711-80  | 4.20  |
| 35     | 2711-38  | 5.22  | 74     | 2711-83  | 1.50  |
| 36     | 2711-39  | 7.30  | 75     | 2711-84  | 1.90  |
| 37     | 2711-40  | 5.40  | 76     | 2711-86  | 2.70  |
| 38     | 2711-41  | 9.00  | 77     | 2711-87  | 2.70  |
| 39     | 2711-43  | 4.90  | 78     | 2711-88  | 2.65  |

Table 4.4 (cont.)

| <b>S. No.</b> | <b>RIL name</b> | <b>Score</b> | <b>S. No.</b> | <b>RIL name</b> | <b>Score</b> |
|---------------|-----------------|--------------|---------------|-----------------|--------------|
| 79            | 2711-89         | 2.70         | 116           | 2711-162        | 3.9          |
| 80            | 2711-92         | 5.90         | 117           | 2711-164        | 3.6          |
| 81            | 2711-93         | 3.40         | 118           | 2711-167        | 5.1          |
| 82            | 2711-94         | 4.65         | 119           | 2711-168        | 3.2          |
| 83            | 2711-100        | 2.40         | 120           | 2711-169        | 5.6          |
| 84            | 2711-101        | 6.80         | 121           | 2711-170        | 4.90         |
| 85            | 2711-102        | 3.20         | 122           | 2711-172        | 1.09         |
| 86            | 2711-103        | 2.30         | 123           | 2711-175        | 1.70         |
| 87            | 2711-104        | 2.70         | 124           | 2711-176        | 2.70         |
| 88            | 2711-105        | 1.10         | 125           | 2711-177        | 4.00         |
| 89            | 2711-106        | 1.23         | 126           | 2711-178        | 3.70         |
| 90            | 2711-107        | 1.90         | 127           | 2711-179        | 1.00         |
| 91            | 2711-108        | 1.30         | 128           | 2711-182        | 1.27         |
| 92            | 2711-110        | 2.70         | 129           | 2711-184        | 9.00         |
| 93            | 2711-111        | 1.00         | 130           | 2711-185        | 1.02         |
| 94            | 2711-112        | 1.08         | 131           | 2711-186        | 1.50         |
| 95            | 2711-113        | 1.34         | 132           | 2711-187        | 2.70         |
| 96            | 2711-115        | 3.80         | 133           | 2711-188        | 1.06         |
| 97            | 2711-116        | 1.18         | 134           | 2711-189        | 3.22         |
| 98            | 2711-117        | 3.6          | 135           | 2711-191        | 2.40         |
| 99            | 2711-119        | 6.4          | 136           | 2711-192        | 1.23         |
| 100           | 2711-120        | 1.2          | 137           | 2711-193        | 8.02         |
| 101           | 2711-122        | 1.12         | 138           | 2711-195        | 5.32         |
| 102           | 2711-123        | 1.02         | 139           | 2711-196        | 8.20         |
| 103           | 2711-125        | 4.08         | 140           | 2711-197        | 6.30         |
| 104           | 2711-127        | 3.4          | 141           | 2711-198        | 1.40         |
| 105           | 2711-129        | 1.4          | 142           | 2711-199        | 9.00         |
| 106           | 2711-130        | 4.9          | 143           | BM71            | 3.30         |
| 107           | 2711-131        | 5.8          | 144           | TN-1            | 9.00         |
| 108           | 2711-133        | 1.5          |               |                 |              |
| 109           | 2711-137        | 1.32         |               |                 |              |
| 110           | 2711-140        | 2.7          |               |                 |              |
| 111           | 2711-143        | 1.7          |               |                 |              |
| 112           | 2711-147        | 5.9          |               |                 |              |
| 113           | 2711-149        | 6.4          |               |                 |              |
| 114           | 2711-150        | 1.3          |               |                 |              |
| 115           | 2711-151        | 4.05         |               |                 |              |

## 4.4 IDENTIFICATION OF NOVEL QTLS FOR BPH TOLERANCE

### 4.4.1 Parental Polymorphism Survey

In the recent past, identification of genes for accurate manipulation of different agronomically important traits in crops was facilitated by molecular marker technology (Yencho *et al.*, 2000). To identify polymorphism in mapping studies, various markers have been developed. Among different types of markers available, SSRs are the best choice as they are highly polymorphic, co-dominant, abundant and simple in nature. They are easily differentiated between homozygote and heterozygote. A huge collection of SSRs were developed in rice (McCouch *et al.*, 2002), which has importance in mapping studies and identification of genes.

Three hundred and fifteen SSR markers spread on all the twelve chromosomes were used for parental polymorphism study between susceptible parent MTU 3626 and resistant parent BM 71. Among 315 SSR markers screened, 77 SSR markers showed polymorphism (Plate 4.3a and 4.3b). The per cent of polymorphism is 24.44% (Figure 4.2). SSR markers which are polymorphic on each chromosome between MTU 3626 and BM 71 and percent of polymorphism on each chromosome were presented in Table 4.5. The polymorphic markers with their locations were showed in Table 4.6. Highest numbers of polymorphic markers (eleven) were identified on chromosome 3 while the least number of markers (four each) were identified on chromosome 8 and chromosome 9.

SSR markers used to identify the targeted regions coupled with trait of interest in genome of rice (McCouch *et al.*, 2002). Polymorphism percent range from 7% to 90% (Cheema *et al.*, 2008) was reported in different studies with a donor of *O. rufipogon* and three recurrent parents of *indica*. Santhanalakshmi *et al.*, 2010 conducted polymorphism survey with 200 SSR markers between Swarna and PTB 33 and only 21 SSR markers were found to be polymorphic.

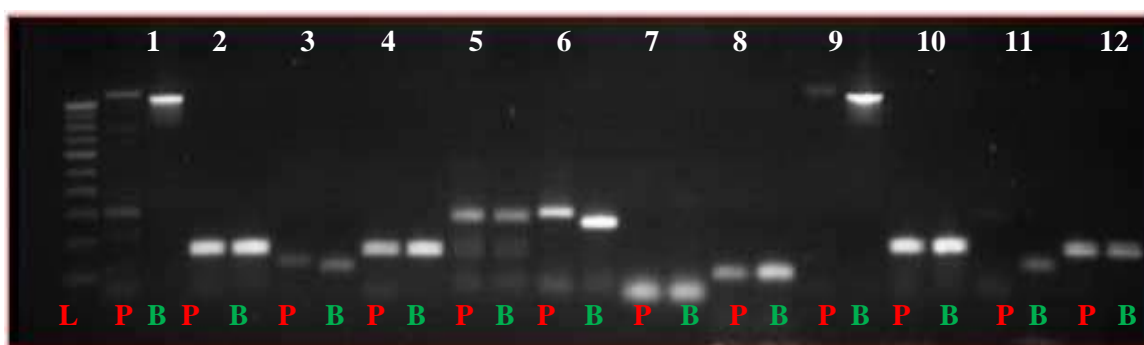


Plate 4.3a Gel image showed parental polymorphism studies on chromosome 1

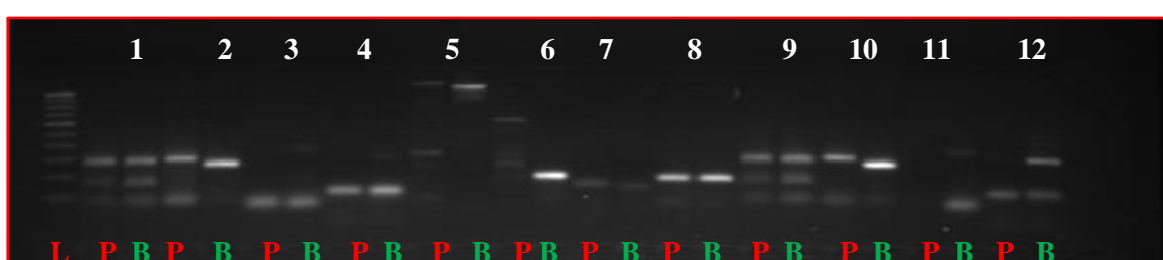


Plate 4.3b Gel image showed parental polymorphism studies on chromosome 11

Markers used in above image are given below:

| S. No. | Markers studied for polymorphism |               |
|--------|----------------------------------|---------------|
|        | Chromosome 1                     | Chromosome 11 |
| 1      | RM472                            | RM286         |
| 2      | RM490                            | RM206         |
| 3      | RM8368                           | RM229         |
| 4      | RM9                              | RM6499        |
| 5      | RM11841                          | RM254         |
| 6      | RM6887                           | RM26459       |
| 7      | RM11312                          | RM6440        |
| 8      | RM10655                          | RM3721        |
| 9      | RM495                            | RM26860       |
| 10     | RM128                            | RM27373       |
| 11     | RM84                             | RM26616       |
| 12     | RM237                            | RM6094        |
| 13     | P (Susceptible parent)           | MTU 3626      |
| 14     | B (Resistant parent)             | BM 71         |

**Table 4.5 SSR markers used for parental polymorphic survey between MTU 3626 and BM 71**

| <b>S. No</b> | <b>Chromosome Number</b> | <b>No. of markers studied</b> | <b>No. of polymorphic markers</b> | <b>% of polymorphism</b> |
|--------------|--------------------------|-------------------------------|-----------------------------------|--------------------------|
| 1            | 1                        | 26                            | 7                                 | 26.92                    |
| 2            | 2                        | 17                            | 7                                 | 41.17                    |
| 3            | 3                        | 22                            | 11                                | 50.00                    |
| 4            | 4                        | 28                            | 7                                 | 25.00                    |
| 5            | 5                        | 39                            | 9                                 | 23.07                    |
| 6            | 6                        | 17                            | 6                                 | 35.29                    |
| 7            | 7                        | 25                            | 6                                 | 24.00                    |
| 8            | 8                        | 29                            | 4                                 | 13.79                    |
| 9            | 9                        | 29                            | 4                                 | 13.79                    |
| 10           | 10                       | 14                            | 5                                 | 35.71                    |
| 11           | 11                       | 37                            | 5                                 | 13.51                    |
| 12           | 12                       | 32                            | 6                                 | 18.75                    |
| <b>Total</b> |                          | <b>315</b>                    | <b>77</b>                         | <b>24.44</b>             |

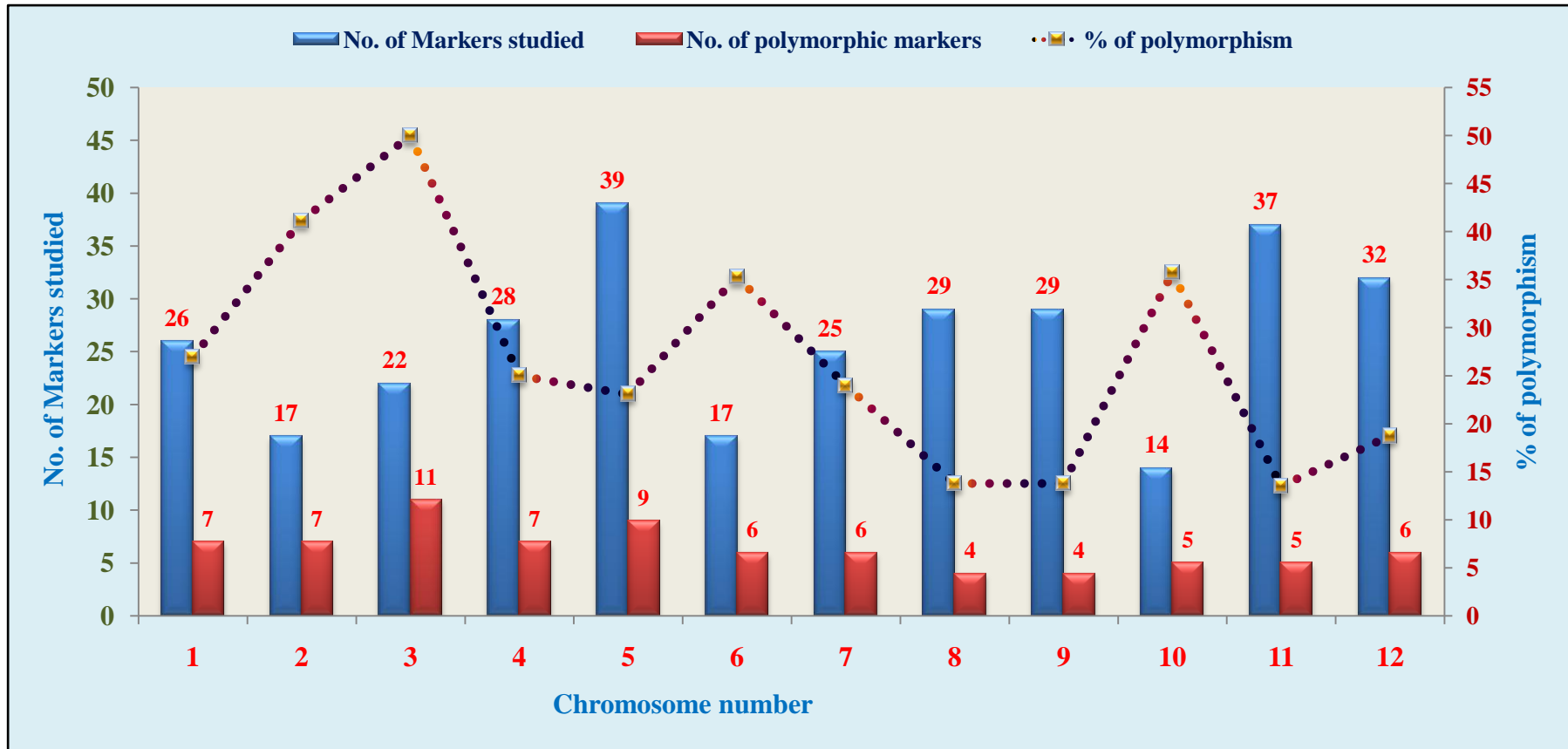


Figure 4.2 Graphical representation of SSR markers across 12 chromosomes and percentage of polymorphism between MTU 3626 and BM 71

**Table 4.6 Polymorphic markers between MTU 3626 and BM 71 with their physical positions (Mbp) on respective chromosomes**

| S. No. | Marker Name | Ch. No | Position | S. No | Marker Name | Ch. No | Position |
|--------|-------------|--------|----------|-------|-------------|--------|----------|
| 1      | RM6887      | 1      | 0.20     | 40    | RM3160      | 5      | 19.98    |
| 2      | RM495       | 1      | 0.21     | 41    | RM18959     | 5      | 25.16    |
| 3      | RM3412      | 1      | 11.58    | 42    | RM589       | 6      | 1.38     |
| 4      | RM10793     | 1      | 12.56    | 43    | RM190       | 6      | 1.76     |
| 5      | RM11069     | 1      | 19.37    | 44    | RM225       | 6      | 3.41     |
| 6      | RM8278      | 1      | 23.81    | 45    | RM253       | 6      | 5.42     |
| 7      | RM472       | 1      | 37.88    | 46    | RM400       | 6      | 28.43    |
| 8      | RM12569     | 2      | 4.28     | 47    | RM340       | 6      | 28.59    |
| 9      | RM3501      | 2      | 10.18    | 48    | RM500       | 7      | 15.91    |
| 10     | RM5578      | 2      | 18.73    | 49    | RM336       | 7      | 21.87    |
| 11     | RM13584     | 2      | 23.90    | 50    | RM8044      | 7      | 24.19    |
| 12     | RM263       | 2      | 25.86    | 51    | RM234       | 7      | 25.47    |
| 13     | RM13893     | 2      | 29.72    | 52    | RM134       | 7      | 26.63    |
| 14     | RM240       | 2      | 31.49    | 53    | RM1335      | 7      | 28.29    |
| 15     | RM231       | 3      | 2.45     | 54    | RM152       | 8      | 0.68     |
| 16     | RM14434     | 3      | 3.43     | 55    | RM23146     | 8      | 20.66    |
| 17     | RM7         | 3      | 9.82     | 56    | RM3496      | 8      | 27.53    |
| 18     | RM251       | 3      | 9.94     | 57    | RM8266      | 8      | 28.44    |
| 19     | RM15466     | 3      | 23.57    | 58    | RM23877     | 9      | 6.40     |
| 20     | RM15488     | 3      | 23.81    | 59    | RM5515      | 9      | 7.09     |
| 21     | RM15524     | 3      | 24.34    | 60    | RM524       | 9      | 12.92    |
| 22     | RM15528     | 3      | 24.41    | 61    | RM24336     | 9      | 15.10    |
| 23     | RM15539     | 3      | 24.58    | 62    | RM244       | 10     | 5.00     |
| 24     | RM426       | 3      | 27.58    | 63    | RM5373      | 10     | 18.72    |
| 25     | RM203       | 3      | 29.16    | 64    | RM25648     | 10     | 18.77    |
| 26     | RM551       | 4      | 0.17     | 65    | RM484       | 10     | 21.06    |
| 27     | RM8213      | 4      | 4.44     | 66    | RM222       | 10     | 23.20    |
| 28     | RM16433     | 4      | 4.62     | 67    | RM202       | 11     | 9.00     |
| 29     | RM261       | 4      | 6.57     | 68    | RM26870     | 11     | 19.41    |
| 30     | RM16569     | 4      | 9.66     | 69    | RM206       | 11     | 22.01    |
| 31     | RM185       | 4      | 18.57    | 70    | RM5766      | 11     | 28.24    |
| 32     | RM252       | 4      | 35.50    | 71    | RM27373     | 11     | 28.25    |
| 33     | RM3529      | 5      | 0.11     | 72    | RM7102      | 12     | 13.21    |
| 34     | RM17990     | 5      | 4.68     | 73    | RM28130     | 12     | 16.70    |
| 35     | RM18004     | 5      | 5.03     | 74    | RM6396      | 12     | 25.03    |
| 36     | RM169       | 5      | 7.49     | 75    | RM28759     | 12     | 26.44    |
| 37     | RM18384     | 5      | 14.78    | 76    | RM4552      | 12     | 26.94    |
| 38     | RM6024      | 5      | 17.75    | 77    | RM1226      | 12     | 27.31    |
| 39     | RM163       | 5      | 19.18    |       |             |        |          |

#### **4.4.2 Linkage Map Construction**

The linkage map was constructed for one hundred and thirty six RILs using data on 77 polymorphic SSR markers with Kosambi mapping function by using the software QTL IciMapping Version 4.1 based on their positions in cM (Figure: 4.3a, 4.3b, 4.3c). The linkage map covered 3433.74 cM involving all chromosomes with an average marker interval of 44.59 cM.

#### **4.4.3 Interval Mapping and Composite Interval Mapping (QIM and QIC) to identify QTLs**

QTL mapping was based on the assumption that linkage disequilibrium between the marker and a chromosomal region effecting the trait under study. Such linkage disequilibrium inferred based on likelihood ratio (LR). In the present study, QTL IciMapping Version 4.1 software was used to identify QTLs by using interval mapping (QIM) and Composite Interval Mapping (QIC). Composite Interval Mapping uses two flanking markers to construct an interval to search for QTL. A LOD score was calculated at each walking step in the intervals. When a peak exceeds the threshold value, it was observed that a QTL has been found at that location.

In the current study three QTLs were identified one on each on chromosome 2, 4 and 12 by interval mapping and composite interval mapping (Table 4.7). Apart from this 2 more QTLs were identified one on chromosome 5 and chromosome 7 using interval mapping (Table 4.7).

**Table 4.7 QTLs identified for tolerant to BPH in the RIL population derived from cross MTU 3626 and BM 71**

| Trait name    | Chromosome | QTL name         | Left marker | Right marker | LOD  |      | PVE (%) |      | Additive effect |       |
|---------------|------------|------------------|-------------|--------------|------|------|---------|------|-----------------|-------|
|               |            |                  |             |              | QIC  | QIM  | QIC     | QIM  | QIC             | QIM   |
| BPH tolerance | 2          | <i>qmbph2.1</i>  | RM263       | RM13893      | 2.17 | 4.21 | 5.96    | 4.46 | 1.73            | 1.98  |
|               | 4          | <i>qmbph4.1</i>  | RM8213      | RM16433      | 2.91 | 2.91 | 1.70    | 1.03 | 0.89            | 0.89  |
|               | 5          | <i>qmbph5.1</i>  | RM163       | RM3160       | -    | 2.91 | -       | 4.40 | -               | 1.95  |
|               | 7          | <i>qmbph7.1</i>  | RM500       | RM336        | -    | 2.81 | -       | 4.42 | -               | 1.93  |
|               | 12         | <i>qmbph12.1</i> | RM4552      | RM1226       | 3.31 | 5.95 | 5.76    | 4.42 | -1.70           | -1.97 |

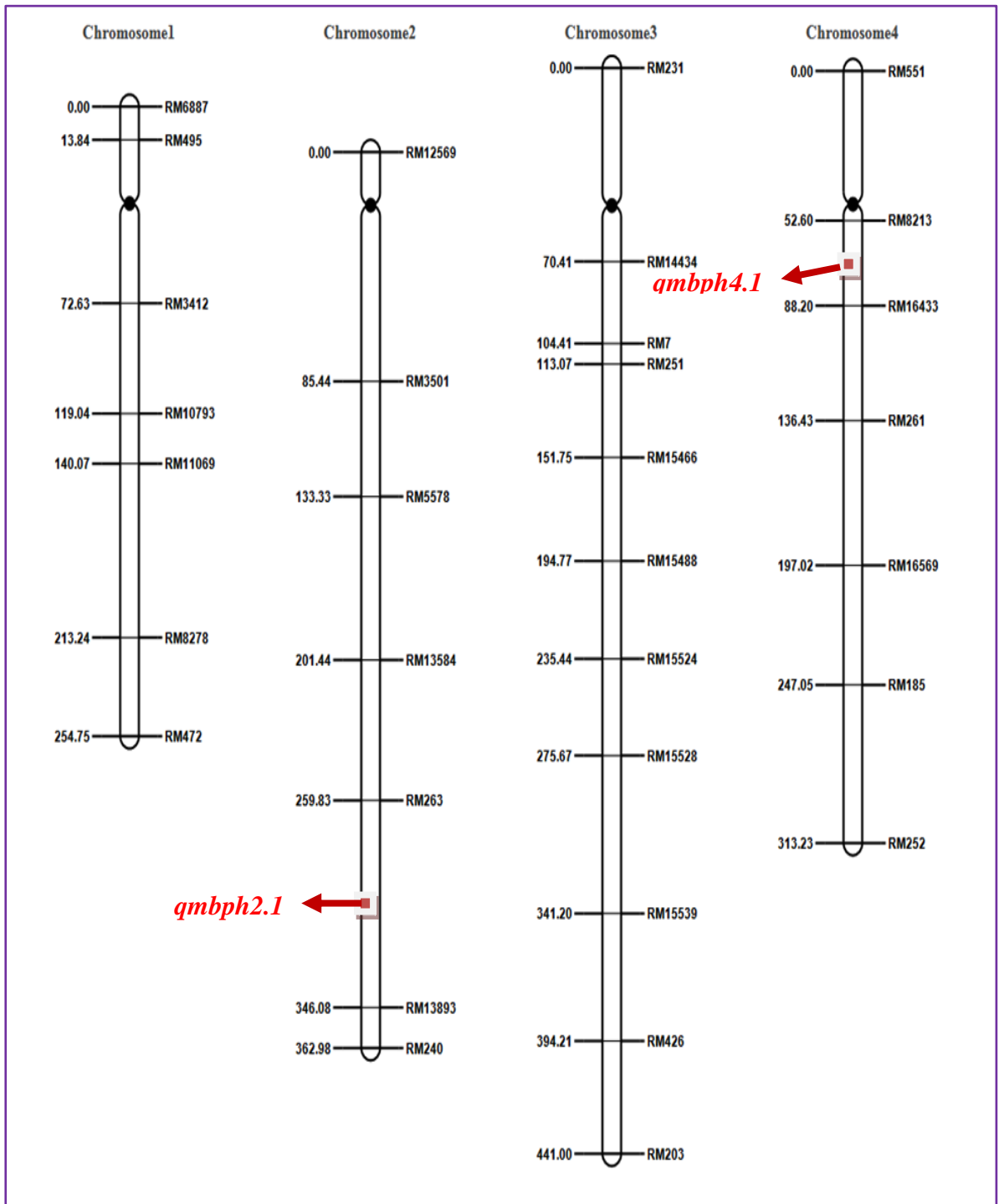


Figure 4.3a Linkage map construction for chromosomes 1, 2, 3 and 4

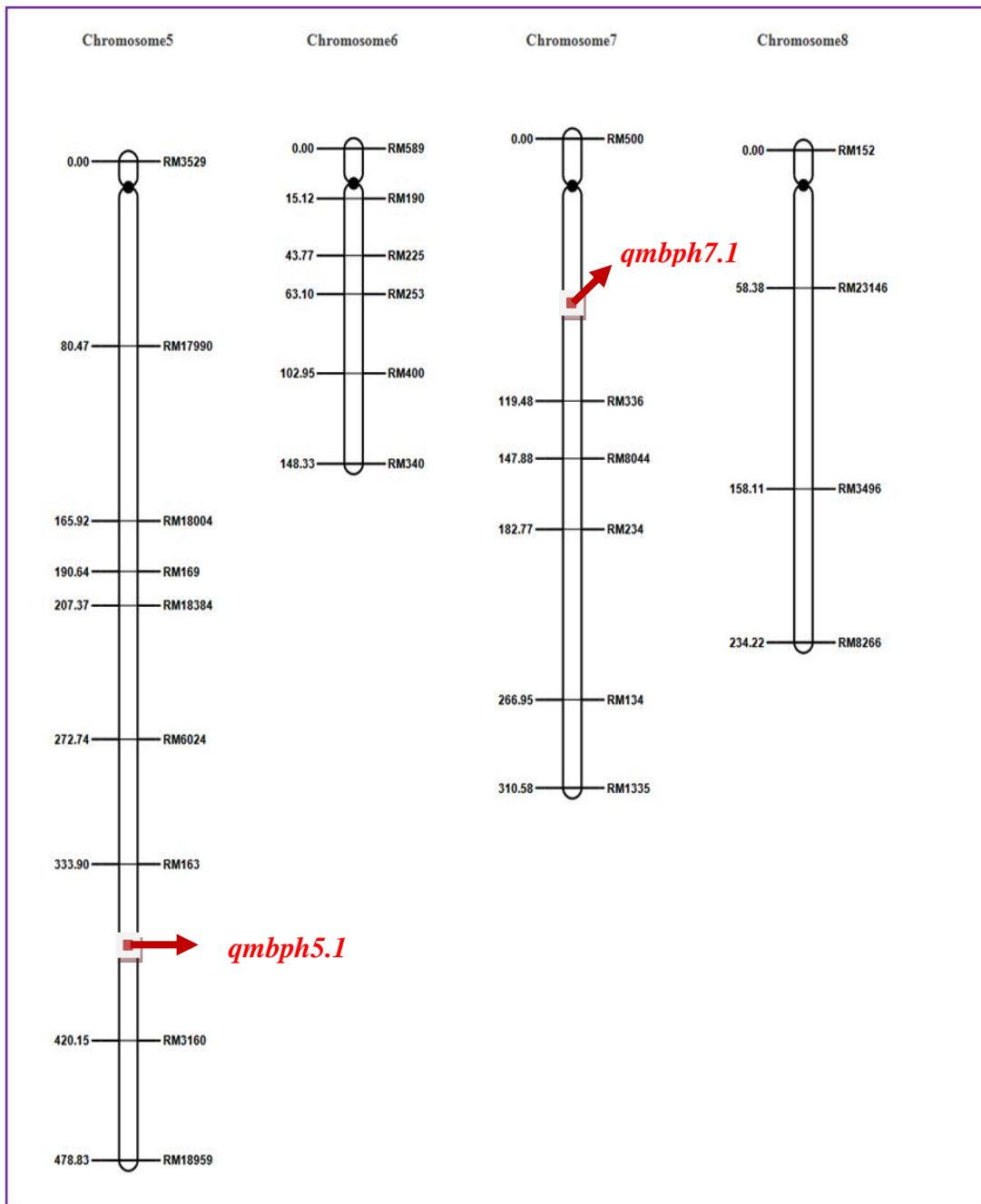
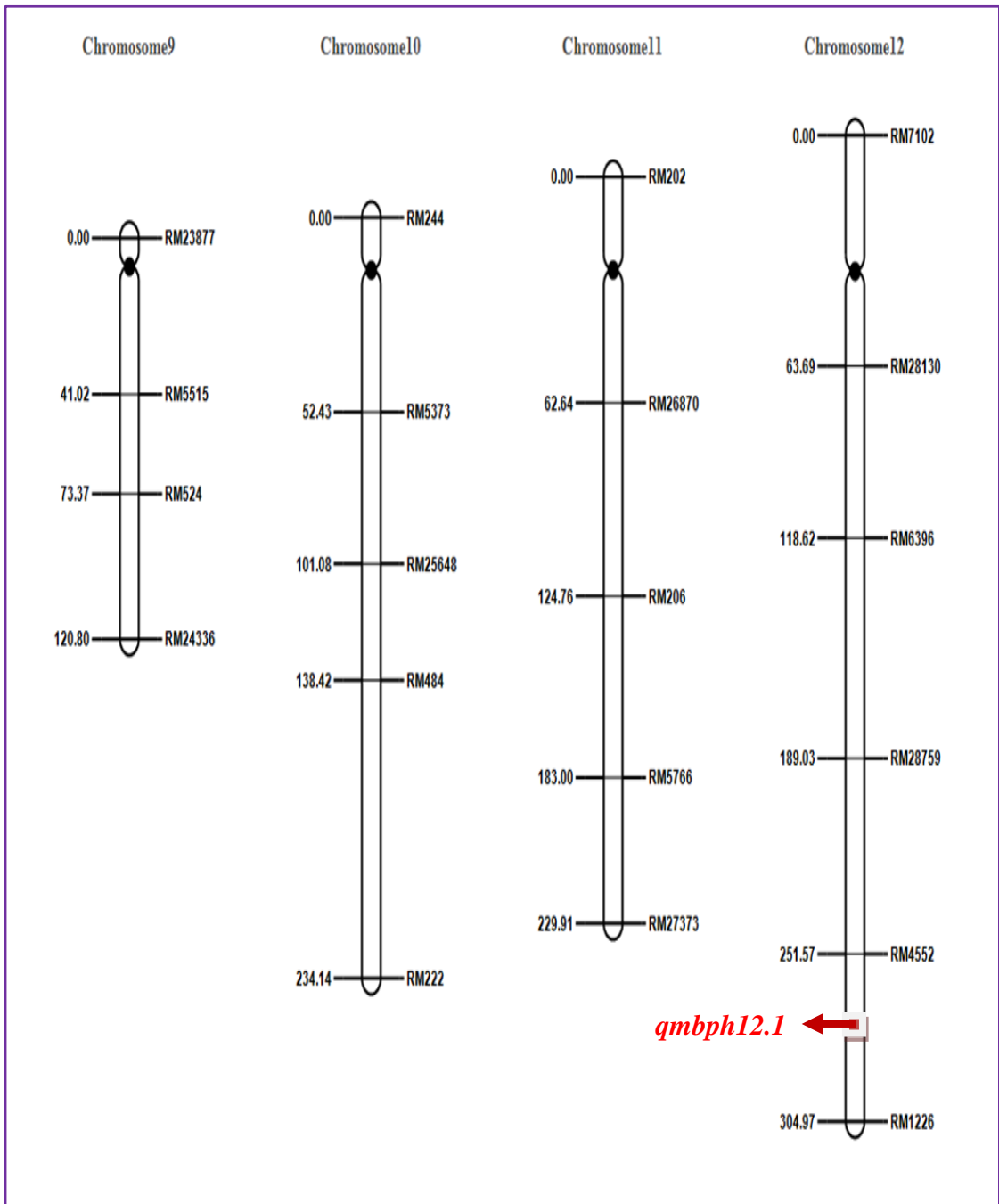


Figure 4.3b Linkage map construction for chromosomes 5, 6, 7 and 8



**Figure 4.3c Linkage map construction for chromosomes 9, 10, 11 and 12**

Composite Interval Mapping (QIC) has identified three QTLs on chromosomes 2, 4 and 12 each.

*qmbph2.1* on chromosome 2 was flanked by the left marker RM263 (Plate 4.4a), positioned at distance of 25.86 cM and right marker RM13893 (Plate 4.4b), positioned at 29.72 cM with phenotypic variance of 5.96% and LOD score of 2.17 (Figure 4.4a) and the QTL is contributed by the BM 71 which is evident by its positive additive effect at an interval of 3.86 cM.

The identified QTL was far away from *BPH 13(t)* gene identified by Liu *et al.*, 2001 in a study involving resistant parent *Oryza eichingeri* and susceptible parent 02428. Two QTLs were identified on chromosome 2 earlier *viz.*, Qbp3 (Ren *et al.*, 2004) and BPH 13(t).

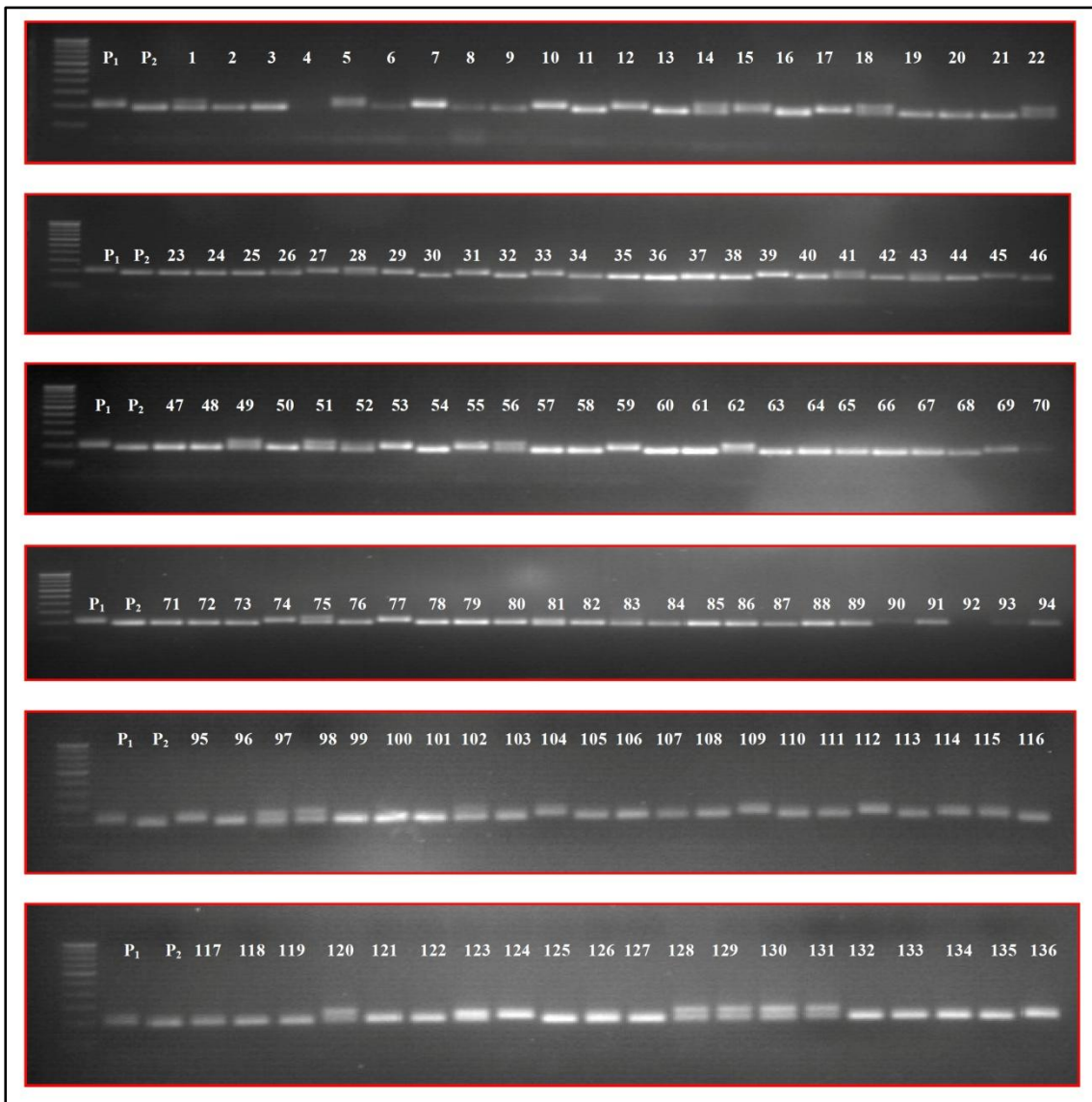
*qmbph4.1* on chromosome 4 was by flanked by the left marker RM8213 (4.44cM) and right marker RM16433 (4.62 cM) with phenotypic variance of 1.70% and LOD value of 2.91 and the QTL contributed by BM 71, position at an interval of 0.18cM (Figure: 4.4b).

The QTL identified in the current study was in the vicinity of *Bph20(t)* reported by Rahman *et al.*, 2009 in a study involving F<sub>2</sub> population of cross between IR71033-121-15 and Junambyeo. Eight QTLs were identified on chromosome 4 earlier.

*qmbph12.1* on chromosome 12 flanked by left marker RM4552 (Plate 4.5a), positioned at distance of 26.94cM and right marker RM1226 (Plate 4.5b), positioned at a distance of 27.37cM with phenotypic variance of 5.76% and LOD score of 3.31 and the QTL contributed by MTU 3626, with an interval 0.43cM (Figure 4.4c).

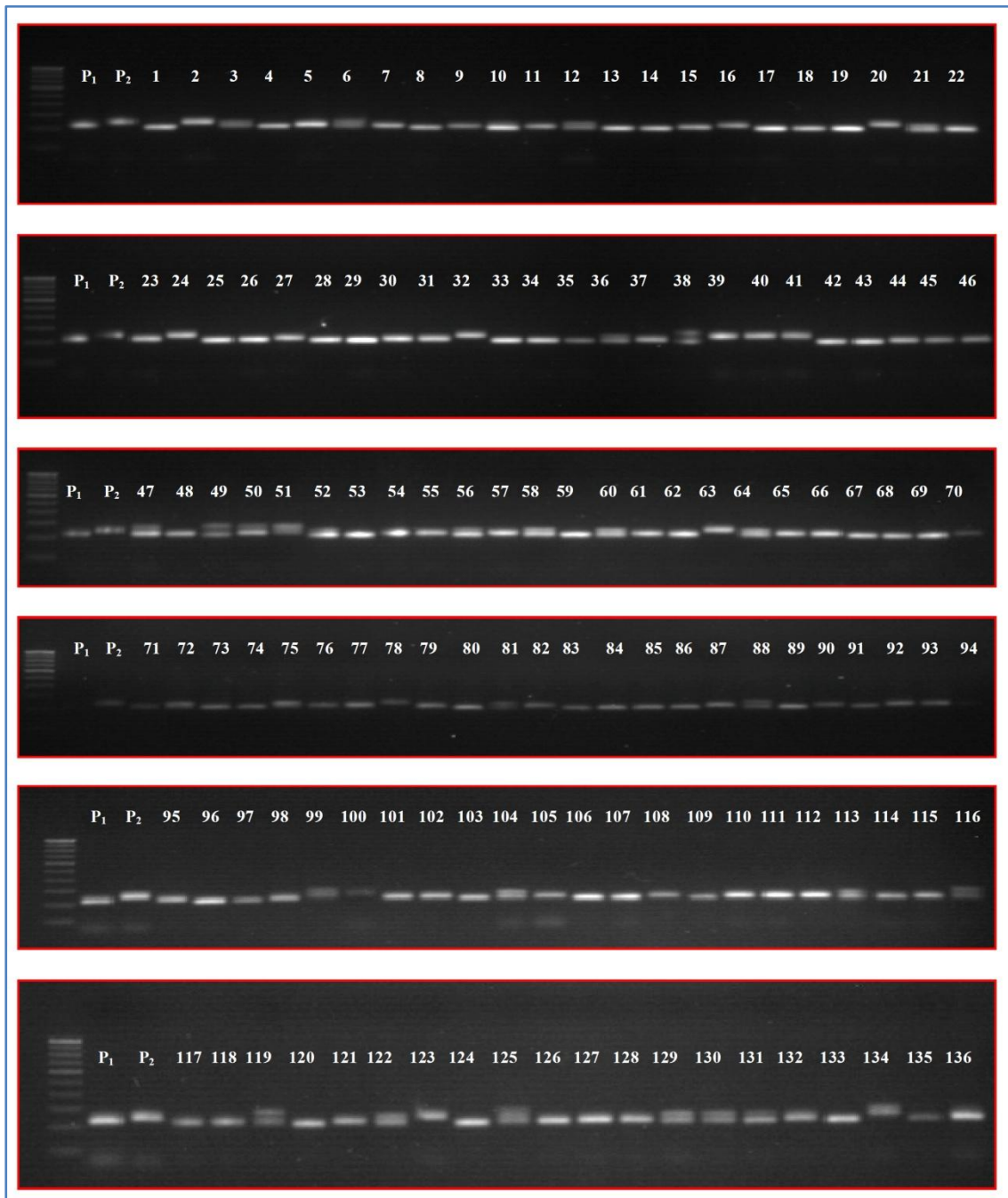
The QTL identified was away from *Bph18(t)* identified by Jena *et al.*, 2006 in a study involving introgression lines of cross between IR31917-45-3-2 and *O. australiensis* (Acc. No. 100882). Eight QTLs were identified on chromosome 12 earlier.

The physical position of the three QTLs identified on chromosomes 2, 4 and 12 along with LOD score is presented in below Figure 4.5.



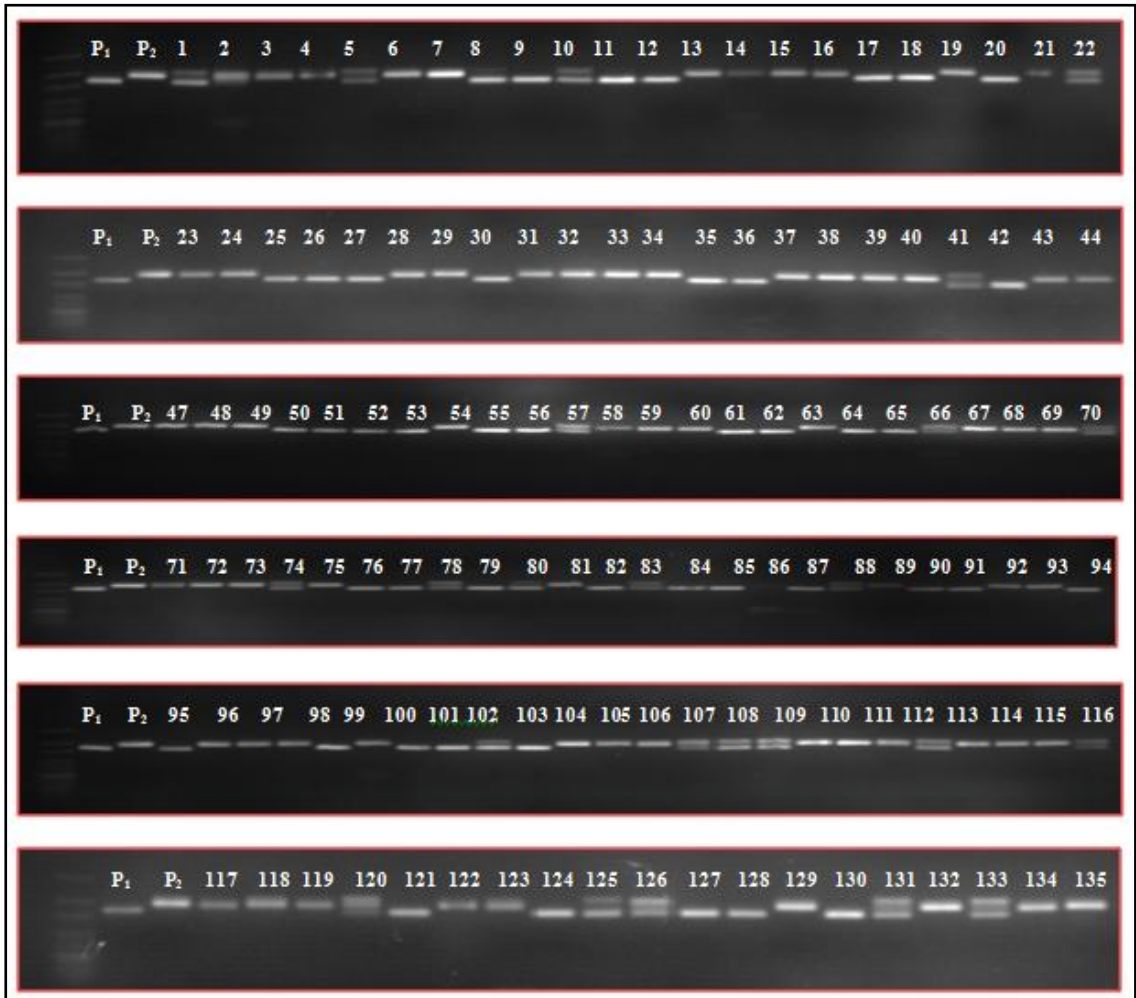
**Plate 4.4a Representative gel image for left flanking marker RM263 (*qmbph2.1*)**

**Note:** P<sub>1</sub>, P<sub>2</sub> and 1-136 RIL names were given in Table 4.8.



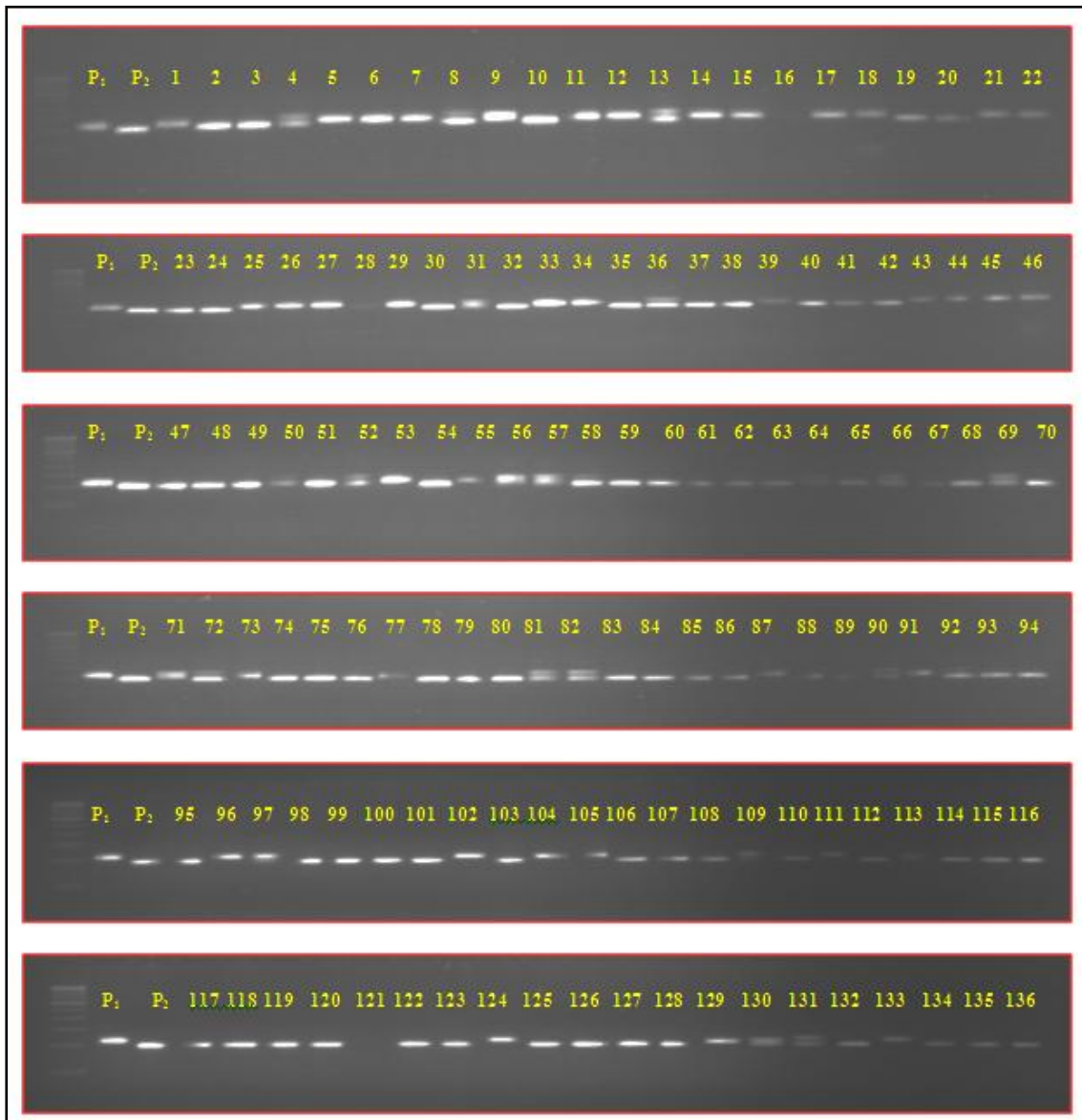
**Plate 4.4b** Representative gel image for right flanking marker RM13893 (*qmbph2.1*)

**Note:** P<sub>1</sub>, P<sub>2</sub> and 1-136 RIL names were given in Table 4.8.



**Plate 4.5a** Representative gel image for left flanking marker RM4552 (*qmbph12.1*)

**Note:** P<sub>1</sub>, P<sub>2</sub> and 1-136 RIL names were given in Table 4.8.



**Plate 4.5b** Representative gel image for right flanking marker RM1226 (*qmbph12.1*)

**Note:** P<sub>1</sub>, P<sub>2</sub> and 1-136 RIL names were given in Table 4.8.

**Table 4.8 Names of RILs used in genotyping with two parents MTU 3626 and BM 71**

| S.No.          | RIL name | S.No. | RIL name | S.No. | RIL name | S.No. | RIL name |
|----------------|----------|-------|----------|-------|----------|-------|----------|
| P <sub>1</sub> | MTU3626  | 40    | 2711-52  | 81    | 2711-104 | 122   | 2711-182 |
| P <sub>2</sub> | BM71     | 41    | 2711-53  | 82    | 2711-105 | 123   | 2711-184 |
| 1              | 2711-1   | 42    | 2711-54  | 83    | 2711-106 | 124   | 2711-185 |
| 2              | 2711-2   | 43    | 2711-55  | 84    | 2711-107 | 125   | 2711-186 |
| 3              | 2711-3   | 44    | 2711-56  | 85    | 2711-108 | 126   | 2711-187 |
| 4              | 2711-4   | 45    | 2711-57  | 86    | 2711-110 | 127   | 2711-188 |
| 5              | 2711-5   | 46    | 2711-58  | 87    | 2711-111 | 128   | 2711-189 |
| 6              | 2711-6   | 47    | 2711-59  | 88    | 2711-112 | 129   | 2711-191 |
| 7              | 2711-7   | 48    | 2711-60  | 89    | 2711-113 | 130   | 2711-192 |
| 8              | 2711-8   | 49    | 2711-61  | 90    | 2711-115 | 131   | 2711-193 |
| 9              | 2711-9   | 50    | 2711-62  | 91    | 2711-116 | 132   | 2711-195 |
| 10             | 2711-11  | 51    | 2711-63  | 92    | 2711-117 | 133   | 2711-196 |
| 11             | 2711-14  | 52    | 2711-64  | 93    | 2711-119 | 134   | 2711-197 |
| 12             | 2711-15  | 53    | 2711-65  | 94    | 2711-120 | 135   | 2711-198 |
| 13             | 2711-17  | 54    | 2711-66  | 95    | 2711-122 | 136   | 2711-199 |
| 14             | 2711-18  | 55    | 2711-67  | 96    | 2711-123 |       |          |
| 15             | 2711-19  | 56    | 2711-68  | 97    | 2711-125 |       |          |
| 16             | 2711-20  | 57    | 2711-69  | 98    | 2711-127 |       |          |
| 17             | 2711-22  | 58    | 2711-71  | 99    | 2711-129 |       |          |
| 18             | 2711-24  | 59    | 2711-72  | 100   | 2711-130 |       |          |
| 19             | 2711-25  | 60    | 2711-73  | 101   | 2711-131 |       |          |
| 20             | 2711-26  | 61    | 2711-74  | 102   | 2711-133 |       |          |
| 21             | 2711-27  | 62    | 2711-75  | 103   | 2711-137 |       |          |
| 22             | 2711-28  | 63    | 2711-76  | 104   | 2711-140 |       |          |
| 23             | 2711-30  | 64    | 2711-77  | 105   | 2711-143 |       |          |
| 24             | 2711-31  | 65    | 2711-78  | 106   | 2711-147 |       |          |
| 25             | 2711-32  | 66    | 2711-79  | 107   | 2711-149 |       |          |
| 26             | 2711-34  | 67    | 2711-80  | 108   | 2711-150 |       |          |
| 27             | 2711-35  | 68    | 2711-83  | 109   | 2711-151 |       |          |
| 28             | 2711-36  | 69    | 2711-84  | 110   | 2711-162 |       |          |
| 29             | 2711-37  | 70    | 2711-86  | 111   | 2711-164 |       |          |
| 30             | 2711-38  | 71    | 2711-87  | 112   | 2711-167 |       |          |
| 31             | 2711-39  | 72    | 2711-88  | 113   | 2711-168 |       |          |
| 32             | 2711-40  | 73    | 2711-89  | 114   | 2711-169 |       |          |
| 33             | 2711-43  | 74    | 2711-92  | 115   | 2711-170 |       |          |
| 34             | 2711-44  | 75    | 2711-93  | 116   | 2711-172 |       |          |
| 35             | 2711-45  | 76    | 2711-94  | 117   | 2711-175 |       |          |
| 36             | 2711-46  | 77    | 2711-100 | 118   | 2711-176 |       |          |
| 37             | 2711-47  | 78    | 2711-101 | 119   | 2711-177 |       |          |
| 38             | 2711-49  | 79    | 2711-102 | 120   | 2711-178 |       |          |
| 39             | 2711-50  | 80    | 2711-103 | 121   | 2711-179 |       |          |

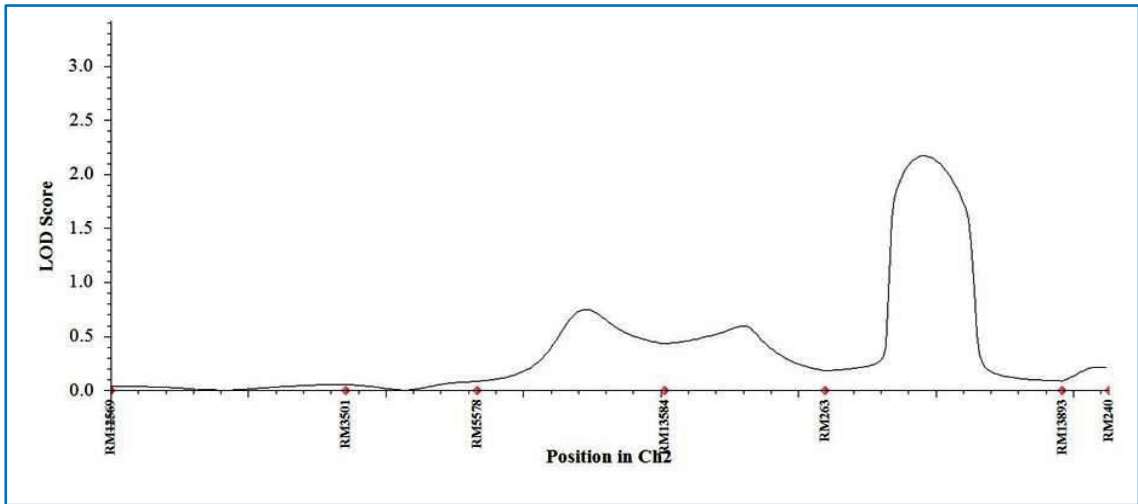


Figure 4.4a LOD curve of composite interval mapping of ch.2 for BPH tolerance QTL *qmbph2.1*

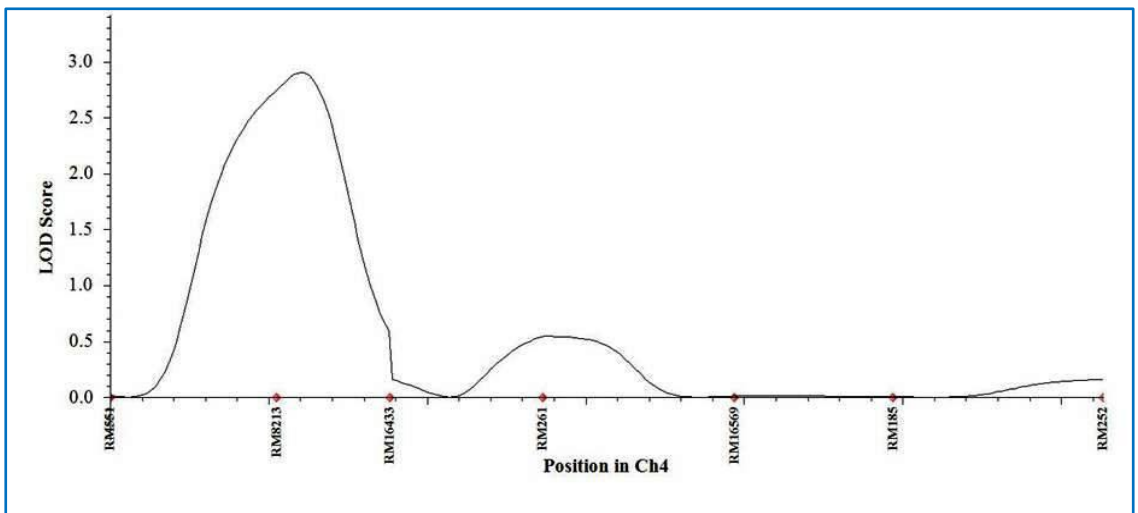


Figure 4.4b LOD curve of composite interval mapping of ch.4 for BPH tolerance QTL *qmbph4.1*

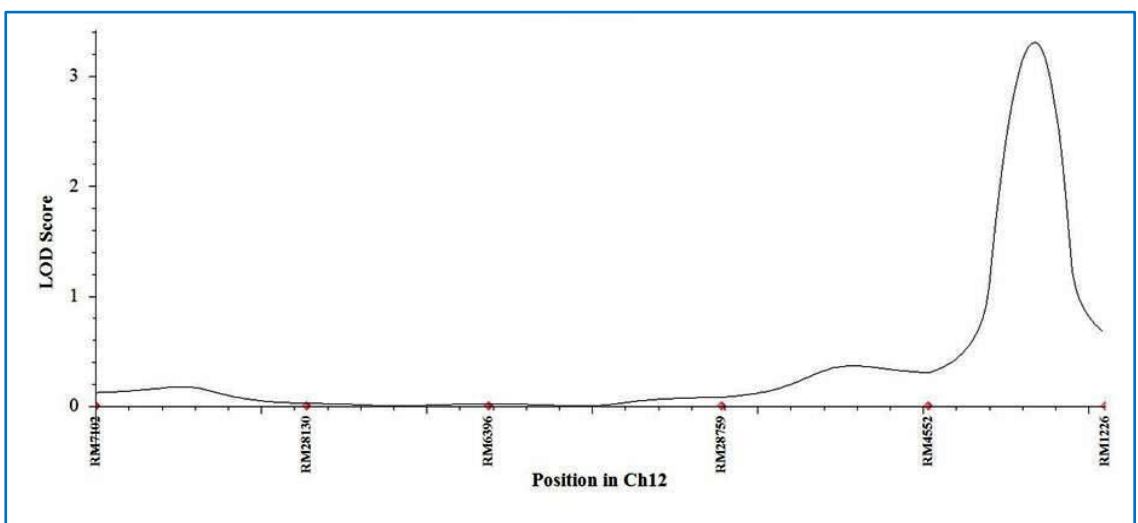
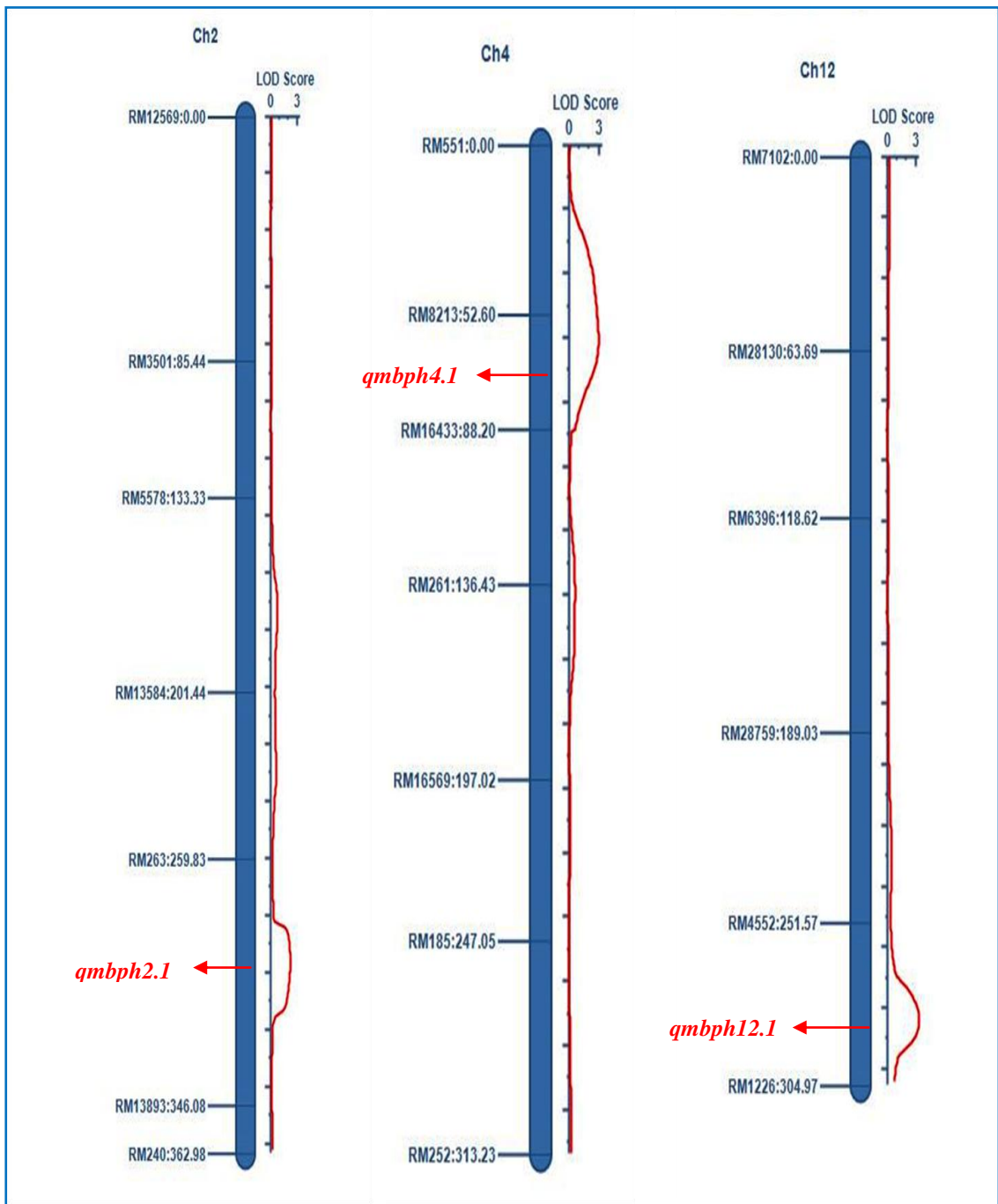


Figure 4.4c LOD curve of composite interval mapping of ch.12 for BPH tolerance QTL *qmbph12.1*



**Chromosome 2**

**Chromosome 4**

**Chromosome 12**

**Figure 4.5 Linkage map and LOD curve for chromosomes 2, 4 and 12 using composite interval mapping**

Interval mapping (QIM) has identified five QTLs, three QTLs on same chromosomes which were furnished in composite interval mapping and another two QTLs on chromosomes 5 and 7 (Table 4.7) and interval markers positions with their sequences were given in Table 4.9.

*qmbph5.1* on chromosome 5 flanked by left marker RM163 (19.18 cM) and right marker RM3160 (19.98 cM) with phenotypic variance of 4.40% and LOD score of 2.91 and the QTL contributed by BM 71, with position at distance of 0.80cM interval.

*qmbph7.1* on chromosome 7 flanked by left marker RM500 (15.91cM) and right marker RM336 (21.87 cM) with phenotypic variance of 4.42% and LOD score of 2.81 and the QTL contributed by BM 71, with position at distance of 5.96cM interval.

Three QTLs viz., *qmbph2.1*, *qmbph4.1* and *qmbph12.1* identified using composite interval mapping explained 4.46, 1.03 and 4.42 percent of phenotypic variance with LOD scores of 2.17, 2.91 and 3.31 respectively.

In addition to above three QTLs identified by composite interval mapping LOD values in interval mapping was (4.21, 2.91, 5.95), two more QTLs *qmbph5.1* and *qmbph7.1* were identified using interval mapping explaining 4.40% and 4.42% of phenotypic variance with LOD scores 2.91 and 2.81 respectively.

**Table 4.9 Respective flanking markers of five QTLs identified with their positions and sequence**

| S. No. | QTL Name         | Marker Interval | Ch. No. | Position | Forward primer             | Reverse primer             |
|--------|------------------|-----------------|---------|----------|----------------------------|----------------------------|
| 1      | <i>qmbph2.1</i>  | RM263           | 2       | 25.86    | AATCTATGGACCTGGGAGGAACC    | TGACGAGAGTGCTACGTTTGAGC    |
|        |                  | RM13893         | 2       | 29.72    | CAGTCTCATTGATGCAGTGTACG    | CCTCTACCTATATGATGCACAACACG |
| 2      | <i>qmbph4.1</i>  | RM8213          | 4       | 4.44     | TGTTGGGTGGGTAAAGTAGATGC    | CCCAGTGATACAAAGATGAGTTGG   |
|        |                  | RM16433         | 4       | 4.62     | TTGCAAGTCTAAAGAGGGAGTGG    | GTAGAGCCCATCTACCTAATTACCG  |
| 3      | <i>qmbph12.1</i> | RM4552          | 12      | 26.94    | GTTGAGTGATGTAGGACGGACACAGC | AGAGTTAGGCCAATTCGACGATGG   |
|        |                  | RM1226          | 12      | 27.31    | TCATCTTGTTGCTTGTGCTGTCC    | GCTACCACCACACATCCTTACTCG   |
| 4      | <i>qmbph5.1</i>  | RM163           | 5       | 19.18    | ATCCATGTGCGCCTTTATGAGGA    | CGCTACCTCCTTCACTTACTAGT    |
|        |                  | RM3160          | 5       | 19.98    | GTGAGGTGGGATGGAAATTAGG     | ACTTCCTCTTGGCCCATTAACC     |
| 5      | <i>qmbph7.1</i>  | RM500           | 7       | 15.91    | AGAAGTGCAGGTTGGCTCTGC      | CACGAATCTCGGAGTGTCTAGGG    |
|        |                  | RM336           | 7       | 21.87    | GTATCTTACAGAGAAACGGCATCG   | GGTTTGTTCAGGTTTCGTCTATCC   |

Interestingly, about half of the BPH resistance genes were identified and mapped to chromosomes 4 and 12 with use of mostly by SSRs. Eight genes, Bph3 (Liu *et al.* 2009), Bph6 (Qiu *et al.* 2013), Bph12 (Yang *et al.* 2002), Bph15 (Yang *et al.* 2004), bph16 (Hirabayashi *et al.* 1998), Bph17 (Sun *et al.* 2007), Bph20 (Rahman *et al.* 2009) and Bph27 (Huang *et al.* 2001) were mapped to chromosome 4 while other eight genes, Bph1 (Kim *et al.*, 2005), bph2 (Sun *et al.* 2007), Bph9 (Su *et al.* 2005), Bph10 (Nguyen *et al.* 1997), Bph18 (Jena *et al.* 2006), bph19 (Chen *et al.* 2006), Bph21 (Rahman *et al.* 2009) and Bph26 (Yara *et al.* 2010) were mapped to chromosome 12, suggesting that these two chromosomes harbor hot-spots for BPH resistance genes.

To summarize the current study, ten RILs *viz.*, 2711 – 31, **2711 – 37** (Statistically significant over best check MTU 1075), 2711 – 50, 2711 – 69, 2711 – 84, 2711 – 88, 2711 – 94, 2711 – 100, 2711 – 168 and 2711 – 191 showed resistant to brown plant hopper with score of less than 5.0 in both the screening methods and on par (Table 4.10) with both the checks MTU 7029 (Swarna) and MTU 1075 (Pushyami).

Five QTLs resistant to BPH were identified in the present study. Among these five QTLs, three QTLs were identified by both composite interval mapping and interval mapping which were named as *qmbph2.1*, *qmbph4.1* and *qmbph12.1* on chromosomes 2, 4 and 12 respectively. Apart from this, two more QTLs were identified by interval mapping (QIM), they named as *qmbph5.1* and *qmbph7.1* on chromosomes 5 and 7 respectively.

**Table 4.10 Performance of RILs for yield and yield attributing traits**

| S. No. | RIL name       | DFP          | Plant height (cm) | Ear bearing tillers per plant | Panicle Length (cm) | Grain yield per plant |
|--------|----------------|--------------|-------------------|-------------------------------|---------------------|-----------------------|
| 1      | 2711-31        | 99.00        | 100.60            | 8.00                          | 29.00               | 17.90                 |
| 2      | <b>2711-37</b> | <b>93.00</b> | <b>119.00</b>     | <b>8.00</b>                   | <b>28.10</b>        | <b>20.36</b>          |
| 3      | 2711-50        | 99.00        | 133.10            | 8.00                          | 24.90               | 16.65                 |
| 4      | 2711-69        | 97.00        | 142.80            | 7.00                          | 29.50               | 16.05                 |
| 5      | 2711-84        | 97.00        | 142.40            | 8.00                          | 28.00               | 16.65                 |
| 6      | 2711-88        | 98.00        | 138.10            | 8.00                          | 29.90               | 19.85                 |
| 7      | 2711-94        | 93.00        | 123.20            | 8.00                          | 26.00               | 16.60                 |
| 8      | 2711-100       | 96.00        | 147.90            | 8.00                          | 29.95               | 17.65                 |
| 9      | 2711-168       | 93.00        | 140.20            | 8.00                          | 30.75               | 16.38                 |
| 10     | 2711-191       | 99.00        | 112.00            | 8.00                          | 32.10               | 16.15                 |
| 11     | MTU 7029       | 119.00       | 106.00            | 8.00                          | 25.40               | 16.00                 |
| 12     | MTU 1075       | 113.00       | 114.70            | 9.00                          | 26.70               | 17.80                 |

## Chapter – V

---

### *Summary and Conclusions*

## Chapter V

# SUMMARY AND CONCLUSIONS

Rice is a major food crop across the globe. Brown plant hopper is one of the major pest in rice growing areas. The current research work was conducted during *kharif*, 2018 at RARS, Maruteru with one hundred and forty two RILs and two checks to study variability, heritability and genetic advance for yield and yield contributing traits in RILs and to identify novel QTLs in the BPH donor BM 71.

The ANOVA showed highly significant differences among the RILs for the five traits under study *viz.*, days to 50% flowering, plant height (cm), number of ear bearing tillers per plant, panicle length (cm) and grain yield per plant (g). For grain yield per plant (g) higher estimates of both GCV and PCV were observed indicating greater variability. High heritability coupled with high genetic advance as per cent of mean was also observed indicating presence of additive gene action, hence improvement for grain yield per plant (g) can be done through simple selection. Moderate heritability and genetic advance as percent of mean was recorded for plant height (cm) and ear bearing tillers per plant indicating presence of both additive and non additive gene actions. Moderate heritability with low genetic advance as percent of mean was observed for days to 50% flowering and panicle length (cm) indicating non additive gene action and selection may not be effective for the above traits.

Phenotyping of one hundred and forty two RILs for BPH tolerance was done by using both by standard seed box technique (seedling screening) and field screening. In seedling screening using standard seed box technique recorded forty four RILs were resistant (score 1 to 3), sixty two RILs were moderately resistant (score 3 to 5), thirty RILs were moderately susceptible (score 5 to 7) and six RILs were susceptible (score 7 to 9); whereas in field screening sixty seven RILs were resistant (score 1 to 3), thirty four RILs were moderately resistant (score 3 to 5), twenty RILs were moderately susceptible (score 5 to 7) and twenty one RILs were susceptible (score 7 to 9). Further, ten RILs *viz.*, 2711 – 31, 2711 – 37, 2711 – 50, 2711 – 69, 2711 – 84, 2711 – 88, 2711 – 94, 2711 – 100, 2711 – 168 and 2711 – 191 showed resistant to brown plant hopper with score of less than 5.0 in both the screening methods and highest grain yield than both the checks MTU 7029 (Swarna) and MTU 1075 (Pushyami).

Three hundred and fifteen SSR markers on all the twelve chromosomes were used for parental polymorphism between susceptible parent MTU 3626 and resistant parent BM 71, and seventy seven SSRs were found to be polymorphic. One hundred and thirty six RILs (six RILs discarded due to their inferiority in phenotyping) were subjected to QTL analysis through QTL Ici Mapping version 4.1. Composite Interval Mapping and interval mapping has identified three QTLs which were named as *qmbph2.1*, *qmbph4.1* and *qmbph12.1* on chromosomes 2, 4 and 12 respectively with LOD scores of 2.17, 2.91 and 3.31 explaining phenotypic variance of 5.96 %, 1.70 % and 5.76 % respectively, while interval mapping explained phenotypic variance up to 4.46 %, 1.03 % and 4.42 % with LOD scores of 4.21, 2.91 and 5.95 respectively. In addition, interval mapping has also identified two more QTLs, *qmbph5.1* and *qmbph7.1* on chromosomes 5 and 7 with phenotypic variance of 4.40 % and 4.42 % and LOD score of 2.91 and 2.81 respectively.

Further, the identified five QTLs on chromosomes 2, 4, 5, 7 and 12 in the present study has to be fine mapped by using more number of polymorphic markers in the identified regions. Putative genes responsible for BPH resistance in the donor also have to be identified for use in the future breeding programmes for development of BPH resistant rice varieties. Further, the RILs (2711 – 31, 2711 – 37, 2711 – 50, 2711 – 69, 2711 – 84, 2711 – 88, 2711 – 94, 2711 – 100, 2711 – 168 and 2711 – 191) on par with the high yielding checks, Swarna and Pushyami coupled with resistance to BPH score similar to BM 71, the resistant RILs may be promoted for evaluation in yield trials.

---

---

## *Literature Cited*

## LITERATURE CITED

- Adhikari, B.N., Joshi, B.P., Shrestha, J and Bhatta, N.R. 2018. Genetic variability, heritability, genetic advance and correlation among yield and yield components of rice (*Oriza sativa* L.). *Journal of Agriculture and Natural Resources*. 1 (1): 149-160.
- Ahmeda, F., Rafii, M.Y., Ismail, M.R., Juraimia, A.S., Rahimc, H.A., Latifd, M.A., Hasana, M.M and Tanweera, F.A. 2016. The addition of submergence-tolerant Sub1 gene into high yielding MR219 rice variety and analysis of its BC<sub>2</sub>F<sub>3</sub> population in terms of yield and yield contributing characters to select advance lines as a variety. *Biotechnology and Biotechnological Equipment*. 30 (5): 853-863.
- Akkaya, M.S., Bhagwat, A.A and Cregan, P.B. 1992. Length polymorphisms of simple sequence repeat DNA in soybean. *Genetics*. 132: 1131-1139.
- Alam, S.N and Cohen, M.B. 1998. Detection and analysis of QTLs for resistance to the brown plant hopper, *Nilaparvata lugens*, in a doubled-haploid rice population. *Theoretical and Applied Genetics*. 97 (8): 1370-1379.
- Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons Inc., New York. 485.
- Anis, G., El-sabagh, A., Ghareb, A and El-Rewainy, I. 2016. Evaluation of promising lines in rice (*Oryza sativa* L.) to agronomic and genetic performance under Egyptian conditions. *Indian Journal of Agronomy and Agricultural Research*. 8 (3): 52-57.
- Bhogadhi, S.C., Bentur, J.S., Rani, C.V.D., Thappeta, G., Yamini, K.N., Kumar, N.A.P., Jamaloddin, M., Swathi, G., Lakshmi, V.J., Bhanu, K.V and Satynarayana, P.V. 2015. Screening of rice genotypes for resistance to brown plant hopper biotype 4 and detection of BPH resistance genes. *International Journal of Life Sciences Biotechnology and Pharma Research*. 4 (2): 90-95.
- Bornare, S.S., Mittra, S.K and Mehta, A.K. 2014. Genetic variability, correlation and path analysis of floral, yield and its component traits in CMS and restorer lines of rice (*Oryza sativa* L.). *Bangladesh Journal of Botany*. 43 (1): 45-52.
- Bosque-Perez, N.A and Buddenhagen, I.W. 1992. The development of host-plant resistance to insect pests: outlook for the tropics. *In Proceedings of the 8th International Symposium on Insect-Plant Relationships*. 235-249.

- Burton, G.W and Devane, E.W. 1953. Estimating heritability in tall fescue (*Festuca arundinaceae*) from replicated clone material. *Agronomy Journal*. 45: 478-481.
- Chandramohan, Y., Srinivas, B., Thippeswamy, S and Padmaja, D. 2016. Diversity and variability analysis for yield parameters in rice (*Oryza sativa* L.) genotypes. *Indian Journal of Agricultural Research*. 50 (6): 609-613.
- Chen, J.W., Wang, L., Pang, X.F and Pan, Q.H. 2006. Genetic analysis and fine mapping of a rice brown plant hopper (*Nilaparvata lugens* Stal) resistance gene bph19 (t). *Molecular Genetics and Genomics*. 275 (4): 321-329.
- Cheema K.K, Bains, N.S, Mangat, G.S., Das A, Vikal, Y., Brar, D.S. 2008. Development of high yielding IR64×*Oryza rufipogon* (Griff.) introgression lines and identification of introgressed allelic chromosome segments using markers. *Euphytica*. 160: 1–9.
- Cheng, X., Zhu, L and He, G. 2013. Towards understanding of molecular interactions between rice and the brown plant hopper. *Molecular plant*. 6 (3): 621-634.
- Collard, B., Jahufer, M., Brouwer, J and Pang, E. 2005. An introduction to markers, quantitative trait loci (QTL) mapping and marker assisted selection for crop improvement: the basic concepts. *Euphytica*. 142: 169–196.
- Deen, R., Ramesh, K., Padmavathi, G., Viraktamath, B.C and Ram, T. 2017. Mapping of brown plant hopper [*Nilaparvata lugens* (Stal)] resistance gene (bph5) in rice (*Oryza sativa* L.). *Euphytica*. 213 (2): 35.
- Dellaporta, S.L., Wood, J and Hicks, J.B. 1983. A plant DNA miniprep: version 2. *Plant Molecular Biology Reporter*. 1: 19-22.
- Devi, K.R., Chandra, B.S., Lingaiah, N., Hari, Y and Venkanna, V. 2017. Analysis of variability, correlation and path coefficient studies for yield and quality traits in rice (*Oryza sativa* L.). *Agricultural Science Digest*. 37 (1): 1-9.
- Directorate of Economics and Statistics. 2017-18. Government of Andhra Pradesh.
- Dutta, P., Dutta, P.N and Borua, P.K. 2013. Morphological traits as selection indices in rice: a statistical view. *Universal Journal of Agricultural Research*. 1 (3): 85-96.
- Falconer, D.S. 1964. An Introduction to Quantitative Genetics. Oliver and Boyd, Edinburgh, London. 312-324.

- Fentie, D., Alemayehu, G., Siddalingaiah, M and Tadesse, T. 2014. Genetic variability, heritability and correlation coefficient analysis for yield and yield component traits in upland rice (*Oryza sativa* L.). *East African Journal of Sciences*. 8 (2): 147-154.
- Fisher, R.A and Yates, F. 1963. *Statistical Tables for Biological, Agricultural and Medical Research*. Oliver and Boyd, Edinburgh, London. 26-27.
- Gallagher, K.D., Kenmore, P.E and Sogawa, K. 1994. Judicial use of insecticides deter planthopper outbreaks and extend the life of resistant varieties in Southeast Asian rice. *In Planthoppers*. 599-614.
- Gemayel, R., Cho, J., Boeynaems, S and Verstrepen, K.J. 2012. Variable Tandem repeats as facilitators of rapid evolution of regulatory and coding sequences. *Genes*. 3: 461–480.
- Girma, B.T., Kitil, M.A., Banje, D.G., Biru, H.M and Serbessa, T.B. 2018. Genetic variability study of yield and yield related traits in rice (*Oryza sativa* L.) genotypes. *Advances in Crop Science and Technology*. 6 (4): 381.
- Habiba, O., Kabir, M.L., Rabby, M.K., Biswas, B.K and Hasanuzzaman, B. 2015. Comparative potential on yield and its related characters in fine Rice. *International Journal of Agronomy and Agricultural Research*. 7 (4): 95-102.
- Harini, A.S., Kumar, S.S., Balaravi, P., Sharma, R., Dass, M.A and Shenoy, V. 2013. Evaluation of rice genotypes for brown plant hopper (BPH) resistance using molecular markers and phenotypic methods. *African Journal of Biotechnology*. 12 (19): 2515-2525.
- Hasan, M.M., Yusop, M.R., Ismail, M.R., Mahmood, M., Rahim, H.A and Latif, M.A. 2015. Performance of yield and yield contributing characteristics of BC<sub>2</sub>F<sub>3</sub> population with addition of blast resistant gene. *Ciencia e Agrotecnologia*. 39 (5): 463-476.
- Heinrichs, E.A., Medrano, F.G and Rapusas, H.R. 1985. Genetic evaluation for insect resistance in rice. *International Rice Research Institute*. 1-356.
- Heong, K.L and Hardy, B. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. *International Rice Research Institute*. 401-428.
- Hirabayashi, H. 1998. Identification of brown plant hopper resistance gene derived from *Oryza officinalis* using molecular markers in rice. *Breeding Science*. 48 (1): 82.

- Hong, S.U.N., Ming, W.A.N.G., Chao, S.U., Qiang, L.I.U., Qu, Z.H.A.I. and Min, W.A.N. 2006. Mapping and marker-assisted selection of a brown planthopper resistance gene *bph2* in rice (*Oryza sativa* L.). *Acta Genetica Sinica*. 33 (8): 717-723.
- Hossain, S., Haque, M.D.M and Rahman, J. 2015. Genetic variability, correlation and path coefficient analysis of morphological traits in some extinct local Aman rice (*Oryza sativa* L.). *Journal of Rice Research*. 4 (1): 1-6.
- Hu, J., Cheng, M., Gao, G., Zhang, Q., Xiao, J and He, Y. 2013. Pyramiding and evaluation of three dominant brown plant hopper resistance genes in the elite indica rice 9311 and its hybrids. *Pest management science*. 69 (7): 802-808.
- Huang, Z., He, G., Shu, L.H., Li, X and Zhang, Q. 2001. Identification and mapping of two brown plant hopper resistance genes in rice. *Theoretical and Applied Genetics*. 102 (6-7): 929-934.
- Idris, A.E and Mohamed, K.A. 2013. Estimation of genetic variability and correlation for grain yield components in rice (*Oryza sativa* L.). *Global Journal of Plant Ecophysiology*. 3 (1): 1-6.
- IRRI (International Rice Research Institute). 2014. Standard Evaluation System for Rice (SES), 5<sup>th</sup> edition.
- Jairin, J., Phengrat, K., Teangdeerith, S., Vanavichit, A and Toojinda, T. 2007. Mapping of a broad-spectrum brown plant hopper resistance gene, *Bph3*, on rice chromosome 6. *Molecular Breeding*. 19 (1): 35-44.
- Jena, K.K and Kim, S.M. 2010. Current status of brown plant hopper (BPH) resistance and genetics. *Rice*. 3 (2): 161-171.
- Jena, K.K., Jeung, J.U., Lee, J.H., Choi, H.C and Brar, D.S. 2006. High-resolution mapping of a new brown plant hopper (BPH) resistance gene, *Bph18* (t), and marker-assisted selection for BPH resistance in rice (*Oryza sativa* L.). *Theoretical and Applied Genetics*. 112 (2): 288-297.
- Jiang, H., Hu, J., Li, Z., Liu, J., Gao, G., Zhang, Q., Xiao, J and He, Y. 2018. Evaluation and breeding application of six brown plant hopper resistance genes in rice maintainer line Jin 23B. *Rice*. 11 (1): 22.
- Johnson, H.W., Robinson, H.F and Comstock, R.E. 1955. Estimates of genetic and environmental variability in soybean. *Agronomy Journal*. 47 (7): 314-318.

- Kar, S., Verulkar, B., Verma and Pali. 2011. Identification of QTLs for brown plant hopper (*Nilaparvata lugens stal.*) resistance in RIL mapping population of rice (*Oryza sativa* L.). *Plant Archives*. 11 (2): 687-692.
- 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.
- Khare, R., Singh, A.K., Eram, S and Singh, P.K. 2014. Genetic variability, association and diversity analysis in upland rice (*Oryza sativa* L.). *SAARC Journal of Agriculture*. 2(2): 40-51.
- Khush, G.S and Brar, D.S. 1991. Genetics of resistance to insects in crop plants. *Advanced Agron*. 45: 223–274.
- Kim, S.M. and Sohn, J.K. 2005. Identification of a rice gene (Bph 1) conferring resistance to brown plant hopper (*Nilaparvata lugens* Stal) using STS markers. *Molecules and Cells*. 20 (1): 30-34.
- Kishore, N.S., Srinivas, T., Nagabhushanam, U., Pallavi, M and Sameera, S.K. 2015. Genetic variability, correlation and path analysis for yield and yield components in promising rice (*Oryza sativa* L.) genotypes. *SAARC Journal of Agriculture*. 13 (1): 99-108.
- Konate, A.K., Zongo, A., Kam, H., Sanni, A and Audebert, A. 2016. Genetic variability and correlation analysis of rice (*Oryza sativa* L.) inbred lines based on agro-morphological traits. *African Journal of Agricultural Research*. 11(35): 3340-3346.
- Kulshreshtha, J.P., Anjaneyulu, A and Padmanabhan, S. Y. 1974. A disastrous brown plant hopper attack in Kerala. *Indian Farming*. 24 (9): 5-9.
- Kumar, K., Sarao, P.S., Bhatia, D., Neelam, K., Kaur, A., Mangat, G.S., Brar, D.S. and Singh, K. 2018. High-resolution genetic mapping of a novel brown plant hopper resistance locus, Bph34 in *Oryza sativa* L. X *Oryza nivara* (Sharma & Shastri) derived interspecific F<sub>2</sub> population. *Theoretical and applied genetics*. 1-9.
- Kumar, R and Kumaravadivel, N. 2018. Genetic Variability and Inter Relationship among the Gene Pyramided BC<sub>4</sub>F<sub>4</sub> Generation Lines for Yield and Yield Attributing Characters in Rice (*Oriza sativa* L.). *International Journal of Current Microbiology and Applied Sciences*. 7 (3): 2502-2507.

- Kumari, S., Sheba, J.M., Marappan, M., Ponnuswamy, S., Seetharaman, S., Pothi, N., Subbarayalu, M., Muthurajan, R and Natesan, S. 2010. Screening of IR50× Rathu Heenati F<sub>7</sub> RILs and identification of SSR markers linked to brown plant hopper (*Nilaparvata lugens* Stal) resistance in rice (*Oryza sativa* L.). *Molecular biotechnology*. 46 (1): 63-71.
- Kurmanchali, M., Kuramnchali, N., Kukreti, A., Naveen, S., Himanshu, C and Mukesh, K. 2019. Study of genetic variability, heritability and genetic advance for various yield attributing and quality traits in basmati rice (*Oryza sativa* L.). *International Journal of Chemical Studies*. 7 (1): 2486-2489.
- Kusuma, B. K., Ravi Kumar, B. N. V. S. R., Rao, N.M and Rao, V.S. 2018. Assessment of Genetic Parameters for Yield and its Attributing Characters in Rice Breeding Lines. *The Andhra Agricultural Journal*. 65(1): 84-85.
- Kusuma, B. K., Rao, N.M., Ravi Kumar, B. N. V. S. R., Jyothula, D. P. B and Rao, V.S. 2018. Screening of rice breeding lines for brown plant hopper resistance using phenotypic and molecular methods. *Indian Journal of Plant Protection*. 46 (1): 8-14.
- Lawson, M.J and Zhang, L. 2006. Distinct patterns of SSR distribution in the *Arabidopsis thaliana* and rice genomes. *Genome Biology*. 7: 13-14.
- Lingaiah, N., Venkanna, V., Cheralu, C and Chandra, B.S. 2014. Variability, heritability and genetic advance for yield and yield attributing traits in midearly genotypes of rice (*Oryza sativa* L.). *International Journal of Advanced Research in Science, Engineering and Technology*. 1 (4): 179-180.
- Liu, Y., Su, C., Jiang, L., He, J.U.N., Wu, H.A.N., Peng, C and Wan, J. 2009. The distribution and identification of brown plant hopper resistance genes in rice. *Hereditas*. 146 (2): 67-73.
- Liu, G.Q., Yan, H.H., Fu, Q., Qian, Q., Zhang, Z.T., Zhai, W.X and Zhu, L.H. 2001. Mapping of a new gene for brown planthopper resistance in cultivated rice introgression from *Oryza eichingeri*. *Chinese Science Bulletin*. 46 (17): 1459-1462.
- Longjam, S and Singh, N.B. 2019. Assessment of heritability and genetic advance for yield contributing characters in hill rice (*Oryza sativa* L.) genotypes of Manipur. *The Pharma Innovation Journal*. 8 (4): 07-11.
- 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: 292-301.

- Maurya, V., Prasad, R., Meena, S., Bisen, P., Loitongbam, B., Rathi, S.R and Singh, P.K. 2018. Assessment of Genetic Variability, Correlation and Path Analysis for Yield and Yield Related Traits in Rice (*Oryza sativa* L.). *International Journal of Agriculture, Environment and Biotechnology*. 935-940.
- McCouch, S.R., Teytelman, L., Xu, Y., Lobas, K.B., Clare, K., Walton, M., Fu, B., Maghirang, R., Li, Z., Xing, Y., Zhang, Q., Kono, I., Yano, M., Fjelstrom, R., DeClerckchneider, D., Cartinhour, S., Ware, D and Stein, L. 2002. Development and Mapping of 2240 new SSR markers for rice (*Oryza sativa* L.). *DNA Research*. 9: 199-207.
- Mohanty, S.K., Panda, R.S., Mohapatra, S.L., Nanda, A., Behera, L., Jena, M., Sahu, R.K., Sahu, S.C and Mohapatra, T. 2017. Identification of novel quantitative trait loci associated with brown plant hopper resistance in the rice landrace Salkathi. *Euphytica*. 213 (2): 38.
- Murata, K., Kawaguchi, M., Ishii, T., Takumi, S., Mori, N and Nakamura, C. 2001. Assignment of a brown plant hopper (*Nilaparvata lugens* Stal.) resistance gene *bph4* to the rice chromosome 6. *Breeding Science*. 51: 13-18.
- Naik, S.B., Divya, D., Sahu, N., Sundaram, R.M., Sarao, P.S., Singh, K., Lakshmi, V.J and Bentur, J.S. 2018. A new gene Bph33 (t) conferring resistance to brown plant hopper (BPH), *Nilaparvata lugens* (Stal) in rice line RP2068-18-3-5. *Euphytica*. 214 (3): 53.
- Nayak, R., Singh, V.K., Singh, A and Singh, P.K. 2016. Genetic variability, character association and path analysis of rice genotypes. *Annals of Plant and Soil Research*. 18 (2): 161-164.
- Nguyen, H.T., Babu, R.C and Blum, A. 1997. Breeding for drought resistance in rice: physiology and molecular genetics considerations. *Crop Science*. 37 (5): 1426-1434.
- Pan, Y., Huang, L., Song, S., Hu, M., Chang, S., Lv, Q., Li, Y., Wang, T., Ouyang, X., Xiao, Y and Fu, X. 2019. Identification of brown plant hopper resistance gene Bph32 in the progeny of a rice dominant genic male sterile recurrent population using genome-wide association study and RNA-seq analysis. *Molecular Breeding*. 39 (5): 72.
- Pandey, V.R., Singh, P.K., Verma, O.P and Pandey, P. 2012. Inter-relationship path coefficient estimation in rice under salt stress environment. *International Journal of Agricultural Research*. 1-16.

- Park, D.S., Song, M.Y., Park, S.K., Lee, S.K., Lee, J.H and Song, S.Y. 2008. Molecular tagging of the Bph1 locus for resistance to brown plant hopper (*Nilaparvata lugens* Stal) through representational difference analysis. *Molecular Genetic Genomics*. 280: 163–72.
- Pathak, M.D., Cheng, C.H and Forturio, M.E. 1969. Resistance to *Nephotettix impicticeps* and *Nilaparvata lugens* in varieties of rice. *Nature*. 223: 502-504.
- Prahalada, G.D., Shivakumar, N., Lohithaswa, H.C., Gowda, D.S., Ramkumar, G., Kim, S.R., Ramachandra, C., Hittalmani, S., Mohapatra, T and Jena, K.K. 2017. Identification and fine mapping of a new gene, BPH31 conferring resistance to brown plant hopper biotype 4 of India to improve rice, (*Oryza sativa* L.). *Rice*. 10 (1): 41.
- Prithnsha, B. (2014). Evaluation of rice differential varieties against raipur brown plant hopper *Nilaparvata lugens* (stal) (Homoptera : Delphacidae) strain. M.Sc. (Ag.) Thesis, Department of Agriculture Entomology, Indira Gandhi Krishi Vishwavidyalaya, Raipur, India.
- Qiu, Y.F., Cheng, L., Liu, F and Li, R.B. 2013. Identification of a new locus conferring antixenosis to the brown plant hopper in rice cultivar Swarnalata (*Oryza sativa* L.). *Genetics and Molecular Research*. 12: 3201-3211.
- Rahman, M.L., Jiang, W., Chu, S.H., Qiao, Y., Ham, T.H., Woo, M.O., Lee, J., Khanam, M.S., Chin, J.H., Jeung, J.U and Brar, D.S. 2009. High-resolution mapping of two rice brown plant hopper resistance genes, Bph20 (t) and Bph21 (t), originating from *Oryza minuta*. *Theoretical and Applied Genetics*. 119 (7): 1237-1246.
- Rahul, S., Mankesh, K., Singh, S.P., Dharamsheela, T., Sweta, S., Anand, K., Amit, K., Mishra and Satyendra. 2018. Studies on genetic variability in rice (*Oryza sativa* L.) for control and complete flash flood Environments. *Journal of Pharmacognosy and Phytochemistry*. 1390-1396.
- Rai, S.K., Suresh B.G., Rai, P.K., Lavanya, G.R., Kumar, R and Sandhya. 2014. Genetic variability, correlation and path coefficient studies for grain yield and other yield attributing traits in rice (*Oryza sativa* L.). *International Journal of Life Sciences Research*. 2 (4): 229-234.
- Ramanjaneyulu, A.V., Shankar, V.G., Neelima, T.L and Shashibhusahn, D. 2014. Genetic analysis of rice (*Oryza sativa* L.) genotypes under aerobic conditions on alfisols. *Society for Advancement of Breeding Research in Asia and Oceania Journal of Breeding and Genetics*. 46 (1): 99-111.

- Rao, G. 2007. Statistics for Agricultural Science. BS Publications, Hyderabad. 2 :262-267.
- Rashmi, D., Saha, S., Loitongbam, B., Singh, S and Singh, P.K. 2016. Genetic variability study for yield and yield components in rice (*Oryza sativa* L.). *International Journal of Agriculture, Environment and Biotechnology*. 10 (2): 171.
- Reddy, G.E and Suresh, B.G. 2014. Variability and genetic parameters for grain yield and its components in rice (*Oryza sativa* L.) genotypes. *Progressive Research*. 9 (1): 175-176.
- Ren, J., Gao, F., Wu, X., Lu, X., Zeng, L., Lv, J., Su, X., Luo, H and Ren, G. 2016. Bph32, a novel gene encoding an unknown SCR domain-containing protein, confers resistance against the brown plant hopper in rice. *Scientific reports*. 6: 1-5.
- Ren, X., Wang, X., Yuan, H., Weng, Q., Zhu, L and He, G. 2004. Mapping quantitative trait loci and expressed sequence tags related to brown planthopper resistance in rice. *Plant Breeding*. 123: 342-348.
- Renganayaki, K., Fritz, A.K., Sadasivam, S., Pammi, S., Harrington, S.E., McCouch, S.R., Kumar, S.M and Reddy, A.S. 2002. Mapping and progress toward map-based cloning of brown plant hopper biotype-4 resistance gene introgressed from *Oryza officinalis* into cultivated rice (*Oryza sativa*). *Crop science*. 42 (6): 2112-2117.
- Sahu, P.K., Sharma, D., Sahu, P., Singh, S., Chaudhary, P.R and Sao, F.C. 2015. Assessment of genetic parameters for various quantitative and qualitative traits in hybrid rice (*Oryza sativa* L.). *International Journal of Tropical Agriculture*. 33 (1): 97-102.
- Sameera, S.K., Srinivas, T., Rajesh, A.P., Jayalakshmi, V and Nirmala, P.J. 2016. Variability and path co-efficient for yield and yield components in rice. *Bangladesh Journal of Agrilculture Research*. 41 (2): 259-271.
- Santhanalakshmi, S., Saikumar, S., Rao, S., SaiHarini, A., Khera, P., Shashidhar, H.E and Kadirvel, P. 2010. Mapping genetic locus linked to brown plant hopper resistance in rice (*Oryza sativa* L.). *International Journal of Plant Breeding and Genetics*. 4 (1): 13-22.
- Sathisha, T.N., Veerasha, B.A., Hanamaratti, N.G., Salimath, P.M., Nagaraju, C.H and Gangashetty, P.I. 2015. Genetic variability for yield, productivity and nutritional traits in diverse traditional land races of rice. *Research Journal of Agricultural Sciences*. 6 (5): 1098-1101.

- Shabanimofrad, M., Rafii, M.Y., Ashkani, S., Hanafi, M.M., Adam, N.A., Harun, A.R., Latif, M.A., Miah, G., Sahebi, M and Azizi, P. 2017. Mapping of QTL s conferring resistance in rice to brown plant hopper, *Nilaparvata lugens*. *Entomologia Experimentalis et Applicata*. 162 (1): 60-68.
- Shahriar, M.H., Robin, A.H.K and Hoque, A. 2014. Diversity assessment of yield, yield contributing traits, and earliness of advanced T-aman rice (*Oryza sativa* L.) lines. *Journal of Bioscience and Agriculture Research*. 1 (2): 102-112.
- Shrivastava, A., Mishra, D.K and Koutu, G.K. 2015. Estimation of genetic parameters of variability for yield and its attributing traits in parental lines of hybrid rice. *Plant Archives*. 15 (1): 571-574.
- Singh, A.K., Nandan, R and Singh, P.K. 2014. Genetic variability and association analysis in rice germplasm under rainfed conditions. *Crop Research*. 47 (1): 7-11.
- Singh, H., Deshmukh, R.K., Singh, A., Singh, A.K., Gaikwad, K., Sharma, T.R., Mohapatra, T and Singh, N.K., 2010. Highly variable SSR markers suitable for rice genotyping using agarose gels. *Molecular breeding*. 25 (2): 359-364.
- Sivasubramanian, S and Madhavamenon, P. 1973. Combining ability in rice. *Madras Agricultural Journal*. 60: 419-421.
- Soundararajan, R.P., Kadirvel, P., Gunathilagaraj, K and Maheswaran, M. 2004. Mapping of quantitative trait loci associated with resistance to brown plant hopper in rice by means of a doubled haploid population. *Crop science*. 44 (6): 2214-2220.
- Su, C.C., Wan, J., Zhai, H.Q., Wang, C.M., Sun, L.H., Yasui, H and Yoshimura, A. 2005. A new locus for resistance to brown plant hopper identified in the indica rice variety DV 85. *Plant breeding*. 124 (1): 93-95.
- Sumanth, V., Suresh, B.G., Ram, B.J and Srujana, G. 2017. Estimation of genetic variability, heritability and genetic advance for grain yield components in rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry*. 6 (4): 1437-1439.
- Sun, L., Liu, Y., Jiang, L., Su, C., Wang, C., Zhai, H and Wan, J. 2007. Identification of quantitative trait loci associated with resistance to brown plant hopper in the *indica* rice cultivar Col. 5 Thailand. *Hereditas*. 144 (2): 48-52.
- Tejaswini, K.L.Y., Kumar, B.N.V.S.R.R., Mohammad, L.A., Raju, S.K., Srinivas, M and Rao, P.V.R. 2016a. Study of genetic parameters in F<sub>5</sub> families of rice (*Oryza sativa* L.). *International Journal of Environment, Agriculture and Biotechnology*. 1 (4): 735-738.

- Tejaswini, K.L.Y., Kumar, B.N.V.S.R.R., Mohammad, L.A., Raju, S.K., Srinivas, M and Rao, P.V.R. 2016b. Genetic Variability, Heritability, Genetic advance and Correlation Studies F<sub>5</sub> families in Rice (*Oryza sativa* L.). *International Journal of Agricultural Science and Research*. 7 (1): 75-82.
- Tetarwal, A.S., Ram, L., Singh, R and Jat, M.K. 2014. Field screening of rice germplasm for resistance against brown plant hopper, *Nilaparvata lugens* (Stal). *Annals of Agricultural Research*. 35 (1).
- Thamarai, M and Soundararajan, R.P. 2017. Reaction of Rice genotypes against specific population of brown plant hopper, *Nilaparvata lugens* (Stal). *Annals of Plant Protection Sciences*. 25 (1): 74-77.
- Toshimenla and Changkija, S. 2013. Genetic variability in yields and its component characters in upland rice of Nagaland. *Indian Journal of Hill Farming*. 26 (2): 84-87.
- Tuwar, A.K., Singh, S.K., Sharma, A and Bhati, P.K. 2013. Appraisal of genetic variability for yield and its component characters in rice (*Oryza sativa* L.). *Biolife*. 1 (3): 84-89.
- United States Department Of Agriculture. 2018-19. Area, Production and Productivity of Rice in World.
- Vanisree, S., Swapna, K., Raju, C.D., Raju, C.S and Sreedhar, M. 2013. Genetic variability and selection criteria in rice. *Journal of Biological and Scientific Opinion*. 1 (4): 341-346.
- Vijaya, I and Shailaja, H. 2016. Assessment of genetic parameters for yield and its related traits in F<sub>2</sub> population of KRH-4 hybrid rice (*Oryza sativa* L.). *International Journal of Agricultural Science and Research*. 6 (3): 87-96.
- Wang, H., Shi, S., Guo, Q., Nie, L., Du, B., Chen, R., Zhu, L. and He, G. 2018. High-resolution mapping of a gene conferring strong antibiosis to brown plant hopper and developing resistant near-isogenic lines in 9311 background. *Molecular breeding*. 38 (8): 107.
- Wang, J., Li, H., Zhang, L and Meng, L. 2016. Integrated Software for Linkage Analysis and Genetic Mapping in Biparental Populations. *The Quantitative Genetics Group, Institute of Crop Science, Chinese Academy of Agricultural Sciences (CAAS), Beijing, China and International Maize and Wheat Improvement Center (CIMMYT), Mexico.*

- Wang, Q., Liu, Y., Hu, J., Zhang, Y., Xie, K., Wang, B., Tuyen, L., Song, Z., Wu, H., Liu, Y and Jiang, L., 2013. Detection of quantitative trait loci (QTLs) for resistances to small brown plant hopper and rice stripe virus in rice using Recombinant Inbred Lines. *International journal of molecular sciences*. 14 (4): 8406-8421.
- Wu, H., Liu, Y., He, J., Liu, Y., Jiang, L., Liu, L., Wang, C., Cheng, X and Wan, J. 2014. Fine mapping of brown plant hopper (*Nilaparvata lugens Stal*) resistance gene Bph28 (t) in rice (*Oryza sativa L.*). *Molecular breeding*. 33 (4): 909-918.
- Yang, H., Ren, X., Weng, Q., Zhu, L and He, G. 2002. Molecular mapping and genetic analysis of a rice brown plant hopper (*Nilaparvata lugens Stal*) resistance gene. *Hereditas*. 136 (1): 39-43.
- Yang, H., You, A., Yang, Z., Zhang, F., He, R., Zhu, L and He, G. 2004. High-resolution genetic mapping at the Bph15 locus for brown plant hopper resistance in rice (*Oryza sativa L.*). *Theoretical and Applied Genetics*. 110: 182–191.
- Yara, A., Phi, C.N., Matsumura, M., Yoshimura, A and Yasui, H. 2010. Development of near-isogenic lines for BPH25 (t) and BPH26 (t), which confer resistance to the brown plant hopper, *Nilaparvata lugens* (Stal.) in indica rice ‘ADR52’. *Breeding science*. 60 (5): 639-647.
- Yencho, G.C., Cohen, M.B and Byrne, P.F. 2000. Applications of tagging and mapping insect resistant loci in plants. *Annual Review of Entomology*. 45: 393-422.

\*Original not seen

---

**Note:** The pattern of literature cited presented above in accordance with the guidelines for Thesis presentation for Acharya N G Ranga Agricultural University, Guntur.

---

---

# *Appendix*

## Appendix – I

### Mean performance of rice RILs and checks for yield contributing traits during *kharif*, 2018

| S. No. | RIL name | Days to 50% flowering | Plant height (cm) | No. of ear bearing tillers per plant | Panicle length (cm) | Grain yield per plant (g) |
|--------|----------|-----------------------|-------------------|--------------------------------------|---------------------|---------------------------|
| 1      | 2711-1   | 100.00                | 116.30            | 7.90                                 | 25.00               | 13.83                     |
| 2      | 2711-2   | 95.00                 | 149.80            | 9.60                                 | 27.80               | 13.58                     |
| 3      | 2711-3   | 96.00                 | 149.20            | 8.95                                 | 29.30               | 12.65                     |
| 4      | 2711-4   | 97.00                 | 133.90            | 8.50                                 | 25.65               | 13.85                     |
| 5      | 2711-5   | 97.00                 | 140.70            | 9.30                                 | 27.00               | 16.05                     |
| 6      | 2711-6   | 100.00                | 118.10            | 9.75                                 | 29.05               | 14.55                     |
| 7      | 2711-7   | 95.00                 | 138.60            | 10.85                                | 30.90               | 12.08                     |
| 8      | 2711-8   | 92.00                 | 155.20            | 10.20                                | 26.80               | 11.93                     |
| 9      | 2711-9   | 97.00                 | 144.10            | 10.40                                | 29.05               | 13.35                     |
| 10     | 2711-11  | 92.00                 | 151.90            | 10.10                                | 27.05               | 12.91                     |
| 11     | 2711-13  | 93.00                 | 134.10            | 7.65                                 | 29.45               | 16.25                     |
| 12     | 2711-14  | 97.00                 | 128.70            | 9.95                                 | 27.80               | 12.05                     |
| 13     | 2711-15  | 92.00                 | 136.50            | 8.15                                 | 29.80               | 10.60                     |
| 14     | 2711-16  | 96.00                 | 103.90            | 9.25                                 | 27.60               | 10.75                     |
| 15     | 2711-17  | 95.00                 | 129.50            | 8.30                                 | 27.75               | 12.95                     |
| 16     | 2711-18  | 96.00                 | 119.80            | 8.00                                 | 28.15               | 13.36                     |
| 17     | 2711-19  | 96.50                 | 137.80            | 8.80                                 | 30.40               | 12.65                     |
| 18     | 2711-20  | 91.00                 | 111.00            | 9.15                                 | 28.05               | 13.45                     |
| 19     | 2711-22  | 98.00                 | 110.50            | 8.00                                 | 27.85               | 11.70                     |
| 20     | 2711-23  | 92.00                 | 110.50            | 8.05                                 | 25.50               | 10.30                     |

| <b>S. No.</b> | <b>RIL name</b> | <b>Days to 50% flowering</b> | <b>Plant height (cm)</b> | <b>No. of ear bearing tillers per plant</b> | <b>Panicle length (cm)</b> | <b>Grain yield per plant (g)</b> |
|---------------|-----------------|------------------------------|--------------------------|---|----------------------------|----------------------------------|
| 21            | 2711-24         | 92.00                        | 110.90                   | 8.75  | 30.55                      | 11.66                            |
| 22            | 2711-25         | 99.00                        | 115.50                   | 9.35  | 29.05                      | 14.50                            |
| 23            | 2711-26         | 96.00                        | 115.30                   | 7.75  | 25.90                      | 13.75                            |
| 24            | 2711-27         | 97.00                        | 128.40                   | 8.40  | 28.40                      | 11.70                            |
| 25            | 2711-28         | 92.00                        | 127.40                   | 10.20                                       | 29.40                      | 13.58                            |
| 26            | 2711-29         | 97.00                        | 142.40                   | 8.30  | 27.70                      | 11.25                            |
| 27            | 2711-30         | 93.00                        | 127.00                   | 7.10  | 27.25                      | 11.72                            |
| 28            | 2711-31         | 98.00                        | 100.60                   | 8.70  | 29.00                      | 17.90                            |
| 29            | 2711-32         | 100.00                       | 116.30                   | 7.90  | 25.00                      | 13.83                            |
| 30            | 2711-33         | 102.00                       | 149.90                   | 9.35  | 27.00                      | 4.05                             |
| 31            | 2711-34         | 93.00                        | 122.50                   | 8.70  | 27.40                      | 11.60                            |
| 32            | 2711-35         | 95.00                        | 119.60                   | 8.15  | 28.80                      | 10.07                            |
| 33            | 2711-36         | 93.00                        | 114.00                   | 7.20  | 27.85                      | 15.72                            |
| 34            | 2711-37         | 93.00                        | 119.00                   | 8.30  | 28.10                      | 20.36                            |
| 35            | 2711-38         | 92.00                        | 128.50                   | 8.40  | 25.50                      | 11.70                            |
| 36            | 2711-39         | 93.00                        | 130.60                   | 8.05  | 29.10                      | 10.43                            |
| 37            | 2711-40         | 99.00                        | 148.40                   | 8.20  | 30.50                      | 16.95                            |
| 38            | 2711-41         | 95.00                        | 147.70                   | 9.10  | 29.40                      | 13.97                            |
| 39            | 2711-43         | 100.00                       | 155.50                   | 8.40  | 28.80                      | 12.10                            |
| 40            | 2711-44         | 99.00                        | 125.40                   | 7.55  | 31.75                      | 9.75                             |
| 41            | 2711-45         | 94.00                        | 133.80                   | 7.60  | 30.50                      | 13.30                            |
| 42            | 2711-46         | 94.00                        | 152.90                   | 8.15  | 28.45                      | 15.80                            |
| 43            | 2711-47         | 94.00                        | 161.50                   | 8.20  | 25.25                      | 13.13                            |

| <b>S. No.</b> | <b>RIL name</b> | <b>Days to 50% flowering</b> | <b>Plant height (cm)</b> | <b>No. of ear bearing tillers per plant</b> | <b>Panicle length (cm)</b> | <b>Grain yield per plant (g)</b> |
|---------------|-----------------|------------------------------|--------------------------|---|----------------------------|----------------------------------|
| 44            | 2711-49         | 96.00                        | 146.80                   | 8.15  | 29.65                      | 12.10                            |
| 45            | 2711-50         | 98.00                        | 133.10                   | 8.05  | 24.90                      | 16.65                            |
| 46            | 2711-52         | 92.00                        | 141.10                   | 9.05  | 27.80                      | 15.75                            |
| 47            | 2711-53         | 100.00                       | 144.10                   | 9.30  | 29.50                      | 16.70                            |
| 48            | 2711-54         | 97.00                        | 145.10                   | 7.70  | 26.00                      | 12.35                            |
| 49            | 2711-55         | 100.00                       | 136.80                   | 7.30  | 30.70                      | 13.05                            |
| 50            | 2711-56         | 93.00                        | 149.40                   | 7.40  | 25.00                      | 12.10                            |
| 51            | 2711-57         | 102.00                       | 140.40                   | 7.90  | 26.55                      | 14.75                            |
| 52            | 2711-58         | 99.00                        | 145.50                   | 7.95  | 27.50                      | 14.91                            |
| 53            | 2711-59         | 100.00                       | 134.40                   | 8.00  | 26.50                      | 12.30                            |
| 54            | 2711-60         | 98.00                        | 152.90                   | 7.70  | 30.70                      | 13.70                            |
| 55            | 2711-61         | 98.00                        | 172.70                   | 7.95  | 29.50                      | 16.30                            |
| 56            | 2711-62         | 101.00                       | 148.60                   | 8.70  | 24.90                      | 8.58                             |
| 57            | 2711-63         | 92.00                        | 162.50                   | 7.70  | 27.05                      | 10.18                            |
| 58            | 2711-64         | 97.00                        | 146.80                   | 8.10  | 27.45                      | 12.80                            |
| 59            | 2711-65         | 101.00                       | 143.20                   | 7.50  | 28.85                      | 13.74                            |
| 60            | 2711-66         | 97.00                        | 110.10                   | 8.25  | 30.00                      | 14.38                            |
| 61            | 2711-67         | 98.00                        | 127.10                   | 7.30  | 30.40                      | 12.05                            |
| 62            | 2711-68         | 101.00                       | 130.40                   | 8.15  | 30.45                      | 14.51                            |
| 63            | 2711-69         | 97.00                        | 142.80                   | 7.60  | 29.50                      | 16.05                            |
| 64            | 2711-71         | 96.00                        | 135.10                   | 7.20  | 28.80                      | 15.86                            |
| 65            | 2711-72         | 96.00                        | 128.80                   | 7.30  | 27.60                      | 14.97                            |
| 66            | 2711-73         | 94.00                        | 140.00                   | 7.60  | 30.50                      | 13.31                            |

| <b>S. No.</b> | <b>RIL name</b> | <b>Days to 50% flowering</b> | <b>Plant height (cm)</b> | <b>No. of ear bearing tillers per plant</b> | <b>Panicle length (cm)</b> | <b>Grain yield per plant (g)</b> |
|---------------|-----------------|------------------------------|--------------------------|---|----------------------------|----------------------------------|
| 67            | 2711-74         | 101.00                       | 140.90                   | 7.60  | 31.50                      | 14.60                            |
| 68            | 2711-75         | 103.00                       | 143.40                   | 8.30  | 30.45                      | 14.72                            |
| 69            | 2711-76         | 92.00                        | 153.00                   | 7.55  | 31.40                      | 12.75                            |
| 70            | 2711-77         | 92.00                        | 120.70                   | 8.40  | 26.85                      | 11.45                            |
| 71            | 2711-78         | 94.00                        | 139.90                   | 7.75  | 28.30                      | 7.86                             |
| 72            | 2711-79         | 92.00                        | 126.90                   | 8.15  | 27.20                      | 9.85                             |
| 73            | 2711-80         | 92.00                        | 135.50                   | 7.90  | 25.60                      | 14.25                            |
| 74            | 2711-83         | 95.00                        | 126.20                   | 9.00  | 12.00                      | 7.50                             |
| 75            | 2711-84         | 96.00                        | 142.40                   | 7.75  | 28.00                      | 16.65                            |
| 76            | 2711-86         | 92.00                        | 104.00                   | 7.75  | 32.15                      | 13.66                            |
| 77            | 2711-87         | 92.00                        | 114.40                   | 8.00  | 27.80                      | 9.35                             |
| 78            | 2711-88         | 97.00                        | 138.10                   | 8.40  | 29.90                      | 19.85                            |
| 79            | 2711-89         | 92.00                        | 132.70                   | 8.05  | 30.80                      | 13.05                            |
| 80            | 2711-92         | 101.00                       | 124.20                   | 8.60  | 29.00                      | 12.95                            |
| 81            | 2711-93         | 95.00                        | 124.40                   | 7.80  | 27.25                      | 12.02                            |
| 82            | 2711-94         | 92.00                        | 123.20                   | 7.60  | 26.00                      | 16.60                            |
| 83            | 2711-100        | 95.00                        | 147.90                   | 8.00  | 29.25                      | 17.65                            |
| 84            | 2711-101        | 100.00                       | 104.90                   | 7.90  | 24.50                      | 11.86                            |
| 85            | 2711-102        | 96.00                        | 146.50                   | 8.60  | 30.80                      | 12.30                            |
| 86            | 2711-103        | 92.00                        | 132.40                   | 7.80  | 28.50                      | 14.15                            |
| 87            | 2711-104        | 97.00                        | 123.80                   | 7.85  | 29.20                      | 12.50                            |
| 88            | 2711-105        | 101.00                       | 130.00                   | 7.85  | 30.65                      | 11.70                            |
| 89            | 2711-106        | 95.00                        | 136.60                   | 7.40  | 28.90                      | 12.80                            |

| <b>S. No.</b> | <b>RIL name</b> | <b>Days to 50% flowering</b> | <b>Plant height (cm)</b> | <b>No. of ear bearing tillers per plant</b> | <b>Panicle length (cm)</b> | <b>Grain yield per plant (g)</b> |
|---------------|-----------------|------------------------------|--------------------------|---|----------------------------|----------------------------------|
| 90            | 2711-107        | 95.00                        | 148.70                   | 7.80  | 28.60                      | 12.61                            |
| 91            | 2711-108        | 101.00                       | 113.80                   | 7.70  | 27.65                      | 11.85                            |
| 92            | 2711-110        | 97.00                        | 118.30                   | 8.80  | 24.00                      | 13.40                            |
| 93            | 2711-111        | 93.00                        | 109.80                   | 8.80  | 25.10                      | 10.65                            |
| 94            | 2711-112        | 96.00                        | 142.50                   | 7.70  | 28.15                      | 15.41                            |
| 95            | 2711-113        | 92.00                        | 126.20                   | 8.00  | 31.20                      | 12.50                            |
| 96            | 2711-115        | 94.00                        | 128.60                   | 8.25  | 25.00                      | 9.90                             |
| 97            | 2711-116        | 93.00                        | 128.50                   | 9.10  | 30.00                      | 10.47                            |
| 98            | 2711-117        | 92.00                        | 130.30                   | 9.00  | 29.90                      | 12.23                            |
| 99            | 2711-119        | 96.00                        | 125.90                   | 9.60  | 29.50                      | 12.50                            |
| 100           | 2711-120        | 93.00                        | 129.90                   | 9.40  | 28.90                      | 11.80                            |
| 101           | 2711-122        | 99.00                        | 132.80                   | 9.75  | 29.30                      | 13.00                            |
| 102           | 2711-123        | 92.00                        | 110.20                   | 8.60  | 30.50                      | 13.15                            |
| 103           | 2711-125        | 91.00                        | 114.10                   | 7.75  | 27.50                      | 11.35                            |
| 104           | 2711-127        | 98.00                        | 131.10                   | 7.70  | 31.00                      | 13.75                            |
| 105           | 2711-129        | 95.00                        | 138.00                   | 9.55  | 27.00                      | 14.30                            |
| 106           | 2711-130        | 93.00                        | 153.50                   | 8.70  | 28.65                      | 13.25                            |
| 107           | 2711-131        | 91.00                        | 126.80                   | 9.95  | 29.00                      | 14.30                            |
| 108           | 2711-133        | 94.00                        | 134.70                   | 10.00                                       | 28.00                      | 15.00                            |
| 109           | 2711-137        | 96.00                        | 115.20                   | 9.65  | 29.75                      | 14.28                            |
| 110           | 2711-140        | 97.00                        | 114.90                   | 10.10                                       | 31.10                      | 10.95                            |
| 111           | 2711-143        | 94.00                        | 127.00                   | 9.00  | 28.95                      | 11.80                            |
| 112           | 2711-147        | 98.00                        | 137.30                   | 9.25  | 26.75                      | 13.83                            |

| <b>S. No.</b> | <b>RIL name</b> | <b>Days to 50% flowering</b> | <b>Plant height (cm)</b> | <b>No. of ear bearing tillers per plant</b> | <b>Panicle length (cm)</b> | <b>Grain yield per plant (g)</b> |
|---------------|-----------------|------------------------------|--------------------------|---|----------------------------|----------------------------------|
| 113           | 2711-149        | 104.00                       | 136.40                   | 9.45  | 29.85                      | 8.05                             |
| 114           | 2711-150        | 104.00                       | 150.70                   | 10.95                                       | 31.05                      | 11.60                            |
| 115           | 2711-151        | 104.00                       | 123.90                   | 11.75                                       | 29.15                      | 7.80                             |
| 116           | 2711-162        | 100.00                       | 119.10                   | 8.30  | 28.25                      | 11.50                            |
| 117           | 2711-164        | 92.00                        | 142.70                   | 8.60  | 27.00                      | 13.00                            |
| 118           | 2711-167        | 96.00                        | 145.90                   | 9.20  | 29.70                      | 15.50                            |
| 119           | 2711-168        | 92.00                        | 140.20                   | 8.70  | 30.75                      | 16.38                            |
| 120           | 2711-169        | 98.00                        | 142.20                   | 10.10                                       | 29.80                      | 13.83                            |
| 121           | 2711-170        | 96.00                        | 138.40                   | 9.65  | 29.90                      | 11.75                            |
| 122           | 2711-172        | 107.00                       | 155.70                   | 9.75  | 30.10                      | 10.25                            |
| 123           | 2711-175        | 96.00                        | 154.90                   | 9.65  | 29.75                      | 15.33                            |
| 124           | 2711-176        | 98.00                        | 136.50                   | 10.70                                       | 31.00                      | 8.75                             |
| 125           | 2711-177        | 104.00                       | 131.70                   | 14.35                                       | 31.25                      | 11.05                            |
| 126           | 2711-178        | 105.00                       | 142.10                   | 11.35                                       | 27.75                      | 13.45                            |
| 127           | 2711-179        | 106.00                       | 156.00                   | 11.25                                       | 27.75                      | 15.25                            |
| 128           | 2711-182        | 106.00                       | 159.50                   | 8.60  | 31.50                      | 9.15                             |
| 129           | 2711-184        | 102.00                       | 141.90                   | 11.50                                       | 28.35                      | 13.30                            |
| 130           | 2711-185        | 103.00                       | 125.10                   | 13.70                                       | 28.80                      | 12.40                            |
| 131           | 2711-186        | 92.00                        | 111.50                   | 8.50  | 28.60                      | 14.08                            |
| 132           | 2711-187        | 103.00                       | 145.00                   | 10.75                                       | 30.35                      | 13.75                            |
| 133           | 2711-188        | 91.00                        | 138.50                   | 9.70  | 30.65                      | 13.30                            |
| 134           | 2711-189        | 102.00                       | 135.30                   | 10.65                                       | 30.75                      | 14.25                            |
| 135           | 2711-191        | 98.00                        | 112.00                   | 8.80  | 32.10                      | 16.15                            |

| S. No. | RIL name    | Days to 50% flowering | Plant height (cm) | No. of ear bearing tillers per plant | Panicle length (cm) | Grain yield per plant (g) |
|--------|-------------|-----------------------|-------------------|--------------------------------------|---------------------|---------------------------|
| 136    | 2711-192    | 97.00                 | 120.00            | 6.70                                 | 31.20               | 13.45                     |
| 137    | 2711-193    | 102.00                | 143.70            | 8.10                                 | 31.60               | 14.33                     |
| 138    | 2711-195    | 96.00                 | 140.00            | 8.15                                 | 28.40               | 12.40                     |
| 139    | 2711-196    | 92.00                 | 137.70            | 7.75                                 | 28.05               | 13.30                     |
| 140    | 2711-197    | 91.00                 | 127.90            | 9.20                                 | 28.10               | 19.40                     |
| 141    | 2711-198    | 93.00                 | 114.00            | 8.70                                 | 25.65               | 11.75                     |
| 142    | 2711-199    | 95.00                 | 143.50            | 7.75                                 | 29.20               | 12.40                     |
| 143    | MTU7029     | 119.00                | 106.00            | 8.40                                 | 25.40               | 16.00                     |
| 144    | MTU1075     | 113.00                | 114.70            | 9.00                                 | 26.70               | 17.80                     |
|        | <b>MEAN</b> | <b>97.00</b>          | <b>133.06</b>     | <b>8.70</b>                          | <b>28.48</b>        | <b>13.13</b>              |
|        | C.D. (0.05) | 4.21                  | 13.42             | 1.83                                 | 3.88                | 2.22                      |
|        | C.V.(%)     | 4.88                  | 11.39             | 15.92                                | 9.46                | 19.85                     |

\*Significant at 5% level

\*\*Significant at 1% level