STUDIES ON MECHANISM OF RESISTANCE TO BROWN PLANTHOPPER, *Nilaparvata lugens* (STAL.) IN RICE

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PAK 9094

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
UNIVERSITY OF AGRICULTURAL SCIENCES
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JULY, 2011 BENGALURU

Affectionately dedicated to

Father, Sri. Chandrashekar, M. J

Mother, Smt. Shashikala, M. C

Sister, Arpitha

And

Chairman

Dr. D. K. Sidde Gowda

DEPARTMENT OF AGRICULTURAL ENTOMOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "**STUDIES ON MECHANISM OF RESISTANCE TO BROWN PLANTHOPPER, *Nilaparvata lugens* (STAL.) IN RICE**" submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (Agriculture) in AGRICULTURAL ENTOMOLOGY** of the University of Agricultural Sciences, Bengaluru, is a record of research work done by **Mr. AKSHAYA, M. C., ID No. PAK 9094** during the period of his study in the University under my guidance and supervision and that no part of thesis has been submitted for the award of any degree, diploma, associateship, fellowship or other similar titles.

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With regardful memories .....

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July, 2011 **(Mr. Akshaya, M. C)**

STUDIES ON MECHANISM OF RESISTANCE TO BROWN PLANTHOPPER, *Nilaparvata lugens* (STAL.) IN RICE

ABSTRACT

The investigations on Evaluation of rice genotypes against brown planthopper population under field and glasshouse, characterization of rice brown planthopper (BPH), *Nilaparvatalugens* (Stal.) population of Mandya using differentials and determination of biochemical factors in select BPH resistant and susceptible rice cultures were conducted at Zonal Agricultural Research Station, V. C. farm, Mandya during 2010-2011. Two hundred and eighty three rice entries were screened in glasshouse and field against BPH. Among the fifty seven PHS entries, CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149 and CR 2712-12; in the fifty three multiple pest resistant entries CORH-3 and DRRH-2; in the one hundred and seventy three NSN1 entries, CR 2698, CR 2702, CR 2618, CR 2707 and HKR 06-47 were found to be resistant to BPH. The studies on the days to wilting, percent unhatchabality of eggs, nymphal survival, honeydew excretion indicated susceptibility of differential varieties *viz.,* RathuHeenati, Sinnasivappu, MR 1523, INRC 3021 and MO1 to the BPH populations of Mandya compared to resistant check PTB 33. The resistant entries had relatively higher content of total phenol (20.61 mg/g), lower content of crude protein (4.14 %), total soluble protein (1.81 mg/g), total soluble sugars (28.447 mg/g) and reducing sugars (15.69 mg/g) compared to susceptible check TN1. Further, the analysis for major nutrients revealed that, the resistant entries had relatively lower content of nitrogen (0.66 %) and higher content of potassium (1.76 %) compared to susceptible check TN1. The micronutrients content (iron, manganese and copper) did not vary among the resistant and susceptible entries except for zinc.Based on these findings, it may be concluded that, the entries *viz.,*CORH-3, CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2698, CR 2702, CR 2618, CR 2707, MAS 946, IET 7575 and IET 8116 (damage score of 1) could be utilized in resistance breeding programme against BPH.

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UAS, GKVK, Bangalore

Dr. D. K. Sidde Gowda
(Major Advisor)

ಶೀರ್ಷಿಕೆ: ಭತ್ತದ ಕಂದು ಜಿಗಿ ಹುಳುವಿನ, *ನೀಲಪರ್ವತ ಲುಜೆಂಸ್* (ಸ್ಟಾಲ್.) ನಿರೋಧಕತೆಯ ಕೌಶಲ್ಯ

ಪ್ರಬಂಧದ ಸಾರಂಶ

ಭತ್ತದ ಕಂದು ಜಿಗಿ ಹುಳುವಿಗೆ ನಿರೋಧಕ ತಳಿಗಳನ್ನು ಗುರುತಿಸಲು, ಮಂಡ್ಯದ ಕಂದು ಜಿಗುಹುಳುವಿನ ಗುಣವನ್ನು ಅರಿಯಲು ಹಾಗೂ ವಿವಿಧ ತಳಿಗಳ ಜೀವ ರಸಾಯನಿಕ ಕಾರಣಗಳನ್ನು ಗುರುತಿಸಲು ಮಂಡ್ಯದ ಕೃಷಿ ಸಂಶೋಧನ ಕೇಂದ್ರ, ವಿ.ಸಿ. ಫಾರಂನಲ್ಲಿ 2010-11ರ ಅವಧಿಯಲ್ಲಿ ಪ್ರಯೋಗಗಳನ್ನು ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು. ಒಟ್ಟು ಎರಡನೂರ ಎಂಬತ್ತೂ್ಕರು ವಿವಿಧ ಭತ್ತದ ತಳಿಗಳನ್ನು ಗಾಜಿನ ಮನೆ ಮತ್ತು ಕ್ಷೇತ್ರ ಪ್ರಯೋಗಗಳಲ್ಲಿ ಕಂದು ಜಿಗಿಹುಳುವಿಗೆ ನಿರೋಧಕ ಗುಣವನ್ನು ಗುರುತಿಸಲು ಬಳಸಲಾಯಿತು. ಇವುಗಳಲ್ಲಿ ದೇಶದ ವಿವಿಧ ಭಾಗಗಳಲ್ಲಿ ಕಂದು ಜಿಗಿ ಹುಳುವಿಗೆ ನಿರೋಧಕತೆ ಹೊಂದಿರುವ ಐವತ್ತೇಳು ತಳಿಗಳು (ಪಿ.ಎಚ್.ಎಸ್). ಅವುಗಳಲ್ಲಿ ಸಿ.ಬಿ 00-15-64, ಸಿ.ಆರ್ 2711-76, ಸಿ.ಆರ್ 2711-114, ಸಿ.ಆರ್ 2711-139, ಸಿ.ಆರ್ 2711-149 ಮತ್ತು ಸಿ.ಆರ್ 2712-12; ಐವತ್ತೂ್ಕರು ವಿವಿಧ ಪೀಡೆ ನಿರೋಧಕ ತಳಿಗಳಲ್ಲಿ, ಸಿ.ಓ.ಆರ್.ಎಚ್-3 ಮತ್ತು ಡಿ.ಆರ್.ಆರ್.ಎಚ್-2; ಒಂದು ನೂರ ಎಪ್ಪತ್ತೂ್ಕರು ರಾಷ್ಟ್ರೀಯ ಸ್ಕ್ರೀನಿಂಗ್ ನರ್ಸರಿ–1 (ಎನ್.ಎಸ್.ಎನ್ -1) ತಳಿಗಳಲ್ಲಿ, ಸಿ.ಆರ್ 2098, ಸಿ.ಆರ್ 2702, ಸಿ.ಆರ್ 2618, ಸಿ.ಆರ್ 2707 ಮತ್ತು ಎಚ್.ಕೆ.ಆರ್ 06-47 ಕಂದು ಜಿಗಿಹುಳುವಿಗೆ ನಿರೋಧಕ ಶಕ್ತಿ ಹೊಂದಿರುವುದು ಕಂಡು ಬಂದಿತು. ಗಿಡ ಬಾಡುವುದಕ್ಕೆ ದಿನಗಳು, ಶೇಕಡ ಒಡೆಯದ ಮೊಟ್ಟೆಗಳು, ಕಂದು ಜಿಗಿಹುಳುವಿನ ಆಪ್ಸರೆಗಳ ಬದುಕುವಿಕೆ, ಸಿಹಿದ್ರವ ಉತ್ಪಾದನೆಯ ಪ್ರಯೋಗವನ್ನು ಕೈಗೊಳ್ಳಲಾಗಿತ್ತು. ಅದರಲ್ಲಿ ರತುಹೀನಾತಿ, ಸಿನ್ನ ಸಿವಪ್ಪು, ಎಂ.ಆರ್.1523, ಐ.ಎನ್.ಆರ್.ಸಿ. 3021 ಮತ್ತು ಎಂ.ಓ–1 ತಳಿಗಳು, ಮಂಡ್ಯದ ಕಂದು ಜಿಗಿಹುಳುವಿಗೆ ನಿರೋಧಕ ತಳಿ ಪಿ.ಟಿ.ಬಿ 33ಕ್ಕೆ ಹೋಲಿಸಿದಾಗ ನಿರೋಧಕ ಶಕ್ತಿ ಹೊಂದಿಲ್ಲದಿರುವುದು ಕಂಡು ಬಂದಿದೆ. ನಿರೋಧಕ ತಳಿಗಳಲ್ಲಿ ನಿರೋಧಕ ರಹಿತ ಟಿ.ಎನ್ 1ಗಿಂತ ಹೆಚ್ಚಿನ ಫಿನಾಲ್ (20.61 ಮಿ.ಗ್ರಾಂ./ಗ್ರಾಂ. ಕಡಿಮೆ ಕಚ್ಚಾ ಸಸಾರಜನಕ (4.14%), ಒಟ್ಟು ಕರಗಬಲ್ಲ ಸಸಾರಜನಕ (1.81 ಮಿ.ಗ್ರಾಂ./ಗ್ರಾಂ.), ಒಟ್ಟು ಕರಗಬಲ್ಲ ಸಕ್ಕರೆ ಅಂಶಗಳು (28.77 ಮಿ.ಗ್ರಾಂ./ಗ್ರಾಂ.) ಮತ್ತು ಕ್ಷೀಣಿಸುವ ಸಕ್ಕರೆಗಳು (15.69 ಮಿ.ಗ್ರಾಂ./ಗ್ರಾಂ.) ಕಂಡು ಬಂದವು. ನಿರೋಧಕ ತಳಿಗಳಲ್ಲಿ ನಿರೋಧಕತೆ ರಹಿತ ತಳಿ ಟಿ.ಎನ್ 1 ಗಿಂತ ಅತ್ಯಂತ ಕಡಿಮೆ ಸಾರಜನಕ (0.66%) ಹಾಗೂ ಹೆಚ್ಚಿನ ಪೊಟ್ಯಾಷಿಯಂ (1.76%) ಕಂಡು ಬಂದಿತ್ತು. ಲಘು ಪೋಷಕಾಂಶಗಳಲ್ಲಿ ಸತುವನ್ನು ಹೊರತುಪಡಿಸಿ ಕಬ್ಬಿಣ, ಮ್ಯಾಂಗನೀಸ್ ಮತ್ತು ತಾಮ್ರದ ಪ್ರಮಾಣ ನಿರೋಧಕ ಮತ್ತು ನಿರೋಧಕತೆ ರಹಿತ ತಳಿಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ಬದಲಾವಣೆ ಕಂಡು ಬರಲಿಲ್ಲ. ಈ ಎಲ್ಲಾ ಅಂಶಗಳನ್ನು ಗಮನಿಸಿದಾಗ ಸಿ.ಓ.ಆರ್.ಎಚ್ -3, ಸಿ.ಬಿ 00-15-64, ಸಿ.ಆರ್ 2711-76, ಸಿ.ಆರ್ 2711-114, ಸಿ.ಆರ್ 2711-139, ಸಿ.ಆರ್ 2711-149, ಸಿ.ಆರ್ 2712-12, ಆರ್.ಪಿ ಬಯೋ 4918, ಸಿ.ಆರ್ 2698, ಸಿ.ಆರ್ 2702, ಸಿ.ಆರ್ 2618, ಸಿ.ಆರ್ 2707, ಎಮ್.ಎ.ಎಸ್ 946, ಐ.ಇ.ಟಿ 7575 ಮತ್ತು ಐ.ಇ.ಟಿ 8116. ತಳಿಗಳು ಭತ್ತದ ಕಂದು ಜಿಗಿಹುಳುವಿಗೆ ನಿರೋಧಕ ಶಕ್ತಿ ಹೊಂದಿರುವುದು ರುಜುವಾತಾಗುತ್ತದೆ ಹಾಗೂ ಈ ತಳಿಗಳನ್ನು ಭತ್ತದ ಕಂದು ಜಿಗಿಹುಳುವಿನ ನಿರೋಧಕ ತಳಿಗಳ ಅಭಿವೃದ್ಧಿಯಲ್ಲಿ ಬಳಸಬಹುದಾಗಿದೆ.

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(ಪ್ರಧಾನ ಸಲಹೆಗಾರರು)

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Introduction

I. INTRODUCTION

Rice is a staple food for a large part of the world's human population, especially in East, South and Southeast Asia, making it the second most consumed cereal grain. In India, the area under rice is 43.18 million ha, with an annual production of 97 million tonnes and an average yield of 2101 kg per ha. The production of rice in India has shown an increasing trend. The demand for rice in India is projected at 128 million tonnes for the year 2012 and will require a productivity level of 3,000 kg per ha, which is significantly greater than the present average yield of 1,930 kg per ha. The Government of India is targeting to achieve an annual total production of 129 million tonnes of rice by 2011-12, with a growth rate of 3.7 per cent along with other food grains (Anon., 2009).

Rice is affected by more than two hundred insects pests of which about a dozen are economically important (Grist and Lever, 1969). Based on published literature, Gunathilagaraj and Ganesh Kumar (1997) listed 537 species of organisms in rice, which included 385 insects, 51 nematodes, 15 mites, 5 earthworms, 7 snails, 2 tadpole shrimps, one eel fish, 9 crabs, 3 large mammals, 4 rodents and 54 birds in India.

Among the several insect pests of rice, brown planthopper (BPH), *Nilaparvata lugens* (Stal.) is a major one which severely damages rice crop successively every year, in most of the Asian countries. In most serious cases of infestation, BPH causes hopper burn and transmits different viral disease (Jena *et al.*, 2006).

In Karnataka, rice is cultivated in an area of 1.4 million ha, with an annual production of 3.45 million tonnes with an average yield per ha of 2470 kg per ha. BPH is an endemic pest in all the major command areas in Karnataka. The pest was first reported in Mandya district of

Karnataka in 1975 (Channabasavanna *et al.*, 1976). Severe outbreak of this pest was noticed during eighties in Cauvery, Bhadra and in Tungabhadra command areas during *Kharif* 2009 and severity was also observed in Haveri, Shimoga, Uttar Kannada, parts of Mandya and Mysore districts (Sidde Gowda and Gubbaiah, 2009).

In recent years, BPH infestations have intensified across Asia, causing heavy yield losses in rice. As the popular rice varieties are susceptible to planthoppers, farmers depend solely on chemical pesticides for controlling this insect, which are expensive in terms of labour, cost and also pose environmental hazards. In addition, overuse of pesticides destroy the natural predators and leads to the development of insecticidal resistance, which results in pest resurgence. The most economical and environment-friendly strategy to control this insect is to grow varieties genetically resistant to BPH.

Though some BPH resistant rice genotypes have been identified, there has been break-down of resistance. The intensive cultivation of rice, late planting and continuous cultivation coupled with excessive use of nitrogenous fertilizers often compels the farmers to use excess application of insecticides to safeguard the crop. Thus the indiscriminate use of insecticides has exacerbated the BPH problem with an upsurge of the pest. Consequently, the pest has become unmanageable in parts of Cauvery and Bhadra command areas of Karnataka. Therefore, an urgent need was felt to take up studies on identification of new donors, pest virulence pattern in Karnataka and mechanism of BPH resistance in rice. Hence, this study was undertaken with the following objectives:

1. Evaluation of selected rice genotypes against brown planthopper population in field and glasshouse at Zonal Agricultural Research Station (ZARS), Mandya.

2. Characterization of rice brown planthopper population using differentials.

3. Determination of few biochemical factors in selected BPH resistant and susceptible genotypes.

Review of Literature

II. REVIEW OF LITERATURE

The literature pertaining to studies on mechanisms of resistance to brown planthopper (BPH), *Nilaparvata lugens* in rice is reviewed and presented here; under appropriate headings.

2.1 Evaluation of select rice genotypes against brown planthopper population in field and glasshouse

Plant resistance is the most economic and desirable method for the management of pests of crop plants. The major mechanisms involved in host plant resistance are antixenosis, antibiosis and tolerance (Painter, 1951). The utilization of plant's own defence mechanisms is an attractive area of research practiced all over the world to manage crop pests and diseases.

Kaneda *et al*. (1981) screened 3,300 cultivars and breeding lines from different regions of the world in Japan. Most of the resistant traditional cultivars came from Kerala, Tamil Nadu and Andhra Pradesh states of Southern India and Sri Lanka. Based on the reaction patterns of these varieties to different biotypes the proportion of resistance genes found in Sri Lankan traditional varieties was different from those in India. About 60 per cent of the Sri Lankan cultivars were found to possess resistance gene *bph2*, in contrast only 10 per cent of the Indian cultivars tested had this gene.

Out of the 1250 rice cultivars and cultures screened against *Nilaparvata lugens*, 59 cultivars and 15 cultures were identified as resistant to the pest. Of these, 12 cultivars had been earlier reported as resistant in other parts of India, while the rest constituted newly identified potential donors for utilization in future breeding programmes (Rao, 1986).

Of the 38 cross combinations screened against *N. lugens* and *Sogatella furcifera* (Hovarth), nine were resistant to both pests, six to *N. lugens* and six to *S. furcifera*. In most of the hybrids, the resistance to *N. lugens* was mainly due to antibiosis, while for *S. furcifera* the mechanism was mainly tolerance (Zhang *et al.*, 1987).

Among the 128 entries assessed at 90 and 110 days after sowing, 10 were free from damage by *N. lugens*, of which IET 8675 derived from the hybrid Mudgo X PTB 33 was resistant to *N. lugens* (Uthamasamy, 1987).

In China, out of the 2231 accessions of rice introduced from IRRI (Philippines), Chianung Si-Pi661020, IR8608-82-1-3-1-3, IR36, Milyang 54, IR9782-111-2-1-2, Suweon 290 and IR21848-65-3-2-2 had resistance to white-backed planthopper (*Sogatella furcifera*) and brown planthopper (*Nilaparvata lugens*) (Shen and Hu, 1988).

Of 128 wild rices (*Oryza* spp.) screened for resistance to *Nilaparvata lugens* in greenhouse tests in India, 83 were resistant to the BPH, *N. lugens* caged on resistant accessions had slow nymphal development, reduced longevity and low fecundity (Velusamy, 1988).

The results of field tests conducted in Bangladesh in 1986-87 to evaluate the resistance of various cultivars of rice to major insect pests are summarized. Of the rice cultivars tested, NS1 was found to be moderately resistant to the *N. lugens* (Husain *et al.,* 1988).

Of the 45 varieties and lines evaluated, Nanjing 3714 (indica) was resistant to *N. lugens* whereas Japonica genotypes were generally more susceptible to BPH (Gu *et al.*, 1989).

Resistance to nine insect pests was assessed in 185 wild rice accessions belonging to 16 species, four natural hybrids and an

unknown *Oryza* species. Nearly 50 per cent of the accessions were resistant to *Nilaparvata lugens* biotypes 1 and 3, more than 35 per cent were resistant to *N. lugens* biotype 2 (Romena *et al.*, 1989).

A total of 42 accessions were evaluated for resistance to *N. lugens*. Eight highly resistant, one resistant and six moderately resistant accessions were identified. Almost all of the highly resistant entries were derived from crosses involving ARC6650 or Velluthacheera (Bai *et al.*, 1989).

A total of 86 rice lines originating from the wild *Oryza officinalis* was screened in the Philippines for resistance to *N. lugens* using the modified seedling bulk test. Of these lines, 40 showed resistance to the pest, 19 with a damage rating of 1 and 21 with a rating of 3 (Luong and Saxena, 1989).

About 400 rice accessions were screened for theirreaction to *N. lugens* in Madhya Pradesh, using the standard seedbox screening technique, of which, seven were resistant to *N. lugens* (Sahu and Shrivastava, 1989).

Rice varieties with genes for resistance *N. lugens* were evaluated in Tamil Nadu, of which Rathu Heenati, Babawee, ARC10550, Swarnalata and PTB 33 were resistant in screening trials, while IR747-B2-6 and ASD 7 were susceptible (Velusamy and Saxena, 1989).

In the laboratory and field trials in Karnataka, rice varieties were screened for their resistance to *N. lugens*. The variety IET-8116 was relatively resistant to the pest (Gubbaiah *et al.*, 1990).

In field study in Tamil Nadu, 87 and 71 promising advanced breeding lines of rice were screened against insect pests, during 1986 and 1987. Of the lines tested, KD14-1-39, RP2068-18-3-5, RP1579-58,

RP1579-1633 and TNAULFR831311 showed multiple resistance to *N. lugens* in both seasons (Rajendran and Adiroubane, 1990).

In an evaluation of >1700 accessions for their resistance to *N. lugens*. Most of the accessions resistant to *N. lugens* were indica as compared to japonica types (Gu *et al.*, 1991).

Entries of rice were screened for resistance to the *N. lugens* in the field in Andhra Pradesh, revealed that BPT 2217, 4363 and 4365 were not damaged by *N. lugens* (Rajendran, 1991).

Resistance to *N. lugens* was evaluated in 195 lines using PTB33 and TN1 as resistant and susceptible checks respectively, of which 54 lines had high levels of resistance (Velusamy, 1991).

A tiller screening test for *N. lugens*, was carried out on 42 rice cultivars resistant to BPH by the bulk seed test. Resistance was shown by 30 cultivars (scores 0-3 on a 0-9 scale where 0 = no damage and 9 = dead) as compared to TN1 (score 9) (Remabai and Nair, 1992).

The nature of resistance in the rice varieties Hotel Samba, Kuruhondarawala, ARC 10550 and Swarnalata was studied. Feeding by *N. lugens* was low on Swarnalata and ARC 10550, with resistant scores of 3 and 5, respectively. Hotel Samba and Kuruhondarawala had susceptibility scores of 9, indicating their lack of tolerance (Hasan and Kamal, 1992).

A total of 24 varieties developed by the Cuu Long Delta Rice Research Institute (CLRRI) were screened for resistance to *N. lugens*. Several varieties were resistant to brown planthopper and these are IR 44592-62, IR 51657, IR 52280-117, OM 269 and OM 1037 (Luong *et al.*, 1992).

The screening of local rice varieties for resistance to *N. lugens* was undertaken in Cuu Long Delta Rice Research Institute (CLRRI). Among which varieties like Luathom, Ba thiet, Bong huong, Ba se, Ballet 56-60 and Cu la were resistant to brown planthopper (Luong, 1992).

A total of 4261 germplasm accessions were screened for their resistance to *N. lugens* of which 181 accessions showed resistance (Zheng and Chou, 1992).

In a collection of 58 IET rice genotypes studied for their reaction to some pests during 1988-92 under field and laboratory conditions. 56 varieties were found to be resistant to BPH (Rana *et al.*, 1994a). Further, Rana *et al.* (1994b) evaluated 500 rice varieties for resistance to BPH during the 1989-90. Subsequently 27 promising entries were then evaluated against *N. lugens* during the following 2 years and they found that 24 varieties were resistant to *N. lugens*.

At Madurai, Tamil Nadu, several rice hybrids were evaluated against *N. lugens* using the seed box screening technique, five hybrids were found to be resistant, 13 hybrids were moderately resistant, 11 were susceptible, and six were highly susceptible (Suresh *et al.*, 1999).

In the Planthopper screening trial (PHS) of the 60 entries four derived from Dhobanumberi and one from Salkathi were promising and entries *viz.,* ACC 3739, CB 05-022, MTU 1114, TU 1115, MTU 1123, MTU 1126, MTU 1128 recorded were found resistance to BPH damage < 5.0 damage score (Anon., 2010).

Performance of 48 rice varieties against *N. lugens* was evaluated in 2007 wherein 16 varieties (combinations) were susceptible while the other 32 varieties (combinations) were highly or moderately resistant to BPH (Sheng *et al.,* 2010).

2.2 Characterization of rice brown planthopper population using differentials

Pathak and Lal (1976) presented tabulated data on the reaction of six varieties with the *Bph2* gene and eight varieties of unknown constitution to infestation by *N. lugens*. Because of the differential reaction of ARC 6650, Gangala and PTB 33, it was suggested that different biotypes of BPH occur in India. Similarly Verma *et al*. (1979) screened rice varieties for resistance to BPH using populations from Southern (Hyderabad) and Northern (Pantanagar) India and clearly demonstrated the existence of a biotype. When exposed to this new biotype, varieties resistant to the Hyderabad population and those resistant to biotypes 1, 2 and 3 at IRRI, Philippines, succumbed to the insect indicating occurrence of a biotype in Northern India which is distinct from that occurring in the Southern part of the country (Pathak and Verma, 1980).

In laboratory studies with six varieties of rice, adult brachypterous females of *N. lugens* made more feeding marks, produced less honeydew and gained less body weight on resistant varieties than on susceptible ones (Baqui, 1989).

The virulence of *N. lugens* biotype-3, reared on rice cultivar ASD 7 and of *N. lugens* colonies collected on Mindanao Island in the southern Phillipines and reared on the widely grown commercial cultivars IR 36 and IR 42 was compared. The criteria used were, extent of plant damage, insect weight, population growth and feeding activity. The Mindanao *N. lugens* colonies reared on IR 36 and IR 42 were more virulent than biotype 3, although ASD 7, IR 36 and IR 42 have the *bph2* gene for *N. lugens* resistance. These results highlight the importance of using insect populations reared on cultivars similar to those grown in farmers fields.

Failure to do so may result in the release of a cultivar that is susceptible to the *N. lugens* field population (Bahagiawati *et al.,* 1989).

The antibiotic effects of resistant rice variety Xiu-Shui 620 on *N. lugens* were examined both in the laboratory and field conditions in Zhejiang, China. The area covered by honeydew produced by the pest on the resistant variety was 37.8% of that covered on the susceptible variety Xiu-Shui 48 (Gao *et al.*, 1990).

The survival of nymphs and population growth of *N. lugens* studied at Tamil Nadu, India on 10 rice varieties revealed that it was highest on CO 22 and lowest on ARC 6650 (Ramaraju and Babu, 1991).

Damage and fecundity of BPH was assessed on five varieties, of which XiuShui 620, Shan You 6 and Bing 664 were resistant to BPH (Yu *et al.*, 1991).

The relative impact of resistance mechanisms such as antixenosis (host preference) and antibiosis (population build-up and feeding rate) against *N. lugens* was studied in rice varieties with different levels of resistance under laboratory conditions. The highly resistant PTB 33 was less preferred for settling and oviposition and recorded a lower percentage of insects settled and fewer eggs laid, than that was observed on TN 1. Antibiosis in PTB 33 and IR 64, the highly resistant and resistant rice varieties, was expressed as a low population build-up and decreased nymphal survival, while the reverse condition was noticed on susceptible TN 1 (Senguttuvan *et al.,* 1991).

In a bulk test of rice seedlings, varieties Dongjinbyeo (japonica (J)) and Pungsanbyeo (tongil (indica) (T)) were susceptible, Hwacheongbyeo (J) was moderately susceptible and Samgangbyeo (T) was resistant to *N. lugens*. Feeding preference tests, honeydew excretion and longevity on

the tiller stage of the rice plants produced results consistent with the bulk test (Kim *et al.*, 1991).

The resistance indices of japonica varieties resistant to *Nilaparvata lugens* are described. The area of honeydew excreted was greater on susceptible than on resistant varieties. The greatest numbers of eggs were deposited on Xiushui 48 (316.2/female) and survival was greatest on this variety (Gao and Bei, 1992).

Laboratory studies were conducted to confirm the resistance of some selected cultivars of rice against *N. lugens*. The wild rices *Oryza officinalis*, *O. latifola* and *O. minuta* were highly resistant to the pest and had the smallest area and quantity of honeydew excreted. The cultivated variety TNAUBPHR 831305 had resistance level similar to that of the resistant check, PTB 33. IR 64 and IR 36 showed moderate resistance whereas, IR 50 was susceptible (Manisegaran *et al.*, 1993).

Seven BPH field populations from different agroecological areas of the Mekong Delta were collected and tested by the modified bulk seedling test to determine changes in BPH biotype. Mudgo (resistance gene *Bph1*) was susceptible to all 7 BPH populations. The resistance of ASD7 (*bph2*) broke down indicating that BPH biotype 2 had developed a new distinct biotype, Babawee (*bph4*) was moderately susceptible or susceptible, and Rathu Heenati (*Bph3*) and PTB 33 (2 genes) were resistant and reveals the development of a new biotype namely the Mekong Delta BPH population (Nguyen *et al.*, 1993).

The amount of honeydew excreted and population growth rate were used to evaluate the resistance of the new rice lines, Hong-Yuan and Tainuo-Xuan to *N. lugens*. The results revealed that, the weight of honeydew excreted and body-weight of adults fed on the above 2 lines were lighter than those fed on susceptible variety TN1. The number of

eggs laid per female, nymphal survival and the next generation population number of the delphacid on these two lines were less than those on TN1 (Zhang *et al.*, 1994).

Seedlings of the four resistant rice varieties Mudgo, ASD7, Rathu Heenati and Babawee and the susceptible TN1 were used to rear *N. lugens* collected from rice fields for 13 generations. Observations on survival, for nearly 10 years, showed that the field populations were mixed populations dominated by biotype 1. Consecutive rearing of 12-13 generations could produce new artificial biotypes (Xiao *et al.*, 1994).

Parafilm sachets were used to monitor the amount of honeydew excretion by individuals of *N. lugens* from natural populations collected from Guangzhou city and Zengcheng County, Guangdong, China, when they were reared on resistant and susceptible rice varieties. The results showed that excretion rates varied significantly with rice cultivar and with individuals on the same cultivar. It is concluded that the populations examined belonged to biotype 1. A combination of honeydew excretion rates and observations of population growth is recommended for biotype determination (Jiang *et al.*, 1994).

Biotypes of *N. lugens* collected in and around the Muda area in Peninsular Malaysia were examined by comparing the amount of honeydew excreted by adult females on 5 standard rice varieties: Mudgo, ASD7, Rathu Heenati, Babawee and TN1. A relatively larger amount of honeydew was discharged on ASD7, this was followed by Mudgo. Little honeydew excretion was recorded on Rathu Heenati and Babawee. A similar trend was also observed in most populations collected from other sites on the west and east coasts of Peninsular Malaysia. Two explanations are considered for this phenomenon, i.e., these biotypes had developed in Malaysia or had come from Sumatra, Indonesia (Ito *et al.*, 1994).

Three wild rice species and 6 cultivated rice varieties were evaluated to determine their mechanisms of resistance to *Nilaparvata lugens*. Wild rice species, *Oryza officinalis*, O. *punctata*, and *O. latifolia* and cultivated rice Rathu Heenati, Babawee, ARC 10550, Swarnalata, PTB 33 and the susceptible TN1 were included in the study. In a free choice seedbox screening test, wild rice species maintained their high levels of resistance to *N. lugens* caged on resistant wild rices had slow nymphal development and low egg hatchability, as compared with *N. lugens* on cultivated resistant varieties (Velusamy *et al.*, 1995).

Laboratory experiments conducted to study the antibiosis mechanism of resistance in 10 rice varieties to *N. lugens*, showed more nymphal survival on the susceptible control variety TN 1, as compared with other varieties, namely Mudgo, ASD 7. Rathu Heenati, Babawee, ARC 6650, UtriRajpan, Udaya, Pratap and PTB 33. Varietal resistance in rice to *N. lugens* was studied by estimating the feeding rate on the basis of the amount of honeydew excretion. The results showed that out of 10 varieties evaluated, TN1 was the most susceptible and PTB 33 was the most resistant variety (Nanda *et al.*, 1997).

The reaction of different seedling stages, antixenosis to feeding and oviposition of *N. lugens* and antibiosis were examined in 2 rice varietal groups, japonica- and tongil-type. The antixenosis to feeding and oviposition was higher on resistant cultivars, than on the susceptible cultivars. The amount of honeydew excreted and the population increase were less on resistant cultivars (Kim *et al.*, 1998).

The feeding and oviposition selectivity of different biotypes of *N. lugens* on TN1 (susceptible variety) and IR26 and ASD7 (two resistant varieties of rice) were compared. There were no significant differences among the selectivities of biotype 3 nymphs on the 3 varieties. Biotype 1

and 3 adults preferred to oviposit on TN1, but biotype 2 preferred to oviposit on IR26 (Lu *et al.*, 1999a).

The virulence and damage of *N. lugens* populations from Guangxi, Yunnan and Zhejiang Provinces, China, were studied. The results indicated that in 1997, the nymphal survival indices of Guangxi and Yunnan populations on Rathu Heenati (*Bph3*) were up to 70.9 and 66.7, respectively. This may imply that the populations in Guangxi and Yunnan have shifted to a new biotype (Lu *et al.*, 1999b).

The virulence characteristics of *N. lugens*, collected from paddy field and greenhouse populations in China, were studied. The results showed that both populations were able to infest the resistant rice variety IR26 (with the resistant gene *Bph1*) implying biotype 2 characters. No significant differences in nymphal feeding preference, survival rate and duration were observed on the resistant rice varieties TN1, IR26, and ASD7 (Lu *et al.*, 1999c).

Native rice varieties were studied for their resistance to *N. lugens*. Ten varieties had low and 11 had moderate honeydew excretion areas. According to the size of excretion area, Chai Nat I was the highly resistant variety. Rice resistance to insects is inversely proportional to the honeydew excretion area of the insect (Phisitkul and Ritmontree, 1999).

Five rice varieties with different resistant genes were used to study the biotypes of brown plant hopper (BPH) collected from different regions of Ninghua, Zhaoan, Jiangyang, Pinghe, Putian, Dehua, Zhouning and Wuping in Fujian Province in recent years. The results showed that the survival rate, population density of BPH and the amount of honeydew excreted by BPH on TN1 were higher than on the other four varieties. It

is suggested that the BPH collected from ten locations in Fujian Province belong to biotype I (Zeng *et al.*, 2000).

The feeding rate of *N. lugens*, was assessed in terms of area and weight of honeydew excreted by adult females on 104 double haploid (DH) rice lines, two parent lines (IR 64 and Azucena), a resistant control (PTB 33) and a susceptible control (TN1). Among the DH lines, the excretion of honeydew was less in DH 210 and DH 558 and maximum in DH 1505. Among the parental lines, feeding rate was lower in IR 64 than in Azucena (Soundararajan *et al.*, 2001).

Antibiosis mechanism of rice resistance to *N. lugens*, operating in 104 double haploid (DH) rice lines derived from a cross IR 64 x Azucena (a traditional upland japonica variety), was studied. DH rice lines showed a greater variation in population buildup, wing form, sex ratio and days taken for wilting. The lines harbouring more nymphs wilted quickly and wilting ranged from 15.33-42.33 days (Soundararajan *et al.*, 2002).

Evaluation of *Oryza minuta* cultivars E13-9 and TN1 for their resistance to the *N. lugens*, was conducted using modified seedbox screening technique. The survival rate of BPH was 18 and 82%, the amount of honey dew was 6.04 and 46.8 mg and the average number of eggs laid was 29.67 and 229.3 on E13-9 and TN1, respectively (Xiao and Zhang, 2002).

A study was carried out to assess the genotypic response to *N. lugens* attack and the possible use of these genotypes in BPH management. The resistant genotypes PTB 33, ADT 45 and ASD 7 and the moderately resistant genotypes CO 43 and KAU 1661 recorded the lowest nymphal preference, fecundity, feeding rate, survival, growth index, population buildup and plant dry weight loss per mg of insect dry weight produced, more unhatched eggs, longer nymphal development

period, days to wilt and higher Functional Plant Loss Index (FPLI) compared with the susceptible genotype TN1. In resistant and moderately resistant genotypes, a greater accumulation of defence enzymes such as peroxidase and polyphenol oxidase in response to *N. lugens* infestation was recorded one day after infestation and more pathogenesis-related protein and chitinase activity was noted 3 days after infestation. The activity was sustained for more than a week after infestation as compared with the susceptible genotype TN1 and reported lower survival rate of BPH nymphs on resistant genotypes was lower than on the susceptible one. The resistant genotypes (ADT 45, PTB 33 and ASD 7) had the lowest survival rate than the susceptible TN1 (Alagar *et al.,* 2007).

Studies on the feeding behaviour of *N. lugens* on some selected rice genotypes revealed, low honeydew excretion and higher feeding marks was related to resistance of rice genotypes against BPH (Alagar *et al.,* 2008).

2.3 Determination of few biochemical factors in select BPH resistant and susceptible genotypes.

The relationship between chemical composition and resistance of 11 rice varieties to *Nilaparvata lugens* was studied under field conditions in neighbouring Andhra Pradesh. The variety PTB 33 had the highest resistance, while MTU7029 was least resistant. It was suggested that the phenol, silica, phosphorus, potassium, calcium, sulphur and iron contents were positively correlated with resistance, while the protein, nitrogen, zinc and manganese contents were negatively correlated with resistance (Sujatha *et al.*, 1987).

The presence of 3 flavonoid C-glycosides (schaftoside and 2 of its isomers) in rice phloem and higher level of these phenolics was found in

the resistant rice variety than in the susceptible ones studied, they may be involved in the resistance of rice to *N. lugens* (Grayer *et al.*, 1994).

Studies were conducted to determine the biochemical basis of *N. lugens* resistance in selected rice cultivars. TN 1 was used as the *N. lugens* susceptible cultivar and compared with the resistant cultivars Mudgo, ASD/7, Rathu Heenati, Babawee, ARC 6650, Utri Rajpan, Udaya, Pratap, and PTB 33. The total soluble sugar collected at 30 and 45 days after sowing (DAS) were determined. At 30 DAS, the total sugar content in TN1 was higher than that in the remaining cultivars. No clear trend was observed in total sugar content at 45 DAS (Nanda *et al.*, 2000).

The contents of total phenols, sugars and N were estimated in healthy and *N. lugens* infested leaves of resistant (INRC 8815, INRC 7069, INRC 8712, INRC 7197, INRC 6153 and INRC 7040) and moderately resistant (INRC 7143, INRC 6165 and INRC 7318) rice cultivars, and in susceptible (TN1) and resistant (PTB 33) controls. BPH infestation increased the phenolic content of the resistant and moderately resistant cultivars. The total phenol content was reduced in TN1 but was increased in PTB 33 after infestation. The total sugar content was highest in TN1 and lowest in PTB 33 before infestation. No marked variation in the sugar content was observed between healthy and infested resistant and moderately resistant cultivars. The reduction in the N content after infestation was more pronounced in TN1, and was only marginal in the resistant cultivars (Loka Reddy *et al.*, 2004).

2.3.1 Total phenol content

Phenols have been implicated in the resistance of rice varieties to insect pests. Samal and Mishra (1978) found that phenolic compounds were high in resistant varieties of rice.

Peraiah and Roy (1979) reported that the brown plant hopper resistant varieties of rice, Shakti and CR.95-952-1 had more phenols than the susceptible variety, Ratna in their shoot apices.

Samal (1982) recorded more total phenols in resistant varieties PTB 33 (at 45 to 60 days) and CR 57-11-2 (at 30, 45 and 65 days) than the susceptible varieties – Jaya and TN1. Further, Samal *et al.* (1982) analysed 14 resistant and two susceptible varieties (45 day old) and found no definite relationship between BPH resistance and phenolic content of the plant.

Brown planthopper resistant rice varieties had high content of phenols (435.562 g) in comparison to susceptible ones (370.390 g/100mg of plant tissue), inferring the presence of more amount of phenols in the resistant varieties may be harmful to the bionomics of BPH and thus less preferred by them (Peraiah *et al.,* 1982).

Sujatha *et al.* (1987) reported that the total phenolic content had negative correlation with the BPH build up on rice cultivars, suggesting that higher quantity of total phenols was associated with resistance of rice cultivars to BPH.

Dharma Reddy and Misra (1995) reported significant differences in the total phenol percentage among the rice varieties against BPH. They observed lowest Phenol content in the variety FH-IO9 (5.33%) and the highest being in DR-92 (9.10%).

Senguttuvan and Sujatha (2000) studied the biochemical basis of resistance in ground nut against leaf miner. The results revealed that the total phenol content was 2.0 mg in the susceptible TMV-7, while it was 2.4 to 2.6 mg/g of leaf sample in the less susceptible genotypes.

2.3.2 Crude protein content

Brown planthopper resistant rice varieties had high content of total proteins (4200 fig) as compared to plant tissue of the susceptible ones (22.75 mg/100mg) (Peraiah *et al.,*1982).

Senguttuvan and Sujatha (2000) studied the biochemical basis of resistance in groundnut against leaf miner. The results revealed that the less susceptible genotypes and susceptible check did not differ markedly for total protein content. The total protein was 18.7 mg in leaf samples of susceptible TMV-7 variety and 16.3 mg in least susceptible, VGN-52.

2.3.3 Total protein content

Samal and Mishra (1978) recorded high total amino acids in resistant varieties. Analysis of the leaf sheaths of four BPH resistant varieties (PTB 33, PTB 21, CR 57-11-2 and MR 1523) and two susceptible varieties (Jaya and TN1) indicated that protein content was more in resistant varieties than in susceptible ones (Samal, 1984). Peng *et al*. (1979) observed that higher amounts of aspartic acid, asparagines, valine, alanine and glumatic acid in susceptible varieties stimulates planthopper feeding 3-5 times more than the resistant varieties. Whereas, Samal (1982) recorded more aminoacids in susceptible varieties. Similarly, Sujatha *et al*. (1987) obtained negative correlation between protien content and varieties resistant to BPH. Further, they reported that the varieties that supported lower- brown plant hopper (BPH) population (11.5 hoppers/plant) had lesser protein content (6.96%) in comparison to susceptible rice variety, MTU-7029 (45.3 hoppers/ plant) recording the highest protein content of 16.4 per cent. From these results, they concluded that the presence of lower quantity of protein was correlated with the resistance of rice varieties to BPH.

Mohan and Venugopal (1999) studied the differential survival of the leaf hopper on resistant and susceptible varieties of cotton. The results revealed that the protein content had positive influence on leaf hopper growth, development and damage and it was found to be high in the susceptible varieties.

Rupali *et al.* (2003) reported that the grain and pod shell tissues of chickpea susceptible cultivars against pod borer were found to contain higher crude protein content than the resistant cultivars at 70 days after sowing.

2.3.4 Total soluble sugars content

Peraiah and Roy (1979) reported substantially more total soluble sugars in shoot apices of BPH resistant varieties of rice, namely Shakti and CR-95-952-1 than in the susceptible one Ratna.

Peraiah *et al.* (1982) from their studies on biochemical nature of brown planthopper resistance and its inheritance pattern in rice concluded that the presence of higher amount of sugars in the susceptible varieties (500µg) than that of resistant varieties (166µg/100mg) acted as feeding stimulant for BPH.

Samal *et al.* (1982) reported less total soluble sugars in BPH resistant rice cultivars as compared to susceptible cultivars.

A study conducted by Sujatha *et al.* (1987) to find out the relationship between the chemical constituents and the resistance of eleven varieties to the brown planthopper did not give any indication of total sugar association with resistance or susceptibility of rice varieties.

Dharma Reddy and Misra (1995) reported that the total soluble sugar percentage appeared to be low in the resistant varieties and high in

the susceptible once of rice against BPH. Similar results were also reported by them in the rice against green leafhopper, *Nephotettix virescens* Distant.

2.3.5 Total reducing sugars content

Sogawa (1971) observed little difference in the total sugar content between healthy and chlorotic leaves of rice. However the amount of reducing sugars such as fructose and glucose was very less in healthy leaves as compared in chlorotic leaves. The brown leaves are fully devoid of sugars.

Samal and Mishra (1978) analysed five BPH resistant varieties *viz.,* PTB 33, PTB 18, PTB 21, CR57-MR1523 and ARC 14529 and two susceptible varieties – Jaya and TN1 and found that total soluble sugars were high in susceptible varieties. Similar results were obtained in an analysis of 14 resistant and two susceptible rice cultivars by Samal (1983). He also observed more reducing sugars in leaf sheath of the susceptible variety TN1 at 60 days and boot leaf stage.

2.3.6 Major nutrients (N, P and K)

Sogawa (1971) studied the feeding preference, excretion of honeydew and probing behaviour of adult females of *N. lugens* on normal rice plants and on those suffering from nitrogen deficiency. Individuals on the nitrogen deficient plants produced less honeydew, than those on normal plants indicated that, the nitrogen deficient plants were less attractive to the females. Since there was no indication of interference with locating vascular bundles by the insects in the N-deficient plants feeding must make them adversely affected by lowered concentration of amino nitrogen. Further he observed reduction in fecundity of the hoppers on the planthoppers to take-up sufficient sap.

Estimation of total nitrogen in 23 resistant and two susceptible varieties of rice to BPH revealed no difference in the percentage of nitrogen between resistant and susceptible varieties or cultures (Samal and Misra, 1978). Samal (1984) recorded more potassium in leaf sheaths of resistant varieties in 45 days old seedlings. Sujatha *et al.* (1987) reported negative correlation between plant nitrogen content and resistance, whereas phosphorus and potassium were positively correlated.

Chen *et al.* (1987) observed that phloem sap in an insect resistant cultivar had low concentration of asparagines than in non-resistant cultivars. Nitrogen and phosphorus deficiency increase asparagines content, hence susceptibility to insect attack may be controlled by regulating the nutrient status of plants by cultivar selection.

2.3.7 Micro nutrients

Samal (1984) analysed rice for micro elements *viz.,* Fe, Mn, Cu, Mg, K and Ca at 45 days and at boot-leaf stage and recorded lower Fe and Zn content in BPH susceptible varieties than in resistant varieties at boot-leaf stage. Sujatha *et al.* (1987) observed that the calcium and iron in the plant were positively correlated with resistance to *N. lugens.*

There was no significant variation in the content of iron, manganese and copper between resistant and susceptible genotypes of rice to BPH infestation (Shivmurthappa, 1993).

Material and Methods

III. MATERIAL AND METHODS

Material used and the methods followed in conducting the studies on evaluation of genotypes against brown planthopper, characterization of BPH population and determination of biochemical factors are described here under.

The present investigations were undertaken during 2010-11 at Zonal Agricultural Research Station, Vishweshvaraiah Canal Farm, Mandya, Karnataka. The experimental area is located in Mandya district at 20^0 30'N latitude and 76^0 50'E longitude, with an altitude of 694.65 meters above the MSL, it receives an annual rainfall of 753.5 mm well distributed over the season. The meteorological data that prevailed during the period of study were collected from Mandya.

3.1 Evaluation of genotypes and cultivars against brown planthopper population in field and glasshouse at Mandya.

3.1.1 Glass house screening

Modified raised seed beds were used to screen the germplasm in the glasshouse (Sidde Gowda, 2009). Two hundred and eighty three germplasms were screened *viz.,* Planthopper Screening lines (fifty seven), Multiple pest resistant entries (fifty three) and National Screening Nurseries-1 lines (one hundred and seventy three). Seed beds were filled with fertilizer enriched puddled soil. Rows of one meter length were drawn leaving 10 cm between rows. Ten rows of test varieties were alternated with one row of susceptible check, TN1. Thirty sprouted seeds of susceptible check TN 1 was sown in the two border rows. In the middle rows, 30 sprouted seeds of selected rice accessions were sown. All the test entries to be screened and susceptible check were sown in different seed beds.

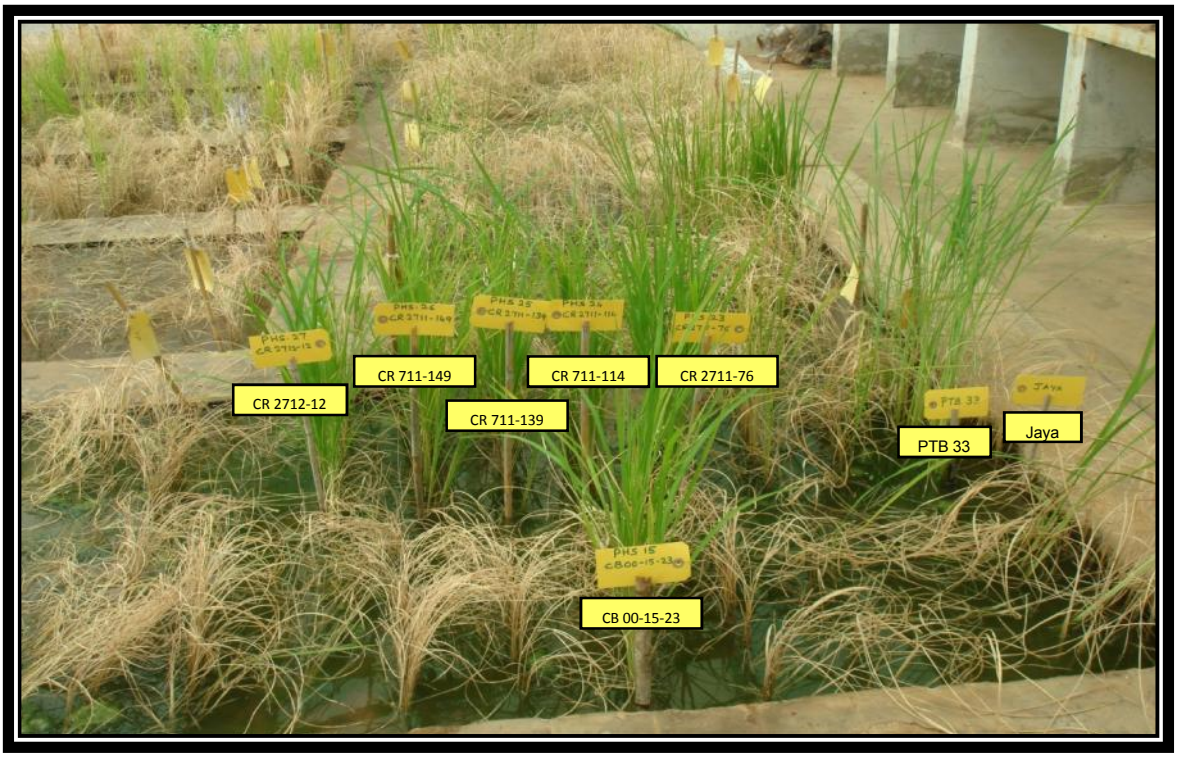

Plate 1. Promising entries of PHS (CR lines) against BPH infestation

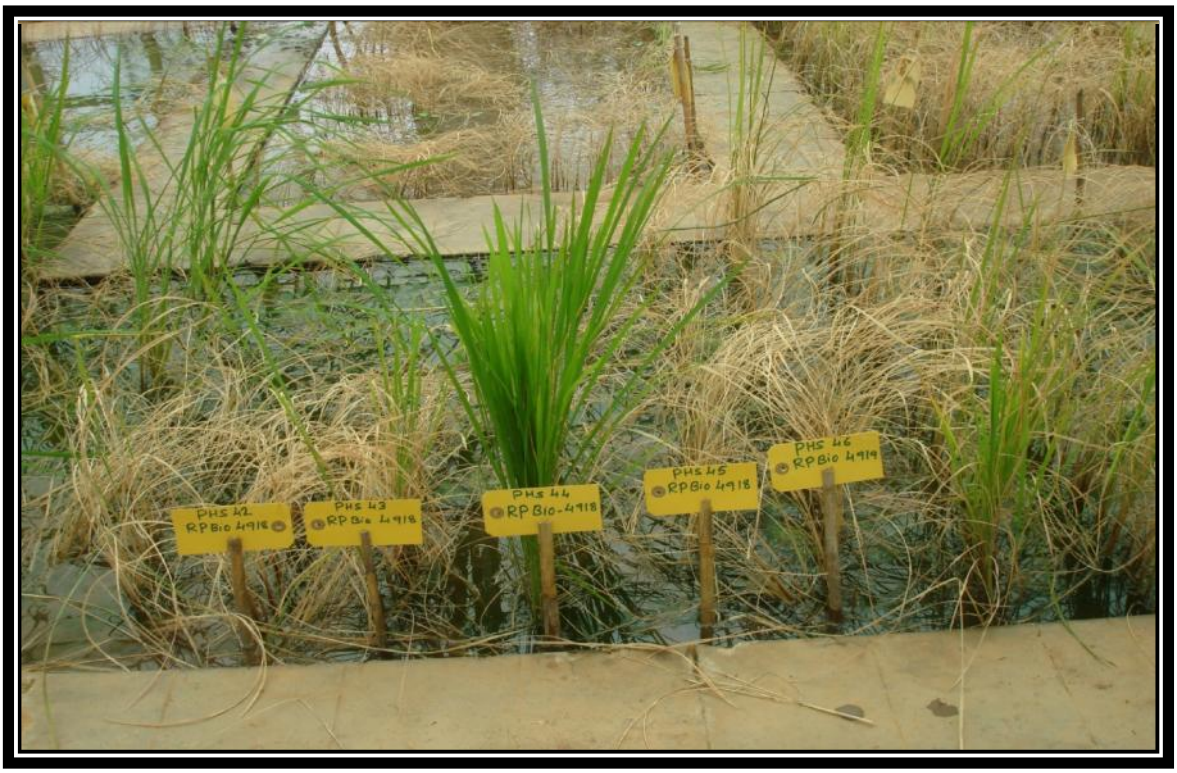

Plate 2. Promising entries of PHS (Breeding lines derived from wild rices) against BPH infestation

Plate 3. Promising entries of PHS (RIL lines) against BPH infestation

Plate 4. Promising entries of multiple pest resistant lines against BPH infestation

When the seedlings were 8-10 days old, with 2-3 leaves, 2nd instar BPH nymphs were released in the seed beds, so as to ensure that each seedling had 6-8 nymphs. When 90 per cent of the plants of the susceptible check TN1 were killed, damage score for entries was recorded. The observations of BPH populations were also recorded on different days after release. The criteria followed for scoring the damage of individual plants was as per standard evaluation system developed by International Rice Research Institute (Anon., 2002)

SCALE (For glasshouse test)	
0	No damage
1	Very slight damage
3	First and 2nd leaves of most plants show partial yellowing
5	Pronounced yellowing and stunting of about 10 to 25% of the plants wilting or dead and remaining plants severely stunted or dying
7	More than half of the plants dead
9	All plants dead

3.1.2 Field screening

Field screening of germplasm (same set screened in the glasshouse) was undertaken at Zonal Agricultural Research Station, Mandya during 2010 in *Kharif* season (Peak period) for BPH incidence. The selected rice accessions were planted in the field in two rows, of ten hills each. Nine rows of test varieties were alternated with one row of susceptible check TN1. All around the test entries, ten rows of tall susceptible, long duration Jaya variety was planted. To maintain adequate BPH infestation, humid conditions was sustained by providing water level of 5 cm above the ground. Polythene sheet barrier of 2.5 feet

height all around the planting area was erected within 15 days after transplanting. Adult and nymphs of BPH were released uniformly in polythene sheet confined area on 30, 40, 50 and 60 days after transplanting. Observations were recorded on per cent hopper burn.

The damage level of each variety is scored by using the rating scale provided by International Rice Research Institute (Anon., 2002).

SCALE (For field test)	
0	No damage
1	Slight yellowing of a few plants
3	Leaves partially yellow but with no hopperburn
5	Leaves with pronounced yellowing and some stunting or wilting and 10-25% of plants with hopperburn, remaining plants severely stunted
7	More than half the plants show wilting or with hopperburn, remaining plants severely stunted
9	All plants dead

3.2 Characterization of rice brown planthopper population of Mandya using differentials.

The reaction of reported resistant sources i.e., differentials against BPH was studied in the glasshouse during *kharif* 2010 at Zonal Agricltural Research Station (ZARS), V. C. Farm, Mandya. The methodology adopted by Alagar *et al.* (2008), Velusamy *et al.* (2006) and Paguia *et al.* (1980) was followed to evaluate the differentials. In all the tests, each differential was treated as a treatment and replicated suitably to fit into statistical analysis.

Plate 5. Promising entries of NSN 1 lines against BPH infestation

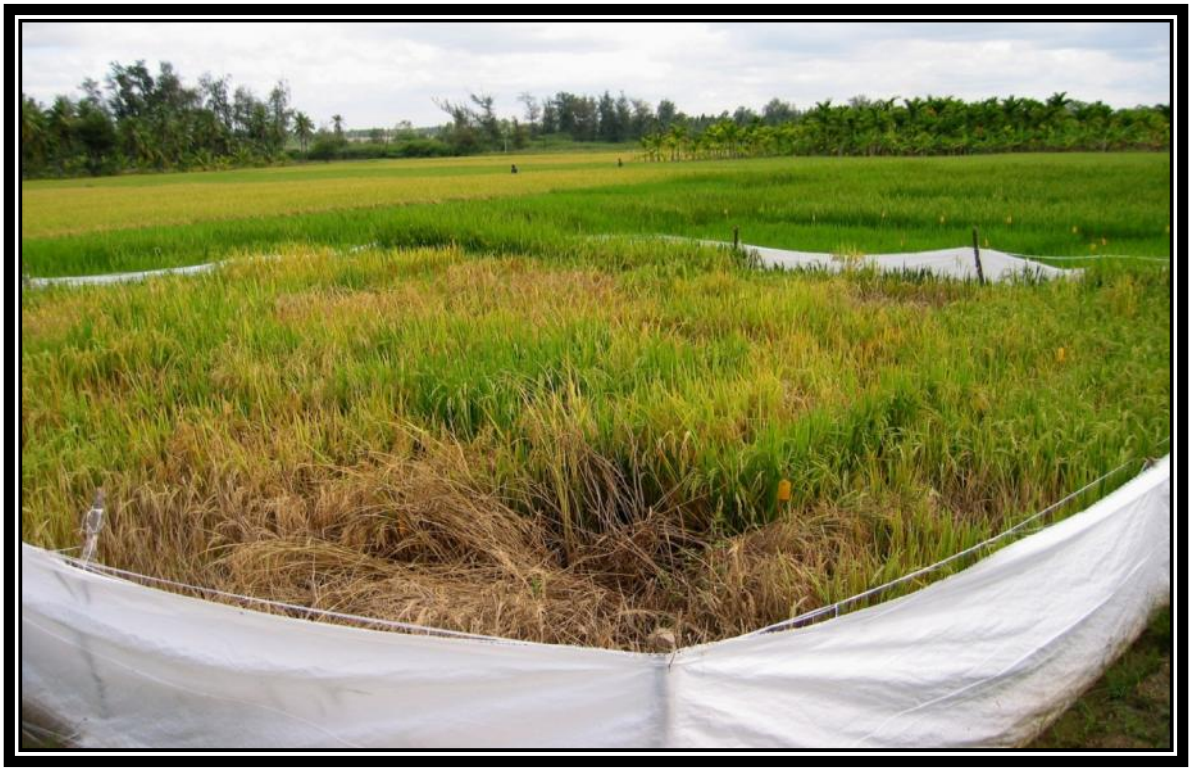

Plate 6. BPH infestation in field screening

1. Screening of differentials in glasshouse
2. Days to wilting
3. Ovicidal test
4. Nymphal survival
5. Adult feeding in the form of honeydew excretion

Differential varieties tested

1. Rathu Heenati
2. MO1
3. PTB 33 (Resistant check)
4. Sinna sivappu
5. TN 1 (Susceptible check)
6. INRC 3021
7. MR 1523

3.2.1 Screening of differentials in glasshouse

Modified raised seed beds were used to screen the differentials in the glasshouse (Sidde Gowda, 2009). Seed beds were filled with fertilizer enriched puddled soil. Rows of one meter length were drawn leaving ten cm between rows. Ten rows of test varieties were alternated with one row of susceptible check TN1. Thirty sprouted seeds of susceptible check TN1 were sown in the two border rows. In the middle rows, 30 sprouted seeds of selected rice accessions were sown. All the test entries to be screened and susceptible check were sown in different seed beds.

When the seedlings were 8-10 days old, with 2-3 leaves, 1st or 2nd instar BPH nymphs were released in the seed beds, so that each seedling had 6-8 nymphs. When 90 per cent of the plants of the susceptible check TN1 was killed, damage score for the entries was recorded.

3.2.2 Days to wilting

The seeds were soaked and the germinated seedlings were sown in 500 ml plastic pots filled with fertilizer enriched puddled soil. Two germinated seeds were planted in each pot and only one healthy seedling was retained after 5-6 days. For each variety, seedlings were raised in 8 pots.

The plants were covered with mylar tubes with ventilating windows. Twenty five 2nd instar nymphs in the mylar cage were released on fifteen days old plants and the open end of the tube was covered with a muslin cloth and fastened with a rubber band.

The plants were observed daily for their health. The number of plants wilted with all leaves dried and per cent plant wilted was recorded. The experiment was terminated at 40 days after the release of nymphs and recorded the number of plants that did not wilt at the end of the study.

3.2.3 Ovicidal test

The seeds were soaked and the germinated seedlings were sown in 500 ml plastic pots filled with fertilizer enriched puddled soil. Two germinated seeds were planted in each pot and retained only one healthy seedling after five-six days. For each variety, seedlings were raised in six pots.

Thirty day old plants were covered with mylar tubes with ventilating windows. One pair of adults i.e. one gravid female (seven days old) and a male released with the help of an aspirator in the mylar cage and the open end of the tube was covered with a muslin cloth and tied with a rubber band.

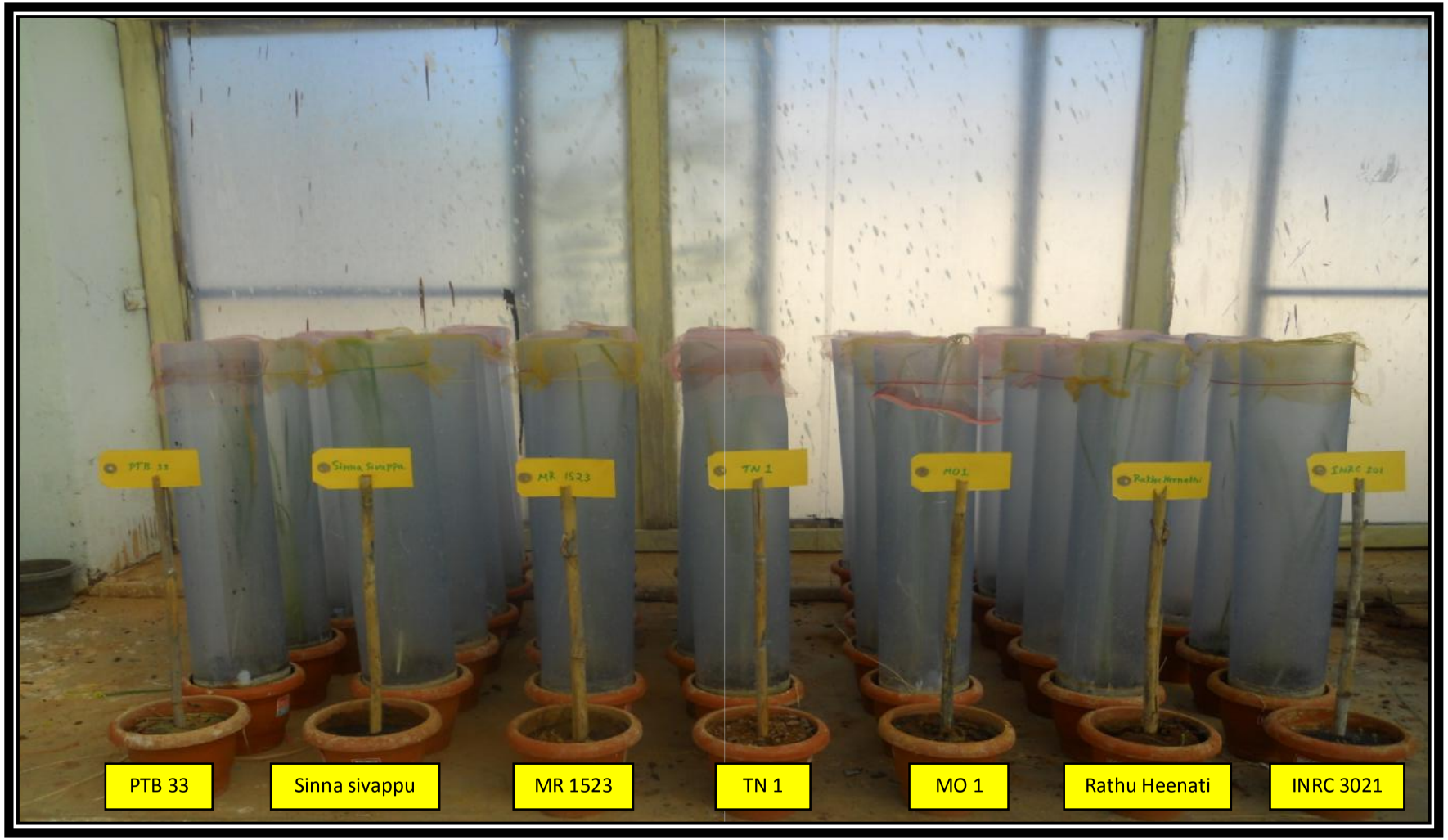

Plate 7. Ovicidal test conducted in glasshouse on rice differentials

The adults were removed on five days after release. The plants were observed for nymphal hatching. The number of hatched nymphs were recorded and removed from the plant. After all the eggs were hatched or when nymphs stop coming out (after 15-20 days of adult release), the plants were cut at the base and examined under stereo binocular microscope, total number of egg masses and number of unhatched eggs were recorded. Unhatched eggs were expressed as percentage of total, which is sum of number of nymphs counted and the number of unhatched eggs.

$$\% \text{ Unhatched eggs} = \frac{\text{Number of unhatched eggs}}{(\text{Number of nymphs} + \text{Number of unhatched eggs})} \times 100$$

3.2.4 Nymphal survival

The seeds were soaked and the germinated seedlings were sown in 500 ml plastic pots filled with fertilizer enriched puddled soil. Two germinated seeds were planted in each pot and only one healthy seedling was retained after 5-6 days. For each variety, seedlings were raised in three pots.

The plants were covered with mylar tubes with ventilating windows. Ten one day old nymphs in the mylar cage were released to fifteen days old plants and the open end of the tube was covered with a muslin cloth and tied with a rubber band.

The plants were observed daily and the number of nymphs that reached adulthood were counted and removed them from the plant. The percent nymphal survival was calculated by

$$\% \text{ Nymphal survival} = \frac{\text{Number of emerged adults}}{\text{Number of released nymphs}} \times 100$$

3.2.5 Adult feeding in the form of honeydew excretion

The seeds were soaked and the germinated seedlings were sown in 500 ml plastic pots filled with fertilizer enriched puddled soil. Two germinated seeds were planted in each pot and retained only one healthy seedling after 5-6 days. For each variety, seedlings were raised in 8-10 pots.

Nine centimeter diameter circles of whatman number 1 filter paper were prepared. A small hole was made in the center of the circle and longitudinal cut was made from the margin to the hole.

Small quantity of bromocresol green powder was added to ethyl alcohol solution in a beaker and mixed thoroughly. Then the solution was taken in a petridish and the filter paper circles were dipped in it and then dried in shade. The papers were again dipped in the solution to get orange colour. Card board sheets were taken and cut into square shapes of 12X12 cm size and a hole was made in the center of the square.

One month old plants were inserted through the hole and the card board squares were kept at the base of the plant and the hole was plugged with nonabsorbent cotton. Polythene sheet and a paper were placed on the card board to prevent moisture absorption by the filter paper.

The treated filter paper circles were placed on the card board at the base of the plant. Small plastic cup without lid were taken and made a small hole at the basal portion of the cup and the plants were inserted through the hole and the inverted cups were place on the filter paper.

One day old 15 BPH females starved for two hours were released into the cup onto the filter paper through the hole and plugged the hole with non-absorbent cotton to prevent escape of the insects.

The BPH adults were allowed to feed for 24 hours at the base of the stem. When the honeydew excreted by BPH come in contact with the filter paper they turn into blue spots. Then the filter papers were taken out and the area of the spots were measured by graph paper method. The area of all the honeydew spots were traced on a millimeter square graph paper and the number of squares within the spots were counted. The area of all the spots were added and expressed the area of honeydew excretion as mm^2 per 5 females.

3.3 Determination of few biochemical factors in select BPH resistant and susceptible genotypes

Sample collection for biochemical analysis

The biochemical estimation was carried out for the genotypes which showed resistance to BPH in glass house and field screening, in comparison with standard resistant (PTB 33) and susceptible check (TN1).

Preparation of oven dried sample

Initially, test varieties grown in the field i.e., uninfested and infested plants were uprooted when the 90 per cent of TN1 (susceptible check) were died and washed with distilled water. No additional fertilizers were added in the field. These samples were dried at 32 ^{0}C in a hot-air oven for 24-48 hours. Vegetative shoot apics of size 0.5cm (approx.) were collected after stripping off the leaves and leaf sheaths of the test varieties and powdered using pestle and mortar. These powdered samples were sieved through a 100 mesh screen and stored in the sealed containers at 4 ^{0}C, until analysis.

3.3.1 Estimation of total phenol content

The total phenol content in each of the samples was estimated by following the procedure suggested by Malick and Singh (1980).

Reagents

1. **Folin - ciocalteau reagent**: Commercial grade reagent was diluted to 1:1 with water.
2. **20% sodium carbonate solution**: 20gm of Na_2CO_3 was dissolved in water and made up to 100ml.
3. **Standard catechol solution**: A stock catechol solution was prepared containing 1mg catechol per ml in water, this solution was diluted as 1:10 to obtain 100µg catechol per ml working standard solution.

Sample extraction

100mg of oven-dried powdered sample was extracted in 10ml of warm 80 per cent ethanol for 1 hour at room temperature, the extract was centrifuged at 6000 rpm for 15 minutes. The supernatant was evaporated to dryness on a water bath and the residue was dissolved in 5ml of water. The alcohol free extract was used for the estimation of total phenols.

Estimation

An aliquot sample of 0.1ml was diluted to 3ml with water and 0.5ml of FCR was added and mixed. Exactly after 3 minutes, 2ml of 20 per cent sodium carbonate solution was added and kept in a boiling water bath for one minute. After cooling under running tap water, the absorbance was read at 650 nm, against the reagent blank in a colorimeter.

A standard graph was constructed with catechol as a standard in the range of 20-100µg. The total phenol content was expressed as the mg per gram of oven–dried sample.

3.3.2 Crude protein

Crude protein was calculated by multiplying the nitrogen content with 6.23, a constant.

3.3.3 Estimation of total soluble protein content

The total soluble protein content of rice plant samples were determined by the procedure given by Lowry *et al.* (1951).

Reagents

1. **Solution A:** 20gm of anhydrous carbonate ($Na_2CO_32H_2O$) and 4g of sodium hydroxide were dissolved in 1000ml of distilled water.
2. **Solution B:** 1ml of 1.35 sodium potassium tartrate and 0.1ml of 5.5% $CuSO_4.5H_2O$ solutions were mixed together.
3. **Solution C:** 50ml solution of A was mixed with 1ml of solution B just before use.
4. **Folin- Ciocalteau reagent (FCR):** The commercial FCR was diluted 1:1 before use.
5. **Standard bovine serum albumin (BSA) solution:** A stock BSA solution was prepared containing 2mg BSA per ml working standard solution.

Sample extraction

100mg of oven dried powdered sample was extracted in 10ml of 0.1M sodium phosphate buffer, pH 7.0 for one hour on a magnetic stirrer at room temperature. The extract was centrifuged at 10,000 rpm for 20

minutes and the supernatant was used for the estimation of total soluble protein content.

Estimation

A known volume of aliquot sample was made up to 1ml with distilled water. To this 5ml of solution C was added and mixed well. After 10 minutes, 0.5ml of FCR was added and mixed immediately. The blue colour developed was read at 660 nm after 30 minutes against a reagent blank in a colorimeter.

A standard graph was constructed using BSA solution as a standard in the range of 20-120µg. The total protein content is expressed as mg per gram of oven dried sample.

3.3.4 Estimation of total soluble sugar content

The total soluble sugar content in each of the samples was estimated by adopting the procedure suggested by Dubois *et al.* (1956).

Reagents

1. **Phenol reagent**: 5gm of redistilled phenol was dissolved in water and made up to 100 ml.
2. **Standard glucose solution**: a stack glucose solution was prepared containing 1mg of glucose per ml in water. The solution was diluted to 1:10 to obtain 100µg glucose per ml working standard solution.

Sample extraction

100gm of oven dried powdered sample was extracted in 10ml of warm 80 per cent ethanol for one hour on a magnetic stirrer at room temperature. The extract was centrifuged at 6000 rpm for 15 minutes. The supernatant was evaporated on a water bath and the residue was

dissolved in 5ml of distilled water, this alcohol free extract was used for the estimation of total soluble sugars.

Estimation

An aliquot of 0.1ml was diluted to 1.0ml with water. 1ml of 5 per cent phenol reagent and 5ml of 98 per cent H_2SO_4 was added and incubated for 10 minutes and the then placed in water bath at 30 ^{0}C for 20 minutes. The absorbance was read at 490 nm against the reagent blank in a colorimeter.

A standard graph was constructed using glucose solution as a standard in the range of 20–100µg. The total soluble sugar content was expressed as mg per gram of oven dried sample.

3.3.5 Estimation of total reducing sugars content

The total reducing sugars content of rice plant samples were determined by the protocol suggested by Nelson (1944).

3.3.6 Major Nutrients

3.3.6.1 Nitrogen

The total nitrogen content in each of the samples was estimated by following the procedure of Bremner (1965).

3.3.6.2 Phosphorus

The phosphorus content of rice plant samples were determined by the wet oxidation procedure outlined by Jackson (1973).

3.3.6.3 Potassium

The di-acid digested sample was used to estimate potassium by using digital flame photometer (Jackson, 1973).

3.3.7 Micronutrients

The di-acid digested samples were used to estimate the micronutrients such as copper, manganese, iron and zinc were estimated by Atomic absorption spectrometer (Lindsey and Norwell, 1978).

3.3.8 Functional Plant Loss Index (FPLI) due to BPH infestation in rice plants

To study the level of tolerance on 30-day-old seedlings, 50 1st instar nymphs were introduced onto each plant. When the plants started to wilt, were collected along with their roots, washed thoroughly, air-dried for 3 hours, then oven-dried at 70^0C for 60 hours and weighed. The functional plant loss index (FPLI) was calculated for all the genotypes by using the following formula (Alagar *et al.,* 2007).

$$FPLI = 1 - \frac{\text{Dry weight of BPH infested plants}}{\text{Dry weight of BPH uninfested plants}} \times 100$$

Experimental Results

IV. EXPERIMENTAL RESULTS

The results of the studies conducted on screening, characterization of Brown planthopper (BPH) population and biochemical characters associated with resistance to *Nilaparvata lugens* on rice during 2010–11 are presented in this chapter under the following headings.

4.1 Evaluation of select rice genotypes against brown planthopper in field and glasshouse at Mandya.

4.1.1 Glasshouse and field screening

The results of the screening trials are presented below. Two hundred and eighty three genotypes were screened in the glasshouse and field to find out their reaction to *N. lugens* infestation. The study included fifty seven planthopper screening lines, fifty three multiple pest resistant entries and one hundred and seventy three national screening nurseries-1 lines.

4.1.1.1 Planthopper Screening (PHS) lines

The germplasms identified as resistant to brown planthopper in different parts of the country were pooled and screened for their reaction to BPH populations of Mandya and the results are presented in table 1. Out of fifty seven entries screened, fourteen were breeding lines developed at Tamil Nadu Agricultural University, Coimbatore, ten breeding lines derived from wild rices, four Recombinant Inbred Lines (RILs) developed at DRR and twenty three lines which were promising against planthoppers in the previous years were revaluated, along with two resistant checks PTB 33 and MO1 and four susceptible checks Abhaya, Kavya, Suraksha and TN1 in glasshouse screening.

Among the fourteen breeding lines, none of the lines were resistant to BPH, except CB 00-15-64, which recorded a damage score of 1 in the glasshouse and 5 per cent hopperburn in field screening (Table 1).

Twenty three lines which were promising against BPH in the previous year i.e., 2009 in different locations of the country showed varied degree of resistance to BPH. Five lines *viz.,* CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149 and CR 2712-12 developed by Central Rice Research Institute, Cuttack, were found to be resistant to BPH with a damage score of 1 and hopperburn of 10 per cent. Rest of the entries were susceptible with a damage score of 7 or 9 and hopperburn of 90 or 100 per cent.

Similarly out of ten breeding lines derived from wild rices, RP Bio 4918 (Sl. No. 42, Table 1) derived from Swarna X *Oryza nivara* was found to be resistant to BPH with a damage score of 1 in glasshouse and 10 % hopperburn in the field. The rest of the entries including cross between Swarna X *O. rufipogan* were susceptible to BPH. Similarly, RIL 8-188, one of the four lines derived from crossing between TN1 X RP 2068, was found to be moderately resistant to BPH with a damage score of 1. However, in the field it recorded 90 per cent hopperburn.

The BPH population was monitored on the entries in the glasshouse after their release. The population ranged from 0 to 128 over the period of 35 days.

Fifteen days after release, the population of BPH ranged from 0 to 31 per 10 plants. Among the breeding lines after fifteen days of release, the highest population of 30 BPH per 10 plants were recorded on the CB 05-022 and lowest population (0/10 plants) in CB 00-15-64 and CB 07-115. The population on twenty three promising lines during previous year 2009 ranged from 0 to 31. Similarly, the population on crosses of

Table 1. Reaction of rice entries against BPH on Planthopper Screening lines (PHS) in glasshouse and field

Sl. No.	Designation	Cross	Damage Score *	Hopper Burn (%) **
	Breeding lines			
1	CB 05-022	-	9	100
2	CB 05-031	-	7	100
3	CB 05-219	-	9	100
4	CB 05-758	-	9	100
5	CB 06-105	-	9	100
6	CB 06-124	-	9	100
7	CB 06-135	-	9	100
8	CB 06-137	-	9	100
9	CB 06-651	-	9	90
10	CB 07-103	-	9	90
11	CB 07-115	-	9	90
12	CB 07-136	-	9	90
13	CB 00-15-23	-	9	90
14	CB 00-15-64	-	1	10
	Promising lines during previous year 2009			
15	CN 1340-76-1-BNKR 23-7-1	IR 42/Patnai 23	9	90
16	CN 1340-76-1-BNKR 23-7-2	IR 42/Patnai 23	9	90
17	CN 1442-4-2-9	CN 1223/CN 540	9	90
18	CR 2346-16	IR 60290-115010101/IR 53508-5-4-1-3-3	9	90
19	CR 2499-68-10	BG 90/IR 65564-44-2-3	9	90
20	CR 2502	NDR 9930077/IR 2644-UBN-1-12	7	70
21	CR 2711-76	-	1	10
22	CR 2711-114	-	1	10
23	CR 2711-139	-	1	10
24	CR 2711-149	-	1	10
25	CR 2712-12	-	1	10
26	CR 661-236-1-3	Savitri/IR 44	9	100
27	IR 64 sub 1	-	9	100
28	JGL 13547	MTU 4870/Godavari Isukalu	9	100
29	MAS ARB 25	IR 64/Azucena/IR 64	9	100
30	NDR 2084	IR 50401-77-2-1-3/IR 42068-22-3-3-1-3	7	90
31	NDR 6240	Selection from Kalanamak (Basti)	9	90
32	NWGR-4105	GR-11//M-61-1-1-1-1-/1-3-2-1-3	9	90

33	OR 2109-2	Indravati/IR 72//Salivahana	9	100
34	OR 2162-5	OR 142-99/Surendra	9	90
35	PBM-1	Pusa Basmati mutant	7	100
36	R 1493-627-755-1-1	GopalBhog/R 405-A-4	9	100
37	TTB 122-33-1	TTB 15-1/Kalinga III	9	100
	Breeding lines derived from wild rices			
38	RP Bio 4918	Swarna/*O. nivara*	9	90
39	RP Bio 4918	Swarna/*O. nivara*	7	100
40	RP Bio 4918	Swarna/*O. nivara*	1	10
41	RP Bio 4918	Swarna/*O. nivara*	9	90
42	RP Bio 4919	KMR 3/*O. rufipogon*	9	90
43	RP Bio 4919	KMR 3/*O. rufipogon*	5	85
44	RP Bio 4919	KMR 3/*O. rufipogon*	7	90
45	RP Bio 4919	KMR 3/*O. rufipogon*	9	90
46	RP Bio 4919	KMR 3/*O. rufipogon*	9	85
47	RP Bio 4919	KMR 3/*O. rufipogon*	9	90
	Recombinant Inbred lines			
48	RIL 8-81	TN1/RP 2068	9	90
49	RIL 8-87	TN1/RP 2068	9	90
50	RIL 8-88	TN1/RP 2068	9	90
51	RIL 8-188	TN1/RP 2068	3	90
	Checks			
52	MO 1	-	9	100
53	PTB 33 (Resistant check)	-	1	5
54	Abhaya	-	9	90
55	Kavya	-	9	90
56	Suraksha	-	9	90
57	TN1 (Susceptible check)	-	9	100

*** Glasshouse**
**** Field**

wild rices ranged from 0 to 8 BPH per 10 plants. On four recombinant inbred lines, the BPH population ranged from 0 to 9 (Table 2).

Twenty one days after release, the population increased dramatically on all the lines. The least population of 15 was recorded on Abhaya and the highest population of 128 per 10 plants on OR 2162-5.

At 35 days, the genotypes CB 05-022 and JGL 13547 recorded nil population of BPH/10 plants and RP Bio 4919 recorded the highest BPH population per 10 plants. The mean population of BPH ranged from 16.67 to 67.33 in CR 661-236-1-3 and NWGR-4105, respectively. The population mean was high in NWGR-4105 (67.33) and CB 06-651 (63.33), while it was low in CR 661-236-1-3 (16.67) and RP Bio 4918 (17.67) (Table 2).

The population of brown planthopper was monitored on different genotypes under planthopper screening. After fifteen days of release the mean population was least in PTB 33 (0.50 ± 0.71) and was highest in breeding lines (11.50 ± 9.89). Twenty one days after release of BPH, the population increased in all lines with highest population of 125.33 ± 62.95 BPH per 10 plants on susceptible check TN1. However, at thirty five days, the population decreased drastically due to wilting of lines (Table 3).

4.1.1.2 Multiple Pest Resistant entries

The multiple pest resistant entries were evaluated for their reaction against BPH population of Mandya. The trial was laid out with fifty three genotypes, comprising of twenty five hybrids, eight lines from Coimbatore, nine lines from DRR, four from Rajendranagar and two from Manipur and with TN1, PTB 33, Abhaya, Kavya and Suraksha as checks.

Table 2. Population of BPH on rice entries of Planthopper Screening lines (PHS) in glasshouse

Sl. No.	Designation	No. of BPH/ 10 Plants			Mean
		15 DAR	21 DAR	35 DAR	
	Breeding lines				
1	CB 05-022	30	85	0	**38.33**
2	CB 05-031	16	73	52	**47.00**
3	CB 05-219	26	99	2	**42.33**
4	CB 05-758	20	84	5	**36.33**
5	CB 06-105	16	69	35	**40.00**
6	CB 06-124	17	123	35	**58.33**
7	CB 06-135	15	72	81	**56.00**
8	CB 06-137	8	64	47	**39.67**
9	CB 06-651	6	104	80	**63.33**
10	CB 07-103	1	84	48	**44.33**
11	CB 07-115	0	83	64	**49.00**
12	CB 07-136	2	32	41	**25.00**
13	CB 00-15-23	4	39	43	**28.67**
14	CB 00-15-64	0	74	46	**40.00**
	Promising lines during previous year 2009				
15	CN 1340-76-1-BNKR 23-7-1	0	44	39	**27.67**
16	CN 1340-76-1-BNKR 23-7-2	0	27	41	**22.67**
17	CN 1442-4-2-9	0	16	55	**23.67**
18	CR 2346-16	4	22	61	**29.00**
19	CR 2499-68-10	0	26	86	**37.33**
20	CR 2502	0	24	82	**35.33**
21	CR 2711-76	0	32	49	**27.00**
22	CR 2711-114	3	80	50	**44.33**
23	CR 2711-139	6	90	35	**43.67**
24	CR 2711-149	0	46	37	**27.67**
25	CR 2712-12	3	72	68	**47.67**
26	CR 661-236-1-3	1	25	24	**16.67**
27	IR 64 sub 1	3	85	62	**50.00**
28	JGL 13547	8	50	0	**19.33**
29	MAS ARB 25	7	20	36	**21.00**
30	NDR 2084	12	48	58	**39.33**
31	NDR 6240	8	53	36	**32.33**
32	NWGR-4105	31	121	50	**67.33**
33	OR 2109-2	19	94	3	**38.67**
34	OR 2162-5	9	128	5	**47.33**
35	PBM-1	20	60	41	**40.33**
36	R 1493-627-755-1-1	0	34	45	**26.33**
37	TTB 122-33-1	11	61	78	**50.00**

	Breeding lines derived from wild rices				
38	RP Bio 4918	7	29	58	**31.33**
39	RP Bio 4918	6	23	79	**36.00**
40	RP Bio 4918	0	35	18	**17.67**
41	RP Bio 4918	0	43	45	**29.33**
42	RP Bio 4919	4	63	61	**42.67**
43	RP Bio 4919	8	72	51	**43.67**
44	RP Bio 4919	1	64	39	**34.67**
45	RP Bio 4919	0	27	89	**38.67**
46	RP Bio 4919	0	29	78	**35.67**
47	RP Bio 4919	2	34	72	**36.00**
	Recombinant Inbred lines				
48	RIL 8-81	0	22	82	**34.67**
49	RIL 8-87	8	63	38	**36.33**
50	RIL 8-88	8	61	36	**35.00**
51	RIL 8-188	9	47	28	**28.00**
	Checks				
52	MO 1	21	43	66	**43.33**
53	PTB 33 (Resistant check)	0	23	60	**27.67**
54	Abhaya	7	15	56	**26.00**
55	Kavya	0	28	46	**24.67**
56	Suraksha	1	23	60	**28.00**
57	TN1 (Susceptible check)	15	100	28	**47.67**

DAR - Days after release

Table 3. Population of BPH on different lines of Planthopper Screening lines (PHS) in glasshouse

Sl. No.	Rice genotypes	No. of BPH / 10 plants			Mean ± SD
		15 DAR	21 DAR	35 DAR	
1	Breeding lines	11.50± 9.89	77.50 ± 23.66	41.38± 25.50	43.45 ± 10.72
2	Promising lines during previous year 2009	6.30 ± 8.01	54.70 ± 32.25	45.26 ± 23.13	35.42 ± 12.39
3	Breeding lines derived from wild rices	2.80 ± 3.19	41.90 ± 17.84	59.00 ± 21.54	34.57 ± 7.41
4	Recombinant Inbred lines	6.25 ± 4.19	48.25 ± 18.89	46.00 ± 24.39	33.50 ± 3.74
5	Resistant check (PTB 33)	0.50 ± 0.71	48.50 ± 36.06	64.00 ± 5.66	37.67 ± 14.14
6	Susceptible check (TN1)	9.67 ± 8.39	125.33 ± 62.95	42.67 ± 50.12	59.22 ± 11.50

SD - Standard deviation ; DAR – Days after release

All the hybrids screened were susceptible to BPH, with a damage score of 9 except CORH-3 and DRRH-2 which recorded a damage score of 1 and 5 in glasshouse and 30 per cent and 60 per cent hopperburn in the field, respectively. The rest of the entries were susceptible to BPH.

Similarly, none of the entries from Coimbatore, Rajendranagar, Directorate of Rice Research (DRR) and Manipur showed resistance to BPH as they also recorded a damage score of 9 in the glasshouse and 100 per cent hopperburn in the field screening (Table 4).

The BPH population was monitored on the lines in the glasshouse after their release.

Fifteen days after release, the population of BPH ranged from 0 to 39 per 10 plants. After fifteen days of release, among the Coimbatore lines, the highest population of 4 BPH per 10 plants were recorded in the CB 06-535 and lowest population (0/10 plants) in CB 06-563, CB 06-803, CB 08-504 and CB 08-534. Similarly, the population on Rajendranagar entries ranged from 0 to 3 BPH per 10 plants. The population on nine DRR lines ranged from 0 to 6. On two Manipur lines, the BPH population ranged from 2 to 5. Similarly, the population on twenty five hybrids ranged from 0 to 39 BPH per 10 plants (Table 5).

After twenty one days of release, the population increased on all the lines. The least population of 0 was recorded on RP 4683-29-2-645, RP 4686-48-1-935 and RP 4687-30-1-648, while the highest population of 160 per 10 plants were recorded on CB 08-534.

Thirty five days after release, the least population of 7 was recorded on JRH-8 and the highest population of 152 per 10 plants was observed on Suraksha. The mean BPH population was low in RP 4683-35-2-746 (17.00) and Indira Sona (17.00), while it was high in PAC-835 (110.33).

Table 4. Reaction of rice entries against BPH on multiple pest resistant lines in glasshouse and field

Sl. No.	Designation	Cross	Damage Score *	Hopper burn (%) **
	Coimbatore lines			
1	CB 06-535	-	9	100
2	CB 06-548	-	9	100
3	CB 06-563	-	9	100
4	CB 06-803	-	9	100
5	CB 08-504	-	9	100
6	CB 08-513	-	9	100
7	CB 08-534	-	9	100
8	CB -08-536	-	9	100
	Rajendranagar lines			
9	RNR C 28	IR 64/IET 9994	9	100
10	RNR 898	Swarna/Tellahamsa	9	100
11	RNR 2378	RNR M 7/RNR 19994	9	100
12	RNR 2765	Heera/BPT 5204	9	100
	DRR lines			
13	RP 4643-51-2-1037	AGANNA/ARC 15831	9	100
14	RP 4683-29-2-645	AGANNA/AC 169	9	100
15	RP 4683-32-1-684	AGANNA/AC 169	9	100
16	RP 4684-35-2-746	AGANNA/AC630	9	100
17	RP 4686-48-1-935	AGANNA/AC355	9	100
18	RP 4687-30-1-648	AGANNA/AC 169	9	100
19	RP 4687-52-2-1192	INRC3021/TN1	9	100
20	RP 4687-52-2-1197	INRC3021/TN1	9	100
21	RP 4688-53-2-1259	INRC3021/W1263	9	100
	Manipur lines			
22	KD-6-18-7-1	Phouren/IR 661-1-1-140-3	9	100
23	WR-26-4-1	Kahaola/KD 4-2-2	9	100
	Hybrids			
24	CORH-3	-	1	30
25	DRH-775	-	9	100
26	DRRH-2	-	5	60
27	DRRH-3	-	9	100
28	GK-5003	-	9	100
29	Indam-200-017	-	9	100
30	Indira Sona	-	9	100
31	JKRH-401	-	9	100
32	JRH-8	-	9	100
33	KRH-2	-	9	100

34	NK-5251	-	9	100
35	PA 6129	-	9	100
36	PA-6444	-	9	100
37	PAC-835	-	9	100
38	PAC-837	-	9	100
39	PHB-71	-	9	100
40	PRH-10	-	9	100
41	PSD-3	-	9	100
42	Sahyadri-1	-	9	100
43	Sahyadri-2	-	9	100
44	Sahyadri-3	-	9	100
45	Sahyadri-4	-	9	100
46	Suruchi	-	9	100
47	US-312	-	9	100
48	RTNRH-10	-	9	100
	Checks			
49	PTB 33 (Resistant check)	-	1	10
50	Suraksha	-	9	100
51	Abhaya	-	9	100
52	Kavya	-	9	100
53	TN1 (Susceptible check)	-	9	100

*** Glasshouse**

**** Field**

Table 5. Population of BPH on rice entries of multiple pest resistant lines in glasshouse

Sl. No.	Designation	No. of BPH/ 10 Plants			Mean
		15 DAR	21 DAR	35 DAR	
	Coimbatore lines				
1	CB 06-535	4	44	122	**56.67**
2	CB 06-548	3	37	93	**44.33**
3	CB 06-563	0	32	75	**35.67**
4	CB 06-803	0	83	51	**44.67**
5	CB 08-504	0	20	89	**36.33**
6	CB 08-513	3	156	84	**81.00**
7	CB 08-534	0	160	60	**73.33**
8	CB -08-536	2	65	71	**46.00**
	Rajendranagar lines				
9	RNR C 28	0	19	115	**44.67**
10	RNR 898	1	27	73	**33.67**
11	RNR 2378	2	35	85	**40.67**
12	RNR 2765	3	45	91	**46.33**
	DRR lines				
13	RP 4643-51-2-1037	0	30	83	**37.67**
14	RP 4683-29-2-645	0	0	37	**12.33**
15	RP 4683-32-1-684	0	21	63	**28.00**
16	RP 4684-35-2-746	0	1	50	**17.00**
17	RP 4686-48-1-935	0	0	52	**17.33**
18	RP 4687-30-1-648	0	0	34	**11.33**
19	RP 4687-52-2-1192	0	11	81	**30.67**
20	RP 4687-52-2-1197	3	38	89	**43.33**
21	RP 4688-53-2-1259	6	45	96	**49.00**
	Manipur lines				
22	KD-6-18-7-1	5	38	53	**32.00**
23	WR-26-4-1	2	63	33	**32.67**
	Hybrids				
24	CORH-3	7	36	48	**30.33**
25	DRH-775	0	17	102	**39.67**
26	DRRH-2	0	24	95	**39.67**
27	DRRH-3	0	52	97	**49.67**
28	GK-5003	0	23	89	**37.33**
29	Indam-200-017	0	34	63	**32.33**

30	Indira Sona	4	24	23	**17.00**
31	JKRH-401	30	72	39	**47.00**
32	JRH-8	39	88	7	**44.67**
33	KRH-2	30	138	16	**61.33**
34	NK-5251	3	113	68	**61.33**
35	PA 6129	17	89	57	**54.33**
36	PA-6444	14	95	122	**77.00**
37	PAC-835	4	216	111	**110.33**
38	PAC-837	0	155	90	**81.67**
39	PHB-71	0	62	104	**55.33**
40	PRH-10	0	52	62	**38.00**
41	PSD-3	0	34	133	**55.67**
42	Sahyadri-1	0	10	140	**50.00**
43	Sahyadri-2	0	27	116	**47.67**
44	Sahyadri-3	0	30	105	**45.00**
45	Sahyadri-4	4	54	126	**61.33**
46	Suruchi	0	58	98	**52.00**
47	US-312	0	72	103	**58.33**
48	RTNRH-10	0	56	78	**44.67**
	Checks				
49	PTB 33 (Resistant check)	1	74	68	**47.67**
50	Suraksha	4	8	152	**54.67**
51	Abhaya	0	29	87	**38.67**
52	Kavya	0	26	125	**50.33**
53	TN1 (Susceptible check)	0	79	99	**59.33**

DAR - Days after release

Table 6. Population of BPH on different lines of multiple pest resistant entries in glasshouse

Sl. No.	Rice genotypes	No. of BPH / 10 plants			Mean ± SD
		15 DAR	21 DAR	35 DAR	
1	Coimbatore lines	1.50 ± 1.69	74.63 ± 55.07	80.63 ± 21.95	52.25 ± 16.81
2	Rajendranagar lines	1.50 ± 1.29	31.50 ± 11.12	91.00 ± 17.66	41.33 ± 5.64
3	DRR lines	1.00 ± 2.12	16.22 ± 17.90	65.00 ± 23.08	27.41 ± 13.84
4	Manipur lines	3.50 ± 2.12	50.50 ± 17.68	43.00 ± 14.14	32.33 ± 0.47
5	Hybrids	6.08 ± 11.16	65.24 ± 48.79	83.68 ± 36.58	51.67 ± 18.53
4	Resistant check (PTB 33)	0.50 ± 0.71	48.50 ± 36.06	64.00 ± 5.66	37.67 ± 14.14
5	Susceptible check (TN1)	9.67 ± 8.39	125.33 ± 62.95	42.67 ± 50.12	59.22 ± 11.50

SD - Standard deviation ; DAR - Days after release

The data on BPH population at 15 days after release, revealed that, *N. lugens* preferred susceptible check TN1 over other genotypes. Similar trend was continued at 21 days after release. The population was lowest in DRR lines (16.22 ± 17.90) followed by Rajendranagar lines (31.50 ± 11.12) (Table 6).

4.1.1.3 National Screening Nurseries-1 (NSN1) lines

These lines were developed by breeders across the country. The trial consisted of one hundred and seventy three genotypes (one hundred and nine Advanced Varietal Trials (AVT) entries, twenty seven hybrids and thirty five popular released varieties and resistant and susceptible check) belonged to NSN1 lines out of two hundred and eighty three genotypes in glasshouse screening.

Among the one hundred and nine AVT lines, four lines *viz.,* CR 2698, CR 2702, CR 2618 and CR 2707 were resistant to BPH, which recorded a damage score of 1 in the glasshouse. In field screening, except CR 2707 and HKR 06-47 all the entries recorded 60 to 100 per cent hopperburn.

Similarly, none of the hybrids were found resistant to BPH in glasshouse as well as in field screening as they recorded damage score of 9 and per cent hopperburn of 80 to 100 per cent, respectively (Table 7).

The BPH population was monitored on the lines in the glasshouse after their release.

Fifteen days after release on AVT lines, the population of BPH ranged from 0 to 16 per 10 plants. Among the hybrids the highest population of 15 BPH per 10 plants were recorded in the *Indam 200-022* and lowest population (0/10 plants) on lines *viz., RTNRH-14*, *CRHR 46*, *ARRH-7434*, *PAC-85143*, *VNR-204*, PA 6201, NK-6355 and RH 1531.

Table 7. Reaction of rice entries against BPH on National Screening Nurseries - 1 lines (NSN 1) in glasshouse and field

Sl. No.	Designation	Cross	Damage Score *	Hopper burn (%) **
	AVT lines			
1	CR 2601	CR 2340-1/BP 235-D-TB-36-8//N 22	9	100
2	CR 2623-IR 55419-04	IR 12979-24-1 (Brown)/UPL RI 5	9	90
3	CR 2634-IR 74371-54-1-1	IR 55419-4-2/Way Rarem	9	100
4	CB 0015-24	IR 64/Norungan//IR 64///IR 64	9	80
5	CB 05-754	(MTU 1066/RR 272-662)// (PMK 3/IR 64)	9	90
6	R 1565-2449-3-1481-1	IR 64/Triguna	9	90
7	R 1207-4-290-1	R 310-37/R 308-6	9	80
8	RNSK-1091-10-1-1	IET 13846/Pusa Basmati 1	9	100
9	NDR 6244	IET 13549/Taroari Basmati	9	80
10	NP-742	PRN 3419/PRN 14	9	100
11	RP 3644-1-19-5-5	Single plant selection	9	80
12	HUBR 10-9	Taroeri Basmati/Jaya	9	90
13	$2K_3$-429-396-2-71-1-21-1-2-0	Basmati 370/IET17948//Basmati 370*2	9	90
14	MAUB 171	Pusa Basmati 1/Type-3	9	80
15	UPR 3027-10-1-1	Sarbati[3]/UPR 2251-17-1	9	100
16	UPR 3027-10-2-1	Sarbati[3]/UPR 2251-17-1	9	60
17	HUR-PB-7	Mutant of Pusa Basmati 1	9	80
18	R 1570-2649-1-1546-1	Swarna/IR 42253	9	80
19	R 1124-69-1-45-1	R 320-300/CheptiGurmatia	9	90
20	CR 2696-IR 83920-B-B-CRA-103-14-1-1-1	-	9	100
21	CR 2697-IR84880-B-CRA-277-2-3-2-1	-	9	80
22	CRR 616-B-2-66-2	Vandana/Apo	9	90
23	CRR 455-109	Kalinga III/WAB 56-50	9	90
24	CRR 427-21 BL-2	Vandana/WAB 56-50	9	100
25	BAU 389-02	Surajmukhi/IR-36	9	80
26	CRR 383-3	N 22/RR 20-5	9	100
27	CRR 427-14 B 1-1-1	Vandana/WAB 56-50	9	100
28	CN 1272-55-105	Swarna/IR 6//Mohan/Khitish	9	100

29	CN 1340-76-1-BNKR 23-7-1	IR 42/Patnai 23	9	100
30	CN 1340-76-1-BNKR 23-7-2	IR 42/Patnai 3	9	100
31	RNR 898	Swarna/TellaHamsa	9	100
32	OR 1878-4	OR 909-4-9/Pankaj	9	90
33	OR 2162-5	OR 142-99/Surendra	9	90
34	OR 1777-4	P 677-50-103-2-9/Badami	9	90
35	R 1837-RF-40	Selection from IR 55419-04-R-25	9	90
36	Re selection of IET 9621	IR 50/Phalguna	9	90
37	KCP 1	Nethravathi/Culture 193	9	80
38	HKR 05-20	PR 114/HKR95-124	9	100
39	HKR 05-22	PR 114/HKR95-124	9	100
40	KJT-3-2-7-72	KJT 3/IR 36	9	90
41	NDR 3323-1-1	NDR 3003/IET 13293	9	90
42	UPR 2937-9-3-1	SPRLR 83030-7-3-2-1-2-3/Pant Dhan 4	9	100
43	OR 2327-23	OR 1206-26-2/IR 62140	9	100
44	CR 2499-68-10	BG 90/IR 65564-44-2-3	9	100
45	CR 2599	Dandi/Naveen//Dandi	9	100
46	R 1521-950-6-843-1	R 827-287/Rastic BR 240-47	9	90
47	NWGR-3119	GR-11/IET 14726/22-1-8-1-1-1	9	90
48	NDR 37031	IR 69010-21-3-2-2-2/IR 68068-99-1-3-3-3//BG 90-2	9	100
49	UPR 2937-5-2-1	SPRLR 83030-7-3-2-1-2-3/Pant Dhan 4	9	100
50	OR 2329-22	OR 1530-8/IR 68181-B-49	9	100
51	TTB 103-21-1	Jaya/Mahsuri	9	90
52	RP 4085-489-205-74	IET 13341/IR 64	9	100
53	HKR 06-103	UPR 1230-9-2/HKR 95-192	9	100
54	TRC-05-2-6-4-39-3-6 (TR 2005-3)	Jagannath/Jaya	9	100
55	NWGR-4013	IET 10750//IET 14741/1-1-6-4-1	9	100
56	UPR 3305-6-1-2	UPR 2495-8-1/Pantdhan 16	9	100
57	RDN 98-2-3-5-14	H.S. 17/TN1	9	100
58	R 1570-2644-2-1547	Swarna/IR 42253	9	100
59	OR 1911-9	Swarna/IR 64	9	100
60	OR 2172-7	IR 64///IR72//Jagannath/NCJ 10	9	100
61	RP 4092-115-12-5-4	IET 15120/IR 64	9	100
62	CR 2649-7	Udaya/IET 16611	9	100

63	CR 2642-52	Naveen/C 101 Lac	9	100
64	NDR 2102	NDR 2064/NDR 2031//NDR 2018	9	100
65	RR 389-7	GM 63/C 22 mutant	9	80
66	WGL 365	Kavya/Abhaya	9	80
67	NR-950	IR 40750/MS-95	9	100
68	OR 2324-8	OR 1206-26-2/IR 57313	9	100
69	HKR 06-47	PR 116/HKR 96-54	3	20
70	PAU 3105-45-3-2	PAU 2338-38-3/PAU 2991-507	9	100
71	NP-5151	NP 4386/NP 4405	9	100
72	RAU 467-79-60	Sita/IR 46	9	100
73	RTN 8-4-2-1-2	IR 58025 B/KLT-3	9	100
74	OR 2329-20	OR 1530-8/IR 68181-B-49	9	100
75	CR 2496	IR 78629-57-3-3-9	9	100
76	WGL 407	BPT 5204/Bhadrakali	9	100
77	RP BIO 4918-22485	Swarna/*O. nivara*	9	100
78	CB 05022	CO 43/ADT 39	9	100
79	R 1530-1196-1-1063-1	Swarna/Krishna Bhog	9	100
80	IR 3727-20-TTB 1-2-3	Abhaya/RD 15//Mahsuri	9	90
81	OR 2150-2	IET 11047/Ramchandi	9	90
82	OR 2329-13	OR 1530-8/IR 68181-B-49	9	100
83	OR 2407-KK-19	Indravati/IR 62181-B-49	9	90
84	OR 2328-5	OR 1206-26-2/OR 1534-129	9	100
85	CR 2569-562	Pallavi/Ranjeet	9	100
86	CR 2597	Ndr 9605/NDR 9830018	9	100
87	R 1835-RF-38	Swarna/IR 4223	9	90
88	R 1218-509-2-452-1	Shymala/Danteshwari//Shyamala	9	90
89	CR 2624-IR 55423-01	UPL RI 5/IR 12979-24-1 (Brown)	9	100
90	RP 4092-128-104-95-12	IET 15120/IR 64	9	90
91	CB 06563	ADT 37/IET 16618	9	90
92	NDR 1131	Narendra 97/Sarjoo 52//N 22	9	90
93	R 1566-2577-2-1530-1	IR 64/Triguna	9	100
94	CR 2698	IR 84896-B-CRA-121-5-1-3-1	1	100
95	CR 2702	IR 84896-CRA-164-17-1-1-5-1	1	100
96	PA 6129 (HC)	-	9	100
97	CR 2618	IR 73898-71-2-6-3	1	100
98	TJP 48	Terna/TJP 28	9	100
99	OR 1734-1-1	Subhadra/NDR 1006	9	90
100	JDP 13-1-RR 419-7	Sneha/Basmati 370	9	90

101	BAU 363-96	Ch-18/R 96-633-1	9	100
102	RR 347-5	Sneha/RR 149-1129	9	90
103	CRR 646-B-12-B	Vandana/Way Raem	9	100
104	CB 06-535	ADT 43/IET 17090	9	90
105	NDR 1135	IRCA 369-28-2-4/RR 151-3	9	90
106	CR 2699	IR 93922-B-CRA-291-4-1-2-1	9	100
107	CR 2707	IR 84898-B-CRA-185-16-1-1-1	1	10
108	25P25	-	9	100
109	KJT 1-11-15-23-26-22	Ratna/E-1	9	100
	Hybrids			
110	*RTNRH-14*	Hybrid	9	100
111	*HRI 166*	Hybrid	9	100
112	*CRHR 46*	Hybrid	9	100
113	*VNR-201*	Hybrid	9	100
114	*Indam 200-022*	Hybrid	9	80
115	*ARRH-7434*	Hybrid	9	100
116	*VNR-202*	Hybrid	9	100
117	*PAC-85143*	Hybrid	9	90
118	*VNR-204*	Hybrid	9	100
119	*US-382*	Hybrid	9	100
120	PA 6201	Hybrid	9	100
121	VNR-207	Hybrid	9	90
122	RH 1531	Hybrid	9	100
123	NK-6355	Hybrid	9	100
124	PNPH-24	Hybrid	9	90
125	HRI-169	Hybrid	9	90
126	US-332	Hybrid	9	90
127	27P31	Hybrid	9	100
128	DRRH-68	Hybrid	9	100
129	TNRH-199	Hybrid	9	100
130	VNR-203	Hybrid	9	100
131	MEPH-106	Hybrid	9	100
132	MEPH-109	Hybrid	9	90
133	27P52	Hybrid	9	100
134	27P88	Hybrid	9	90
135	PG-7140	Hybrid	9	100
136	CRHR 35	Hybrid	9	100
	Popular released varieties			
137	Rasi	-	9	100
138	MAS 26	-	3	40
139	Pusa basmati -1	-	9	100
140	Taraori basmati	-	9	100
141	IR 64	-	5	70
142	MAS 946	-	1	20

143	Anjali	-	9	100
144	Vandana	-	9	100
145	Varalu	-	9	100
146	Swarna	-	9	90
147	Pooja	-	9	90
148	Samba mahsuri (BPT 5204)	-	9	100
149	Annada	-	9	90
150	Govind	-	9	100
151	Narendra 97	-	9	100
152	Tulasi	-	9	100
153	Jaya	-	9	100
154	KRH 2	-	9	100
155	NDR 359	-	9	100
156	Triguna	-	9	100
157	PR 113	-	9	100
158	Lalat	-	9	80
159	Sasyasree	-	9	100
160	MTU 1010	-	9	90
161	Jaldidhan 6(NC)	-	9	90
162	Aditya	-	9	90
163	HR 12	-	9	100
164	Vikramarya	-	9	100
165	Nidhi	-	9	90
166	CH 45	-	9	80
167	Benibhog	-	9	80
168	Swarnadhan	-	9	90
169	IR 50	-	9	100
170	Ajaya	-	9	100
171	Suraksha	-	9	90
	Checks			
172	PTB 33 (Resistant check)	-	1	5
173	TN1 (Susceptible check)	-	9	100

*** Glasshouse**

**** Field**

Similarly, the population at twenty one days after release the population increased dramatically on all the lines. On AVT lines, it ranged from 10 to 200 BPH per 10 plants in NP-742 and MAUB 171, respectively. Among the hybrids the population ranged from 38 (*ARRH-7434*) to 195 (*HRI 166*).

Thirty five days after release, the population increased on all the lines. The least population of two BPH/10 plants was recorded on $2K_3$-429-396-2-71-1-21-1-2-0 and the highest BPH population of 322 per 10 plants on CR 2707. The population mean varied from 4.67 to 145.00 in NP-742 and CR 2707, respectively (Table 8).

The pest preferred susceptible check TN1 as compared to other genotypes at 15 days of release. Similar trend was observed at 21 days after release. After 35 days of release, the highest BPH population was found in AVT lines (64.89 ± 63.17) and resistant check PTB 33 (64.00 ± 5.66). But the mean BPH population in different lines *viz.,* AVT lines, hybrids and popular released varieties were not much varied (Table 9).

Two hundred and eighty three genotypes were screened for resistance to brown planthopper, *N. lugens* in glasshouse and field. Observations on population of BPH at different days and damage score were recorded in glasshouse and per cent hopperburn was recorded in field screening. Among the entries screened twenty genotypes *viz.,* CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, RIL 8-188 (PHS lines), CORH-3, DRRH-2 (multiple pest resistant lines), HKR 06-47, CR 2698, CR 2702, CR 2618, CR 2707, MAS 26, IR 64, MAS 946 (NSN 1 lines), IET 7575 and IET 8116 were found promising against BPH with a damage score of 1 to 5 (Table 10).

Among the fifty seven PHS entries, seven genotypes followed the damage score of 1, one genotype of 3, one genotype of 5, six genotypes of

Table 8. Population of BPH on rice entries of National Screening Nurseries - 1 lines (NSN1) in glasshouse

Sl. No.	Designation	No. of BPH/ 10 Plants			Mean
		15 DAR	21 DAR	35 DAR	
	AVT lines				
1	CR 2601	6	68	6	**26.67**
2	CR 2623-IR 55419-04	11	86	7	**34.67**
3	CR 2634-IR 74371-54-1-1	3	82	6	**30.33**
4	CB 0015-24	6	85	4	**31.67**
5	CB 05-754	0	68	7	**25.00**
6	R 1565-2449-3-1481-1	6	70	3	**26.33**
7	R 1207-4-290-1	0	51	10	**20.33**
8	RNSK-1091-10-1-1	0	70	9	**26.33**
9	NDR 6244	0	69	3	**24.00**
10	NP-742	0	10	4	**4.67**
11	RP 3644-1-19-5-5	0	29	5	**11.33**
12	HUBR 10-9	0	50	3	**17.67**
13	$2K_3$-429-396-2-71-1-21-1-2-0	0	62	2	**21.33**
14	MAUB 171	0	200	4	**68.00**
15	UPR 3027-10-1-1	3	177	5	**61.67**
16	UPR 3027-10-2-1	0	148	4	**50.67**
17	HUR-PB-7	6	110	3	**39.67**
18	R 1570-2649-1-1546-1	3	94	3	**33.33**
19	R 1124-69-1-45-1	6	74	9	**29.67**
20	CR 2696-IR 83920-B-B-CRA-103-14-1-1-1	8	136	12	**52.00**
21	CR 2697-IR84880-B-CRA-277-2-3-2-1	7	88	155	**83.33**
22	CRR 616-B-2-66-2	10	89	76	**58.33**
23	CRR 455-109	7	104	11	**40.67**
24	CRR 427-21 BL-2	4	69	10	**27.67**
25	BAU 389-02	6	83	13	**34.00**
26	CRR 383-3	0	83	64	**49.00**
27	CRR 427-14 B 1-1-1	0	133	127	**86.67**
28	CN 1272-55-105	0	68	15	**27.67**
29	CN 1340-76-1-BNKR 23-7-1	0	64	30	**31.33**
30	CN 1340-76-1-BNKR 23-7-2	0	27	53	**26.67**
31	RNR 898	5	66	122	**64.33**
32	OR 1878-4	0	130	55	**61.67**
33	OR 2162-5	0	174	59	**77.67**
34	OR 1777-4	0	99	39	**46.00**
35	R 1837-RF-40	9	114	20	**47.67**
36	Re selection of IET 9621	7	114	74	**65.00**
37	KCP 1	7	96	32	**45.00**
38	HKR 05-20	0	81	60	**47.00**

39	HKR 05-22	16	86	53	**51.67**
40	KJT-3-2-7-72	12	86	68	**55.33**
41	NDR 3323-1-1	4	68	61	**44.33**
42	UPR 2937-9-3-1	5	81	78	**54.67**
43	OR 2327-23	3	69	47	**39.67**
44	CR 2499-68-10	5	42	60	**35.67**
45	CR 2599	6	62	46	**38.00**
46	R 1521-950-6-843-1	4	52	76	**44.00**
47	NWGR-3119	0	50	118	**56.00**
48	NDR 37031	0	63	102	**55.00**
49	UPR 2937-5-2-1	0	79	99	**59.33**
50	OR 2329-22	0	53	71	**41.33**
51	TTB 103-21-1	4	47	55	**35.33**
52	RP 4085-489-205-74	3	36	73	**37.33**
53	HKR 06-103	5	58	98	**53.67**
54	TRC-05-2-6-4-39-3-6 (TR 2005-3)	3	54	98	**51.67**
55	NWGR-4013	0	74	66	**46.67**
56	UPR 3305-6-1-2	0	55	72	**42.33**
57	RDN 98-2-3-5-14	9	69	67	**48.33**
58	R 1570-2644-2-1547	5	78	98	**60.33**
59	OR 1911-9	4	58	87	**49.67**
60	OR 2172-7	0	68	108	**58.67**
61	RP 4092-115-12-5-4	3	67	67	**45.67**
62	CR 2649-7	3	63	74	**46.67**
63	CR 2642-52	0	73	81	**51.33**
64	NDR 2102	3	35	82	**40.00**
65	RR 389-7	2	34	85	**40.33**
66	WGL 365	4	48	117	**56.33**
67	NR-950	5	117	13	**45.00**
68	OR 2324-8	2	143	18	**54.33**
69	HKR 06-47	0	156	124	**93.33**
70	PAU 3105-45-3-2	2	87	72	**53.67**
71	NP-5151	7	109	40	**52.00**
72	RAU 467-79-60	4	107	35	**48.67**
73	RTN 8-4-2-1-2	0	86	16	**34.00**
74	OR 2329-20	2	77	19	**32.67**
75	CR 2496	8	113	88	**69.67**
76	WGL 407	4	97	11	**37.33**
77	RP BIO 4918-22485	11	88	19	**39.33**
78	CB 05022	3	115	24	**47.33**
79	R 1530-1196-1-1063-1	9	127	30	**55.33**
80	IR 3727-20-TTB 1-2-3	4	113	17	**44.67**
81	OR 2150-2	9	123	20	**50.67**
82	OR 2329-13	9	126	36	**57.00**
83	OR 2407-KK-19	13	101	16	**43.33**
84	OR 2328-5	11	140	48	**66.33**
85	CR 2569-562	7	124	32	**54.33**

86	CR 2597	7	32	221	**86.67**
87	R 1835-RF-38	4	49	159	**70.67**
88	R 1218-509-2-452-1	5	34	107	**48.67**
89	CR 2624-IR 55423-01	6	73	189	**89.33**
90	RP 4092-128-104-95-12	3	55	172	**76.67**
91	CB 06563	0	93	161	**84.67**
92	NDR 1131	0	47	147	**64.67**
93	R 1566-2577-2-1530-1	0	75	161	**78.67**
94	CR 2698	0	60	252	**104.00**
95	CR 2702	0	47	243	**96.67**
96	PA 6129 (HC)	4	103	104	**70.33**
97	CR 2618	3	113	289	**135.00**
98	TJP 48	2	87	37	**42.00**
99	OR 1734-1-1	2	91	30	**41.00**
100	JDP 13-1-RR 419-7	0	88	13	**33.67**
101	BAU 363-96	0	52	33	**28.33**
102	RR 347-5	0	63	73	**45.33**
103	CRR 646-B-12-B	6	56	41	**34.33**
104	CB 06-535	4	60	83	**49.00**
105	NDR 1135	7	118	31	**52.00**
106	CR 2699	0	115	87	**67.33**
107	CR 2707	3	110	322	**145.00**
108	25P25	5	139	63	**69.00**
109	KJT 1-11-15-23-26-22	6	118	46	**56.67**
	Hybrid				
110	*RTNRH-14*	0	142	38	**60.00**
111	*HRI 166*	5	195	25	**75.00**
112	*CRHR 46*	0	152	23	**58.33**
113	*VNR-201*	4	76	89	**56.33**
114	*Indam 200-022*	15	118	83	**72.00**
115	*ARRH-7434*	0	38	51	**29.67**
116	*VNR-202*	10	77	79	**55.33**
117	*PAC-85143*	0	115	82	**65.67**
118	*VNR-204*	0	63	77	**46.67**
119	*US-382*	4	35	82	**40.33**
120	PA 6201	0	94	11	**35.00**
121	VNR-207	5	74	104	**61.00**
122	RH 1531	0	62	43	**35.00**
123	NK-6355	0	95	58	**51.00**
124	PNPH-24	3	105	20	**42.67**
125	HRI-169	7	98	52	**52.33**
126	US-332	5	76	34	**38.33**
127	27P31	2	68	30	**33.33**
128	DRRH-68	3	113	15	**43.67**
129	TNRH-199	2	129	4	**45.00**
130	VNR-203	6	97	11	**38.00**
131	MEPH-106	8	168	9	**61.67**

132	MEPH-109	4	145	10	**53.00**
133	27P52	8	141	6	**51.67**
134	27P88	5	163	19	**62.33**
135	PG-7140	9	132	8	**49.67**
136	CRHR 35	4	80	74	**52.67**
	Popular released varieties				
137	Rasi	0	43	53	**32.00**
138	MAS 26	4	62	232	**99.33**
139	Pusa basmati -1	0	75	52	**42.33**
140	Taraori basmati	0	90	46	**45.33**
141	IR 64	0	111	232	**114.33**
142	MAS 946	0	101	222	**107.67**
143	Anjali	0	75	76	**50.33**
144	Vandana	0	88	34	**40.67**
145	Varalu	0	82	14	**32.00**
146	Swarna	0	76	255	**110.33**
147	Pooja	0	84	36	**40.00**
148	Samba mahsuri (BPT 5204)	0	91	12	**34.33**
149	Annada	0	79	10	**29.67**
150	Govind	7	82	6	**31.67**
151	Narendra 97	5	77	3	**28.33**
152	Tulasi	11	67	41	**39.67**
153	Jaya	7	98	92	**65.67**
154	KRH 2	0	60	31	**30.33**
155	NDR 359	0	55	44	**33.00**
156	Triguna	0	53	44	**32.33**
157	PR 113	0	77	22	**33.00**
158	Lalat	8	111	17	**45.33**
159	Sasyasree	4	146	137	**95.67**
160	MTU 1010	7	167	195	**123.00**
161	Jaldidhan 6(NC)	0	111	41	**50.67**
162	Aditya	5	89	30	**41.33**
163	HR 12	0	78	17	**31.67**
164	Vikramarya	0	90	33	**41.00**
165	Nidhi	0	67	51	**39.33**
166	CH 45	0	85	4	**29.67**
167	Benibhog	0	54	15	**23.00**
168	Swarnadhan	0	95	14	**36.33**
169	IR 50	0	91	4	**31.67**
170	Ajaya	5	175	6	**62.00**
171	Suraksha	18	98	4	**40.00**
	Checks				
172	PTB 33 (Resistant check)	1	74	68	**47.67**
173	TN1 (Susceptible check)	14	197	1	**70.67**

DAR - Days after release

Table 9. Population of BPH on different lines of National Screening Nurseries - 1 (NSN 1) in glasshouse

Sl. No.	Rice genotypes	No. of BPH / 10 plants			Mean ± SD
		15 DAR	21 DAR	35 DAR	
1	AVT lines	3.67 ± 3.58	84.00 ± 34.50	64.89 ± 63.17	50.85 ± 22.10
2	Hybrid	4.04 ± 3.77	105.59 ± 40.33	42.11 ± 31.34	50.58 ± 11.87
3	Popular released varieties	2.31 ± 4.11	88.09 ± 28.72	60.71 ± 74.54	50.37 ± 28.44
4	Resistant check (PTB 33)	0.50 ± 0.71	48.50 ± 36.06	64.00 ± 5.66	37.67 ± 14.14
5	Susceptible check (TN1)	9.67 ± 8.39	125.33 ± 62.95	42.67 ± 50.12	59.22 ± 11.50

SD - Standard deviation ; DAR – Days after release

Table 10. Damage score on different lines against BPH infestation in glasshouse

Genotypes	No. of entries screened *	Damage score					
		0	1	3	5	7	9
PHS	57	-	8	1	1	6	41
Multiple pest resistant lines	53	-	2	-	1	-	50
NSN 1	173	-	6	2	1	-	164
Total	**283**	**-**	**16**	**3**	**3**	**6**	**255**

*** Inclusive of resistant and susceptible check**

Table 11. Population of BPH and damage score of select rice genotypes

Sl. No.	Genotypes	Mean population of BPH per 10 plants	Damage score
1	CORH-3	30.33	1
2	CB 00-15-64	40.00	1
3	CR 2711-76	27.00	1
4	CR 2711-114	44.23	1
5	CR 2711-139	43.67	1
6	CR 2711-149	27.67	1
7	CR 2712-12	47.67	1
8	RP Bio 4918	17.67	1
9	CR 2698	104.00	1
10	CR 2702	96.67	1
11	CR 2618	135.00	1
12	CR 2707	145.00	1
13	MAS 946	107.67	1
14	IET 7575	175.00	1
15	IET 8116	160.00	1
16	RIL 8-188	28.00	3
17	HKR 06-47	93.33	3
18	MAS 26	99.33	3
19	DRRH-2	39.67	5
20	IR 64	114.33	5
21	PTB 33	47.67	1
22	TN1	70.67	9
23	Jaya	65.67	9

7 and remaining forty genotypes of 9. In fifty three multiple pest resistant lines one each genotypes scored 1 and 5. Among one hundred and seventy three NSN 1 entries six genotypes scored 1, two genotypes of 3, one genotype of 5 and remaining one hundred and sixty three genotypes scored 9 (Table 11).

4.2 Characterization of rice brown planthopper population of Mandya using differentials.

The results of the experiments conducted during the course of the investigation to characterize the BPH, *N. lugens* population of Mandya are presented in table 7, 8 and 9. The parameters such as reaction in glasshouse, days to wilt, ovicidal test, nymphal survival and honeydew secretion were studied on seven rice differentials in glasshouse.

4.2.1 Screening of differentials in glasshouse

All the differentials were found susceptible as they recorded a damage score of 9, except PTB 33 which showed a damage score of 1. The observation of population mean was recorded over different days. The resistant check PTB 33 was superior over the all other differentials which was having a mean BPH population (20.50), followed by Rathu Heenati (34.25), Sinna sivappu (42.50), MR 1523 (62.50), INRC 3021 (77.50), MO1 (89.75) and TN1 (142.00) (Table 12).

The highest population was reported in susceptible check TN1 (142.00) as compared to resistant check PTB 33 (20.50).

4.2.2 Days to wilting

Among the various differentials, only 37.63 % of the plants wilted in PTB 33 after 35.63 days. Among the differentials, the days to wilting ranged from 18.25 to 21.88 days. However, there was no significant

difference among differentials. All the plants in susceptible check TN1 wilted within 9.63 days after the release of BPH (Table 13).

4.2.3 Ovicidal test

The per cent unhatched eggs was significantly higher in PTB 33 (80.38 %), followed by Rathu Heenati (73.01), Sinna sivappu (69.95), MR 1523 (58.94), INRC 3021 (55.97), MO1 (53.24) than in the susceptible check TN1 (36.79). Among the differentials tested to assess the egg laying behaviour of BPH, it was observed that PTB 33 (63.33), followed by Sinna sivappu (94.83), MR 1523 (104.5), MO1 (123.83), INRC 3021 (124.33), Rathu Heenati (130.33) had the lower fecundity as compared to the susceptible check TN1 (247.17) (Table 13).

4.2.4 Nymphal survival

Survival rate of BPH nymphs was lower on resistant genotype PTB 333 (23.33) as compared to the other differentials tested. The survival rate of BPH nymphs was 63.33, 56.67, 53.33, 53.33 and 43.33 in INRC 3021, MO1, MR 1523, Sinna sivappu and Rathu Heenati, respectively. The highest survival rate of BPH nymphs (96.97) was observed in susceptible genotype TN1 (Table 13).

4.2.5 Adult feeding in the form of honeydew excretion

There was a significant difference among the plant differentials. The highest feeding rate was observed in susceptible check TN1 (449.8 mm^2), followed by Sinna sivappu (301.0), MO1 (273.2), MR 1523 (261.8), INRC 3021 (182.4) and Rathu Heenati (123.8). The feeding rate was least in resistant genotype PTB 33 (68.4).

Table 12. Screening of rice differentials in glasshouse against BPH population

Differentials	Number of BPH per 10 plants				Total	Mean	Damage score
	20 DAR	30 DAR	40 DAR	50 DAR			
MO1	51	137	138	33	359	**89.75**	9
INRC 3021	67	59	173	11	310	**77.50**	9
Rathu Heenati	24	6	89	18	137	**34.25**	9
MR1523	51	27	165	7	250	**62.50**	9
Sinna sivappu	34	26	96	14	170	**42.50**	9
TN1	35	26	184	323	568	**142.00**	9
PTB33	16	22	40	4	82	**20.50**	1

Note: DAR - Days after release

Table 13. Ovicidal test, Nymphal survival and Days to wilt of BPH on rice differentials

Differentials	Fecundity (A)	Unhatchability of eggs (%) (B)	Nymphal Survival (%) (B)	Days to wilt (A)	Plants wilted (%) (B)
MO 1	123.83 (11.17)^{c}	53.24 (46.86)^{d}	56.67 (48.85)^{bc}	18.25 (4.37)^{b}	100 (89.96)^{b}
INRC 3021	124.33 (11.19)^{c}	55.97 (48.44)^{cd}	63.33 (54.78)^{c}	18.88 (4.44)^{b}	100 (89.96)^{b}
Rathu Heenati	130.33 (11.43)^{c}	73.01 (58.72)^{b}	43.33 (41.07)^{b}	21.88 (4.78)^{b}	100 (89.96)^{b}
MR 1523	104.50 (10.26)^{b}	58.94 (50.16)^{c}	53.33 (43.08)^{b}	19.25 (4.47)^{b}	100 (89.96)^{b}
Sinna sivappu	94.83 (9.77)^{b}	69.65 (56.69)^{b}	53.33 (43.08)^{b}	19.38 (4.50)^{b}	100 (89.96)^{b}
TN 1	247.17 (15.75)^{d}	36.79 (37.34)^{e}	96.67 (82.75)^{d}	9.63 (3.24)^{c}	100 (89.96)^{b}
PTB 33	63.33 (8.01)^{a}	80.38 (63.75)^{a}	23.33 (31.00)^{a}	34.63 (5.97)^{a}	37.63 (37.80)^{a}
F'-test	*	*	*	*	*
SEM±	**0.25**	**0.80**	**2.96**	**0.13**	**0.31**
CD @ p=0.05	**1.04**	**2.36**	**8.67**	**0.39**	**0.91**

***Significant at p=0.05. Fecundity and unhatchability of eggs – 5, nymphal survival – 3 and Days to wilt and plants wilted – 8 replications respectively. A= values in parenthesis are √x+1 transformed and B= values in parenthesis are angular transformed.**
Means followed by same letter in each column do not differ significantly by DMRT

The number of honeydew secreted spots did not differ significantly among different rice cultures. However, the number of honeydew secreted spots were more in TN1 (8.2), followed by MO1 (7.0), INRC 3021 (6.8), MR 1523 (6.8), Sinna sivappu (6.6), Rathu Heenati (6.4) and resistant check PTB 33 (5.8) (Table 14).

4.3 Determination of few biochemical factors in select BPH resistant and susceptible rice cultures

The results of the experiments conducted during the course of the investigation to understand the influence of biochemical constituents on resistance of BPH, *N. lugens* are presented in table 15, 16 and 17. The biochemical constituents such as total soluble protein, total soluble sugars, total reducing sugars and total phenols and nutritional constituents like nitrogen, phosphorus, potassium and micronutrients were analysed for the twenty genotypes which were found to have varied degrees of resistance to BPH in the glasshouse and field screening.

4.3.1 Total Phenols

The total phenolic content in twenty three genotypes of rice as influenced by feeding of *N. lugens* during crop growth under ambient field conditions is presented in Table 15.

There was a significant variation in the phenolic content among different rice genotypes. In the resistant group, the phenolic content was higher. CR 2618 recorded the highest phenolic content of 25.38 mg/g and was at par with CR 2707 (23.70) and IET 7575 (23.46). The resistant check PTB 33 recorded 22.15 mg/g of phenolic content and was at par with CR 2711-76, CR 2702, CR 2707, IET 7575, IET 8116 with 21.82, 21.83, 23.70, 23.46 and 22.53 mg/g of phenolic content, respectively.

Table 14. Honeydew excretion by BPH on different rice differentials

Differentials	No. of spots	Area (mm^2)
MO 1	7.00[a]	273.20[c]
INRC 3021	6.80[a]	182.60[e]
Rathu Heenati	6.40[a]	123.80[f]
MR 1523	6.80[a]	261.80[d]
Sinna sivappu	6.60[a]	297.00[b]
TN 1	8.20[a]	449.80[a]
PTB 33	5.80[a]	68.40[g]
F'-test	**NS**	*****
SEM±		**1.92**
CD @p=0.05		**7.98**

***Significant at p=0.05. Means followed by same letter in each column do not differ significantly by DMRT**

However, all the genotypes recorded significantly higher phenolic content as compared to TN1 (12.34 mg/g) and Jaya (12.63 mg/g).

4.3.2 Crude protein

All the genotypes recorded significantly lower crude protein content as compared to TN1 (7.25 mg/g) and Jaya (6.92 mg/g). The crude protein content was significantly lower in PTB 33 (2.60 mg/g) compared to all other genotypes, but was at par with DRRH-2, CR 2711-139, CR 2712-12 with 2.76, 3.36 and 3.18 mg/g of crude protein respectively. In resistant group, the genotype was superior over the all other genotypes which was having an crude protein content. CR 2698 (3.61), CR 2702 (3.86), CR 2618 (3.95), RP Bio 4918 (3.99), CR 2711-76 (4.11), IET 8116 (4.17), CR 2711-149 (4.24), CB 00-15-64 (4.30), IET 7575 (4.30), CR 2707 (4.36), CR 2711-114 (4.67), MAS 946 (4.76), CORH-3 (4.80), HKR 06-47 (4.86), MAS 26 (4.92), RIL 8-188 (5.07) and IR 64 (5.13), respectively (Table 15).

In the susceptible group, the crude protein content was high. The genotype, TN1 which had highest crude protein content of 7.25 per cent and the lowest crude protein content was found in Jaya (6.92 per cent).

4.3.3 Total soluble protein

Statistical analyses revealed significant variation in the total soluble protein content among resistant and susceptible rice genotypes. Among the resistant group, the lowest total soluble protein was recorded in IET 7575 (1.02), followed by PTB 33 (1.09), IET 8116 (1.21), RP Bio 4918 (1.40), CR 2711-139 (1.47), CR 2698 (1.53), MAS 946 (1.56), CR 2618 (1.58), CR 2702 (1.61), CR 2711-76 (1.73), CB 00-15-64 (1.76), CORH-3 (1.80), CR 2711-114 (1.84), CR 2707 (1.89), CR 2712-12 (1.91), CR 2711-149 (1.98), MAS 26 (2.03), RIL 8-188 (2.08), HKR 06-47 (2.25), DRRH-2 (3.06) and IR 64 (3.17) (Table 15).

In the susceptible group, the soluble protein content was high. Jaya had 4.55 mg per g, while TN1 had 4.83 mg per g of soluble protein content, respectively.

4.3.4 Total soluble sugars

The significant variations were observed in the total soluble sugar content among the resistant and susceptible genotypes. The soluble sugar content was low in the resistant group as compared to the susceptible group. IET 8116 recorded 18.31 mg per g followed by PTB 33 (18.43) < IET 7575 (19.28) < CR 2711-149 (20.01) < CR 2707 (20.26) < CR 2711-76 (20.64) < CR 2698 (20.85) < CB 00-15-64 (22.66) < MAS 946 (24.03) < CR 2702 (25.42) < CR 2618 (26.44) < CR 2711-139 (27.35) < RP Bio 4918 (28.27) < CORH-3 (30.53) < CR 2712-12 (32.34) < CR 2711-114 (33.73) < RIL 8-188 (40.24) < DRRH-2 (41.94) < MAS 26 (41.99) < IR 64 (42.27), and < HKR 06-47 (42.82) (Table 15).

The soluble sugar content was higher in the susceptible group. The genotype Jaya registered soluble sugar content of 85.68 mg per g, while TN1 was having 87.35 mg per g of soluble sugar, respectively.

4.3.5 Total reducing sugars

There was a significant variation in the total reducing sugars content among the genotypes. The lowest reducing sugar content of 9.69 mg/g was observed in resistant check PTB 33 and it differed significantly with all the other genotypes, except with IET 7575 (11.43 mg/g). However, IET 7575 was at par other resistant genotypes *viz.,* CORH-3, RP Bio 4918, CR 2702, CR 2707, IET 8116 with 12.31, 12.97, 12.38, 12.23 and 12.34 mg/g of reducing sugars, respectively (Table 15).

Table 15. Total phenols, crude protein, total soluble proteins, total soluble sugars and total reducing sugars in select rice genotypes upon BPH feeding

	Sl. No.	Genotypes	Total phenols (mg/g)	Crude protein (%)	Total soluble proteins (mg/g)	Total soluble sugars (mg/g)	Total reducing sugars (mg/g)
Resistant Group	1	CORH-3	19.93^{efg}	4.80^{fghij}	1.80^{abcde}	30.53^{fg}	12.31^{bc}
	2	CB 00-15-64	19.85^{efg}	4.30^{defghij}	1.76^{abcde}	22.66^{bc}	14.19^{cde}
	3	CR 2711-76	21.82^{bcdef}	4.11^{cdefghi}	1.73^{abcde}	20.64^{ab}	15.28^{ef}
	4	CR 2711-114	21.31^{cdef}	4.67^{fghij}	1.84^{bcde}	33.73^{h}	15.42^{ef}
	5	CR 2711-139	19.66^{fgh}	3.36^{abcd}	1.47^{abcde}	27.35^{e}	18.53^{gh}
	6	CR 2711-149	20.47^{defg}	4.24^{defghij}	1.98^{cde}	20.01^{ab}	14.39^{cde}
	7	CR 2712-12	19.84^{efg}	3.18^{abc}	1.91^{bcde}	32.34^{gh}	17.32^{fg}
	8	RP Bio 4918	21.29^{cdef}	3.99^{cdefgh}	1.40^{abcd}	28.27^{fe}	12.97^{bcd}
	9	CR 2698	19.74^{efgh}	3.61^{bcde}	1.53^{abcde}	20.85^{ab}	15.45^{ef}
	10	CR 2702	21.83^{bcdef}	3.86^{cdef}	1.61^{abcde}	25.42^{cde}	12.38^{bc}
	11	CR 2618	25.38^{a}	3.95^{cdefg}	1.58^{abcde}	26.44^{de}	15.02^{de}
	12	CR 2707	23.70^{ab}	4.36^{efghij}	1.89^{bcde}	20.26^{ab}	12.23^{bc}
	13	MAS 946	20.04^{efg}	4.76^{fghij}	1.56^{adcde}	24.03^{cd}	14.30^{cde}
	14	IET 7575	23.46^{abc}	4.30^{defghij}	1.02^{a}	19.28^{a}	11.43^{ab}
	15	IET 8116	22.53^{bcd}	4.17^{defghij}	1.21^{abc}	18.31^{a}	12.34^{bc}
	16	RIL 8-188	18.30^{ghi}	5.07^{ij}	2.08^{de}	40.24^{i}	21.56^{i}
	17	HKR 06-47	18.47^{ghi}	4.86^{ghij}	2.25^{e}	42.82^{i}	20.87^{ij}
	18	MAS 26	18.59^{ghi}	4.92^{hij}	2.03^{cde}	41.99^{i}	19.38^{hi}
	19	DRRH-2	17.42^{hi}	2.76^{ab}	3.06^{f}	41.94^{i}	22.17^{i}
	20	IR 64	17.03^{i}	5.13^{j}	3.17^{f}	42.27^{i}	22.23^{i}
	21	PTB 33	22.15^{bcdf}	2.60^{a}	1.09^{ab}	18.43^{a}	9.69^{a}
Susceptible group	22	TN1	12.34^{j}	7.25^{k}	4.83^{g}	87.35^{j}	32.24^{k}
	23	Jaya	12.63^{j}	6.92^{k}	4.55^{g}	85.68^{j}	30.26^{j}
Resistant group mean			**20.61**	**4.14**	**1.81**	**28.47**	**15.69**
Susceptible group mean			**12.49**	**7.08**	**4.69**	**86.51**	**31.25**
Overall mean			**19.90**	**4.40**	**2.06**	**33.51**	**17.04**
F'-test			*	*	*	*	*
SEM±			**0.73**	**0.29**	**0.24**	**0.97**	**0.67**
CD @ p=0.05			**2.15**	**0.86**	**0.70**	**2.86**	**1.96**

***Significant at p=0.05. Means followed by same letter in each column do not differ significantly by DMRT**

The susceptible check TN1 (32.24) and Jaya (30.26) recorded significantly higher total reducing sugars compared to other resistant genotypes.

4.3.6 Major Nutrients

There were significant differences between resistant and susceptible genotypes with respect to nitrogen and potassium contents, while it was non-significant with respect to phosphorus content.

4.3.6.1 Nitrogen

Statistical analysis revealed significant variations in nitrogen content among the resistant and susceptible genotypes. In the resistant group, the nitrogen content was lower. The resistant check PTB 33 recorded the lowest nitrogen content of 0.42 per cent and it was at par with CR 2711-139 (0.54), CR 2712-12 (0.51) and DRRH-2 (0.44). The genotype CR 2698 recorded 0.58 per cent nitrogen content and it was at par with CB 00-15-64, CR 2711-76, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2702, CR 2618, CR 2707, IET 7575, IET 8116 and DRRH-2 with 0.69, 0.66, 0.54, 0.68, 0.51, 0.64, 0.62, 0.63, 0.70, 0.69, 0.67 and 0.44 of nitrogen content ,respectively. However, all the genotypes recorded significantly lower nitrogen content as compared to TN1 (1.16 %) and Jaya (1.11 %) (Table 16).

4.3.6.2 Phosphorus

The phosphorus content in twenty three genotypes belonging to two groups during crop growth under ambient field conditions is presented in table 16.

There were no significant variations in the phosphorus content among the resistant and susceptible genotypes. However, among the twenty three genotypes, CR 2698 and CR 2618 recorded the highest and

lowest, 0.18 and 0.09 per cent phosphorus content, respectively (Table 16).

4.3.6.3 Potassium

There was a significant variation in the potassium content among different rice genotypes. In the resistant group, the potassium content was higher. The resistant check PTB 33 recorded the highest potassium content of 2.41 per cent and was at par with IET 7575 (2.22) and IET 8116 (2.34). The genotype MAS 946 recorded 1.94 per cent of potassium content and was at par with CORH-3, CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2698, CR 2702, CR 2618, CR 2707, IET 7575 and IET 8116 with 1.53, 1.58, 1.79, 1.62, 1.86, 1.85, 1.67, 1.84, 1.73, 1.55, 1.92, 1.73, 2.22 and 2.34 per cent potassium content, respectively. However, all the genotypes recorded significantly higher potassium content as compared to TN1 (1.13 %) and Jaya (1.32 %) (Table 16).

4.3.7 Micro Nutrients

Difference in micronutrient content *viz.*, iron, manganese, zinc and copper in the resistant and susceptible genotypes was found to be non-significant.

4.3.7.1 Iron

The iron content in twenty three genotypes belonging to the two groups during crop growth under ambient field conditions is presented in the table 17.

The iron content did not vary statistically among the resistant and susceptible genotypes. However, among the 23 genotypes, CR 2702 and IET 7575 recorded the highest (595.68 ppm) and lowest, 264.22 ppm of iron content, respectively (Table 17).

Table 16. Major nutrients content in select rice genotypes upon BPH feeding

	Sl. No.	Genotypes	N (%)	P (%)	K (%)
Resistant Group	1	CORH-3	0.77^{fghij}	0.13^{a}	1.53^{defg}
	2	CB 00-15-64	0.69^{defghij}	0.14^{a}	1.58^{defg}
	3	CR 2711-76	0.66^{cdefghi}	0.10^{a}	1.79^{cdef}
	4	CR 2711-114	0.75^{fghij}	0.15^{a}	1.62^{defg}
	5	CR 2711-139	0.54^{abcd}	0.11^{a}	1.86^{cde}
	6	CR 2711-149	0.68^{defghij}	0.12^{a}	1.85^{cde}
	7	CR 2712-12	0.51^{abc}	0.16^{a}	1.67^{def}
	8	RP Bio 4918	0.64^{cdefgh}	0.09^{a}	1.84^{cde}
	9	CR 2698	0.58^{bcde}	0.18^{a}	1.73^{def}
	10	CR 2702	0.62^{cdef}	0.12^{a}	1.55^{defg}
	11	CR 2618	0.63^{cdefg}	0.09^{a}	1.92^{bcde}
	12	CR 2707	0.70^{efghij}	0.15^{a}	1.73^{def}
	13	MAS 946	0.76^{fghij}	0.11^{a}	1.94^{bcd}
	14	IET 7575	0.69^{defghij}	0.13^{a}	2.22^{abc}
	15	IET 8116	0.67^{defghij}	0.14^{a}	2.34^{ab}
	16	RIL 8-188	0.81^{ij}	0.12^{a}	1.65^{def}
	17	HKR 06-47	0.78^{ghij}	0.17^{a}	1.47^{defg}
	18	MAS 26	0.79^{hij}	0.14^{a}	1.33^{fg}
	19	DRRH-2	0.44^{ab}	0.15^{a}	1.41^{efg}
	20	IR 64	0.82^{j}	0.11^{a}	1.46^{defg}
	21	PTB 33	0.42^{a}	0.15^{a}	2.41^{a}
Susceptible group	22	TN1	1.16^{k}	0.16^{a}	1.13^{g}
	23	Jaya	1.11^{k}	0.14^{a}	1.32^{fg}
Resistant group mean			**0.66**	**0.13**	**1.76**
Susceptible group mean			**1.14**	**0.15**	**1.23**
Overall mean			**0.71**	**0.13**	**1.71**
F'-test			*	**NS**	*
SEM±			**0.05**		**0.19**
CD @p=0.05			**0.14**		**0.38**

***Significant at p=0.05. Means followed by same letter in each column do not differ significantly by DMRT**

4.3.7.2 Manganese

There was no significant variation observed in the manganese content among the resistant and susceptible genotypes. However, the genotypes CR 2711-114 and CORH-3 recorded the highest and lowest, 270.98 and 123.07 ppm of manganese content, respectively (Table 17).

4.3.7.3 Zinc

There was a significant variation in the zinc content among different rice genotypes. In the resistant group, the zinc content was higher. The genotype HKR 06-47 recorded the highest zinc content of 84.95 ppm and was at par with CORH-3 (70.52), CR 2711-114 (67.78), CR 2702 (70.54), CR 2707 (75.31), DRRH-2 (67.45) and IR 64 (73.33). The resistant check PTB 33 recorded 64.84 per cent of zinc content and was at par with CORH-3, CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2698, CR 2702, CR 2618, CR 2707, MAS 946, IET 7575, IET 8116, RIL 8-188, MAS 26, DRRH-2 and IR 64 with 70.52, 46.96, 58.54, 67,78, 49.07, 64.13, 57.69, 64.19, 47.72, 70.54, 64.55, 75.31, 57.19, 59.23, 50.77, 62.64, 56.28, 68.45 and 73.33 ppm of zinc content, respectively. However, all the genotypes recorded significantly higher zinc content as compared to TN1 (42.78 ppm) and Jaya (45.32 ppm) (Table 17).

4.3.7.4 Copper

There was no significant variation in copper content among the resistant and susceptible genotypes. However, the genotypes CR 2712-12 and PTB 33 recorded the lowest and highest, 24.35 and 54.65 ppm of copper content, respectively (Table 17).

Table 17. Micro nutrients content in select rice genotypes upon BPH feeding

	Sl. No.	Genotypes	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Resistant group	1	CORH-3	502.51^{a}	123.07^{a}	70.52^{ab}	50.02^{a}
	2	CB 00-15-64	443.74^{a}	194.82^{a}	46.96^{def}	35.65^{a}
	3	CR 2711-76	432.76^{a}	152.24^{a}	58.54^{bcdef}	30.60^{a}
	4	CR 2711-114	553.01^{a}	270.98^{a}	67.78^{abc}	53.83^{a}
	5	CR 2711-139	346.09^{a}	131.40^{a}	49.07^{cdef}	30.69^{a}
	6	CR 2711-149	551.55^{a}	221.73^{a}	64.13^{bcde}	28.04^{a}
	7	CR 2712-12	438.93^{a}	177.55^{a}	57.69^{bcdef}	24.35^{a}
	8	RP Bio 4918	563.72^{a}	123.79^{a}	64.19^{bcde}	32.14^{a}
	9	CR 2698	343.26^{a}	169.56^{a}	47.72^{def}	37.58^{a}
	10	CR 2702	595.68^{a}	257.40^{a}	70.54^{ab}	48.42^{a}
	11	CR 2618	467.51^{a}	178.05^{a}	64.55^{bcde}	27.87^{a}
	12	CR 2707	377.79^{a}	260.12^{a}	75.31^{ab}	52.12^{a}
	13	MAS 946	440.23^{a}	152.07^{a}	57.19^{bcdef}	34.45^{a}
	14	IET 7575	264.22^{a}	239.32^{a}	59.23^{bcdef}	52.23^{a}
	15	IET 8116	568.56^{a}	177.65^{a}	50.77^{cdef}	44.75^{a}
	16	RIL 8-188	490.01^{a}	125.82^{a}	62.64^{bcde}	40.26^{a}
	17	HKR 06-47	331.43^{a}	163.07^{a}	84.95^{a}	39.30^{a}
	18	MAS 26	565.68^{a}	256.41^{a}	56.28^{bcdef}	42.77^{a}
	19	DRRH-2	326.80^{a}	179.54^{a}	68.45^{abc}	38.53^{a}
	20	IR 64	474.47^{a}	219.56^{a}	73.33^{ab}	48.91^{a}
	21	PTB 33	542.01^{a}	143.08^{a}	64.84^{bcd}	54.65^{a}
Susceptible group	22	TN1	545.84^{a}	228.57^{a}	42.78^{f}	48.08^{a}
	23	Jaya	526.51^{a}	224.99^{a}	45.32^{ef}	27.99^{a}
Resistant group mean			**458.09**	**186.53**	**62.55**	**40.34**
Susceptible group mean			**536.18**	**226.78**	**44.05**	**38.04**
Overall mean			**464.88**	**190.03**	**60.94**	**40.14**
F'-test			**NS**	**NS**	*	**NS**
SEM±					**2.90**	
CD @ p=0.05					**8.50**	

***Significant at p=0.05. Means followed by same letter in each column do not differ significantly by DMRT**

4.3.8 Functional Plant Loss Index (FPLI) due to BPH infestation in rice plants

The Functional Plant Loss Index (FPLI) due to BPH infestation was more in susceptible genotypes *viz.,* Jaya (67.48 %) and TN1 (64.12). While, in resistant group, IR 64 (34.65) followed by DRRH-2 (33.80), MAS 26 (31.46), RIL 8-188 (29.11), HKR 06-47 (25.49), RP Bio 4918 (22.874), CR 2711-76 (21.56), CR 2712-12 (18.78), CR 2711-149 (18.75), CR 2711-114 (18.01), CB 00-15-64 (17.74), CORH-3 (17.58), CR 2711-139 (16.07), CR 2707 (9.56), MAS 946 (8.10), CR 2698 (7.75), CR 2702 (7.22), CR 2618 (6.92), IET 8116 (6.29), and IET 7575 (5.95) and resistant check PTB 33 (5.78) recorded lower FPLI (Table 18).

Table 18: Functional Plant Loss Index (FPLI) due to BPH infestation on rice genotypes

	Sl. No.	Genotypes	BPH Uninfested Plant Weight (gm)	BPH Infested Plant Weight (gm)	FPLI
Resistant group	1	CORH-3	16.50	13.60	17.58
	2	CB 00-15-64	18.60	15.30	17.74
	3	CR 2711-76	26.90	21.10	21.56
	4	CR 2711-114	16.10	13.20	18.01
	5	CR 2711-139	22.40	18.80	16.07
	6	CR 2711-149	19.20	15.60	18.75
	7	CR 2712-12	18.10	14.70	18.78
	8	RP Bio 4918	18.80	14.50	22.87
	9	CR 2698	28.40	26.20	7.75
	10	CR 2702	27.70	25.70	7.22
	11	CR 2618	28.90	26.90	6.92
	12	CR 2707	29.30	26.50	9.56
	13	MAS 946	28.40	26.10	8.10
	14	IET 7575	35.30	33.20	5.95
	15	IET 8116	30.20	28.30	6.29
	16	RIL 8-188	21.30	15.10	29.11
	17	HKR 06-47	20.40	15.20	25.49
	18	MAS 26	21.30	14.60	31.46
	19	DRRH-2	21.30	14.10	33.80
	20	IR 64	35.50	23.20	34.65
	21	PTB 33	27.70	26.10	5.78
Susceptible group	22	TN1	26.20	9.40	64.12
	23	Jaya	28.60	9.30	67.48
Resistant group mean			**24.40**	**20.38**	**17.37**
Susceptible group mean			**27.40**	**9.35**	**65.80**
Overall mean			**24.66**	**19.42**	**21.52**
T'-test					*

***Significant at p=0.05**

Discussion

V. DISCUSSION

Brown planthopper (BPH) is the sucking pest of rice. In recent years, the infestation of BPH on rice is on the increase. Resistant cultivars are sought as the major tactic in an integrated approach to rice insect pest management. The identification of insect-resistant rice germplasms and its resistance mechanisms to insect pests has been an integral part of the success of the 'Green Revolution' and has increased the profitability of rice production, minimized safety risks to farmers and contributed to a more healthful environment (Alagar *et al.*, 2007).

Hence, in this present study, attempts have been made to screen genotypes of rice for resistance to BPH infestation, to find out the resistant genotypes of rice through the studies on days to wilt, oviposition, nymphal survival, honey dew excretion and estimation of biochemical constituents of promising genotypes of rice associated with BPH resistance. The findings of this study are discussed below.

5.1 Evaluation of select rice genotypes against brown planthopper populations in field and glasshouse.

The use of resistant genotypes has been exploited as an effective method of pest control by itself and can also be integrated with other methods of control in pest management. Thus, this approach in the management of pests can be highly effective and remunerative. Growing of such genotypes will help in getting good yields even if there is a pest attack. In the present study, the rice genotypes collected across the country were screened against BPH, in order to identify the genotypes resistant to BPH, so that these genotypes could be used in the rice breeding programme to incorporate resistant source in elite breeding lines. Identification of new donors and the gene(s) involved in resistance is of paramount importance for breeding varieties with durable and

multiple resistance to these pests. Further, the gene identification helps in pyramiding of genes from different sources and gene stacking for multiple resistance with the help of molecular tools is the major thrust area for improving and stabilising rice production in irrigated as well as rainfed ecosystems (Wu *et al.,* 2002).

5.1.1 Glasshouse and field screening

Two hundred and eighty three rice genotypes were screened against BPH in glasshouse and field to identify the resistance to *N. lugens*.

Among the fifty seven plant hopper screening entries, none of the fourteen breeding lines were resistant to BPH except CB 00-15-64, which recorded a damage score of 1 in the glasshouse and 5 per cent hopperburn in field screening. In ten breeding lines derived from wild rices, RP Bio 4918 derived from Swarna X *Oryza nivara* was found to be resistant to BPH with a damage score of 1 in glasshouse and 10 per cent hopperburn in the field. Of the four recombinant inbred lines derived from TN1/ RP 2068, only one line showed moderate resistance to BPH with a damage score of 3. In the twenty three lines which were promising against BPH, in the previous years, at different locations of the country, five lines *viz.,* CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149 and CR 2712-12, developed by Central Rice Research Institute, Cuttack, were found to be resistant to BPH with a damage score of 1 and hopperburn of 10 per cent. The mean population of BPH per 10 plants ranged from 16.67 to 67.33.

Among the entries with multiple resistance to insect pests and diseases, all the hybrids screened were susceptible to BPH, with a damage score of 9 except CORH-3 and DRRH-2 which recorded a damage score of 1 and 5 in glasshouse and 30 per cent and 60 per cent

hopperburn in the field respectively. Similarly none of the entries from Coimbatore, Rajendranagar, DRR and Manipur showed resistance to BPH as they recorded a damage score of 9 in the glasshouse and 100 per cent hopperburn in field screening. The mean BPH population was low in RP 4683-35-2-746 (17.00) and Indira Sona (17.00), while it was high in PAC-835 (110.33).

In National Screening Nurseries -1 (NSN1) lines among the one hundred and seventy three entries, four lines *viz.,* CR 2698, CR 2702, CR 2618 and CR 2707 were resistant to BPH, which recorded a damage score of 1 in the glasshouse, while and in the field screening, except CR 2707 and HKR 06-47, all the entries recorded 60 to 100 per cent hopperburn. Among twenty seven hybrids, none of the hybrids were found resistant to BPH in glasshouse and as well as in field conditions. The population of BPH per 10 plants varied from 4.67 to 145.00 in NP-742 and CR 2707, respectively. It is clear from the studies that CR 2707 was highly resistant to BPH as it recorded a damage score of 1 inspite of higher population on it (Figure 1).

Bahagiawati *et al.* (1989) observed the varied reaction of IR 36 and IR 46 to different biotypes of BPH. Similarly, Sidde Gowda (2009) and Sidde Gowda and Gubbaiah (2009) screened 14,190 accessions of rice under Planthopper screening (PHS), National screening nursery (NSN) and Germplasm evaluation against major pests (GEMP) and identified 386 donors processing varied degree of resistance to BPH. Dharma Reddy and Misra (1995) observed the damage ratings of varieties CR 115-107, Culture 1, Jaya and IR 8 were intermediate ranging from 2.8 to 4.6 at 7 days after infestation (DAI) in comparison to 8.6 rating in TN1 and was significantly low on PTB 33 (0.3). Rice cultivars IET 7575, IET 8116, IET 8110, IET 9912, IET 9873 and BPT 2217 were identified as BPH resistant varieties (Gubbaiah and Revanna, 1992; Shivamurthappa,

1993) and IET 7575 (Gubbaiah and Vidyachandra, 1985) and IET 8116 (Gubbaiah *et al.,* 1990) were released as BPH tolerant varieties for cultivation in southern Karnataka and MTU-2077, IET 8110 and MTU-2070 identified as resistance to BPH in Tungabhadra project area (Dronavali, 2005).

The mean BPH population on different germplasm varied considerably. Though some of the lines had higher population compared to susceptible check TN1, they were found to resistant to BPH as indicated in the damage score. Likewise, Soundararajan *et al.* (2005) recorded significantly low BPH population on PTB 33 followed by IR 64 and was high in TN1. However, Kim *et al.* (1991) reported that even the resistant varieties could support high population buildup and observed a decline in population levels when the plant matured, which was inconformity with the present findings.

5.2 Characterization of rice brown planthopper population of Mandya using differentials.

Due to lack of precise studies under controlled conditions, information on performance of identified sources of BPH resistance carrying specific genes for resistance is lacking. Hence it is not clear about the use of specific genes in the breeding programme. For instance, though markers are available for *Bph 10*, *Bph 13* and *Bph 18* genes are reported in the literature, performance of these genes against various BPH populations across the country is not known. Precise genetics and markers associated with BPH and WBPH resistance are not identified for well-known donar parents like PTB 33, Sinna sivappu, etc. Hence the following studies are initiated in Mandya. In this background experiments were conducted to characterize the BPH populations of Mandya using different parameters and the results are discussed below.

5.2.1 Screening of differentials in glasshouse

The highest mean BPH population was observed on TN1 (142.00) compared to all other differentials, thus indicating that other were not preferred by BPH for feeding and settlement on the plant (Figure 2). Similarly Alagar *et al.* (2007) observed lowest nymphal preference in case of moderately resistant genotypes such as ADT 45, PTB 33, CO 43 and ASD 7 compared to susceptible genotype TN1.

5.2.2 Days to wilting

The number of days of wilting was higher in all the differentials compared to TN1. This indicated that, the diffrentials such as MO1, INRC 3021, Rathu Heenati, MR 1523 and Sinna sivappu were resistant to BPH compared to TN1 (Figure 3). Similarly, Alagar *et al.* (2007) observed, days to wilting varying from 21.40 to 39.40 in different genotypes as against 17 days in case of TN1.

Likewise, Soundararajan *et al.* (2002) observed 15.33 to 42.33 days to wilting in case of rice lines derived from a cross IR 64 X Azucena.

5.2.3 Ovicidal test

The number of eggs laid by an insect greatly varies depending on the host plant preference. In the present study, significantly less number of eggs were laid in the differentials compared to susceptible check TN1, thus indicating their non-preference for egg laying. Similarly the percent unhatched eggs were more in case of resistant differentials compared to susceptible genotype TN1 (Figure 4). Similar observations were also made by Senguttuvan *et al.* (1991) and Alagar *et al.* (2007), where in, they reported less number of eggs and higher percent of unhatched eggs on PTB 33 compared to susceptible check TN1. Wu *et al.* (1986) observed that the resistant accessions were nonpreferred and *N. lugens* caged on

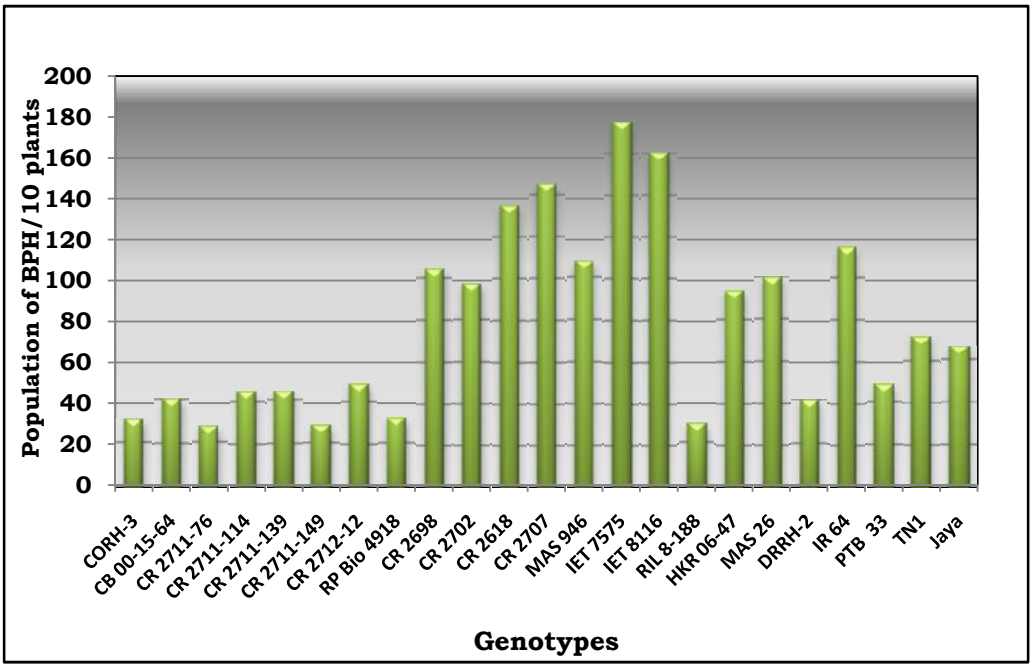

Figure 1. Population of BPH in select rice genotypes

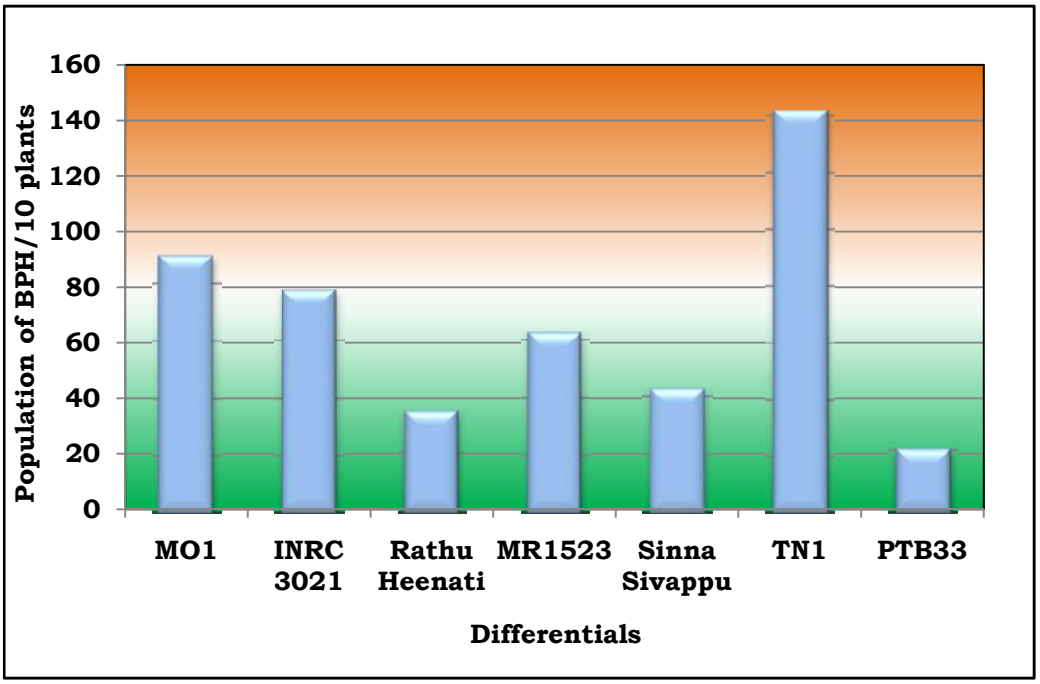

Figure 2. Population of BPH on rice differentials in glasshouse

resistant accessions had low food, fecundity and consequently low populations.

5.2.4 Nymphal survival

The nymphal survival was found more in TN1 (96.67 %), while it was less in PTB 33 (23.33 %) (Figure 4). Similar results were obtained by Zeng *et al.* (1992) while studying the resistance of 4 rice varieties to *Nilaparvata lugens* at 30, 34 and 60 days after sowing. Senguttuvan *et al.* (1991) observed decreased nymphal survival in PTB 33 and IR 64, the highly resistant and resistant rice varieties, while the reverse condition in susceptible TN 1.

Similarly, Alagar *et al.* (2007) reported lower survival rate of BPH nymphs on resistant genotypes was lower than on the susceptible one. The resistant genotypes like ADT 45, PTB 33 and ASD 7 had the lowest survival rate than susceptible TN1. Zhang *et al.* (1994) reported less nymphal survival of the delphacid, *Nilaparvata lugens* on Hong-Yuan and Tainuo-Xuan than on TN1.

5.2.5 Adult feeding in the form of honeydew excretion

The number of honeydew secreted spots by BPH was more in TN1 (8.2) while it was less in PTB 33 (5.8). There was a significant difference among the plant differentials in feeding rate of BPH. The study revealed that the feeding rate was more in TN1 (449.8 mm^2) and was least in PTB 33 (68.4 mm^2) (Figure 5). Similar results were obtained by Paguia *et al.* (1980) where they found more area of honeydew excretion on filter papers in susceptible variety (TN1) compared to resistant varieties (Mudgo and ASD 7). Likewise Kim *et al.* (1998) reported less amount honeydew excretion on resistant cultivars.

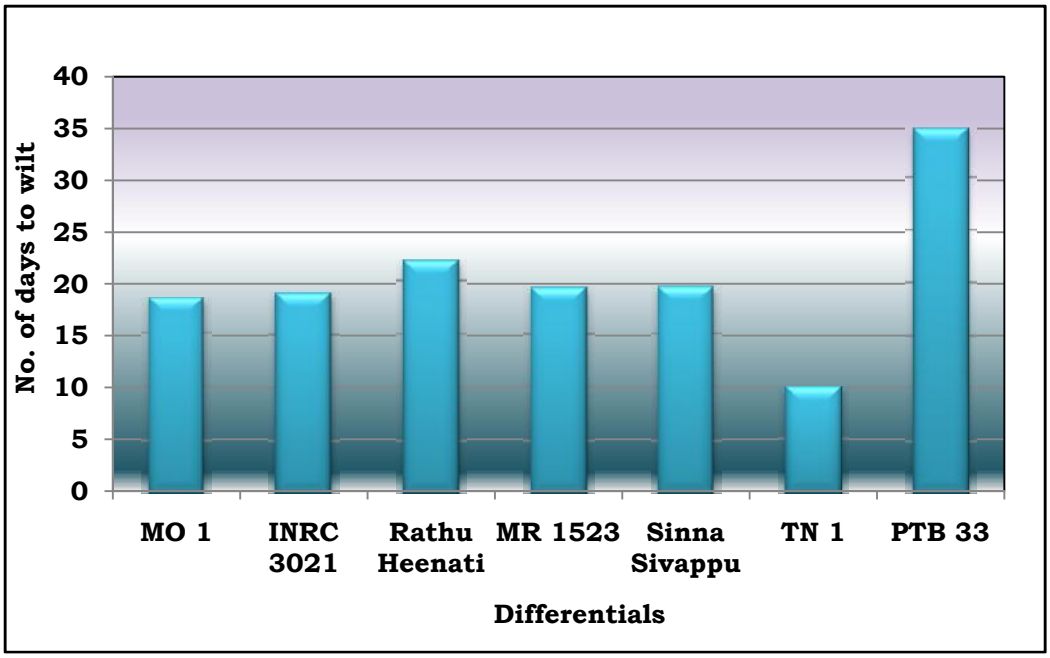

Figure 3. Days to wilting of rice differentials against BPH infestation

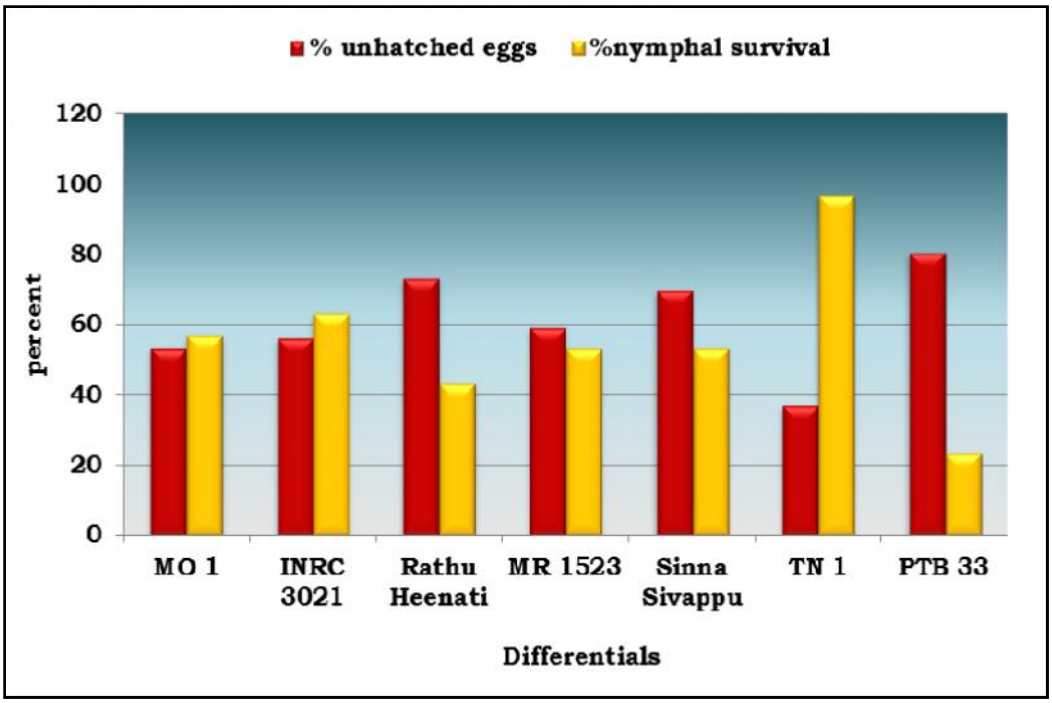

Figure 4. Per cent unhatched eggs and per cent nymphal survival of BPH on rice differentials

5.3 Determination of few biochemical factors in select BPH resistant and susceptible genotypes

Earlier studies revealed that biochemical constituents such as total soluble proteins, total soluble sugars, phenolics, etc., have been reported to contribute to the biochemical basis of tolerance to insect pests (Painter, 1951, 1958; Beck, 1965; Schoonhoven, 1968).

5.3.1 Total phenol content

Phenols have been reported as antinutritional factors and as potential defences against pests. Several kinds of phenolic compounds occur naturally in plants and are known to be associated with plant defence mechanisms because of their accumulation near the wounded and infected tissues (Levin, 1971). The higher levels of phenols may contribute towards tolerance by acting as antifeedants and repellants (Girish, 2005), Sahoo and Patnaik (2003) and Rupali *et al.* (2003) who reported defensive role of phenols in pigeonpea and chickpea, respectively. Phenols in a fairly large concentration may ward of the insect pest because of their direct toxicity (Mohan *et al.,* 1987) and the adverse effects on the activities of digestive enzymes lower the quality of the protein (Singh and Jotwani, 1980) and as an antinutritional factor (Murkute *et al.,* 1993).

It was evident from the results that the level of phenol was higher in the resistant genotypes than in the susceptible ones. The highest phenolic content was found in CR 2618 (25.38 mg/g) and the lowest was in TN1 (12.34 mg/g, respectively). Thus, higher phenolic content had contributed towards resistance against BPH damage (Figure 6).

The resistant genotypes showed higher levels of phenols over the susceptible ones. The present study were in agreement Shivmurthappa (1993) and Loka Reddy *et al.* (2004), who reported reduction in total

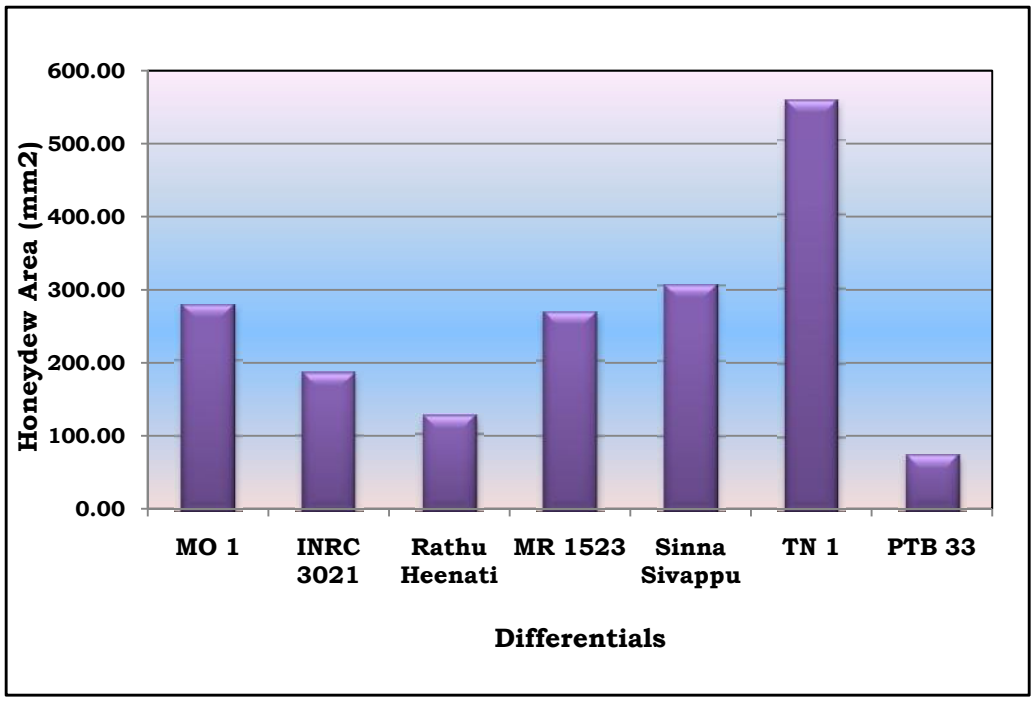

Figure 5. Feeding rate (honeydew area) of BPH on rice differentials

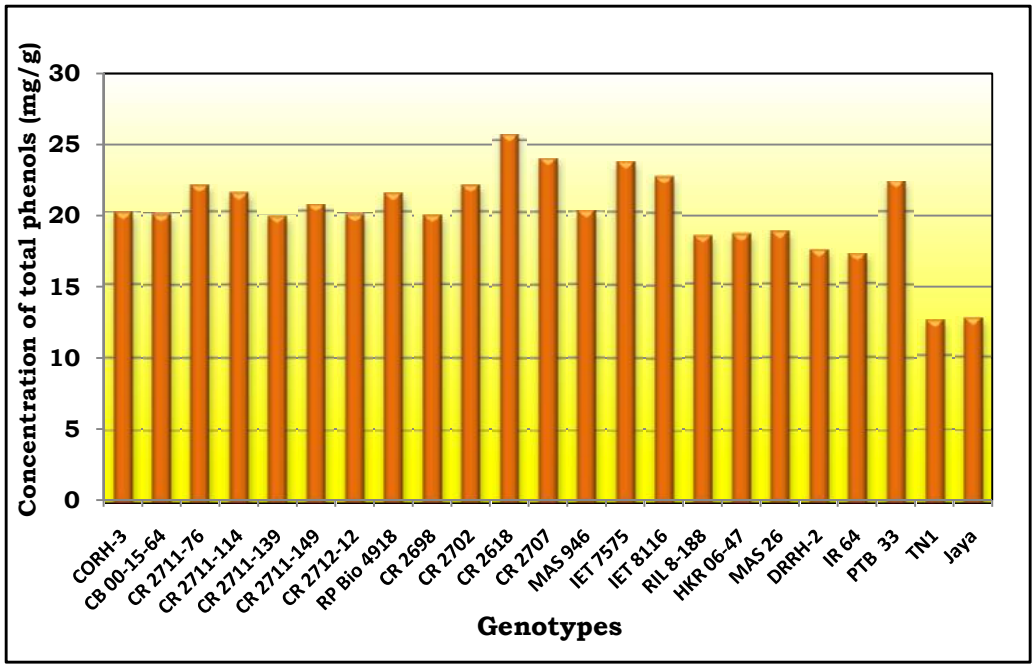

Figure 6. Total phenol content in select rice genotypes against BPH infestation

phenols in susceptible check TN1, and increased phenol content in the resistant check PTB 33 after BPH infestation.

5.3.2 Crude protein content

It was evident from the results that the level of crude proteins was low in the resistant genotypes than in the susceptible ones. The highest crude protein content was found in TN1 (7.25 %) and the lowest was in PTB 33 (2.60 %, respectively). Thus, lower crude protein content had contributed resistance against BPH damage.

The resistant genotypes showed low levels of crude protein over the susceptible ones. The present findings of more crude protein content in susceptible varieties is in agreement with the results of Peng *et al.* (1979) and Samal (1982).

5.3.3 Total soluble protein content

The total soluble protein content was lower in the resistant group over the susceptible ones. Though the lowest soluble protein content was observed in IET 7575 (1.02 mg/g) the other genotypes *viz.,* CORH-3, CB 00-15-64, CR 2711-76, CR 2711-139, RP Bio 4918, CR 2698, CR 2702, CR 2618, CR 2707, MAS 946 and IET 8116 also recorded on par protein content. The higher soluble protein content found in the susceptible group as compared to the resistant one may be responsible for the susceptibility for BPH damage. The literature on total soluble protein content is scanty with respect to rice infested with BPH. However, Girish (2005), Bhat *et al.* (1981), Senguttuvan and Sujatha (2000) observed higher soluble protein content in the susceptible genotypes as compared to that in the resistant ones of fieldbean, cotton and groundnut against bruchid, jassid and leaf miner, respectively.

5.3.4 Total soluble sugars content

In the present study, significant variation in the total soluble protein content was observed among the resistant and susceptible genotypes. The lowest soluble sugars content was found in IET 8116 (18.31 mg/g) and the highest was in TN1 (87.31 mg/g) (Figure 7). The resistant genotypes which had lower levels of sugars over the susceptible genotypes might act as phagostimulants as reported by Cook (1977) and Malik (1978). The total soluble sugars were also reported relatively less in the resistant genotypes in comparison to the susceptible ones as reported by Sujatha *et al.,* 1987 in BPH susceptible varieties (Tellahamsa and Jaya) of rice.

5.3.5 Total reducing sugars content

It was evident from the results that the level of reducing sugars was low in the resistant genotypes than in the susceptible ones. The highest reducing sugars content was found in TN1 (32.24 mg/g) and the lowest was in PTB 33 (9.69 mg/g, respectively). Thus, lower reducing sugar content had contributed towards resistance against BPH damage (Figure 7).

The resistant genotypes showed low levels of reducing sugars over the susceptible ones. The reducing sugars were also reported relatively less in the resistant genotypes in comparison to the susceptible ones of rice against BPH (Shivmurthappa, 1993) and on fieldbean against Bruchid (Girish, 2005). A study conducted by Mohan and Venugopal (1999) on differential survival of the leaf hopper on resistant and susceptible varieties of cotton to link resistance with non-preference and antibiosis mechanism revealed that the reducing sugars were low in resistant entries.

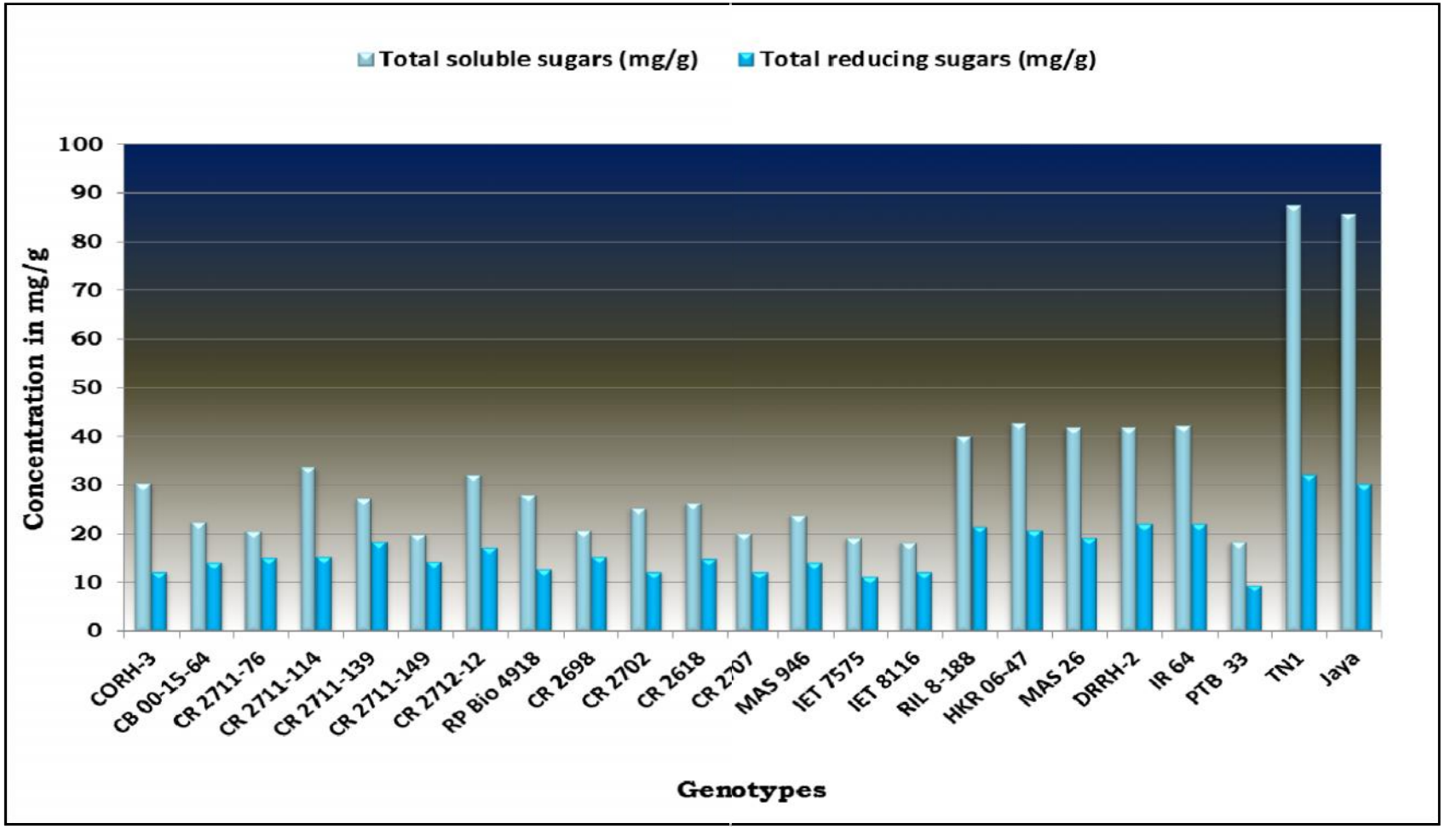

Figure 7. Total soluble sugars and total reducing sugars in select rice genotypes against BPH infestation

5.3.6 Major nutrients

5.3.6.1 Nitrogen

Enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation and pest infestation. The nitrogen content was lower in the resistant group over the susceptible ones. Less reduction of nitrogen is in majority of the resistant varieties indicated less depletion of the proteins such low depletion is due to lack of phagostimulatory amino acids in resistant varieties as observed by Sogawa (1971). The lowest nitrogen content was observed in PTB 33 (0.42 %) and the highest was in TN1 (1.16 %), respectively (Figure 8). Similar results were also reported by Samal and Mishra (1978).

The present study showed that nitrogen was low in resistant genotypes which were comparable with the findings of Sujatha *et al.* (1987) who recorded low nitrogen in the BPH resistant varieties and Subbarao and Perraju (1976) who proved that rice strains resistant to first instar larvae of *Tryporyza incertulas* (Walker) was due to low content of nitrogen. The results were in conformity with the findings of Sogawa (1971). However, Samal and Mishra (1978) found no difference in per cent nitrogen in brown planthopper resistant and susceptible rice varieties.

5.3.6.2 Phosphorus

Phosphorus is a major component in ATP, the molecule that provides “energy” to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material (DNA and RNA) (Charles *et al.,* 2004).

It was evident from the results that there was no significant difference in phosphorus content between resistant and susceptible genotypes. However, the highest phosphorus content was observed in CR 2698 (0.18 %) and the lowest was in CR 2618 (0.09 %). Which is in corroboration of earlier studies done by Shivmurthappa (1993). Loka Reddy *et al.,* 2004 reported that the phosphorus content did not show much difference among the resistant and susceptible cultures indicating that phosphorus had no role in offering resistance or susceptibility of rice cultures to BPH infestation.

5.3.6.3 Potassium

Potassium induced changes in rice plant had profound effect on insect-host interactions. Increase in K in rice plant caused reduction in the feeding rate of BPH (Vaithilingam *et al.,* 1976) and the rate of population build-up of BPH and green leafhopper, *Nephotettix* sp. (Subramanian and Balasubramanian, 1976). It was evident from the results that the level of potassium was higher in the resistant genotypes than in the susceptible ones. The highest potassium content was found in PTB 33 (2.41 %) and the lowest was in TN1 (1.13 %, respectively). Thus, higher potassium content had contributed resistance towards BPH damage (Figure 8).

Observation of high potassium content in resistant varieties is in agreement with several earlier workers (Subbarao and Perraju, 1976; Samal, 1984 and Sujatha *et al.,* 1987). Samiayyan and Janarthanan (1988) suggested that the reduction in populations of GLH, WBPH and BPH at high dose of potassium was partly due to the fertilizer enhancing protein synthesis in the sap, making the plant less favourable for the reproduction of sucking pests.

5.3.7 Micro nutrients

5.3.7.1 Iron

The iron content did not vary between resistant and susceptible genotypes. The lowest iron content was observed in IET 7575 (264.22 ppm) and the highest was in CR 2702 (595.68 ppm), respectively. This results were in agreement with the findings of Shivmurthappa (1993).

5.3.7.2 Manganese

There was no significant difference in manganese content in resistant group over the susceptible ones. The lowest manganese content was observed in CORH-3 (123.07 ppm) and the highest was in CR 2711-11-114 (270.98 ppm).

The present study was in agreement with the findings of Shivmurthappa (1993) in *kharif* 1989 but differed with the results of *kharif* 1990.

5.3.7.3 Zinc

Zinc plays an important role in many biochemical reactions within the plants. Plants such as rice, maize and sorghum shows reduced photosynthetic carbon metabolism due to zinc deficiency. Zinc is also a part of several other enzymes such as superoxide dismutase and catalase, which prevents oxidative stress in cells. It was evident from the results that there was a significant difference in zinc content between resistant and susceptible genotypes. The highest zinc content was observed in HKR 06-47 (84.62 ppm) and the lowest was in TN1 (42.78 ppm) (Figure 9).

Similar results were obtained by Cayton *et al.* (1984) who reported significant difference in the content of zinc in the resistant (IR 36) and susceptible variety (IR 26) of rice.

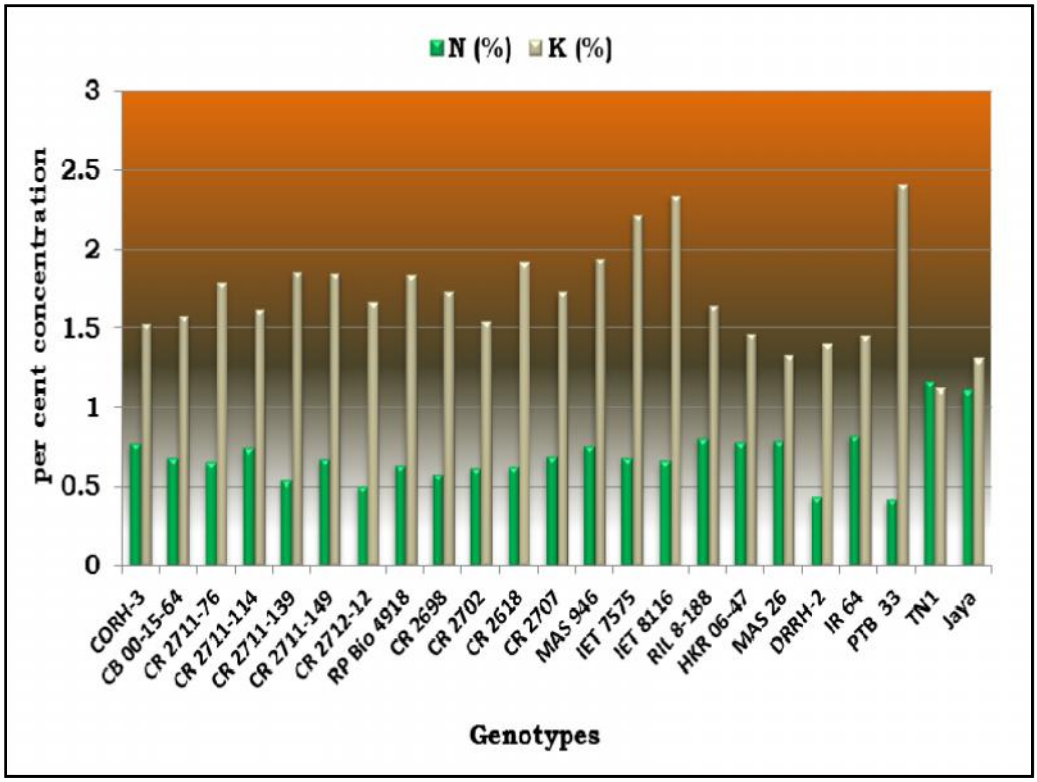

Figure 8. Effect of BPH feeding on the major nutrients (N and K) in select rice genotypes

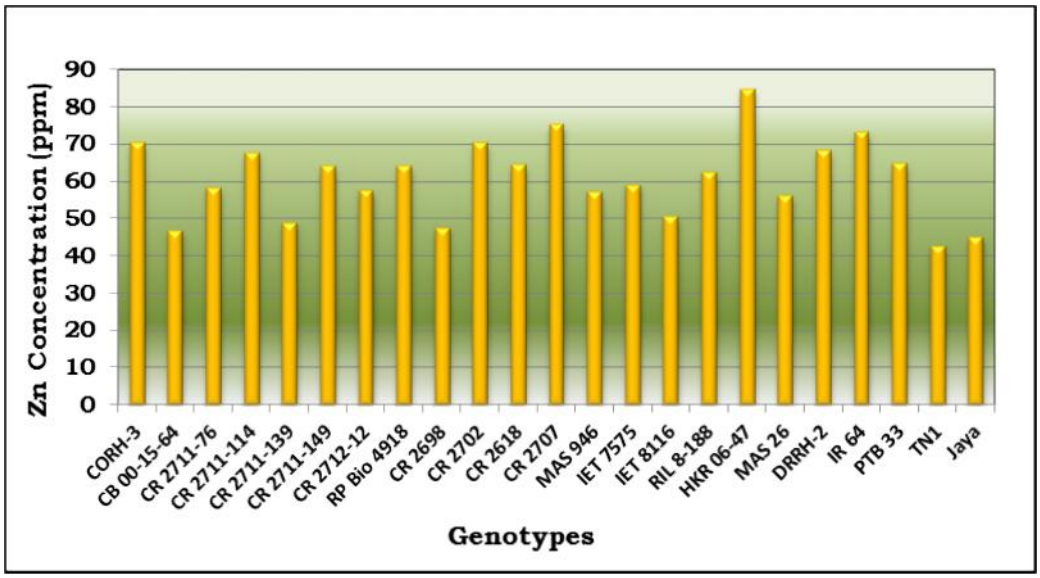

Figure 9. Zinc content in select rice genotypes against BPH infestation

5.3.7.4 Copper

The copper content was non-significant between resistant and susceptible genotypes. The lowest copper content was observed in CR 2712-12 (24.35 ppm) and the highest was in PTB 33 (54.65 ppm), respectively. Similar observations were made by Shivmurthappa (1993).

5.3.8 Functional Plant Loss Index (FPLI) due to BPH infestation in rice plants

All the resistant genotypes recorded lower FPLI compared to susceptible genotypes Jaya and TN1. The present findings were in conformity with Alagar *et al.* (2007), who reported lowest FPLI in PTB 33 compared to susceptible genotype TN1. Further it was observed that *Oryza rufipogan* and *O. nivara* had lower FPLI compared to *O. perenis* and IR 26 (Wu *et al.,* 1986).

Summary

VI. SUMMARY

Studies were conducted on mechanisms of resistance to brown planthopper (BPH), *Nilaparvata lugens* in rice during *kharif* 2010 at the Zonal Agricultural Research Station, V. C. Farm, Mandya. The principle objectives of the study were i) Evaluation of select rice genotypes against brown planthopper populations under field and glasshouse conditions in Mandya, ii) Characterization of rice brown planthopper population of Mandya using differentials and iii) Determination of few biochemical factors in select BPH resistant and susceptible rice cultures. The findings of the study are summarized below.

Among the fifty seven PHS entries, fourteen breeding lines were susceptible to BPH except CB 00-15-64, of the ten breeding lines derived from wild rices, RP Bio 4918 derived from Swarna X *Oryza nivara* was found to be resistant to BPH and in twenty three lines which were promising against BPH in the previous year 2009, five lines *viz.,* CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149 and CR 2712-12 were found to be resistant to BPH. The mean population of BPH was high in NWGR-4105 (67.33) and was low in CR 661-236-1-3 (16.67).

In the fifty three multiple pest resistant entries, all the hybrids screened were susceptible to BPH, with a damage score of 9 except CORH-3 and DRRH-2 which recorded a damage score of 1 and 5. Similarly none of the entries from Coimbatore, Rajendranagar, DRR and Manipur showed resistance to BPH. The population mean was low in RP 4683-35-2-746 (17.00) while it was high in PAC-835 (110.33).

Among the one hundred and seventy three NSN1 entries, four lines *viz.,* CR 2698, CR 2702, CR 2618 and CR 2707 were resistant to BPH in glasshouse. However, in field screening except CR 2707 and HKR 06-47 all the entries were found susceptible to BPH. Similarly among twenty

seven hybrids screened, none of the hybrids were found resistant to BPH in glasshouse, as well as in field conditions. The population mean was high in CR 2707 (145.00) and was low in NP-742 (4.67).

The studies on the days to wilting, percent unhatchability of eggs, nymphal survival, honeydew excretion indicated susceptibility of differential varieties *viz.,* Rathu Heenati with *Bph3* and *Bph17* genes and other resistant differentials like, Sinna sivappu, MR 1523, INRC 3021 and MO1 to the BPH populations of Mandya compared to resistant check PTB 33.

Eighteen entries which were found to be resistant to BPH in the glasshouse and field screening were subjected to biochemical analysis in comparision with resistant check PTB 33 and susceptible check TN1. The resistant entries had relatively higher content of total phenol (20.61 mg/g), lower content of crude protein (4.14 %), total soluble protein (1.81 mg/g), total soluble sugars (28.447 mg/g) and reducing sugars (15.69 mg/g) compared to susceptible check TN1.

Among the resistant group entries, IET 7575, CR 2711-76, CR 2711-139, CR 2698, CR 2618, CR 2707, IET 8116, CORH-3, CB 00-15-64, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2702, MAS 946 and DRRH-2 were highly promising compared to resistant check PTB 33.

The biochemical analysis major nutrients revealed that, the resistant entries had relatively lower content of nitrogen (0.66 %), higher content of potassium (1.76 %) and no variation in phosphorus compared to susceptible check TN1. Among the resistant group entries, *viz.,* CR 2711-139, CR 2712-12, IET 7575, IET 8116 and DRRH-2 were highly promising compared to resistant check PTB 33.

The micronutrients content (iron, manganese and copper) did not vary among the resistant and susceptible entries except for zinc.

The overall results revealed that the tolerance or resistance among the rice genotypes infested by *N. lugens* may be attributed to the lower levels of crude protein, total soluble protein, total sugar and reducing sugar content; higher levels of total phenol and potassium content and lower functional plant loss index (FPLI). Based on these findings, it may be concluded that, the entries *viz.,* CORH-3, CB 00-15-64, CR 2711-76, CR 2711-114, CR 2711-139, CR 2711-149, CR 2712-12, RP Bio 4918, CR 2698, CR 2702, CR 2618, CR 2707, MAS 946, IET 7575 and IET 8116 (damage score of 1) could be utilized in resistance breeding programme against brown planthopper.

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