INSECT PEST - NATURAL ENEMY - HOST PLANT INTERACTION STUDIES WITH SPECIAL REFERENCE TO THE BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal).

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

I hereby declare that this thesis entitled "**Insect pest — natural enemy — host plant interaction studies with special reference to the brown planthopper, *Nilaparvata lugens* (Stal)**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled "**Insect pest — natural enemy — host plant interaction studies with special reference to the brown planthopper, *Nilaparvata lugens* (Stal)**" is a record of research work done independently by Ms. Haseena Bhaskar, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the Advisory Committee of **Ms. Haseena Bhaskar,** a candidate for the degree of **Doctor of Philosophy in Agriculture** agree that the thesis entitled "**Insect pest — natural enemy — host plant interaction studies with special reference to the brown planthopper, *Nilaparvata lugens* (Stal)**" may be submitted by Ms. Haseena Bhaskar, in partial fulfilment of the requirement for the degree.

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Introduction

INTRODUCTION

The brown planthopper, *Nilaparvata lugens* (Stal) has attained prominence as a major pest of rice throughout the Asian Subcontinent. The pest was managed by evolution of resistant varieties, but the development of newer biotypes which broke down the resistance has added to the woes of the Asian farmer. The current trend in integrated pest management using resistant varieties has to take into account the intricate relationship that exist between levels of BPH resistance, the natural enemy complex and the possibility of biotype build up. It was identified that at least five biotypes exist now in BPH and that present in Kerala and other parts of South India is BPH 5. In many instances, it would be more beneficial to go in for moderate levels of resistance coupled with pest suppression using parasitoids and predators. Mismanagement of the ecosystem with abuse of insecticides has also added to the severity of the problem. Shifts in the weather conditions caused by such factors like global warming and ENSO (El-Nino/Southern Oscillations) have also indirectly affected build up of populations of thermophilic insects like BPH. To develop a data base on the tritrophic relationships involving the host plant, BPH and its natural enemies, it was important that the factors which contributed to the resistance/ susceptibility of the host plant to the pest and existence of factors like allelochemicals or morphological features of the host plant be investigated. Information on the biotic potential of the pest and the natural enemy complex under the three regimes of susceptibility, moderate resistance and high resistance were to be evaluated. The above information was to be generated from the most extensive rice tract of Kerala and hence Kuttanad,rightly called as the rice bowl of Kerala, was selected for this study. The experiments centred on the following objectives.

1. Investigation on the biology of BPH on susceptible, moderately resistant and resistant rice cultivars.
2. The extend of predation/parasitism of BPH on these varieties.
3. Evaluation of plant characters that contribute to the resistance/susceptibility.

4. Chemical analysis of the selected varieties to find out the mechanisms of resistance.
5. Biology of the most predominant natural enemy as influenced by the varieties and population build up of BPH.

The importance of the current study was vindicated by two outbreaks of BPH during 1998-99 in Kuttanad and Palakkad.

Review of Literature

REVIEW OF LITERATURE

Brown planthopper, *Nilaparvata lugens* (Stal)

Distribution, infestation and out breaks

Brown planthopper, which was insignificant as a pest of rice, shot itself into prominence after the 1970's coinciding with the introduction of high yielding varieties of rice and intensive cultivation.

Heavy infestations by *N. lugens* occurred on rice grown in Tamil Nadu and Kerala in 1972 (Das *et al.*, 1972).

It was suggested that the introduction of high yielding varieties and the associated application of high levels of nitrogenous fertilizers, together with continuous cropping and dense planting had enabled the BPH to exploit its high reproductive potential leading to outbreaks of the pest in most Asian countries (Kisimoto, 1977; Heinrichs, 1977). The brown planthopper is widely distributed throughout South, South East and East Asia (Dyck, 1977).

Outbreaks of this pest were recorded in Bangladesh in 1977(Alam and Karim, 1977). By 1979 the pest has become very serious and *N. lugens* was reported to be the foremost pest of rice throughout most of Asia (IRRI, 1979). Dyck *et al.* (1979) suggested that the change to modern rice cultural practices had been the major cause of the upsurge in the density of and damage by the planthopper in the 1970's.

Based on field studies in Philippines, Peralta *et al.* (1983) concluded that insecticidal spraying in BPH infested plots where varieties rated resistant to the pest were grown, destroyed natural enemies allowing the BPH populations to develop unchecked.

Smith *et al.* (1984) reviewed the factors contributing to the resurgence of *Nilaparvata lugens* on rice in several Asian countries. The reasons for resurgence included suppression of natural enemies following intensive broad-spectrum insecticide application, insecticide induced plant growth and stimulation of reproduction by the pest following insecticide application.

Chelliah and Uthamasamy (1986) reported that resurgence of *N. lugens* was induced by organophosphorus compounds, carbamates and synthetic pyrethroids, especially when applied at sublethal doses.

A reduction in the natural enemy population and low persistent toxicity of insecticides applied for the pest control were found to be causing resurgence of rice BPH (Krishniah and Kalode, 1987).

Thakur *et al.* (1991) recorded *N. lugens* outbreak in Madhya Pradesh during Kharif of 1988-89.

Indiscriminate application of insecticides in the early stages of the rice cropping season was found to cause resurgence of BPH as a result of increased mortality of natural enemies (Banerjee, 1996).

Biology of *N. lugens*

Following severe outbreaks of *N. lugens* in Alleppey and Trichur Districts of Kerala, Nalinakumari and Mammen (1975) carried out laboratory studies on the biology of the delphacid. The incubation period, nymphal development from egg to adult, and life span of adult males, normal adult females and brachypterous adult females averaged 8.1, 21.6, 18.4, 21 and 5.6 days, respectively. The oviposition period lasted 10-28 days, and females laid an average of 232.4 eggs each.

Studies on the biology of *N. lugens* by Thomas (1977) revealed that the incubation period and nymphal duration averaged 8.0 and 14.0 days respectively. On an average the life cycle was completed in 22.0 days. The macropterous male, female and the brachypterous female lived for 18.0, 21.4 and 13.8 days respectively. The brachypterous female, though short lived, laid on an average 209.6 eggs as against 228.3 eggs laid by the macropterous female during the life time.

Khaire and Dumbre (1981) observed that in laboratory, females of *N. lugens* laid an average of 568.4 eggs and the hatching percentage was 78.66. The egg stage lasted 10.0 days. The five larval instars occupied 2.5, 3.0, 4.5, 5.5 and 4.5 days respectively, adult male and female life span were 16.5 and 27.0 days and the pre-oviposition and oviposition periods 2.0 and 26 days.

Effect of varietal resistance on the biology of BPH

Host-biology relation studies on *N. lugens* showed that susceptible varieties exert marked favourable effects on the survival, speed of development and growth index of nymphs and on longevity and fecundity of adults. The resistant variety Ptb 33 suppressed the speed of development of the nymphs, caused mortality among them and reduced the life span and fecundity of the adults (Thomas, 1977).

Nymphs of *N. lugens* caged on resistant varieties showed a slightly slower rate of growth than those on a susceptible variety, but the life span of adult females was not significantly different (Oya and Hirao, 1985).

Misra *et al.* (1988) observed that adult longevity fecundity, egg hatchability and growth index of *N. lugens* was significantly lower on the resistant cultivars, Daya, Pratap, Sinna Sivappu and IET 7575 than on the susceptible control, Jaya.

Basit and Saharia (1988) reported that resistant varieties had an adverse effect on BPH in terms of development, survival and egg production resulting in a shorter life span of the surviving adults.

Compared to the susceptible control Taichung-Native 1 (TN-1), the highly resistant and resistant varieties to BPH, PTB 33 and IR 64 expressed a low population build up, increased nymphal duration, decreased nymphal survival, high growth index and decreased feeding rate of BPH (Senguttuvan *et al.*, 1991).

Cheng and Sun (1992) found a reduction in the nymphal survival, adult fertility and net reproductive rate and an increase in the length of nymphal stage in *N. lugens* reared on resistant varieties compared with susceptible control.

Zhou and Zhang (1992) reported that the survival of first to fourth instar nymphs of BPH on resistant variety ASD7 was low compared with a susceptible control, TN-1, while the survival of fifth instar nymphs, dry weight and fertility of the adults were comparable. On the variety Hugenkang, the survival of first to fourth instar nymphs was similar to that of control, but the survival of fifth instar nymphs, dry weight and fertility of adults was less than those of the delphacids on the control variety.

Natural enemies of rice brown planthopper

Information on the natural enemies of rice planthoppers has been reviewed by Otake (1977), Chiu (1979) and Greathead (1979).

Predators

Stapley (1975, 1976) credited *Cyrtorhinus lividipennis* Reuter with preventing outbreaks of *N. lugens* in irrigated rice in Solomon Islands.

Predators known to attack *N. lugens* in Japan include *C. lividipennis*, spiders and *Microvelia douglasi* (Otake, 1977).

In IRRI rice fields, *C. lividipennis* and *Lycosa pseudoannulata* were considered to be the most important predators of BPH (Dyck and Orlido, 1977).

Ooi *et al.* (1978) reported the association of the predators *C. lividipennis*, *Casnoidea interstitialis*, *Paederus fuscipes* and *Coccinella arcuata* during the outbreaks of *N. lugens* in West Malaysia.

Samal and Misra (1978) recorded a carabid beetle, *Casnoidea indica* predating on the nymphs and adults of BPH. The beetle consumed on an average 6.4 and 6.6 nymphs and adults respectively.

Coccinella arcuata and *C. lividipennis* were reported as promising biocontrol agents of rice BPH (Mancharan and Jayaraj, 1979).

Studies in Mandya in Karnataka by Manjunath (1979) revealed the presence of two species of Coccinellidae, one species each of Carabidae, Nabidae and Reduviidae as predators of BPH.

During 1979, *Solenopsis geminata,* a species of ant, was found feeding on BPH nymphs in Moncompu (Thomas *et al.*, 1980).

Kenmore (1980) described *C. lividipennis* as an opportunistic predator that exploits outbreaks of BPH only after other control factors have failed.

Numerous species of predatory arthropods have been recorded in rice fields - especially in Thailand - where Yasumatsu *et al.* (1981) made comprehensive inventories of predatory species present and their numbers.

Certain predators of *N. lugens* are consistently reported in large numbers in several countries and laboratory prey consumption rates have been estimated for several of them (Greathead, 1982).

Unlike generalists, the mirids, *Cyrtorhinus* spp. and *Tytthus* spp. are specialist predators on homopteran eggs inserted into plant tissues although they prey to some extend on young nymphs. *C. lividipennis* is the most abundant and frequently encountered predatory species in rice fields (Greathead, 1982).

Studies on the predator *C. lividipennis* suggested that it was ineffective except during outbreaks (Knight *et al.*, 1982).

Immature and adult snails of *Lymnaea auriculata* were observed feeding on nymphs and adults of *N. lugens* in rice fields at CRRI, Orissa (Samal *et al.*, 1984).

The wolf spider *Lycosa pseudoannulata* (Boesenberg & Strand) was considered as a major regulator of BPH populations (Kenmore *et al.*, 1984).

Nakasiji and Dyck (1984) suggested *Microvelia douglasi atrolineata* Bergoth as an important brown planthopper mortality factor.

Three predators, *Paederus fuscipes, Brumus suturalis* and *L. pseudoannulata* were observed in large numbers associated with leaf and planthoppers in summer paddy in Chattisgarh region of Madhya Pradesh (Kaushik *et al.*, 1986).

Wolf spider *L. pseudoannulata,* four jawed spider *Tetragnatha* sp., Staphylinid beetle *Paederus fuscipes* and Carabid beetle *Ophionea indica* were reported to be the important predators of rice BPH found in Mekong Delta (Chou, 1987).

Survey on predators of *N. lunges* in Tamil Nadu following an outbreak of the pest revealed the presence of large numbers of *Tetragnatha armatissimus, C. lividipennis* the nabid, *Stenonabis tagalicus* and the reduviid *Polididus armatissimus* (Peter, 1988).

Studies on *Hydrometra lineata,* a predator of *N. lugens* in China, revealed that an adult *Hydrometra* consumed an average of three third instar nymphs or 1.7 mature nymphs of *N. lugens* per day (Wu, 1988).

The Staphylinid *Paederus fuscipes* was found at population densities of 5-20 beetles/m^2 in rice fields in Tamil Nadu (Rajendran and Gopalan, 1988). Studies on predation showed that the number of *N. lugens* consumed per day averaged 8.7 adults.

Natural enemies of *N. lugens* in rice include the predators *C. lividipennis, Harmonia octomaculata, Microvelia* sp. and several species of Araneae (Gupta and Pawar, 1989).

Rajendran and Devarajah (1990) recorded the insect predators on plant and leafhoppers in rice fields of Sri Lanka which includes *C. lividipennis, Micraspis discolor, H. octomaculata, P. fuscipes* and an anthocorid.

A species of the mirid genus *Tytthus* was found preying on colonies of BPH in Philippines. Adult females attacked eggs of the pest at an average of 14 eggs/day with a maximum of 32. They also preyed on nymphs, but at lower rates (Basilio and Heong, 1990).

Predatory coccinellids, *M. sexmaculata, Coccinella* spp. and *Brumus* spp. were observed preying on *N. lugens* (Thakur *et al.*, 1991).

Heong *et al.* (1992) reported the dominant predators of leaf and planthoppers in Philippines which include *M. douglasi atrolineata, C. lividipennis,* the spiders - *Pardosa pseudoannulata* and *Atypena (Callitrichia) formosana* Oi and parasitoids - *Tetrastichus formosana* and *Pseudogonatopus flavifemur.*

Gupta and Pawar (1992) described the spiders, coccinellids and carabids as the most important natural enemies of rice pest including *N. lugens.*

The predatory water strider, *Limnogonus fossarum* did not only prey on BPH that fell into the water, but also attacked BPH on the plant (Almazan and Heong, 1992).

In rice fields in Karnataka, *Polytoxus* sp. was recorded preying on adults of BPH (Gubbiah *et al.*, 1993).

Studies by Wu *et al.* (1993) showed that the magnitude of the main positive effect of predation on *N. lugens* varied with the predator species in diminishing order as follows: *Clubiona japonicola, P. fuscipes, T. praedonia* and *Ummeliata insecticeps*. *Pirata subpiraticus* resulted in the greatest negative effect.

Surface dwelling waterbugs such as *Mesovelia* sp. and *L. fossarum* feed on planthoppers and other soft bodied insects that fell into the paddy water (Ooi and Shepard, 1994).

Cyrtorhinus lividipennis

Pawar (1975) in a survey of plant hoppers and leaf hoppers in rice growing areas of Himachal Pradesh observed *C. lividipennis* attacking eggs and nymphs of *N. lugens*. This was the first record of the mirid attacking the pest in India.

C. lividipennis was found preying on the rice pest *N. lugens* at Bapatla, Andhra Pradesh, during Kharif in 1975 (Murthy *et al.*, 1976). Studies on the seasonal abundance of the two species showed that the predator was capable of rapid multiplication and was able to control *N. lugens* under favourable conditions.

Pathak and Saha (1976) found the mirid preying on the nymphs of *N. lugens* in the Tarai region of India.

Knight *et al.* (1982) reviewed the quantitative information on the effect of natural enemies on *N. lugens* attacking rice in tropical agro-ecosystems. Studies in Philippines on the mirid egg-predator *C. lividipennis* suggested that it was ineffective except during outbreaks.

Peter (1988) reported that *C. lividipennis* was the most abundant predator associated with *N. lugens* in Tamil Nadu during an outbreak of the pest in 1987.

Abundance of rice pests was studied at two sites in Orissa (Chakraborthy *et al.*, 1990). It was found that *N. lugens* and *C. lividipennis* were the most abundant pest and natural enemy respectively in the rice ecosystem.

Wei and Yong (1991) suggested that in a constant temperature environment (28 C), adults of *C. lividipennis* on rice exhibited a clear aggregative response in areas of dense prey, *N. lugens* population. The numbers of *N. lugens* killed were however density dependent.

Study on the population fluctuations of *N. lugens, Sogatella furcifera, Nephotettix virescens, N. nigropictus* and their predator *C. lividipennis* in the Bilaspur district of Haryana indicates that the mirid appeared slightly later than the pests, but its population increased quickly to coincide with that of the pests (Balasubramanian *et al.*, 1988). At the beginning of the observations, the ratio of the rice hoppers to the mirid were 4:1, 1.6:1 and 5:1 in 1981, 1982 and 1983 respectively. At the pre harvest stage (105 days after transplanting), these ratios were 1:1.6, 1:1 and 1:1.14.

Predation efficiency of *C. lividipennis* on *N. lugens*

Mortality of rice plant and leafhopper nymphs due to predation by *C. lividipennis* ranged between 20 and 99.7 per cent as compared with 8 to 9 per cent natural mortality for those nymphs not exposed to the mirid. Under field conditions a predator : prey ratio of 1:4 was found to control damage by *N. lugens* to rice (Pophaly *et al.*, 1978).

The predatory potential of adults of *C. lividipennis* on first and fourth instar numphs of *N. lugens* was investigated in green house studies in Tamil Nadu, India (Rajendran *et al.*, 1987). An adult of *C. lividipennis* consumed a mean of 5.89 and 2.79 first and fourth instar nymphs of *N. lugens* per day, respectively.

In a laboratory study, Rejendram and Devarajah (1987) investigated on the predation of eggs, nymphs and adults of *N. lugens* by nymphs and adults of *C. lividipennis*. Adult males consumed an average of 2.07 eggs, 0.24-0.11 nymphs and 0.16 adults/day, while females consumed 3.3 eggs, 0.21-0.08 nymphs and 0.17 adults/day. Nymphs consumed 1.07-3.05 eggs and 0.38-0.05 nymphs/day.

Manti and Shepard (1990) studied the consumption of eggs of *N. lugens* by the mirid *C. lividipennis* in the laboratory. Daily and total consumption of eggs was higher in females than in males, but maximum life span was shorter in females (16 days) than in males (26 days). Egg consumption by both males and females was highest one day after emergence of the mirid. Total life time consumption by males and females was 61.23 and 143.68 eggs, respectively. Average consumption per day was 8.98 eggs for females and 2.36 for males.

Predation on the eggs of brown plant hopper *N. lugens* by *C. lividipennis* was observed in an untreated rice field in Indonesia during the 1987-88 dry season. TN-1 plants with the eggs of the pest were exposed in the field. Predation increased with the increase in the mirid population and was highest (17.71±2.57%) 91 days after transplanting when the mirid population was 1.25/hill (Manti, 1991).

Experiments conducted to determine the predation of *C. lividipennis* on the eggs of *N. lugens* (Laba and Heong, 1996) showed that the searching efficiency and handling time of the *C. lividipennis* female was higher than that of the male. But based on the higher feeding ability of the female, it was considered that the female mirid was more effective than the male.

Biology of *C. lividipennis*

Pophaly *et al.* (1978) studied the biology of *C. lividipennis* on plant and leafhoppers in rice. They observed that the egg, nymphal and adult stages of the predator lasted 7, 11 and 40 days respectively and that the female laid an average of 147 eggs.

A study conducted in the laboratory on the development, life span and fecundity of *C. lividipennis* revealed the developmental period of the mirid as 20 days with usually five instars. The adult life span and fecundity, and the intrinsic rate of increase of the mirid population were higher when it was fed eggs of *N. lugens* than when these were not provided. The maximum number of plant hopper eggs eaten per day was 22, 18 and 6 by the female, male and third instar nymph of the mirid respectively. The mirid preferred plant hopper eggs to nymphs (Holling *et al.*, 1985).

The biology of the predatory mirid *C. lividipennis* was studied in the laboratory on eggs of *Drosophila, N. lugens, Sogatella furcifera* and *Nephotettix* sp. (Geetha *et al.*, 1992). About 82.4, 62.3, 66.7, 53.0 and 31.3 per cent of mirid nymphs passed through 5 instars on the five prey species, respectively. Nymphal duration varied from 12.3 days on *N. lugens* to 14.82 days on *Drosophila*. The growth index, sex ratio, longevity and fecundity were high on eggs of *N. lugens*.

In another laboratory study Geetha *et al.* (1993) investigated the oviposition behaviour of *C. lividipennis* on rice and weeds. No influence of plant age on fecundity and egg hatchability was found on pieces of rice leaves 15-60 days old provided as substrates for oviposition. Fecundity averaged 67.1 eggs/5 females when these were provided with nymphs of *N. lugens* as compared with 20.7 eggs/5 females for no food. Ovipositional preference was highest on rice followed by *Oryza punctata, O. officinalis, Cyperus rotundus* and *Digitaria sanguinalis*.

Life tables were constructed for the predatory mirid *C. lividipennis* under laboratory condition (Kumar and Velusamy, 1995). The innate capacity of increase for the mirid was 0.13 with *N. lugens* alone as prey, but reached 0.30 with a mixture of *N. lugens* and *S. furcifera* nymphs.

Spiders

Samal and Misra (1975) reported about 20 species of spiders preying on *N. lugens* on rice fields in India. Salticids were the most voracious feeders, followed by lycosids and oxyopids.

In the dry season rice crop at Bapatla three species of predatory spiders, *Pardosa annandalei, Argiope pulchella* and *Tetragnatha* sp., operating at different vertical levels in the crop kept populations of *N. lugens* in check (Rao *et al.*, 1978).

Thomas *et al.* (1979) reported the occurrence of large number of spiders (average 2/hill) on rice crops in Kuttanadu, Kerala where *N. lugens* is endemic. Six days after the insecticide application during an outbreak of the BPH on the main punja season crop, both spider and plant hopper populations were lesser than on untreated rice. Populations increased again 2 weeks after treatment. During the next crop season when insecticide application was negligible, spider populations were large and plant hopper populations were small. In field cage tests, the seven spider species found to be efficient predators of *N. lugens* were *Lycosa* sp., *Pholcus* sp., *Marpissa mandali, Tetragnatha* sp., *Linyphia* sp., *Oxyopes sakuntalae* and *Argiope undata*.

A field investigation showed that there were 76 species in 13 families of spiders in the paddy fields in mountainous areas of South Zhejiang (Cheng, 1989). They were mainly in Salticidae, Araneidae, Lycosidae, Tetragnathidae, Pisauridae, Theridiidae, Erigonidae, Clubionidae, Thomisidae, Oxyopidae and Linyphiidae. Of the arthropod predators, 31.4 per cent was found to be spiders.

A survey conducted to study the abundance, diversity and food web of spiders in and around the Bangladesh Rice Research Institute Farm showed twelve species belonging to ten genera under eight families (Kamal *et al.*, 1990). *Oxyopes javanus* and *Tetragnatha javana* were found to be the common species in three rice environments ie, seed bed, irrigated rice field and weedy fallow. Irrigated rice fields had richer and more diverse spider fauna. *L. pseudoannulata, O. javanus, T. javana* and *Plexippus* sp. were more abundant than the other species in all the three situations.

Reddy (1991) studied the co-variation between insects in a rice field and the important spider species. Most common spiders were *Pardosa (Lycosa) pseudoannulata, Atypena formosana* and *Tetragnatha maxillosa. T. maxillosa* population appeared to be directly related to the number of dipterans. Similar relationships were found between *A. formosana* and BPH, WBPH, dipterans and all hoppers. *P. pseudoannulata* populations, however, were not related to BPH and WBPH.

In a survey to study the density of spiders and their prey in the paddy fields by sweeping method, ten to fourteen families were caught in the study area (Murata, 1995). Tetragnathid spiders were the most abundant followed by thomisids and clubionids. The spider density fluctuated quite synchronously with the densities of plant hoppers and leaf hoppers.

Predation efficiency of *Lycosa pseudoannulata* and other spiders

The average number of BPH preyed upon by a female *O. insecticeps* was 1.5 times more than that of the male (Nasu, 1967).

Kiritani *et al.* (1972) reported that *Lycosa* fed on brown plant hoppers and green leaf hoppers in a ratio of 5:2.

Sassaba *et al.* (1973) found the feeding rate of *Lycosa* on BPH to be higher during day than at night.

The functional responses of the females of *L. pseudoannulata* in searching the BPH were more efficient than GLH (IRRI, 1978).

Callitrichia sp, *Oxyopes* sp and *L. pseudoannulata* killed BPH more efficiently (0.5, 3 and 2 BPH per day respectively) than *Tetragnatha* and *Argiope* sp. (IRRI, 1976, 1978).

In the laboratory, *Pardosa annandalei* consumed an average of 18 adults/day. *Argiope pulchella* and *Tetragnatha* sp. which were in webs at the top of the plants, consumed an average of 16 and 14 adults per day, respectively (Rao *et al.*, 1978).

Kang and Kiritani (1975) stated that overwintering population of *Nephotettix cincticeps* could be reduced to half due to the efficient activity of *L. pseudoannulata* during winter.

Narasimha *et al.* (1978) observed *Pardosa annandalei* for the first time feeding on BPH @ 18 adults/day. *Argiope pulchella, Tetragnatha sutherlandi* and *Pardosa suwatrova* were also found effective against the BPH.

In Taiwan, the predation rates of *Lycosa* observed in the laboratory were 3.08 and 4.28 adult BPH for the second and fourth instar spiderlings, while 13.52 and 11.48 adult BPH for adult female and adult male spiders respectively (Chiu, 1979).

A comparison of predatory behaviour among the male and female of *L. pseudoannulata* showed that the females killed significantly more hoppers (9 BPH/day) than the males (5 BPH/day) (IRRI, 1980).

Spiders appeared to be the most important predators of WBPH nymphs and adults for green house trials. *L. pseudoannulata* killed 1.5 WBPH/day, while *O. javanus* killed 2.3 WBPH/day. *Argiope catenulata* and *T. japonica* were less important spider species killing one WBPH per day (IRRI, 1980).

Chou (1987) reported that predatory potential of *L. pseudoannulata* against third instars of BPH was 8.5/day followed by *Tetragnatha* sp. (6.1/day).

Heong and Rubia (1989) studied the functional responses of adult females of *L. pseudoannulata* exposed to adults of *N. lugens* and *Nephotettix virescens* in green house experiments. The spiders searched more efficiently for *N. lugens* than for *Nephotettix virescens* and also had shorter handling time, resulting in higher plateau of prey attacked.

The predation rates of both the sexes in *L. pseudoannulata* and *T. javana* in the laboratory were 9.16 and 5.07 adult WBPH/day for females and males of *L. pseudoannulata,* while it was 1.30 and 0.57 WBPH/day for females and males of *T. javana* (Nirmala, 1990).

Bhathal and Dhaliwal (1990) studied the feeding efficiency of six predators of WBPH, and reported that *Salticus scenius* Clerck was the most efficient predator eating 4.95 nymphs/day followed by *Oxyopes pondae* (3.76), *Pardosa birmanica* (3.67), *Thomisus* sp. (3.45), *Neoscona nautica* (2.25) and *Casnoidea indica* (1.18).

The predation of *Pardosa pseudoannulata* attacking *N. lugens* and the mirid predator *C. lividipennis* was studied by Heong *et al.* (1991). The attack rate was greater and handling time shorter for *C. lividipennis*. However when caged with the two prey, *P. pseudoannulata* showed a significant preference for *N. lugens* at a lower prey population.

Kamal *et al.* (1992) reviewed that *L. pseudoannulata* was the most efficient predator of GLH when compared to *T. javana* and *O. javanus*.

Microvelia douglasi atrolineata

The veliid bug *M. d. atrolineata* has been noted as a predator of the green rice leafhopper *Nephotettix cincticeps* (Otake, 1977).

Kenmore (1980) reported *M. douglasi atrolineata* as an important predator of rice BPH.

Ban and Kiritani (1980) conducted a comparative study of aquatic insect densities in paddy fields in Southern Japan. They found that *M. douglasi* predominated the rice fields.

Chen and Chiu (1982) reported that both the nymphs and adults of *M. douglasi* which walked rapidly over any water surfaces in rice field, preyed on nymphs and adults of the planthopper, as well as other insects falling into the water.

In India the veliid *M. d. atrolineata* was reported preying on *N. lugens* for the first time in Karnataka (Gubbiah,1983). Adults and nymphs of the bug *M. D. atrolineata* were found on the surface of water near rice plant infested with the planthopper.

Predation efficiency

Gubbiah (1983) observed that when the BPH nymphs dropped into the water, *M. douglasi* paralysed them and fed on them, as many as six bugs attacking one nymph. The bugs fed voraciously on nymphs in the first and second instars.

Studies conducted to evaluate the role of *M. d. atrolineata* as predator of BPH revealed that prey consumption varied with the stage of both the prey and the predator (Nakasiji and Dyck, 1984). Successful attacks generally decreased as developmental stage of the prey increased and with the number of predators involved in the attack. In most cases the searching rate of the adult predator seemed to be higher than that of the 5th instar predators.

Coccinellid predators

Abraham *et al.* (1973) reported large numbers of the coccinellid, *Coccinella arcuata* feeding on *N. lugens* during heavy infestation in Kerala.

Abraham and Mathew (1975) reported that the average number of *N. lugens* eaten per day by larvae in the four instars and by the adults of *C. arcuata* was 15, 18, 25, 27 and 29 respectively. The predator population was largest during February-March.

Mancharan and Jayaraj (1979) reported *C. arcuata* as a promising biological control agent of *N. lugens*.

Coccinella repanda and *Menochilus sexmaculatus* were predacious on *N. lugens* in Mandya (Manjunath, 1979).

Samal and Misra (1982) observed the larvae of *C. repanda* feeding on nymphs of *N. lugens* on rice at Cuttack. Prey consumption averaged 98 third instar nymphs per day in the laboratory.

Adults of *Brumoides suturalis* (F.) were found preying on nymphs and adults of *Sogatella furcifera* and nymphs of *Nephotettix virescens* in New Delhi (Garg and Sethi, 1983).

Larvae of *Micraspis discolor* were found preying on nymphs and adults of *N. lugens* of rice in Cuttack. *M. discolor* preferred 3rd instar nymphs of the delphacid as prey and consumed an average of 57 of them during the entire larval stage under laboratory conditions (Samal and Misra, 1985).

Brumus suturalis, Coccinella septumpunctata, M. sexmaculatus and *Scymnus* sp. were found associated with rice leaf and plant hoppers (Kaushik *et al.*, 1986).

Thakur *et al.* (1991) observed *Menochilus sexmaculata, Coccinella* sp. and *Brumus* spp. preying on *N. lugens* in North Eastern Madhya Pradesh.

Parasitoids

Otake (1977) developed a standard "trapping" method using artificially infested potted rice plants containing eggs which are exposed in the field for estimating egg parasitism.

The parasitoid complex on nymphs and adult BPH include Dryinidae, Strepsiptera and Pipunculidae (Miura *et al.*, 1977; Otake *et al.* 1976).

Studies in Sri Lanka showed that nymphs and adults of *N. lugens* were parasitized by Elenchidae, Dryinidae and Pipunculidae (Otake, 1977).

In the rice fields of Mandya, *N. lugens* was reported to be parasitised by two species of Dryinidae and one species each of Elenchidae and Halictophagidae, the most numerous among which was *Elenchus* sp. (Manjunath, 1979).

In a study by Kenmore (1980), a positive correlation between percentage egg parasitism and time was obtained.

Of the five species of dryinid parasitoids, *Pseudogonatopus nudus* was dominant on BPH reaching up to 18 per cent parasitism (Chandra, 1980a).

Substantial rates of parasitism, by Pipunculidae on nymphs and adults of BPH was found at IRRI (Chandra, 1980b).

Parasitoid complex of *N. lugens* in the rice fields of different countries has been listed by Greathead (1982).

The egg parasitoids, *Oligosita tachikawi* and *Anagrus armatus* and the nymphal adult parasitoids *Gonatopus* spp. were recorded in Andhra Pradesh (Bentur and Kalode, 1985).

Seasonal abundance of parasitism in nymphs and adults of *N. lugens* was monitored in Laguna Province, Philippines (Pena and Shepard, 1986). The major parasitoids were three species of dryinids and a species of Strepsipteran, *Elenchus yasumatsui*.

Parasitoids of *N. lugens* in rice included the egg parasitoids *Anagrus* sp. and *Oligosita* sp. and nymphal adult parasitoids belonging to Dryinidae, Pipunculidae and Strepsiptera (Gupta and Pawar, 1989).

Yadav and Pawar (1989) noticed four species of dryinids, *Ecthrodelphax fairchildii* Perkins, *Haplogonatopus apicalis* Perkins, *Pseudogonatopus* nr. *pusanus olmi* and *P. hospes* Perkins parasitising the nymphs and adults of *N. lugens* and *S. furcifera*.

Fowler *et al.* (1991) reported that the eggs of *N. lugens* were parasitised by the mymarid *Anagrus* sp. nr. *flaveolus* and *A. optabilis* and the trichogrammatid *Oligosita* sp. Level of egg parasitism varied from zero to 54 per cent per plant. It was also suggested that the overall egg parasitism was positively related to the host egg density.

Dryinid parasitoids

Waloff (1975) reported considerable parasitism of five species of plant hoppers in rice by the dryinid, *Dicondylus bicolor*.

Five species of the family Dryinidae, *Pseudogonatopus nudus*, *P. flavifemur*, *Haplogonatopus* sp. and *Echthrodelphax fairchildii* were recorded for the first time parasitizing rice BPH in the Philippines (Chandra, 1980). A key to distinguish these species was given.

Chandra (1980) reported the population of dryinids to be higher usually during July-October (wet season) at which time parasitism might attain 40 per cent. Parasitism was lower at other times of the year.

Three new techniques of rearing dryinids parasitising host hoppers were developed by Chandra (1980). The techniques included laboratory rearing technique for detailed observations, a device for transporting and rearing field-collected hoppers to estimate percentage parasitism and a breeding technique.

Chua and Dyck (1982) assessed the potential of *Pseudogonatopus flavifemur* as a biocontrol agent of *N. lugens* with respect to host preference, functional response, aggregative response and searching efficiency and found the parasitoid as a promising bio-control agent of the pest. The female parasitoid was reported to be capable of destroying 466 hosts in its life time.

The functional response of *P. flavifemur* was investigated in the laboratory by Holling *et al.* (1984) by offering *N. lugens* nymphs. The response was found to be sigmoid (Holling's Type III). There was an apparent increase in handling time per host as the number of female parasites increased.

Studies on the parasitism of *P. flavifemur* by Kim *et al.* (1988) revealed that 63 per cent of the female parasitoids preferred third instar nymphs for oviposition, followed by second (17.2%), fourth (12.0%) and fifth instar nymphs (3.6%). First instar nymphs and adults were not parasitised.

The nymphs and adults of *N. lugens* were parasitised by the dryinids, *Ecthrodelphax fairchildii, Haplogonatopus apicalis, Pseudogonotopus* nr. *pusanus* and *P. hospes* (Yadav and Pawar, 1989).

Rates of parasitism and host-feeding by the dryinid *Dicondylus indianus* on *N. lugens* varied with the host availability and parasitoid age (Sahragard *et al.*, 1991). The period of intensive egg laying shifted from a later to an earlier age as host availability increased. The dryinids oviposited and fed less at lower host densities.

In rearing cages in Ludhiana, parasitization of *S. furcifera* by *Haplogonatopus* was examined. The rate of parasitism was highest (60%) on brachypterous females and lowest (14.8%) on nymphs (Shukla *et al.*, 1996).

Pathogens

The fungal pathogen *Entomophthora coronata* and *Hirsutella* sp. were periodically found to kill BPH in the rice fields at IRRI, Philippines (IRRI, 1973).

Dyck and Orlido (1977) reported infection of *N. lugens* by *Entomophthora coronata*.

The white muscardine fungus *Beauveria bassiana* has been reported in Cuttack to be pathogenic on BPH for the first time (Srivastava and Nayak, 1978).

Heavy infection of *N. lugens* by a *Hirsutella* sp. has been recorded at IRRI (Chandra, 1978).

Samal *et al.* (1978) observed high mortality in the BPH population in the rearing cages due to an entomogenous fungus, *Entomophthora fumosa*.

The pathogen *Fusarium oxysporum* was reported effective against BPH at a higher concentration under field conditions in Kerala (Kuruvila and Jacob, 1979).

Studies in Madurai on the influence of biotic factors on the incidence of *N. lugens* proved *Verticillium lecanii* as a promising biocontrol agent (Mancharan and Jayaraj, 1979).

Adults of *N. lugens* were found susceptible to the fungal pathogen, *Paecilomyces farinosus* causing over 90 per cent mortality (Kuruvilla and Jacob, 1980).

Gunathilagaraj *et al.* (1987) noticed natural mycosis of rice BPH in the insectary culture due to *Absidia corymbifera*. Regular monitoring in the rice fields indicated that the maximum natural infection was 60 per cent during January and the minimum incidence was 4 per cent during April to July.

The pathogen *E. fumosa* was found infecting *N. lugens* (Gupta and Pawar, 1989).

Narayanaswamy *et al.* (1992) reported the infection of *N. lugens* in the rice fields of Tamil Nadu by a fungus, *Pandora delphacis*.

Nematodes

An unidentified parasitic nematode has been recorded causing substantial mortality (20%) in Sri Lanka (Otake *et al.*, 1976) and a *Hexamermis* in India (Manjunath, 1978) but nematode parasitism was reported to be low in Philippines (Chandra, 1978).

Population dynamics of BPH and its natural enemies

In rice fields in Kerala, the population of *C. arcuata,* a predatory coccinellid on *N. lugens* was largest during February-March (Abraham and Mathew, 1975).

Studies on the seasonal abundance of *N. lugens* and the predator *C. lividipennis* during Kharif in Andhra Pradesh showed that the predator was capable of rapid multiplication and had the ability to control the pest under favourable conditions (Murthy *et al.*, 1976).

Kalode (1976) reported that in the Kharif season in Hyderabad, *N. lugens* remained below the economic threshold level during the initial stages of growth of the crop as a result of ecological factors, including predation by *C. lividipennis* and spiders.

Studies in West Malaysia on the predators of BPH showed that short increase in the pest population in July was followed by massive increases in the number of its predator *C. lividipennis* (Ooi *et al.*, 1978). The population of two other predators, *Casnoidea interstitialis* and *Paederus fuscipes* also increased suddenly in August.

During an outbreak of BPH in Kuttanad during the main punja season (October-February) crop six days after the insecticides had been applied, both the spider and the plant hopper populations were less than on untreated rice. Populations increased again two weeks after treatment. During the next crop season, when insecticide application was negligible, spider populations were large and plant hopper populations small (Thomas *et al.*, 1979).

The most favourable period for population increase of BPH was found to be between the second week of August and the second week of October in Tamil nadu (Varadharajan, 1979). The peak activity period of the pests occurred from the beginning to the end of September.

The rice crops harvested during October-November were found infested with greater numbers of *N. lugens* than those harvested earlier. Infestation was also higher when plants were close together (Mancharan and Jayaraj, 1979).

Studies carried out at Moncompu, Kerala showed that *N. lugens* was present in the field throughout the year with a major population peak in January-March for the main rice crop and a minor peak in August-September for the second crop (Nair *et al.*, 1980).

Kenmore (1980) reported that the veliid, *M.d.atrolineata* did not appear to show a density - related response to BPH population.

In the rice fields in Taiwan, *M. douglasi* appeared about two weeks after transplanting and its population increased in size before the occurrence of *N. lugens* and declined as the water in the fields drained (Chen and Chiu, 1982).

The population of *M. douglasi* in the rice fields of Karnataka infested with *N. lugens* was recorded as 10-12 bugs per 400 cm^2 in the milky-ripe stage (Gubbiah, 1983).

In Konkan region of Maharashtra *N. lugens* adults first appeared in mid September and reached peak numbers in November, coinciding with flowering, and the dough and grain formation stages (Khaire and Dumbre, 1984).

Kenmore *et al.* (1984) reported a strong correlation between *L. pseudoannulata* density and peak population of brown plant hopper.

During Kharif season in Uttar Pradesh, the populations of *N. lugens* developed early in the rice crop. There was no correlation between peak population density and crop age (Misra and Reddy, 1985).

Studies in rice fields in China revealed the population dynamics of the spider *Lycosa pseudoannulata* to be significantly correlated with those of *N. lugens* (Zhou and Chen, 1986).

L. pseudoannulata exhibited a positive correlation with the hopper population in rice, the population reaching a peak in the month of May (Khaushik *et al.*, 1986), while the predators, *Paederus fuscipes* and *Brumus suturalis*, exhibited a negative correlation.

Peter (1988) reported that the population density of *N. lugens* peaked at 125.86 nymphs/hill 50 days after transplanting while that of the most abundant predator *C. lividipennis* was 18.65 nymphs/hill in rice fields in Tamil Nadu following an outbreak of the pest.

Observations on the population fluctuation of rice, leaf and plant hoppers and their predator *C. lividipennis* showed that the mirid appeared slightly later than the pests but its population increased quickly to coincide with that of the pests. The ratio of rice hopper and mirid were 4:1, 1.66:1 and 5:1 in 1981, 1982 and 1983 respectively in the beginning. At the pre-harvesting stage these ratios were 1:1, 1:16 and 1:1.14 (Balasubramanian *et al.*, 1988).

A significant positive correlation was found between the dynamic changes in the population of spiders and *N. lugens* in the paddy fields in mountainous areas of South Zhejang, China (Cheng, 1989).

In a study on the abundance of major insect pests of rice in Karnataka, during a period from September to June, *N. lugens* was observed to occur throughout the period with peak abundance in November and May (Srinivasa *et al.*, 1991).

In the rice ecosystems in Philippines, delphacid populations were characterised by high initial densities, which reached a peak and were followed by a decline with low growth rates. Populations of the predators *C. lividipennis* and *M. douglasi atrolineata* were similar, except that the population numbers peaked at a later stage and growth rates were higher (Heong *et al.*, 1992).

Abundance of spiders and their prey insects was investigated in fields under sustainable and customary cultivation in Japan (Murata, 1995). The spider densities were higher in the sustainable cultivation field than in the customary cultivation field. It was also observed that the spider density fluctuated quite synchronously with the densities of planthoppers and leafhoppers including *N. lugens*.

Mei *et al.* (1995) studied the natural population dynamics of rice plant hoppers in China. The results showed that the multiplication rate of *N. lugens* was not related to the number of immigrants but was closely related to the growth stage of the rice plants. The maximum population of the pest was observed at the booting to late heading stage.

Effect of weather parameters on population dynamics of *N. lugens*

In Tamil Nadu crops harvested during October-November were infested with greater numbers of *N. lugens* than those harvested earlier. Mean maximum temperature and hours of sunshine showed a positive correlation while wind velocity showed a negative correlation with the period of peak infestation (Mancharan and Jayaraj, 1979).

N. lugens population in Kuttanad rice tract was significantly influenced by climatic factors especially rainfall in association with high relative humidity (negative correlation) and high temperatures (positive correlation) (Nair *et al.*, 1980).

In Taiwan, during the years of BPH outbreak, there were 3-4 typhoons during July and August with mean temperature below 28 C and relative humidity over 80 per cent in the interim period which favoured reproduction and long distance migration of the pest (Lui, 1988).

Studies carried out at different localities in Karnataka showed that the effect of moonlight was more pronounced than the effect of weather factors on the light trap catches of *N. lugens* and other rice pests. Catches of *N. lugens* were greatest around full moon (Srinivasa *et al.*, 1990).

A significant association existed between the outbreaks of *N. lugens* in Japan and the occurrence of El Nino/Southern oscillation (ENSO) years. Eleven of the 13 outbreaks recorded occurred in the years immediately after ENSO events. It was suggested that changes in precipitation patterns might affect *N. lugens* outbreaks (Morishita, 1992).

Isichaikul and Ichikawa (1993) reported relative humidity as the most important environmental factor determining the microhabitat of nymphs of *N. lugens* which preferred a relative humidity of more than 90 per cent.

Shen and Wu's (1993) study on population occurrence of *N. lugens* revealed inhibitory effects of heavy rain and high temperature (> 26 C) on the pest population.

Studies in Kuttanad using light traps and weather parameters showed that rainfall, temperature and relative humidity did not influence populations of *N. lugens* (Joseph *et al.*, 1994).

Very humid micro environments were reported to be essential for the nymphs of *N. lugens* to develop on rice (Isichaikul *et al.*, 1994).

Resistant varieties

Varietal resistance to the BPH under field conditions was reported by Indian scientists in 1954 (Khush, 1977).

More than 500 indica varieties and lines have been found resistant to the BPH in screening conducted in Philippines, Japan, Korea, Taiwan, Thailand, Indonesia, India, Sri Lanka and the Solomon Islands (Choi, 1979).

A derivative from the cross between Mudgo and IR 8 yielded a BPH resistant line in 1967 (Pathak and Saxena, 1980).

Velusamy *et al.* (1987) evaluated 10 traditional hill rice cultivars for resistance to BPH and found all the varieties highly resistant to BPH.

Dhal and Panda (1987) evaluated field resistance of 13 cultivars to BPH including Jaya and Ratna as susceptible checks.

Murthy *et al.* (1988) screened 200 traditional cultivars of Madhya Pradesh in Hyderabad for resistance to BPH of which 16 were resistant and eight moderately resistant.

Aruna (Mo 8) derived from Jaya x PTB 33 was released in 1990 as resistant to BPH (Bai *et al.*, 1991). It also showed resistance to many pests.

The high yielding varieties such as Co 42, PY 3 and IET 7575 are also resistant to BPH. Several BPH resistant varieties such as IR 36 and IR 64 have been released by IRRI (Chelliah, 1991).

Velusamy (1991) evaluated 195 breeding lines derived from *Oryza officinalis* for resistance to the Indian population of BPH, of which 54 exhibited high levels of resistance.

Zhang and Chou (1992) screened 4,261 germplasm accessions for resistance to BPH. One hundred and eighty one germplasm accessions were resistant to BPH.

In a breeding programme in Maruteru, Andhra Pradesh, resistant donors ARC 6650 and ARC 5984 and popular high yielding local variety sowbhagya were used, resulting in the release of six promising BPH resistant varieties during 1986-91 (Suryanarayana *et al.*, 1993).

KSB 54, a variety with moderate resistance to the Mekong Delta population of BPH was released in 1992 (Duong and Pham, 1993).

Twenty-one IR varieties were tested against BPH population in a glasshouse at Raipur (Pophaly and Rana, 1993a). Only IR 62 and IR 64 were resistant. IR 34, IR 36, and IR 56 were moderately resistant.

Pophaly and Rana (1993b) evaluated 900 Madhya Pradesh Rice Research Institute cultivars to locate better sources of BPH resistance. Sixty-nine cultivars were found resistant to BPH indicating that the germplasm maintained in the Institute are a rich source of resistance to

Genetics of BPH Resistance

Differences in varietal resistance to BPH under field conditions were noted by Israel and Rao (1954).

Clear cut differences in varietal resistance to BPH under greenhouse conditions were first noted at IRRI in 1967 (IRRI, 1968; Pathak *et al.*, 1969).

Sources of resistance to BPH have also been identified in Taiwan (Chang and Chen, 1971; Chow and Cheng, 1971) and India (Krishna *et al.*, 1977; Kalode *et al.*, 1978).

Studies on the inheritance of resistance to BPH by Athwal *et al.* (1971) showed that resistance in the varieties Mudgo, Co 22 and MTV 15 was controlled by a single dominant gene designated as bph 1. A single recessive gene, designated bph 2, conveyed resistance in ASD 7. Bph 1 and bph 2 are closely linked and no recombination between them has been observed.

Chen and Chang (1971) also reported that a single dominant gene controls the resistance in Mudgo.

Martinez and Khush (1974) investigated in two breeding lines of rice the inheritance of resistance originating from crosses of susceptible parents (IRRI, 1970). One of the lines, IR 747 B2-6 possessed Bph 1 for resistance, the other line, IR 1154-243, possessed bph 2. TKM 6, the parent of the former is susceptible to BPH but a small number of the F_2 progenies from its crosses with other susceptible varieties such as TN 1, IR 8 or IR 24 are resistant. It was hypothesized that TKM 6 is homozygous for Bph 1 as well as for a dominant inhibitory gene I-Bph 1 which inhibits Bph 1.

After the BPH outbreak in India in 1973 and in Sri Lanka in 1974, varieties with known resistance to the insect in other countries such as Mudgo, ASD 7 and IR 26 were tested in India and Sri Lanka. All these varieties were found susceptible - a clear indication that the BPH populations in South Asia belonged to a different biotype (Khush, 1977).

In a genetic analysis of 28 resistant varieties, Lakshminarayana and Khush (1977) found nine varieties with Bph 1 and 16 with bph 2. A single dominant gene, which conveys resistance in Babawee (bph 4) segregates independently of bph 2. Resistance in PTB 21 was found to be controlled by one dominant and one recessive gene.

Genetic analysis of 20 resistant varieties by Sidhu and Khush (1978) showed that seven varieties have Bph 3 for resistance and 10 have bph 4. Resistance in the remaining three varieties was found to be governed by two genes.

Several BPH resistant varieties with the recessive gene bph 2 were developed from crosses with the breeding line CR 94-13 from CRRI (Khush, 1979).

Resistance in certain varieties has been broken down due to the development of new biotypes of BPH. Such selection of biotype has been reported to be more rapid on monogenic or oligogenic rather than on polygenic resistance varieties (Pathak and Khush, 1979).

Choi (1979) pointed out that, although a large number of resistant varieties exist, varieties that are resistant in one country are not necessarily resistant in other countries.

Utri Rajapan, a local Indonesian cultivar, has been found to be tolerant to all the three BPH biotypes at IRRI (Panda and Heinrichs, 1983).

Nine genes have been reported to govern resistance to BPH (Athwal *et al.*, 1971; Lakshminarayana and Khush, 1977; Nemoto *et al.*, 1989). The differential reactions of varieties to infestation by BPH in South and South East Asia have also been reported which documents the existence of differential biotype in these locations (Chelliah, 1991).

The BPH population in Hanoi was considered to be biotype 2 because it damaged Mudgo and IR 26 (both with Bph 1 resistant gene) but did not damage ASD 7, IR 36 or CR 94-13 (all with bph 2 gene). Varieties in Tien Giang possessing Bph 1 and bph 2 and Babawee (bph 4) were susceptible. Neither population damaged Rathu Heenati (Bph 3) clearly indicating that the BPH population in Tien Giang was more virulent than the Hanoi population (Thuat *et al.*, 1992).

Chau (1993) reported a new biotype of BPH in the Mekong Delta which was completely different from those in the Philippines, Bangladesh, Sri Lanka and India.

Cohen *et al.* (1997) reported the presence of one or more minor genes for *N. lugens* resistance in IR 64 in addition to the major gene, Bph 1.

Mechanism of resistance

When a uniform number of *N. lugens* nymphs were caged on individual plants, those infesting the variety 'Mudgo' usually died within 10 days without becoming adults, while those on susceptible varieties survived and grew in the normal way. Also adult insects caged on 'Mudgo' had a shorter life span and produced fewer nymphs than those caged on the variety 'Pankhari 203' (Pathak *et al.*, 1969).

Adult *N. lugens* have been found to feed much less on 'Mudgo' than on Pankhari 203 and TN-1 plant. The observation indicated that 'Mudgo' plant either lack the feeding stimulus for *N. lugens* or contain a substance strongly repellent to them (Pathak *et al.*, 1969).

Studies on the interaction between *N. lugens* and host plant showed that in most cases resistance was attributed to antibiosis (Kalode and Krishna, 1979). There was a correlation between the level of resistance at the seedling stage and that at the other stages. The resistance was predominantly qualitative.

In the case of BPH in certain rice accessions namely, Triveni (Ho *et al.*, 1982, Panda and Heinrichs, 1983), PTB 21 and Co42 (Bharathi, 1991) tolerance has been found to be the major component of resistance.

Oya and Hirao (1985) reported the mechanism of resistance of *N. lugens* in two Japonica-type breeding lines of rice, Saikai 165 and Saikai 168 to be associated with non-preference by the delphacid and antibiosis.

Senguttuvan *et al.* (1991) reported that antibiosis in PTB 33 and IR 64, the highly resistant varieties, was expressed as a low population build-up, increased nymphal duration, decreased nymphal survival, high growth index and decreased feeding rate, while the reverse condition was noticed on the susceptible TN 1. The highly resistant PTB 33 was less preferred for settling and oviposition.

Studies on mechanisms of resistance have been carried out in rice hoppers and antixenosis and antibiosis mechanisms have been reported for all the hoppers (Chelliah, 1991).

The major mechanisms of resistance in rice to BPH were found to be non-preference and antibiosis in highly resistant varieties while on moderately resistant or tolerant varieties, tolerance was the major mechanism followed by a fairly high level of antibiosis and non-preference (Bharathi, 1991). It was also suggested that non-preference characters found to be involved in many of the BPH resistant varieties were due to gustatory rather than olfactory or visual stimuli.

The resistance reaction and chemical composition of the resistant varieties indicated the presence of a higher degree of antibiosis in Pundia, a higher degree of tolerance in Mahia bankoi, considerable tolerance and antibiosis in Landi Sarakanti, and the absence of these factors in TN 1 (Mishra and Misra, 1993).

The cultivar, IR 64, showed slight to moderate levels of antibiosis, antixenosis and tolerance to *N. lugens* populations collected from Central Luzon, Philippines (Cohen *et al.*, 1997).

Biochemical basis of resistance

Yoshihara *et al.* (1980) suggested oxalic acid as a chemical factor governing varietal resistance in rice to *N. lugens*; the concentration of which was significantly lower in the fresh tissues of susceptible plants than in the resistant ones.

Oxalic acid isolated from the leaf sheaths of rice variety Mudgo was identified as a potent sucking inhibitor for *N. lugens* (Yoshihara *et al.*, 1980).

Leaf sheath analysis of 45 day old rice seedling of four resistant and two susceptible varieties to *N. lugens* revealed that total silica content in leaf sheath may not be responsible for resistance (Samal and Misra, 1983).

Antibiosis in five cultivars resistant to *N. lugens* was attributed to magnesium oxide, chlorophyll and esterase isozyme contents (Kim *et al.*, 1985).

Studies on the relationship between chemical composition and resistance of eleven rice varieties to *N. lugens* in the fields in Andhra Pradesh suggested that phenol, silica, phosphorous, potassium, calcium, sulphur and iron contents were positively correlated with resistance while protein, nitrogen, zinc and manganese were negatively correlated with resistance (Sujatha *et al.*, 1987).

Chino *et al.* (1987) reported that phloem sap from an insect resistant cultivar had lower concentrations of asparagine than that from non-resistant cultivars.

Mishra and Misra (1991) reported varieties resistant to *Sogatella furcifera* such as Pundia and Landi Sarakanti possessing lower concentration of amino acids, phenols, sugars and chlorophyll as compared with susceptible TN 1.

The role of silica in the resistance of rice plants to *Sogatella furcifera* was investigated in the laboratory (Mishra and Misra, 1992). All the resistant varieties tested had higher concentration of silica than the susceptible ones.

Studies on the chemical composition of rice varieties resistant to *Sogatella furcifera* indicated that they had higher concentration of silica, iron, zinc and manganese and lower concentration of nitrogen, phosphorus, potassium, calcium, magnesium and copper compared to the susceptible variety TN 1 (Mishra and Misra, 1993).

A higher level of three phenolics - flavanoid C - glycosides found in the rice stem extracts were reported to be involved in the resistance of rice to *N. lugens* (Grayer *et al.*, 1994).

Some volatile compounds identified including the terpene aldehyde 3,7-dimethyl-26-octadienal extracted from leaves and leaf sheaths of rice cultivars were suggested to have a role in resistance to BPH (Mahatheer *et al.*, 1995).

Influence of varietal resistance on the performance of natural enemies of rice planthoppers

Mortality of *N. lugens* due to predators, *L. pseudoannulata* and *C. lividipennis* was comparatively higher on resistant than on susceptible cultivars (Kartohardjono and Heinrichs, 1984).

Results of a study on the impact of varietal resistance in rice and predation on the mortality of *Sogatella furcifera* indicate that the integration of varietal resistance and predation by *L. pseudoannulata*, *C. lividipennis* and *Harmonia octomaculata* would provide effective control of *S. furcifera* populations under field conditions (Salim and Heinrichs, 1986).

Mortality of *N. virescens* nymphs due to the predator *C. lividipennis* was significantly higher on resistant varieties compared to susceptible and moderately resistant varieties (Myint *et al.*, 1986).

Senguttuvan and Gopalan (1990) determined the impact of varietal resistance and predators by *C. lividipennis* on *N. lugens*. The level of predation on eggs and nymphs differed between the varieties with apparently high predation on resistant varieties.

The Predatory spider *Lycosa* sp. consumed relatively higher populations of GLH, BPH and WBPH when caged together on resistant cultivars than on susceptible ones (Kalode *et al.*, 1990).

In a study of the predators of *N. lugens* on five rice varieties in Fujian China, fluctuations in the population dynamics of the delphacid allowed the development of ecological resistance in the rice which was obvious only in the moderately resistant varieties (Li and Liu, 1992).

The combination of varietal resistance and *L. pseudoannulata* played an important part in the control of *N. lugens* and *Nephotettix virescens*. The mortality of *N. lugens* ranged from 96 per cent on the resistant IR 62 variety to 97.67 per cent on the moderately resistant IR 64 variety in the presence of *L. pseudoannulata* (Kumar and Velusamy, 1996).

Rice variety could influence the development, survival and fecundity of the parasitoid *Anagrus nilaparvatae* directly through the physical structure of the plant or indirectly through the eggs of the host, *N. lugens* (Gen *et al.*, 1996). There was a highly significant negative correlation between the rate of emergence and fecundity of the parasitoid and the siliceous cell density on the back of rice leaf sheaths. The fecundity and body size were very significantly positively correlated with the egg size of *N. lugens* which was influenced by rice variety.

Predator - *N. lugens* ratios were generally higher on resistant varieties than susceptible varieties in insecticide free plots of Mekong Delta, Vietnam (Cuong *et al.*, 1997).

Materials and Methods

MATERIALS AND METHODS

3.1 Assessment of the population of *Nilaparvata lugens* (Stal)and its natural enemies

Field surveys were conducted in Kole lands and Kuttanad to assess the population of the rice brown plant hopper and their natural enemies.

3.1.1 Kole land

The survey was conducted during February-April, 1996 on the rice variety Triveni in five cents area at a farmers field in Kole land. No insecticide was applied in the field during the period of survey. The populations of BPH and its predators were counted from the field at weekly intervals starting from two weeks after transplanting till the harvest of the crop. Population counts were made visually from ten hills which were selected randomly by moving diagonally in the plot. The area between four adjacent rows was taken as equivalent to one hill to count the predators floating on water.

3.1.2 Kuttanad

Random field surveys were conducted to assess the population of the plant hopper and major natural enemies in farmers' fields at different locations in Kuttanad during the main crop season in 1997-1998 and the additional crop season, 1998 which were receiving the normal insecticidal treatments. The variety grown in all the selected locations was Jyothi. The population of *N. lugens* and their natural enemies were counted visually from 10-15 hills selected randomly from each location.

3.2 Population dynamics of *N. lugens* and its natural enemies on rice

The investigations were conducted during February-April, 1998 on three rice varieties, Jaya (Susceptible), Jyothi (Moderately resistant) and Kanakom

(Resistant) at the rice fields of Rice Research Station, Moncompu. The rice varieties were sown on December 31, 1997. Normal agronomic practices were followed and no insecticide was applied in the experimental fields. The experiment was laid out in a randomised complete block design with 5 x 4 m plot size and the three varieties replicated eight times (Plate 1). The populations of *N. lugens* and its natural enemies were counted from the experimental fields at weekly intervals starting from a month after sowing for nine weeks. Population counts were made from five hills which were selected randomly by moving diagonally within each plot. The area between four adjacent hills was taken as equivalent to one hill to count the predators floating on water. The pupa of the dryinid, *Pseudogonatopus* sp. on leaf was counted to account its population. Nymphs and adults (Plate 2a & 2b) of *N. lugens* and other predators were counted visually in-situ from these hills.

The data were analysed using split plot designs with varieties as main plot and weeks as subplot.

3.3 Correlation of population of *N. lugens* and its natural enemies with weather factors

The influence of weather factors on the population of *N. lugens* and also its natural enemies was assessed using coefficients of correlation. For this purpose, relative humidity the maximum/minimum temperature and sunshine hours were correlated with the population of *N. lugens* and its natural enemies. The effect of host population on the natural enemy build up was also assessed.

3.4 Mass culture of *N. lugens* in the laboratory

Cylindrical rearing cages made with polythene sheets supported on iron frame were used for rearing *N. lugens* in the net house. The top ends of these cages were covered with muslin cloth (plate 3).

The culture of *N. lugens* was originally collected from the field. It was multiplied in the net house on potted 30 days old rice plants of variety Jaya

Plate 1. Field lay-out to study the population dynamics of *N. lugens* and its natural enemies

Plate 2a. Nymphs of *N.lugens*

Plate 2b. Adult Females of *N.lugens*

Plate 3. Rearing cages of *N. lugens*

(Plate 4). The plants were periodically replenished when they succumbed to the feeding by *N. lugens*. This culture was utilised for the biology studies on the three test varieties.

3.5 Population growth studies

Three weeks (twenty one days) old seedlmgs of the three test varieties were transplanted in soil in 22 cm diameter clay pots. Each variety was replicated five times. Forty five days old plants were caged and simultaneously infested with five pairs (male and female) of 3 day old adult *N. lugens* per cage. Progenies resulting from the five pairs were counted at twenty one days after infestation.

3.6 Studies on the biology of *N. lugens*

Forty five days old rice seedlings of the three test varieties Jaya (susceptible), Jyothi (moderately susceptible), and Kanakom (resistant) were used for the study. The seedlings were planted singly in plastic cups and enclosed in mylar film cages. The open end of the cage was closed using muslin cloth. A pair of freshly emerged adults were introduced into the cage. Fresh plants were introduced into it daily, till the insects died. The exposed plants were taken out and examined under binocular microscope to count the eggs. Observations were recorded on the pre-oviposition, oviposition period, fecundity and longevity.

To determine the nymphal duration freshly emerged first instar nymphs were reared out singly on 45 days old rice seedlings of the three varieties in plastic cups and enclosed in mylar film cages.

Nymphal survival on each variety was studied by releasing 30 first instar nymphs of *N. lugens* and counting the number of surviving hoppers ten days after infestation.

3.7 Influence of varieties on the predatory/parasitic potential of the natural enemies of *N. lugens*

Predatory potential of *Cyrtorhinus lividipennis* Reuter, *Lycosa pseudoannulata, Microvelia douglasi atrolineata* Bergoth, *Pseudogonatopus* sp. and *Micraspis* sp. and the parasitic potential of *Pseudogonatopus* sp. on *N. lugens* on the three test varieties Jaya, Jyothi and Kanakom was studied in the net house, Rice Research Station, Moncompu. The methodology followed for the different predators is given below.

3.7.1 Determination of predatory potential of *C. lividipennis*

3.7.1.1 Mass rearing

C. lividipennis was mass reared according to the procedure given by Manti (1990), but replacing the oviposition cages and emergence cages with mylar cages.

3.7.1.2 Predation on eggs of *N. lugens*

Forty five days old potted plants of varieties Jaya, Jyothi and Kanakom were covered with mylar film cages of 90 cm x 17.5 cm separately (Plate 5). The plants were maintained with three tillers and each variety replicated five times. The plants were infested with three brachypterous females of *N. lugens* for oviposition and three adult mirids introduced into each cage 24 hours later. Both the pest and predator were confined for seven days. The emerging nymphs from each cage were counted until hatching ceased after which the tillers were dissected and the unhatched preyed upon eggs counted. The total number of eggs laid was arrived at by adding the number of nymphs emerged with the number of eggs preyed upon. The percentage predation was calculated as follows:

$$\text{Predation (\%)} = \frac{\text{No. of eggs preyed upon}}{\text{Total no. of eggs laid}} \times 100$$

Plate 4. Potted rice seedlings used for *N. lugens* rearing

Plate 5. Mylar cages used to study the predatory potential of *C.lividipennis*

3.7.1.3 Predation on nymphs

Thirty freshly emerged *N. lugens* nymphs and five freshly emerged mirid adults were introduced into 45 days old potted plants of the three test varieties separately and caged. Each variety was also maintained without the predator. The plants were observed for the number of surviving *N. lugens* nymphs after 10 days. The percentage predation was calculated using Abbot's formula.

3.7.2 Determination of predatory potential of *L. pseudoannulata*

Forty five days old potted plants of the test varieties were trimmed to three tillers and enclosed in mylar film cages (17.5 cm diameter x 90 cm height) with a 12 x 16 cm window at the top covered by nylon mesh. Freshly emerged nymphs of *N. lugens* were introduced at the rate of 20 and 40 per cage followed by 24 hrs starved adult spider. The treatments were replicated five times. The check consisted of *N. lugens* caged on the test varieties in the absence of spiders. Observations on mortality were made two days after the insects were introduced into the cage and repeated at two days interval until ten days after infestation. At the time of observation, *N. lugens* mortality was recorded and the dead and preyed upon *N. lugens* were replaced with live hoppers reared on plants of the same age as the test plants (Kartohardjono and Heinrichs, 1984). The percentage predation by the spider was calculated using Abbot's formula.

3.7.3 Determination of predatory/parasitic potential of *Pseudogonatopus* sp.

3.7.3.1 Mass rearing

Field collected pupae of the dryinid were kept in glass vials individually for adult emergence. The adults were released into potted rice plants containing numerous third to fifth instar nymphs of *N. lugens* confined in mylar cages at the rate of five females per cage. After two days the live female parasites were collected and used again, while the hosts on the plants were kept for eight days. After this time the parasite pupae formed were collected and stored in glass vials for emergence.

3.7.3.2 Predatory/parasitic potential

The feeding potential of the dryinid was studied on *N. lugens* reared on the three test varieties separately at two prey densities of 10 and 20 third instar nymphs. The nymphs were introduced into long test tubes containing one rice tiller with roots dipped in water followed by a mated female *Pseudogonatopus* sp. Each experiment was run for 24 hours after which the parasite was removed, the dead hoppers (due to parasite feeding) were counted, and the live hopper reared until parasitism was evident. Each parasite after removal was introduced into another test tube and the feeding/ parasitic potential for 24 hours observed for the next four days.

3.7.4 Determination of the predatory potential of *M. douglasi atrolineata*

3.7.4.1 Laboratory culture

A stock culture of *M. douglasi* was established using adults which were collected from the paddy fields in the Rice Research Station, Moncompu. Insects were reared in plastic trays, filled with 2-3 cm of water. The bugs were fed with a mixture of various kinds of arthropods which had been collected from light traps and stored in a freezer. Water and feed were changed every alternate day.

3.7.4.2 Predation by *M. douglasi*

Forty five days old potted plants of the test varieties were trimmed to three tillers and enclosed in mylar film cages. Freshly emerged nymphs of *N. lugens* were introduced into the cage at two prey densities of 20 and 40 first instar nymphs followed by five adults of *M. douglasi*. Control plants were maintained without the predator. The plants were observed for the number of surviving nymphs after five days. The percentage predation was arrived at by using Abbot's formula.

3.7.5 Determination of the predatory potential of *Micraspis* sp.

Forty five days old potted plants of the test varieties were trimmed to three tillers and enclosed in mylar film cage separately. Twenty freshly emerged *N. lugens* nymphs and one starved (24 hrs) adult *Micraspis* beetle were introduced into each cage. Each variety was also maintained without the predator. The plants were observed for the number of surviving *N. lugens* nymphs after five days. Applying Abbot's formula, the percentage predation was arrived at.

3.8 Influence of varieties on the biology of *C. lividipennis*

The biology of the mirid was studied using eggs laid within 24 hours before the beginning of experiment in rice stem tissues of the three test varieties. The tissues of the different varieties containing eggs were placed separately in small plastic cups. The top of the cup was covered with muslin cloth. After recording the incubation period, each of the newly emerged nymphs of the mirid was transferred individually to a test tube. The nymphs were fed with *N. lugens* eggs laid on the respective varieties. The number of instars was determined based on nymphal exuviae under a binocular microscope.

Adults were sexed after emergence, paired in test tubes and maintained like nymphs. Rice seedlings of the respective varieties were provided for oviposition. The number of eggs laid were recorded daily on each variety until the death of the female, replenishing the males if they died. The oviposition substrate was replaced daily.

The longevity, fecundity and pre-oviposition periods were determined by observing the number of days the adults remained alive after emergence, the number of eggs laid by the female till death and the number of days taken to lay the eggs after emergence respectively.

3.9 Anatomical studies of the rice culm

The anatomy of the stem of the three varieties was observed taking cross sections. The sections were stained with safranin and observed under microscope. Cell wall thickness, air column size and size of the cells were measured using a micrometer. The nature and distribution of the vascular bundles were also studied.

3.10 Analysis of the chemical composition of the rice culm

Sixty days old rice stems of the three varieties were analysed for total sugars, phenols, crude fibre, silica, major nutrients, N, P and K and minor nutrients, Ca, Mg, Zn, Cu and Mn.

The samples were dried in a hot air oven at 70 C. The dried samples were powdered and composite samples analysed.

The total N content of the samples was determined by microkjeldahl digestion and distillation method (Jackson, 1967). For the determination of P, K, micronutrient elements and silica content, triacid extract of the plant material was made use of. Crude silica was estimated by filtering the sample extract through Whatman No.1 filter paper and burning the paper with residue of the sample to ashes. The ash was cooled and weighed to give an estimate of crude silica. Phosphorus was determined by Vanado-molybdo phosphoric yellow colour method (Jackson, 1967). Potassium was determined by using flame photometer. Ca, Mg, Zn, Cu and Mn were determined in the extract using an atomic absorption spectrometer. Phenols in the sample were estimated following Folin-ciocalteu method. Total sugars and crude fibre in the plant sample were determined following the method of Dubois *et al.* (1951) and Meynard (1970) respectively.

Results

RESULTS

4.1 Assessment of population of *Nilaparvata lugens* (Stal) and its natural enemies

4.1.1 Kole land

The population of *N. lugens* was very low in the field till the first week of March coinciding the vegetative phase of the crop. Its population started increasing from 50 days after transplantation till harvest, and reached maximum of 35 hoppers per 10 hills. *Cyrtorhinus lividipennis* Reuter and *Microvelia douglasi atrolineata* Bergoth were observed to be the predominant species of predators followed by the spider, *Atypena formosana* (Oi) (Table 1).

The population of *C. lividipennis* increased with the population of *N. lugens* in the field and a maximum of 39 mirids were observed per 10 hills corresponding to 35 hoppers whereas the population of *M. d. atrolineata* declined from second week of March as the water level in the field receded. As many as 101 bugs per 10 hills were recorded in the field during the last week of February (Table 1).

4.1.2 Kuttanad

Table 2 gives the population of *N. lugens* and its natural enemies in the Karappadam tracts of Kuttanad during the main crop season, 1997-98 at flowering stage. Among the different locations, Champakulam recorded the maximum population of *N. lugens* of 6 hoppers per hill followed by Ayyanadu (5.0/hill), Ramankari (4.8/hill) and Vadakkethollayiram (4.1/hill). *C. lividipennis* seemed to be the predominant predator regulating the hopper population in the field with the populations of 8.0, 5.1, 3.1 and 3.5 bugs/hill, respectively in the fields of Champakulam, Ayyanadu, Ramankari and Vadakkethollayiram.

Table 1. Population of BPH and its natural enemies in Kole lands during February-April, 1996

DAT	Number of insects/10 hills							
	BPH	*Cyrtorhinus*	*Lycosa*	*Tetragnatha*	*Atypena*	*Oxyopes*	*Phidippus*	*Microvelia*
15 DAT	4.0	1.0	0.0	0.0	2.0	1.0	0.0	33.0
22 DAT	6.0	6.0	0.0	0.0	2.0	0.0	1.0	32.0
29 DAT	5.0	3.0	1.0	0.0	7.0	0.0	0.0	44.0
36 DAT	3.0	1.0	1.0	2.0	9.0	0.0	2.0	101.0
43 DAT	7.0	3.0	0.0	0.0	2.0	0.0	0.0	45.0
50 DAT	14.0	17.0	0.0	0.0	2.0	0.0	0.0	0.0
51 DAT	27.0	25.0	0.0	1.0	4.0	1.0	0.0	0.0
64 DAT	35.0	39.0	1.0	0.0	4.0	1.0	0.0	0.0
71 DAT	27.0	38.0	0.0	0.0	22.0	0.0	0.0	0.0

DAT - Days after transplanting

Table 2. Population of BPH and its natural enemies during the flowering stage of the crop in the karappadam tracts of Kuttanad during Rabi 1997-98

Locality	Average number of insects/hill								
	BPH	*Cyrtorhinus*	*Lycosa*	*Tetragnatha*	*Atypena*	*Pseudogonatopus*	*Paederus*	*Microvelia*	*Ophionea*
Ayyanadu	5.0	5.10	0.70	0.10	2.40	0.00	0.00	0.00	0.20
Puthankari	3.0	5.80	0.00	0.40	0.60	0.00	0.50	0.00	0.00
Vadakkethollayiram	4.1	3.50	0.10	0.00	0.20	0.10	0.10	0.00	0.00
Pudhiyottu-varambinakom	0.0	1.30	0.00	0.00	0.00	0.20	0.00	0.00	0.00
Nedumudi	0.0	3.10	0.00	0.20	0.50	0.00	0.00	0.00	0.00
Ayvelikkadu	1.9	0.30	0.10	0.20	0.00	0.10	0.00	0.00	0.00
Maniyankari	0.60	10.60	0.20	0.00	2.20	0.00	0.00	0.00	0.00
Thekke Arayiram	0.40	1.20	0.60	0.40	1.00	0.20	0.20	0.00	0.00
Devasamkari	0.60	1.50	0.20	0.10	0.80	0.00	0.10	0.00	0.00
Champakulam	6.00	8.00	0.60	0.10	0.90	0.20	0.00	1.60	0.00
Kidangara	1.70	2.50	0.30	0.10	0.40	0.40	0.10	1.70	0.40
Ramankari	4.80	3.10	0.60	0.50	1.60	0.00	0.00	0.00	0.00

The population of *N. lugens* and its natural enemies in different locations in kayal area of Kuttanad during the main crop season 1997-98 is presented in Table 3. A high population of 45.6 hoppers per hill was found in Sreemoolam Kayal where hopper burn was noticed (Plate 6a and b). The population of *C. lividipennis* was also high in this field (19.8/hill). The paddy fields of C block recorded a population of 14.3 hoppers and 3.0 mirids per hill. The populations of *N. lugens* and the mirid predator per hill were 5.2 and 5.0 in Onpathinayiram and 5.0 and 12.3 in I Block respectively.

During the additional crop 1998 in Kuttanad, the heavily insecticide treated fields recorded very high population of *N. lugens* in the post-flowering phase. The predator population was nearly negligible. A pest outbreak situation resulted and hopper burn occurred in Pandarakulam (254.2 hoppers/hill), Thadathilpadam (89.70 hoppers/hill), Champinpuram (84.7 hoppers/hill) and Pallathuruthy (41.0 hoppers/hill) (Table 4).

4.2 Population dynamics of *N. lugens* and its natural enemies as influenced by varieties

4.2.1 *N.lugens*

In the experimental fields, the maximum population of *N. lugens* was observed in the first week of February, a month after sowing the crop (25.63/ five hills). A steady decline in the population occurred in the next four weeks in the variety Jaya. *N. lugens* disappeared in the field from second week of March. In Jyothi (16.13/ five hills) and Kanakom (11.75/ five hills) the peak population was recorded during the second week of February with a steady decline in the subsequent weeks and reaching zero by the third week of March. No hoppers were observed in the field from second week of March. Among the varieties, Jaya recorded maximum population of *N. lugens* (8.69/five hills) followed by Jyothi (5.58/five hills) and Kanakom (4.17/five hills) (Table 5).

Table 3. Population of BPH and its natural enemies during flowering stage of the crop in the kayal tracts of Kuttanad during Main crop 1997-98

Locality	No. of insects/hill								
	BPH	*Cyrtorhinus*	*Lycosa*	*Tetragnatha*	*Atypena*	*Pseudogonatopus*	*Paederus*	*Microvelia*	*Ophionea*
Venattukadu	2.7	9.7	0.00	0.30	0.10	0.00	0.00	0.0	0.10
Rajapuram	1.2	4.0	0.00	0.20	0.00	0.20	0.20	0.0	0.20
Sreemoolam	45.6	19.8	0.00	0.30	0.20	0.00	0.00	0.0	0.00
'C' block	14.3	3.0	0.60	0.20	1.70	0.20	0.00	0.0	0.00
Onpathinayiram	5.0	12.3	0.30	0.00	1.30	0.10	0.10	0.0	0.00
'I' block	5.2	5.0	0.00	0.00	0.00	0.00	0.00	0.0	0.00

Table 4. Population of BPH and its natural enemies in the karappadam tracts of Kuttanad during additional crop 1998

Locality	No. of insects/hill								
	BPH	*Cyrtorhinus*	*Lycosa*	*Tetragnatha*	*Atypena*	*Pseudogonatopus*	*Paederus*	*Microvelia*	*Ophionea*
Valluvankadu	0.0	1.00	0.50	0.00	0.0	0.30	1.70	0.00	0.10
Mampuzhakari	0.0	0.00	1.00	0.20	0.0	0.20	1.90	0.40	0.10
Thayankari	0.0	0.50	0.40	0.00	0.0	0.10	0.30	0.10	0.20
Devasamkari	0.0	0.00	0.00	0.00	0.0	0.00	0.30	0.00	0.00
Pallathuruthy	0.0	0.00	0.70	0.00	0.0	0.40	0.00	0.20	0.20
Kadunnangadu	0.0	0.00	0.50	0.00	0.0	0.50	0.40	0.20	0.00
Manalady	0.0	0.00	0.30	0.00	0.0	0.10	0.00	0.20	0.00
Padachal	0.0	0.00	0.40	0.00	0.0	0.00	0.60	0.10	0.00
Edampadam	0.0	0.50	0.30	0.00	0.0	0.00	0.10	0.00	0.20
Chempinpuram	84.7	0.00	0.20	0.00	0.0	0.30	0.00	0.00	0.00
Mampuzhakari	23.0	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Pandarakulam	254.2	0.80	1.60	0.00	0.0	1.20	8.80	0.00	0.00
Enpathumpadam	3.5	0.60	0.00	0.00	0.0	0.10	0.00	0.00	0.00
Thadathilpadam	89.7	0.00	0.30	0.00	0.0	0.00	0.00	0.00	0.00
Pudhiyottu-varambinakam	2.9	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Pallipuram	5.3	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
Pallathuruthy	41.2	0.40	0.40	0.00	2.2	0.50	5.10	1.00	0.10
Pongapadam	2.00	0.20	0.00	0.00	0.2	0.00	0.00	0.00	0.00
Ehumankari	8.50	2.30	0.40	0.10	0.5	0.10	0.00	0.00	0.00

Table 5. Field population of *N. lugens* as influenced by varieties

Week	Number of insects/5 hills (Transformed values)		
	Jaya	Jyothi	Kanakom
February 1st	5.155A (25.625)	3.993C (15.250)	3.249DE (9.750)
2nd	4.495B (19.375)	4.061C (16.125)	3.541D (11.750)
3rd	4.068C (15.750)	2.989E (8.250)	2.859EF (7.500)
4th	3.612D (12.125)	2.878EF (7.625)	2.556F (5.875)
March 1st	2.512F (5.375)	1.941G (2.875)	1.856G (2.500)
2nd	1.000H (0.000)	1.052H (0.125)	1.052H (0.125)
3rd	1.000H (0.000)	1.000H (0.000)	1.000H (0.000)
4th	1.000H (0.000)	1.000H (0.000)	1.000H (0.000)
April 1st	1.000H (0.000)	1.000H (0.000)	1.000H (0.000)
Mean	2.649a (8.694)	2.213b (5.583)	2.012c (4.167)

* Figures in parentheses are means in original scale


Plate 6a & 6b. Hopper burn in the paddy fields of Sreemoolam kayal

Plate 7a. *C. lividipennis* - Nymph

Plate 7b. *C. lividipennis* - Adults

Plate 9. *Tetragnatha maxillosa*

Plate 8. *Lycosa pseudoannulata*

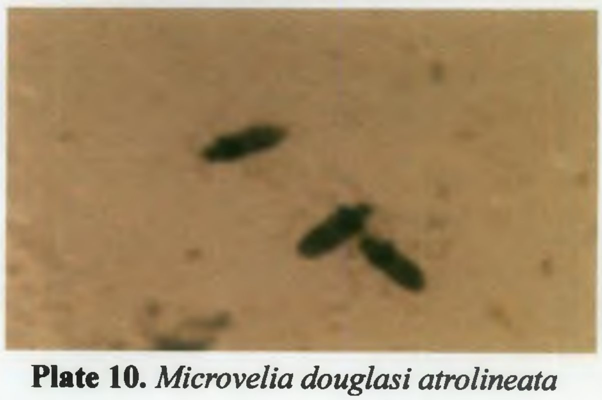

Plate 10. *Microvelia douglasi atrolineata*

4.2.2 Natural enemies

The predatory complex of *N. lugens* comprised of the predatory mirid *C. lividipennis* (Plate 7a & 7b), the wolf spider, *L. pseudoannulata* Boesenberg and Strand (Plate 8), long Jawed spider, *Tetragnatha maxillosa* Thorell (Plate 9), dwarf spider, *A. formosana*, the Veliid bug, *M. douglasi atrolineata* Bergoth (Plate 10), the dryinid, *Pseudogonatopus* sp. (Plate 11a, 11b, 11c & 11d) and the predatory beetles, *Micraspis* sp. (Plate 12) and *Ophionea nigrofasciata* (Schmidt-Goebel) (Plate 13).

The population of *C. lividipennis* was maximum during the first week of February in all the three varieties with 10.13, 4.88 and 5.63 bugs/five hills respectively in Jaya, Jyothi and Kanakam. The mirid started disappearing from the field from the third week of March with the declining population of *N. lugens*. Among the varieties, the mirid population was more in Jaya (2.82/ five hills) followed by Kanakom (2.26/five hills) and Jyothi (2.10/ five hills) (Table 6).

L. pseudoannulata was observed throughout the crop period in all the varieties except during the last week in Jyothi. However, a decline in its population was evident beyond second week of March. Maximum population was recorded in Kanakom (6.88/ five hills) during the first and second weeks of February, while the population on Jaya (6.75/ five hills) and Jyothi (6.88/ five hills) peaked during the second week of February (Table 7).

The population of *T. maxillosa* was generally low in the fields. Though maximum population of the spider was recorded during the second week of February in Jyothi (0.75/five hills), there was no significant difference in its population among the varieties. However, the population was found to decrease as the crop stage advanced (Table 8).

The population of *A. formosana* was low during the first three weeks and peaked during the second week of March in all the three varieties (45.38, 41.38

Plate 11a. *Pseudogonatopus* sp. - Adult

Plate 11b. *N. lugens nymph* parasitised by *Pseudogonatopus* sp.

Plate 11c. *N. lugens* adult parasitised by *Pseudogonatopus* sp.

Plate 11d. *Pseudogonatopus* sp. - Pupa

Plate 12. *Micraspis* sp.

Plate 13. *Ophionea nigrofasciata*

Table 6. Field population of *C. lividipennis* as influenced by varieties

Week		Number of insects/5 hills(Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	3.281 A (10.125)	2.400 BC (4.875)	2.559 BC (5.625)
	2nd	1.878 DEF (2.750)	1.850 EF (2.625)	2.124 CDE (3.750)
	3rd	2.320 BC (4.750)	2.292 BCD (4.625)	2.294 BCD (4.750)
	4th	2.628 B (6.000)	2.461 BC (5.375)	2.224 BCDE (4.125)
March	1st	1.401 GH (1.125)	1.445 GH (1.250)	1.514 FG (1.500)
	2nd	1.206 GH (0.625)	1.052 H (0.125)	1.155 GH (0.500)
	3rd	1.000 H (0.000)	1.000 H (0.000)	1.000 H (0.000)
	4th	1.000 H (0.000)	1.000 H (0.000)	1.000 H (0.000)
April	1st	1.000 H (0.000)	1.000 H (0.000)	1.052 H (0.125)
Mean		1.746 a (2.819)	1.611 b (2.097)	1.658 ab (2.264)

* Figures in parentheses are means in original scale

Table 7. Weekly field population of *L. pseudoannulata* as influenced by varieties

Week		Number of spiders/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	2.346^{BC} (4.625)	2.666^{AB} (6.250)	2.797^{A} (6.875)
	2nd	2.764^{A} (6.750)	2.778^{A} (6.875)	2.788^{A} (6.875)
	3rd	1.816^{EFGHIJ} (2.375)	1.607^{EFGHIJ} (1.625)	1.866^{DEFGHI} (2.500)
	4th	2.315^{BCD} (4.500)	2.189^{CDE} (3.875)	2.048^{CDEF} (3.250)
March	1st	2.291^{BCD} (4.500)	1.742^{EFGHIJ} (2.500)	1.878^{DEFGH} (2.625)
	2nd	2.096^{CDE} (3.500)	2.074^{CDE} (3.625)	1.928^{CDEFG} (3.000)
	3rd	1.576^{GHIJ} (1.625)	1.412^{IJKLM} (1.125)	1.372^{JKLM} (1.000)
	4th	1.372^{JKLM} (1.000)	1.451^{HIJKL} (1.250)	1.783^{EFGHIJ} (2.500)
April	1st	1.052^{LM} (0.125)	1.000^{H} (0.000)	1.155^{KLM} (0.375)
Mean		1.959^{a} (3.222)	1.880^{a} (3.014)	1.957^{a} (3.222)

* Figures in parentheses are means in original scale

Table 8. Field population of *T. maxillosa* as influenced by varieties

Week		Number of spiders/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	1.207 ABC (0.500)	1.143 ABCD (0.375)	1.259 AB (0.625)
	2nd	1.104 BCD (0.250)	1.299 A (0.750)	1.274 AB (0.625)
	3rd	1.000 D (0.000)	1.195 ABC (0.500)	1.092 BCD (0.250)
	4th	1.000 D (0.000)	1.000 D (0.000)	1.000 D (0.000)
March	1th	1.092 BCD (0.250)	1.000 D (0.000)	1.000 D (0.000)
	2th	1.000 D (0.000)	1.000 D (0.000)	1.000 D (0.000)
	3th	1.052 CD (0.125)	1.104 D (0.000)	1.000 D (0.000)
	4th	1.000 D (0.000)	1.000 D (0.000)	1.000 D (0.000)
April	1st	1.000 D (0.000)	1.000 D (0.000)	1.000 D (0.000)
Mean		1.050 a (0.125)	1.082 a (0.208)	1.066 a (0.167)

* Figures in parentheses are means in original scale

and 39.75/five hills respectively in Jaya, Jyothi and Kanakam). The population was almost nil during the first week of April (Table 9).

The Veliid bug, *M. d. atrolineata* was observed in the field at a moderate level. The bugs were absent in the field in the third week of February in Jaya and Jyothi and almost negligible in Kanakom. Maximum population was recorded in the last week of March in all the three varieties (24.75, 23.63 and 25.75/five hills respectively in Jaya, Jyothi and Kanakam). During subsequent weeks, water was let out of the field and no bugs were present (Table 10).

The coccinellid beetle *Micraspis* sp. was present in very few numbers in the field till the second week of March after which it increased gradually with maximum population of 20.25, 19.75 and 20.5 beetles/ five hills respectively in Jaya, Jyothi and Kanakom during the first week of April (Table 11).

Population of *Pseudogonatopus* sp. was present for only the first three weeks of observation in all the varieties and disappeared from the last week of February. The population did not vary among the varieties (Table 12).

The Carabid beetle, *O. nigrofasciata* appeared in the field at very low level during the third week of February and increased gradually attaining a peak level of 25.37, 24.38 and 25.63/five hills respectively in Jaya, Jyothi and Kanakom during the first week of April (Table 13).

4.3 Correlation of the field population of *N. lugens* and various natural enemies in different varieties

Correlation coefficients of the population of *N. lugens* to the populations of the various natural enemies are given in Table 14. The populations of the natural enemies *C. lividipennis*, *L. pseudoannulata*, *T. maxillosa* and *Pseudogonatopus* sp. showed a significant positive correlation with the populations of *N. lugens* on all the three varieties in the field whereas, the populations of *A. formosana*,

Table 9. Field population of *A. formosana* as influenced by varieties

Week		Number of spiders/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	3.048^{F} (8.750)	2.649^{F} (6.625)	2.938^{F} (7.750)
	2nd	2.564^{F} (6.625)	2.740^{F} (7.000)	2.640^{F} (6.625)
	3rd	3.083^{F} (8.750)	2.376^{F} (5.000)	2.645^{F} (7.000)
	4th	5.272^{BC} (27.250)	5.242^{BC} (26.625)	4.532^{CDE} (20.500)
March	1st	4.059^{DE} (15.875)	4.350^{DE} (18.125)	3.872^{E} (14.375)
	2nd	6.778^{A} (45.375)	6.492^{A} (41.375)	6.311^{A} (39.750)
	3rd	5.346^{B} (27.875)	4.339^{DE} (18.250)	4.678^{BCD} (21.875)
	4th	5.234^{BC} (26.500)	5.247^{BC} (26.750)	5.121^{BC} (25.250)
April	1st	1.092^{G} (0.250)	1.000^{G} (0.000)	1.270^{G} (1.125)
Mean		4.053^{a} (18.583)	3.826^{b} (16.634)	3.789^{b} (16.028)

* Figures in parentheses are means in original scale

Table 11. Field population of *Micraspis* sp as influenced by varieties

Week		Number of insects/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	1.207[EF] (0.500)	1.268[DEF] (0.750)	1.000[F] (0.000)
	2nd	1.299[DEF] (0.750)	1.268[DEF] (0.750)	1.274[DEF] (0.625)
	3rd	1.372[DEF] (1.000)	1.430[DEF] (1.125)	1.430[DEF] (1.125)
	4th	1.805[D] (2.500)	1.567[DEF] (1.750)	1.732[DE] (2.250)
March	1st	1.574[DE] (1.750)	1.673[DE] (2.125)	1.512[DEF] (1.625)
	2nd	1.523[DEF] (1.625)	1.000[F] (0.000)	1.660[DE] (2.125)
	3rd	2.874[C] (7.375)	3.461[B] (11.250)	2.900[C] (7.625)
	4th	4.798[A] (17.625)	4.115[A] (16.625)	4.254[A] (17.875)
April	1st	4.604[A] (20.250)	4.551[A] (19.750)	4.632[A] (20.500)
Mean		2.284[a] (5.931)	2.259[a] (6.014)	2.263[a] (5.972)

* Figures in parentheses are means in original scale

Table 12. Field population of *O. nigrofasciata* as influenced by varieties

Week		Number of insects/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	1.000H (0.000)	1.000H (0.000)	1.000H (0.000)
	2nd	1.000H (0.000)	1.000H (0.000)	1.000H (0.000)
	3rd	1.475GH (1.250)	1.052H (0.125)	1.195H (0.500)
	4th	1.667FG (2.125)	1.775FG (2.250)	1.985EF (3.000)
March	1st	2.633D (6.625)	2.354DE (5.000)	2.762CD (6.875)
	2nd	2.584D (6.250)	2.589D (6.250)	3.343B (10.375)
	3rd	3.258B (9.750)	3.150BC (9.000)	3.443B (10.875)
	4th	5.071A (24.750)	4.833A (23.125)	4.917A (23.375)
April	1st	5.129A (25.375)	5.024A (24.375)	5.150A (25.625)
Mean		2.646ab (8.458)	2.531b (7.792)	2.755a (8.958)

* Figures in parentheses are means in original scale

Table 13. Field population of *Pseudogonatopus* sp. as influenced by varieties

Week		Number of insects/5 hills (Transformed values)		
		Jaya	Jyothi	Kanakom
February	1st	1.299ABC (0.750)	1.320ABC (0.875)	1.195BCD (0.500)
	2nd	1.412A (1.125)	1.372AB (1.000)	1.155Cd (0.375)
	3rd	1.207BCD (0.500)	1.195BCD (0.500)	1.195BCD (0.500)
	4th	1.000D (0.000)	1.052D (0.125)	1.000D (0.000)
March	1st	1.000D (0.000)	1.000D (0.000)	1.000D (0.000)
	2nd	1.000D (0.000)	1.000D (0.000)	1.000D (0.000)
	3rd	1.000D (0.000)	1.000D (0.000)	1.000D (0.000)
	4th	1.000D (0.000)	1.000D (0.000)	1.000D (0.000)
April	1st	1.000D (0.000)	1.000D (0.000)	1.000D (0.000)
Mean		1.102a (0.264)	1.104a (0.278)	1.061a (0.153)

* Figures in parentheses are means in original scale

Table 14. Correlation coefficients of the field population of BPH and its natural enemies on different varieties

Natural enemies	Jaya	Jyothi	Kanakom
C. lividipennis	0.760**	0.643**	0.798**
L. pseudoannulata	0.547**	0.741**	0.671**
T. maxillosa	0.287*	0.380**	0.595**
Atypena sp.	-0.446**	-0.365**	-0.353**
Microvelia douglasi	-0.423**	-0.425**	-0.271*
Micraspis sp.	-0.592**	-0.515**	-0.551**
Pseudogonatopus sp.	0.564**	0.581**	0.485**
O. nigrofasciata.	-0.698**	-0.593**	-0.715**

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

M. douglasi, Micraspis sp. and *O. nigrofasciata* were negatively correlated with those of *N. lugens* in the three varieties.

4.4 Correlation of the population of *N. lugens* and its natural enemies and weather parameters

Among the weather parameters correlated, the minimum temperature alone showed significant correlation with the population of *N. lugens* and some of the natural enemies.

In all the three varieties, it showed a highly significant negative correlation with the populations of *N. lugens* and *Pseudogonatopus* sp. whereas the correlation was positive with the populations of *Micraspis* sp. and *O. nigrofasciata* (Table 15,16 and 17).

The population of the predatory mirid, *C. lividipennis* was significantly correlated with the minimum temperature in only Kanakom, where a significant negative correlation existed between them (Table 15).

The correlation between the minimum temperature and the populations of *L. pseudoannulata* and *T. maxillosa* in all the three varieties were negative (Tables 15, 16 and 17).

4.5 Influence of varieties on the population growth of *N. lugens*

Among the varieties, Kanakom had the lowest *N. lugens* population (79.8/hill). Where as the populations on susceptible Jaya was highest (519.0/hill) and those on Jyothi intermediate (352.6/hill) (Table 18).

4.6 Influence of varieties on the biology of *N. lugens*

The biology of *N. lugens* was investigated in the laboratory on three rice varieties, Jaya (susceptible), Jyothi (moderately resistant) and Kanakom (resistant). The results of the study are given below.

Table 15. Correlation coefficients of the population of *N. lugens*, its natural enemies and weather parameters (Jaya)

	Weather parameters			
	Maximum temperature	Minimum temperature	Relative humidity	Sunshine hours
N. lugens	-0.598	-0.875**	0.190	0.120
C. lividipennis	-0.767	-0.659	0.119	0.255
L. pseudoannulata	-0.319	-0.790*	0.427	-0.049
T. maxillosa	-0.757	-0.740*	0.119	0.147
A. formosana	0.085	0.350	0.539	0.035
M. douglasi	0.044	0.394	0.505	-0.459
Micraspis sp.	0.430	0.793*	-0.555	-0.440
Pseudogonatopus sp.	-0.298	-0.865**	0.205	-0.037
O. nigrofasciata	0.298	0.824**	-0.497	-0.439

Table 16. Correlation coefficients of the population of *N. lugens*, its natural enemies and weather parameters (Jyothi)

	Maximum temperature	Minimum temperature	Relative humidity	Sunshine hours
N. lugens	-0.504	-0.878**	0.210	-0.003
C. lividipennis	-0.527	-0.604	0.177	0.191
L. pseudoannulata	-0.477	-0.811**	0.378	-0.071
T. maxillosa	-0.222	-0.775*	0.304	0.112
A. formosana	0.166	0.346	0.503	-0.132
M. douglasi	0.148	0.459	0.481	-0.457
Micraspis sp.	0.346	0.780*	-0.515	-0.351
Pseudogonatopus sp.	-0.428	-0.884**	0.196	0.013
O. nigrofasciata	0.487	0.828**	-0.508	-0.440

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

Table 17. Correlation coefficients of the population of *N. lugens*, its natural enemies and weather parameters (Kanakom)

	Maximum temperature	Minimum temperature	Relative humidity	Sunshine hours
N. lugens	-0.420	-0.875**	0.232	0.010
C. lividipennis	-0.552	-0.787*	0.192	0.203
L. pseudoannulata	-0.491	-0.848**	0.376	-0.158
T. maxillosa.	-0.482	-0.880**	0.168	0.019
A. formosana	0.142	0.353	0.528	-0.035
M. douglasi	0.121	0.434	0.527	-0.562
Micraspis sp.	0.451	0.803**	-0.547	-0.430
Pseudogonatopus sp.	-0.420	-0.840**	0.175	0.247
O. nigrofasciata	0.516	0.856**	-0.499	-0.377

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

Table 18. Population growth of *N. lugens* as influenced by varieties

Variety	Population of BPH*					
	Replication					
	1	2	3	4	5	Mean
Jaya	511	538	472	622	452	519.00 a
Jyothi	367	383	305	297	411	352.60 b
Kanakom	78	99	65	56	101	79.80 c
CD						68.03

*Total number of nymphs and adults per plant

4.6.1 Incubation period, nymphal duration and nymphal survival

The incubation period of *N. lugens* eggs observed were 7.5, 8.5 and 8.6 days respectively on Jaya, Jyothi and Kanakom. It was significantly low on Jaya compared to the other two varieties. Nymphal duration and percentage nymphal survival of the hopper differed significantly among the varieties with a shorter nymphal duration (13.0 days) and higher percentage of nymphal survival (82.26) recorded on Jaya. On Kanakom, *N. lugens* nymphs took longer time to complete its development (17.9 days). Whereas on Jyothi the nymphs completed its development in 14.0 days. Only 38.66 per cent of nymphs survived on Kanakom compared to 65.66 per cent on Jyothi (Table 19).

4.6.2 Adult longevity

On the resistant variety Kanakom, males lived for only a shorter period (6.4 days) compared to the other two varieties, Jaya (14.6 days) and Jyothi (12.8 days). Longevity of female hoppers (brachypterous) was also significantly shorter on Kanakom (12.4) as against 20.6 days and 19.2 days respectively on Jaya and Jyothi. Macropterous females lived longer on Jaya (27.0 days) than on Jyothi (18.80) (Table 20).

4.6.3 Fecundity, pre-oviposition and oviposition periods

Fecundity of brachypterous hoppers of *N. lugens* was significantly lower on Kanakom (25.17 eggs). Brachypterous forms laid on an average 227.5 and 190.67 eggs and macropterous forms 225.33 and 167.33 eggs on Jaya and Jyothi respectively (Table 21).

The pre-oviposition period and oviposition period of brachypterous forms showed significant differences when reared on the three varieties. On the variety Jaya, they laid eggs for a longer period of 15.83 days. While on Kanakom, the oviposition period lasted for only 8.5 days. The pre-oviposition period

Table 19. Incubation period, nymphal duration and nymphal survival of BPH as influenced by varieties

Varieties	Incubation period (days)	Nymphal duration (days)	Nymphal survival (%)
Jaya	7.50 b	13.00 c	82.26 a
Jyothi	8.50 a	14.00 b	65.66 b
Kanakom	8.60 a	17.90 a	38.66 c
CD	0.54	0.80	5.20

Table 20. Adult longevity of BPH as influenced by varieties (days)

Varieties	Female		Male
	Macropterous	Brachypterous	
Jaya	27.00 a	20.60 a	14.60 a
Jyothi	18.80 b	19.20 a	12.80 a
Kanakom	-	12.40 b	6.40 b
CD	2.77	2.00	2.67

Table 21. Fecundity, pre-oviposition and oviposition periods of BPH as influenced by varieties

Variety	Fecundity (No.)		Pre-oviposition period (days)		Oviposition period (days)	
	Macropterous	Brachypterous	Macropterous	Brachypterous	Macropterous	Brachypterous
Jaya	225.33 a	227.50 a	1.67 b	1.33 c	16.83 a	15.83 b
Jyothi	167.33 b	190.67 a	2.83 a	2.50 b	17.00 a	17.67 a
Kanakom	-	25.17 b	-	4.67 a	-	8.50 c
CD	39.17	43.01	1.01	0.79	2.60	1.61

recorded were 1.33, 2.5 and 4.67 days respectively on Jaya, Jyothi and Kanakom (Table 21).

It was observed that there was no macropterous forms developed on the resistant variety Kanakom. Oviposition period of macropterous forms did not differ significantly on Jaya (16.85 days) and Jyothi (17.0 days) whereas significant differences in their pre-oviposition period was observed between the varieties (1.67 and 2.83 days respectively) (Table 21).

4.7 Influence of varieties on the predatory potential of natural enemies on *N. lugens*

Predatory potential of the various natural enemies was studied in the net house providing *N. lugens* reared on the three test varieties as prey. The results are detailed below.

4.7.1 Predatory potential of *C. lividipennis*

Predation by the mirid was significantly higher on both the eggs (29.37%) and the nymphs (44.0%) of *N. lugens* reared on the variety Kanakom. No significant difference in the predation was recorded on the hopper nymphs reared on Jaya (31.82%) and Jyothi (35.28%). The mirid predated more eggs on Jyothi (20.17%) than on Jaya (17.6%) (Table 22).

4.7.2 Predatory potential of *L. pseudoannulata*

The spiders consumed more prey when reared on Kanakom at both the lower (37.24%) and the higher prey densities (41.5%). At the lower prey density of 20 *N. lugens* nymphs, the percentage predation by the spider did not vary significantly on varieties Jaya (27.88%) and Jyothi (30.80%). However, at the higher prey density of 40 nymphs, the predator consumed significantly more prey on Jyothi (33%) than on Jaya (30.25%) (Table 23).

Table 22. Predation of BPH eggs and nymphs by *C. lividipennis* as influenced by varieties

Varieties	Predation percentage on	
	Eggs	Nymphs
Jaya	17.60[c]	31.82[b]
Jyothi	20.17[b]	35.28[b]
Kanakom	29.37[a]	44.00[a]
CD	1.32	6.07

Table 23. Predation of BPH by *L. pseudoannulata* as influenced by varieties

Varieties	Percentage predation at prey densities	
	20	40
Jaya	27.88[b]	30.25[c]
Jyothi	30.80[b]	33.00[b]
Kanakom	37.24[a]	41.50[a]
CD	5.26	1.79

4.7.3 Predatory/Parasitic potential of *Pseudogonatopus* sp.

The varieties did not show any influence on the prey consumption of *Pseudogonatopus* sp. at the lower prey density. But at the higher prey density the dryinid consumed more prey (6.16 hoppers) on Kanakom compared to Jaya (6.0 hoppers) and Jyothi (5.68 hoppers) (Table 24).

At the host density of 20 *N. lugens* nymphs, *Pseudogonatopus* sp. parasitized significantly more hopper nymphs (3.96) on Jyothi followed by Jaya (3.64) and Kanakom (3.0). But at the host density of 10 nymphs, the rate of parasitism did not vary significantly among the varieties (Table 25).

4.7.4 Predatory potential of *M. douglasi atrolineata*

Table 26 presents the percentage predation of *N. lugens* nymphs by *M. douglasi* in the three varieties. At a prey density of 20 hopper nymphs, no significant differences in the rate of predation was observed among the varieties. However, at a higher prey density of 40 nymphs, the bugs predated significantly more on the resistant variety Kanakom (Table 26).

4.7.5 Predatory potential of *Micraspis* sp.

The percentage predation of *N. lugens* nymphs by the beetle was significantly higher on Kanakom (24.86%) compared to Jaya (16.83%) at the prey density of 20 hopper nymphs (Table 27). Whereas no significant difference in predation was observed between Kanakom and Jyothi.

4.8 Influence of varieties on the biology of *C. lividipennis*

4.8.1 Nymphal duration and adult longevity

On the variety Kanakom, the mirid nymphs took significantly more time to develop into adult (11.8 and 16.0 days respectively for male and female) compared to those on Jaya (10.8 and 13.6 days) and Jyothi (10.2 and 13.5 days) (Table 28).

Table 24. Predatory potential of *Pseudogonatopus* sp. on BPH as influenced by varieties

Varieties	No. of BPH consumed/day at two prey densities	
	10	20
Jaya	3.04	6.00[ab]
Jyothi	2.80	5.68[b]
Kanakom	3.08	6.16[a]
CD	NS	0.48

Table 25. Rate of parasitism of BPH by *Pseudogonatopus* sp. as influenced by varieties

Varieties	No. of BPH parasitised/day at two host densities	
	10	20
Jaya	2.12	3.64[b]
Jyothi	1.92	3.96[a]
Kanakom	1.88	3.00[c]
CD	NS	0.31

Table 26. Predation percentage of *N. lugens* by *M. douglasi atrolineata* as influenced by varieties

Varieties	Prey density	
	20	40
Jaya	6.458	11.972[b]
Jyothi	11.3.62	8.974[b]
Kanakom	7.944	20.126[a]
CD	NS	4.98

Table 27. Predation percentage of *N. lugens* by *Micraspis* sp. as influenced by varieties

Varieties	Prey density 20
Jaya	16.832[b]
Jyothi	21.128[ab]
Kanakom	24.960[a]
CD	6.12

Adults lived shorter on Kanakom (7.0 and 10.0 respectively for male and female) whereas the longevity of those reared on Jaya and Jyothi did not differ significantly (Table 28).

4.8.2 Fecundity, incubation, pre-oviposition and oviposition periods

While the varieties did not show any influence on the incubation period of the mirid eggs, fecundity varied significantly among them. The mirid laid more number of eggs when reared on Jaya (22.4) and fewer number of eggs on Kanakom (13.8) (Table 29).

The predator oviposited for a significantly longer period on Jaya (9.2 days) compared to Jyothi (7.6 days) and Kanakom (6.2 days). The pre-oviposition period recorded was shortest on Jaya (2.0 days) and highest on Kanakom (3.2 days) (Table 29).

4.9 Anatomical difference of the culm of the varieties

Table 30 depicts the anatomical features of the culm of the varieties Jaya, Jyothi and Kanakom.

Cuticle of the culm of Kanakom was found to be significantly thicker (37.35 μ) compared to those of Jaya (31.19 μ) and Jyothi (32.34 μ).

The size of the air column and cell in the culm of Jaya were significantly larger (317678.09 μ^2) whereas they did not differ significantly between Jyothi (170969.88 μ^2) and Kanakom (133803.25 μ^2).

Examination of the sections revealed that the variety Kanakom has got a very well developed and thick bundle sheath (Plate 14a & 14b). The degree of development of the bundle sheath was less in the other two varieties (Plates 15, 16a & 16b). In Kanakom, patches of schlerenchyma tissue were found distributed

Table 28. Nymphal duration and adult longevity of *C. lividipennis* as influenced by varieties

Varieties	Nymphal duration (days)		Adult longevity (days)	
	Male	Female	Male	Female
Jaya	10.80^{b}	13.60^{b}	9.40^{a}	13.00^{a}
Jyothi	10.20^{b}	13.60^{b}	10.00^{a}	12.80^{a}
Kanakom	11.80^{a}	16.00^{a}	7.00^{b}	10.00^{b}
CD	1.15	1.15	1.07	1.42

Table 29. Fecundity, incubation, pre-oviposition and oviposition periods of *C. lividipennis* as influenced by varieties

Varieties	Fecundity (No.)	Incubation period (days)	Pre-oviposition period (days)	Oviposition period (days)
Jaya	22.40^{a}	8.25^{a}	2.00^{b}	9.20^{a}
Jyothi	18.00^{b}	8.50^{a}	2.60^{ab}	7.60^{b}
Kanakom	13.80^{c}	8.63^{a}	3.20^{a}	6.20^{b}
CD	3.38	0.53	1.13	1.53

Plate 14 a & b. Vascular bundle of culm - var. Kanakom

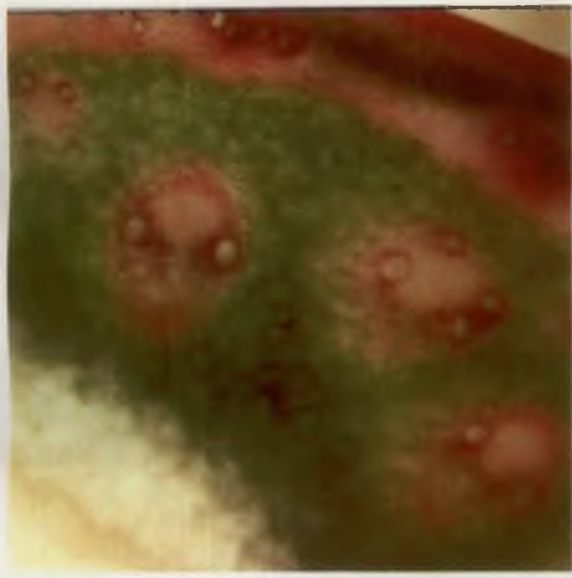

Plate 15. Vascular bundle of culm - var. Jyothi

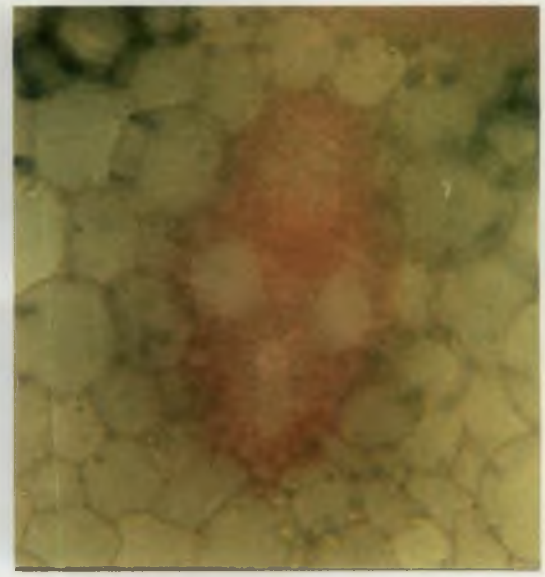

Plate 16 a. Vascular bundle of culm - var. Jaya

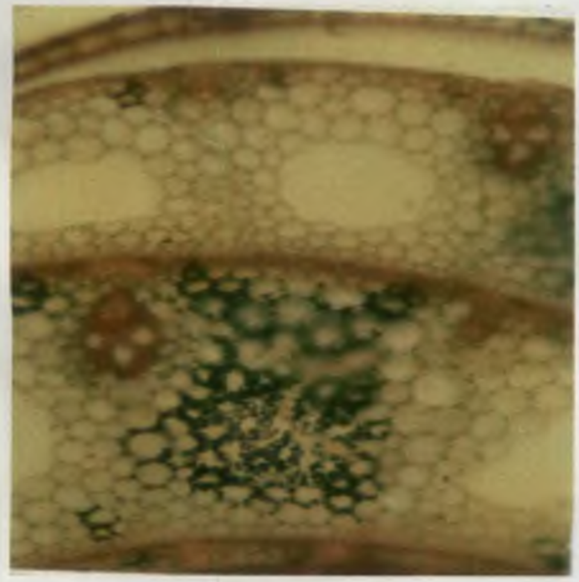

Plate 16 b. Vascular bundle of culm - var. Jaya

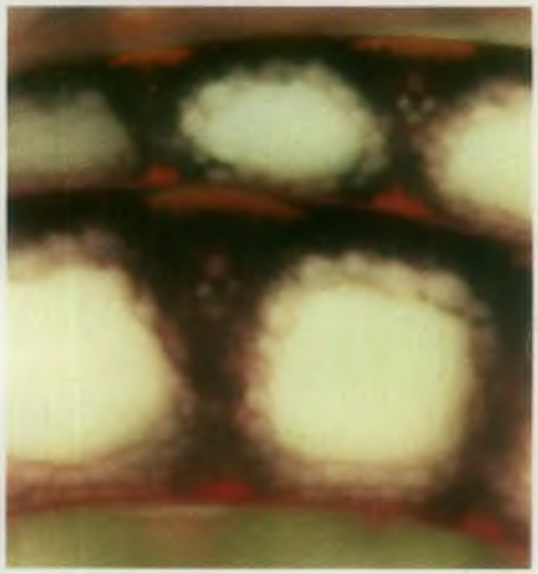

Plate 17. Schlerenchyma tissues in the culm - var. Kanakom

Table 30. Cuticle thickness, air column size and cell size of the rice culm as influenced by varieties

	Cuticle thickness μ	Air column size (length x breadth) μ^2	Cell size (length x breadth) μ^2
Jaya	31.19[b]	317678.09[a]	3632.30[a]
Jyothi	32.34[b]	170969.88[b]	1848.05[b]
Kanakom	37.35[a]	133803.25[b]	2256.46[b]
CD	3.24	43243.11	664.08

above the vascular bundles at regular intervals (Plate 17a & b). Such schlerenchymous tissue were absent in Jaya and Jyothi.

4.10 Chemical composition of the stem of the rice varieties

Results of the chemical analysis of the three varieties under study are presented in Table 31. The percentage content of N (1.2%) and K (2.31%) was found to be higher in Jaya. In Kanakom, K content was a low of 1.61 per cent while P content was a high of 0.31 per cent.

The concentration of the minor elements Ca, Mg and Cu were more in the stem of Jaya (253.36 ppm, 225.16 ppm & 17.08 ppm respectively), whereas the concentrations of Zn and Mn were higher in Kanakom (61.0 ppm & 495.43 ppm), followed by Jyothi (51.07 ppm & 458.43 ppm). While crude fibre content, total sugars and phenols did not found to vary among the varieties, crude silica content was high in Kanakom (14.01%).

Table 31. Chemical composition of the culm (60 days old) of different rice varieties

Variety	N (%)	P (%)	K (%)	Ca (ppm)	Mg (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)	Crude fibre (%)	Crude silica (%)	Total sugars (%)	Total phenols (ppm)
Jaya	1.21	0.30	2.31	253.36	225.16	17.08	45.36	410.21	20.94	9.84	1.06	9.31
Jyothi	0.93	0.28	1.89	228.86	206.49	11.07	51.07	458.43	19.06	10.19	1.07	9.22
Kanakom	0.90	0.31	1.61	215.14	187.04	11.0	61.0	495.43	20.89	14.01	1.30	9.51

Discussion

DISCUSSION

5.1 Assessment of population of *Nilaparvata lugens* (Stal) and its natural enemies

5.1.1 Population in Kole lands

The population fluctuation of the brown planthopper (BPH), *N. lugens* and its natural enemies in Kole land is given in Table 1. The population of *N. lugens* was generally low in the field where moderately tolerant variety Triveni was grown. A maximum population of 35 hoppers per 10 hills was recorded 64 days after transplanting which is far below the economic threshold level (ETL) of 25 to 30 insects per hill (Anon., 1996). As the population of *N. lugens* increased, the population of the predator *Cyrtorhinus lividipennis* Reuter also increased showing a density dependent relationship, suggesting that the mirid is an important factor and major predator regulating the population of *N. lugens*. A similar observation was made by Ooi (1992) in Malaysia, who suggested that *C. lividipennis* was a major mortality factor in insecticide free plots and kept the hopper population below the ETL. Regulation of the hoppers below ETL by the mirid was also reported by Kalode (1976).

The decrease in the population level of *Microvelia douglasi atrolineata* Bergoth as the crop growth advanced may be attributed to the receding water level in the field. The bug is an aquatic predator and can be very abundant in flooded fields (Shepard *et al.*, 1987). A similar trend in the population of the bug was reported in the rice fields of Taiwan (Chen and Chiu, 1982).

5.1.2 Population in Kuttanad during Rabi 1997-98

In the karappadam tracts, the population of *N. lugens* never reached the ETL during rabi season and were regulated by *C. lividipennis* and spiders (Table 2). During the same season, in the kayal area outbreaks of *N. lugens* occurred in two localities, Sreemoolam and `C' block (Table 3). In these fields the ratio of *N. lugens* to *C. lividipennis* was quite high indicating the insufficiency in the mirid population to exercise control over the hoppers. The low population of the mirid is probably due to the indiscriminate use of insecticides in these fields (Personal communication).

5.1.3 Population in Kuttanad during Kharif '98

During Kharif '98, the fields in Kuttanad received heavy insecticidal treatment to contain the menace of gall fly resulting in mortality of natural enemies in the field as indicated by low counts of *C. lividipennis* and spiders. This must have caused the severe outbreaks of BPH in several localities as seen in Table 4. Indiscriminate application of insecticides especially in the early stages of the rice cropping season has been reported to cause resurgence of the BPH due to increased mortality of the natural enemies (Banerjee, 1996).

5.2 Population dynamics of *N. lugens* and its natural enemies as influenced by season and varieties

The average population of *N.lugens* and various natural enemies in different varieties from February to April 1998 is depicted in Fig.1.

5.2.1 Population dynamics of *N. lugens*

In all the three varieties, the population of *N. lugens* was more during the first two weeks of February with a steady decline thereafter (Table 5, Fig 2). By the second week of March, the hopper population disappeared from the fields. Earlier studies by Nair *et al.* (1980) also showed that the hopper population reached a peak during January to March in Moncompu rice fields in the main crop season. Maximum population of *N. lugens* recorded on Jaya and the minimum population on Kanakom can be attributed to their varietal susceptibility and resistance respectively. Results of earlier studies in Kuttanad (Nair *et al.*, 1980; Joseph *et al.*, 1994) are not mutually agreeable. A negative correlation between BPH population and rainfall in association with high relative humidity was obtained by Nair *et al.* (1990). They also found that high temperatures had a positive correlation on the population of *N. lugens*. Studies of Joseph *et al.* (1994)

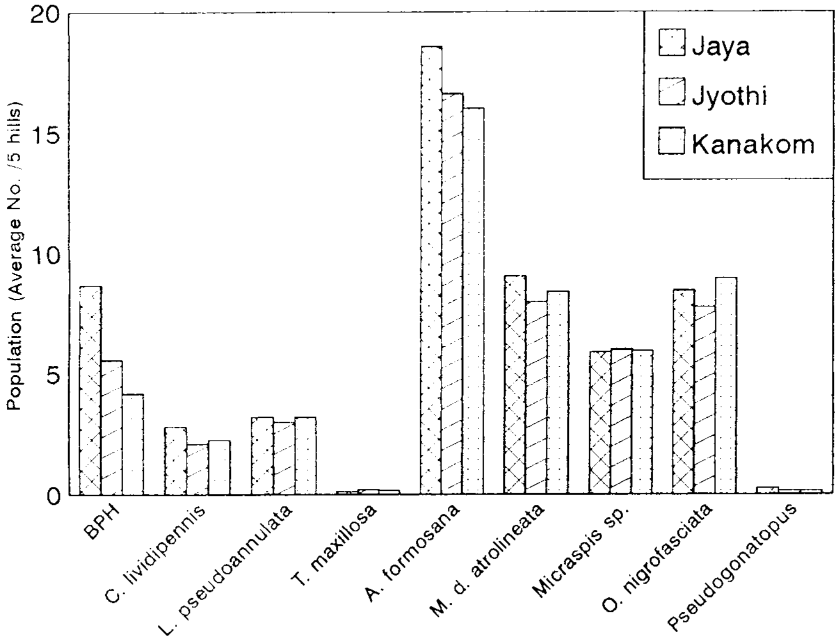

Fig.1. Population of BPH and its natural enemies in different varieties.

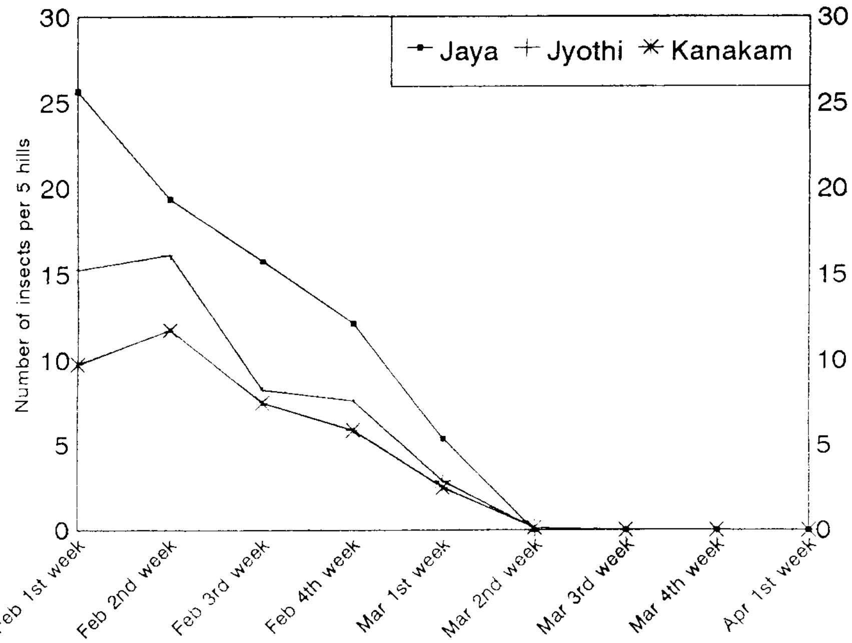

Fig.2 Population of N.lugens as influenced by varieties

based on light trap catches did not show any influence for rainfall, temperature or relative humidity on the BPH population. It is known that under constant temperature above 33°C, the BPH population dwindles (Bae and Pathak, 1970). There is also evidence that all life stages other than macropterous females are not tolerant of high temperature (Domingo and Heong, 1992). Since outbreaks of BPH are associated with brachypterous females (Dyck *et al.*, 1979) which are susceptible to high temperature an increase in temperature beyond 33-35°C which usually occurs in Kuttanad after February would have caused a reduction in BPH counts. In the peculiar topographical and micro environmental conditions prevalent in Kuttanad, the water level in the field recedes fast by March. This drop in water level coupled with an increasing temperature (Appendix I) causes the suppression of the biotic potential of BPH.

5.2.2 Population dynamics of *C. lividipennis*

Population of the predator, *C. lividipennis* (Table 6, Fig 3) also showed a peak during February and declined with the downward trend in the population of *N. lugens*, suggesting a density dependant relationship with the hopper as reported by Ooi *et al.* (1978). Predator population on Jaya and Kanakom did not differ significantly. The prey-predator ratio was lowest on the resistant variety Kanakom and highest on the susceptible variety Jaya. Similar observations in Philippines indicated that the prey-predator ratio of *N. lugens* : *C. lividipennis* was generally low and most favourable for effective biocontrol in the resistant varieties (Kartohardjono and Heinrichs, 1984). A low prey-predator ratio would mean that there are more predators per unit prey population and same is very effective in pest suppression. The resistant varieties reduce the fitness of the BPH and their vigour is also reduced. These are usually attributed to both antixenosis and antibiosis. Under such reduced fitness even though the general population level of BPH may be lower, it is further reduced by an increased searching by the predators. Since *C. lividipennis* is the most predominant of the biocontrol agents effecting suppression of BPH, it is only natural that the resistant and moderately resistant varieties caused a lower prey-predator ratio.

5.2.3 Population dynamics of *L. pseudoannulata* and *T. maxillosa*

The varieties did not cause any significant difference in the populations of the spiders, *L. pseudoannulata* and *T. maxillosa* on their canopy (Table 7 & 8; Fig 4 & 5). The populations of the spiders showed a positive correlation with those of *N. lugens*. Such a relationship between the populations of spiders and plant hoppers were also observed in many hopper infested rice fields (Luo, 1985; Zhou and Chen, 1986). Spiders being active predators not restricted by the confines of the plant canopy and plant morphology but they mainly depend on the population of the prey. Thus when BPH population dwindles and is no longer in a position to support their life, they would be migrating to fields where they have sufficient food.

5.2.4 Population dynamics of *A. formosana, M. d. atrolineata, Micraspis* sp. and *O. nigrofasciata*

The correlation between the populations of *N. lugens* and those of the predators, *Atypena formosana* (Ooi), *M. d. atrolineata, Micraspis* sp. and *Ophionea nigrofasciata* was negative in the three varieties as shown in Table 14. In the field the population of these predators were found to increase even when the population of *N. lugens* declined (Table 9, 10, 11 and 12). The appearance of these predators in the absence of *N. lugens* was possible probably because of the complexity of their host range. It was reported that the predatory beetles, *Micraspis* sp. and *O. nigrofasciata* though feed on rice plant hoppers, do not cause major mortality (Ooi and Shepard, 1994). *M. d. atrolineata* being an aquatic predator disappears from the fields with letting out of water. In the case of *Micraspis* sp. it has already been reported that they are pollen feeders also (Shepard and Rapusas, 1989). This explains the increase in their population when the crop comes to the flowering stage due to increased food availability even though the BPH population is decreasing. With regard to *M. d. atrolineata* and *O. nigrofasciata*, there is a possibility that they actively prey on the younger instars of lepidopteran pests which tend to increase from the flowering stage onwards.

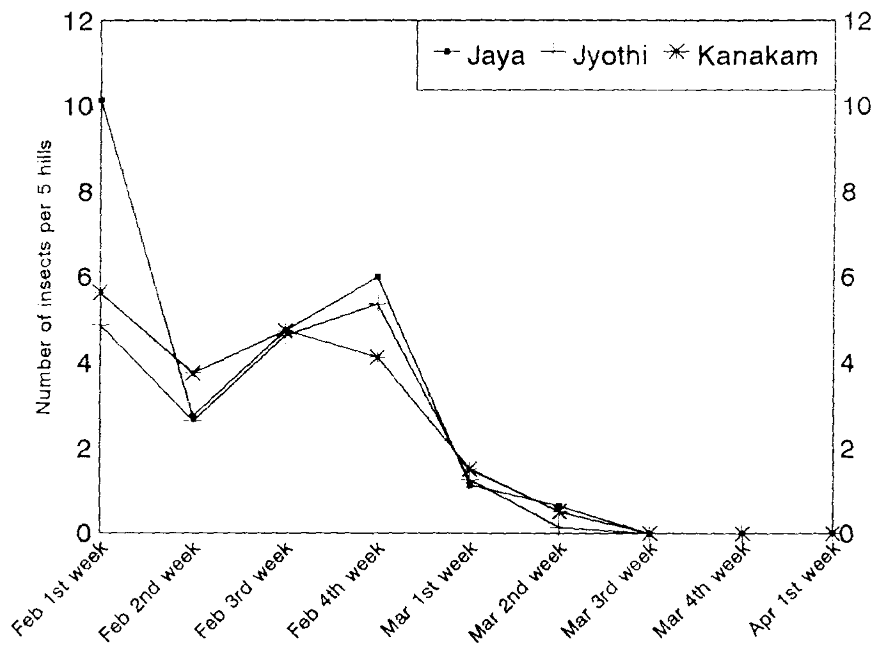

Fig.3 Population of *C.lividipennis* as influenced by varieties

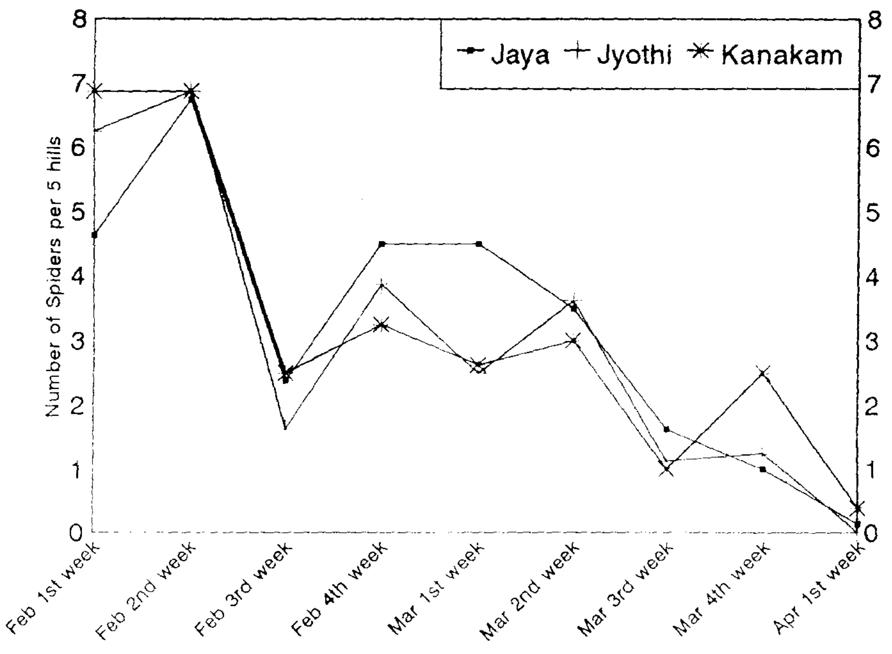

Fig.4 Population of L.pseudoannulata as influenced by varieties

5.2.5 Population dynamics of *Pseudogonatopus* sp.

Pseudogonatopus sp. was present in the field for only the first three weeks of February when the *N. lugens* population was more and disappeared with decreasing population of the hoppers (Table 13 & Fig 6). The parasitism of *N. lugens* by several species of dryinid parasitoids including *Pseudogonatopus* sp. was found to rise gradually with the rise in population of the hoppers in Philippines (Chandra, 1980b) indicating a density dependent relationship. A similar trend in the population of the dryinid has been observed by Pena and Shepard (1986). Our results further emphasise these observations but also points out the low efficacy of *Pseudogonatopus* sp. in the population management of BPH in Kerala as indicated by very low counts of *Pseudogonatopus*. A valid explanation for the very low population of dryinids in the BPH infested fields is wanting at present.

5.2.6 Correlation of the population of *N. lugens* and its natural enemies to weather parameters

The population of *N. lugens* and its natural enemies were correlated with weather parameters separately for the three varieties as shown in Table 15, 16 and 17. The minimum temperature showed a highly significant negative correlation with the population of *N. lugens* in all the varieties. Other weather parameters like relative humidity, sunshine hours and maximum temperature did not show any influence on the hopper population. Studies by Joseph *et al.* (1994) in Kuttanad using light traps and weather parameters too showed that relative humidity and maximum temperature did not influence the population of *N. lugens*. It thus becomes apparent that the most important factor in the population build up of *N. lugens* is a low minimum night temperature in Moncompu. Probably during winter months of October to December when the low temperature are in the favourable range of 21-24° C, the maximum temperature does not reach the favourable range of 28-30°C (Dale, 1994). This might again limit the population of BPH.

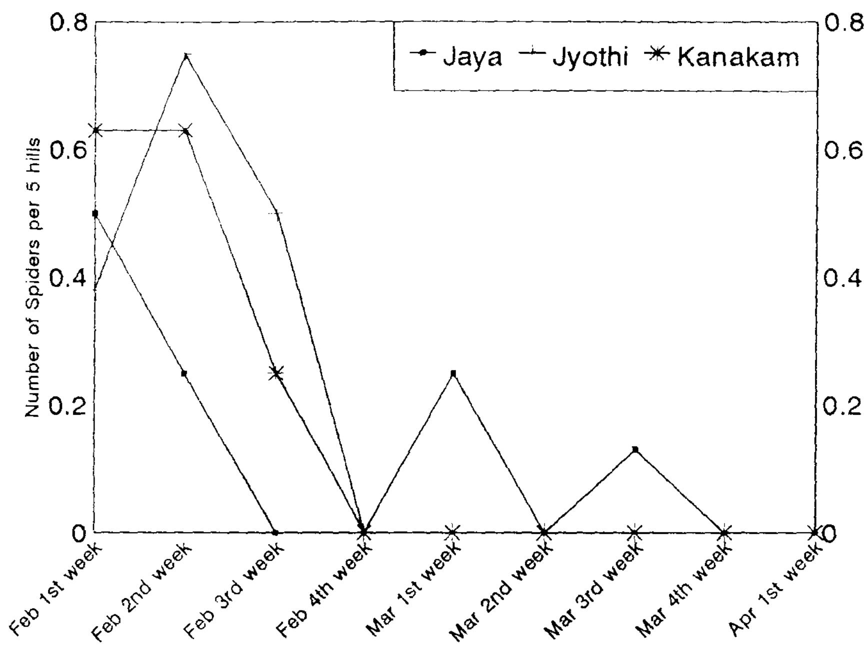

Fig.5 Population of *T. maxillosa* as influenced by varieties

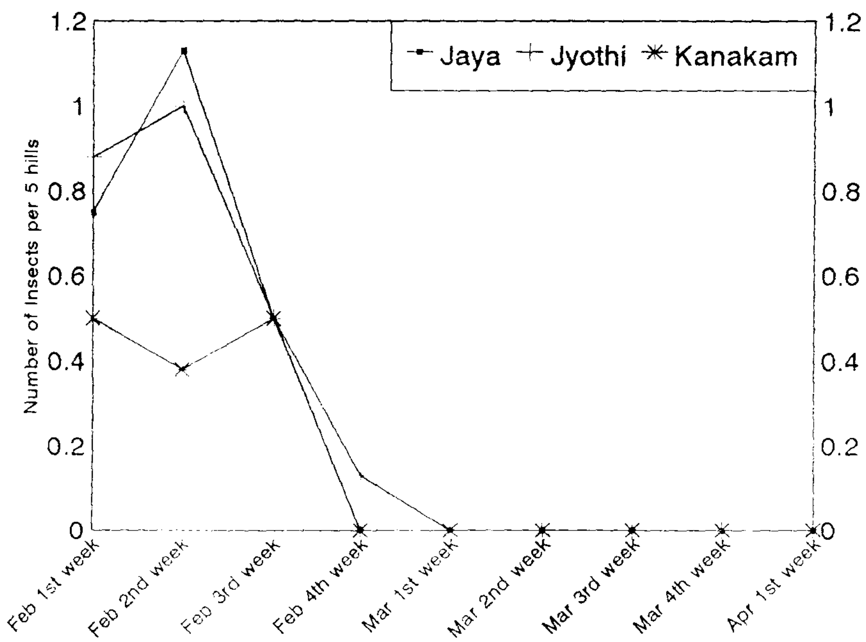

Fig.6 Population of *Pseudogonatopus* sp. as influenced by varieties

The populations of the natural enemies, *L. pseudoannulata, T. maxillosa* and *Pseudogonatopus* sp. were also negatively correlated with the mean minimum temperature. Whereas those of *Micraspis* sp. and *O. nigrofasciata* were positively correlated. The positive correlation between the populations of *L. pseudoannulata, T. maxillosa* and *Pseudogonatopus* sp. with the population of *N. lugens* and negative correlation of the population of *Micraspis* sp. and *O. nigrofasciata* with those of *N. lugens* explains this relationship. This also indicates the thermophilic nature of *O. nigrofasciata* and *Micraspis* sp.

The population of the predatory mirid *C. lividipennis* showed a significant negative correlation with minimum temperature in only the resistant variety Kanakom. This may probably be due to the antibiosis effects produced by the plant. Populations of BPH on the resistant variety have a reduced fitness and there is a corresponding lack of fitness for *C. lividipennis* also, which feeds on these BPH prey. This makes it more prone to fluctuations in weather.

5.3 Influence of varieties on the population growth of *N. lugens*

Table 18 depicts the population growth of *N. lugens* on different varieties. The lowest population of 79.8 hoppers was observed on the resistant variety Kanakom, while it was as high as 519/plant in the susceptible variety Jaya. This indicates the highest level of antibiosis by Kanakom. The population growth test conducted in the laboratory (2.2) is in conformity to the report of Kartohardjono and Heinrichs (1984) where the population of *N. lugens* was highest on susceptible variety, intermediate on moderately resistant variety and lowest on resistant variety. Low population build up of the hoppers on resistant variety has also been reported by Senguttuvan *et al.* (1991).

5.4 Influence of varieties on the biology of *N. lugens*

5.4.1 Incubation period, nymphal duration and nymphal survival

Table 19 shows the incubation period, nymphal duration and nymphal survival of BPH on different varieties. The susceptible variety Jaya recorded shorter nymphal duration (13.0 days), while the resistant variety Kanakom showed longer nymphal duration (17.9 days). Percentage nymphs surviving on the plants were more on the susceptible variety (82.26%), while on the resistant variety, a decreased nymphal survival (38.66%) was noted. There is thus a very clear demarcation between resistant, moderately resistant and susceptible varieties on their capabilities for resisting population build up of BPH. Shorter nymphal duration would mean more number of generations per unit crop season. Since the percentage of nymphs surviving on the susceptible variety is more than twice the percent on the resistant variety, it is evident that within a single generation of BPH itself there will be more than two fold increase in the population on the susceptible varieties.

5.4.2 Adult longevity

The adult hoppers lived longer on Jaya compared to Kanakom (Table 20). The increased longevity of adults on the susceptible varieties adds to the geometrical growth of BPH population by increased egg layings. So this is a typical case of population flare up where susceptible varieties will have many-fold increase over the résistant varieties. Thus the importance of growing resistant varieties in endemic areas is emphasised. The results clearly indicate the prevalence of antibiosis in the variety Kanakom, which is responsible for its resistance. Several authors have reported antibiosis as a mechanism of resistance in rice varieties to *N. lugens* (Kalode and Krishna, 1979; Oya and Hirao, 1985; Chelliah, 1991 and Senguttuvan *et al.*, 1991).

5.4.3 Fecundity, pre-oviposition and oviposition periods

It was also seen that brachypterous females laid more number of eggs on Jaya and Jyothi (Table 21). On Kanakom only very few eggs were laid. The oviposition period was also shorter and pre-oviposition period longer on Kanakom. This shows the hopper's lower preference of Kanakom for oviposition. Resistant varieties like PTB 33 were earlier been reported to be less preferred for oviposition by *N. lugens* (Senguttvan *et al.*, 1991). Fecundity of *N. lugens* was observed to be significantly lower on resistant cultivars than on susceptible control Jaya (Misra *et al.*, 1988). These observations bring home the importance of the multitude of factors from the egg stage itself like lesser number of eggs laid, longer pre-oviposition period and reduced oviposition period on the resistant variety in bringing down the population. Lower number of eggs and shorter oviposition period is an antixenosis factor in Kanakom.

Further, it was found that macropterous forms did not develop on the resistant variety. Macropterous forms which are reported to be responsible for immigration, develop when a certain population density is attained (Kisimoto, 1977). Since the population build up was poor on Kanakom macropterous forms did not develop on it.

5.5 Predatory potential of natural enemies on *N. lugens* as influenced by varieties

5.5.1 *C. lividipennis*

Percentage predation on eggs and nymphs of *N. lugens* by the mirid predator is represented in Table 22 & Fig 7. Significant difference was observed in the predation level of *C. lividipennis* on eggs of *N. lugens* among the varieties. The predation was high in Kanakom (29.37%) followed by Jyothi (20.17%), but it was lowest (17.6%) in Jaya. The high percentage predation on resistant variety might be attributed to less number of eggs laid and equal predation imposed on them. Similar observation was made in resistant and susceptible varieties of rice on the predation of *N. lugens* eggs by *C. lividipennis* (Senguttuvan and Gopalan, 1990).

The predation on nymphs of *N. lugens* was 44.0 per cent in the resistant variety Kanakom, which was more than on the other two varieties. However, the varieties Jaya and Jyothi did not differ significantly in the predation level. Higher predation on resistant varieties can be attributed to the greater movement of *N. lugens* on it in search of a suitable feeding site (Kartohardjono and Heinrichs, 1984; Salim and Heinrichs, 1986 and Senguttuvan and Gopalan, 1990). This is also due to a decreased fitness of BPH nymphs on the resistant variety induced probably by antibiosis from the resistant plant.

5.5.2 *L. pseudoannulata*

The predation percentage of *N. lugens* nymphs by the predator at two prey densities is depicted in Table 23 & Fig 8. There was significant difference among the varieties in the levels of *N. lugens* mortality at prey density of 40 nymphs. Mortality of *N. lugens* was highest in the resistant variety Kanakom, intermediate in the moderately resistant Jyothi and lowest in the susceptible variety Jaya. At prey density of 20 hopper nymphs also the predation level was highest on Kanakom. However, no significant difference in predation was observed between Jaya and Jyothi at the lower prey density. Increased predation rate on resistant varieties has been reported by Kartohardjono and Heinrichs (1984) who attributed it to the greater movement of *N. lugens* in search of a suitable feeding site, where as in susceptible variety, they remain feeding in one location longer. Because *L. pseudoannulata* and possibly other predators only attack moving prey, the predation rate would be expected to be higher on the resistant than on the susceptible variety, where the prey moves more frequently.

5.5.3 Predatory/parasitic potential of *Pseudogonatopus* sp.

Table 24 (Fig 11) and Table 25 (Fig 12) represent the rate of predation and parasitism respectively by *Pseudogonatopus* sp. on *N. lugens* nymphs at two host densities. Predatory potential of the dryinid, *Pseudogonatopus* sp. was not found to vary among the varieties at the lower prey densities. However, at higher host densities, the number of *N. lugens* nymphs attacked was more on all the

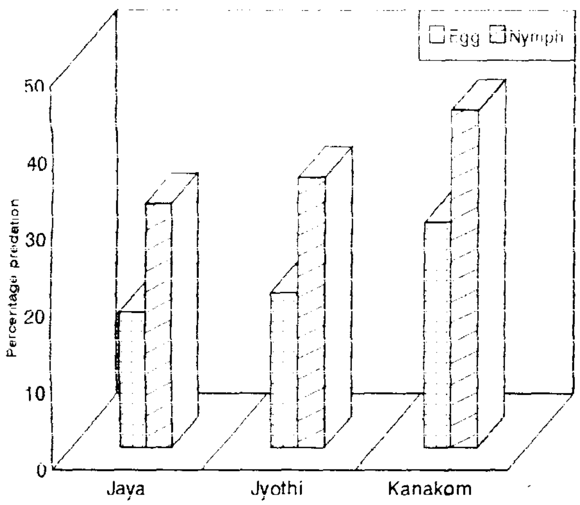

Fig.7. *Cyrtorhinus lividipennis*

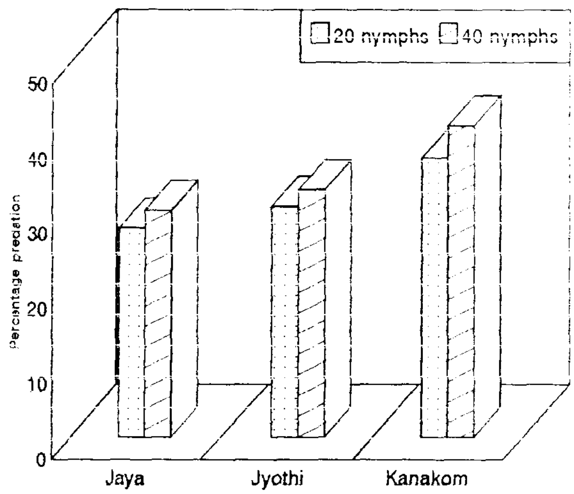

Fig.8 *Lycosa pseudoannulata*

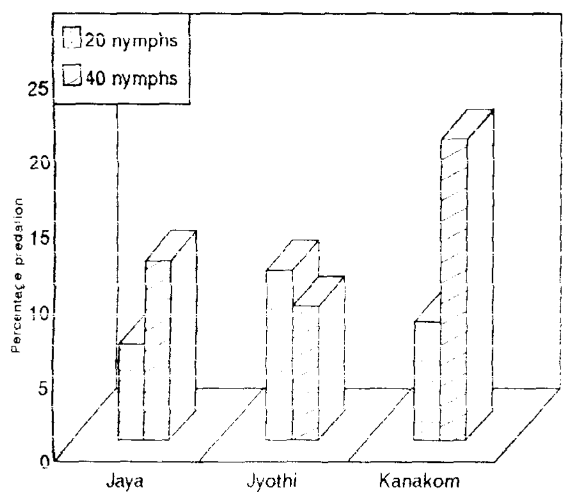

Fig.9 *Microvelia douglasi atrolineata*

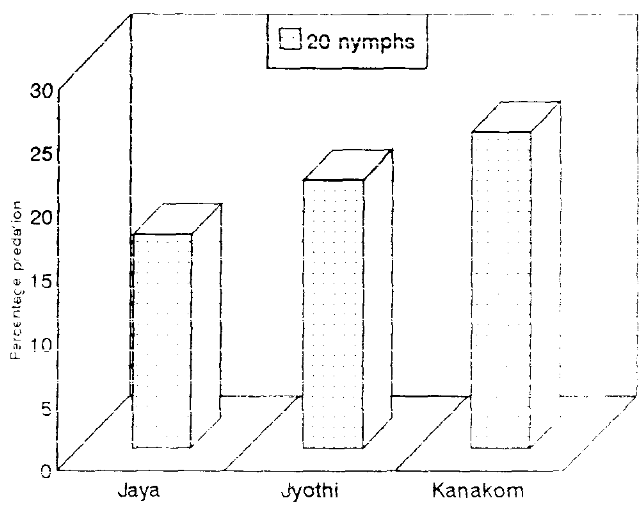

Fig.10 *Micraspis sp.*

Predation of BPH by various natural enemies as influenced by varieties.

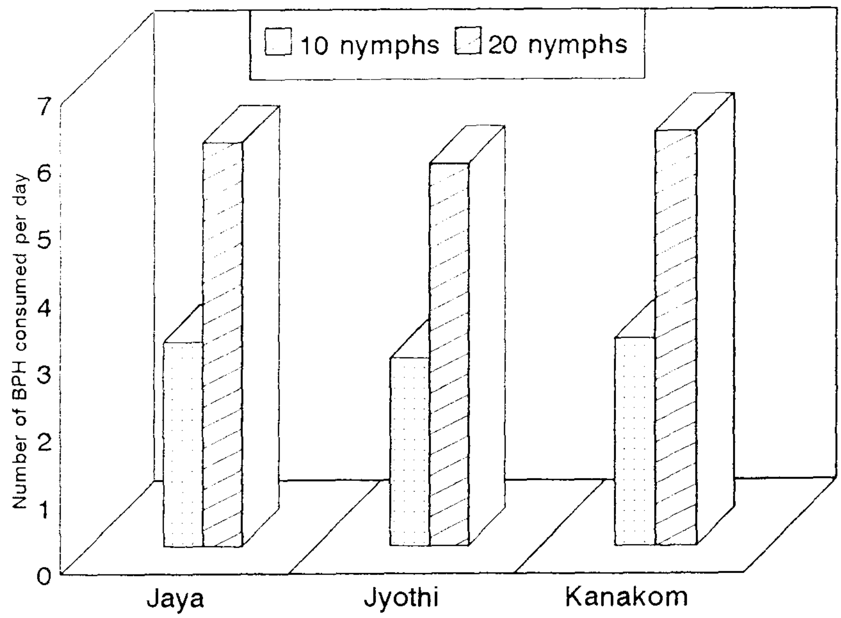

Fig.11 Predatory potential of Pseudogonatopus sp. on BPH at two prey densities as influenced by varieties

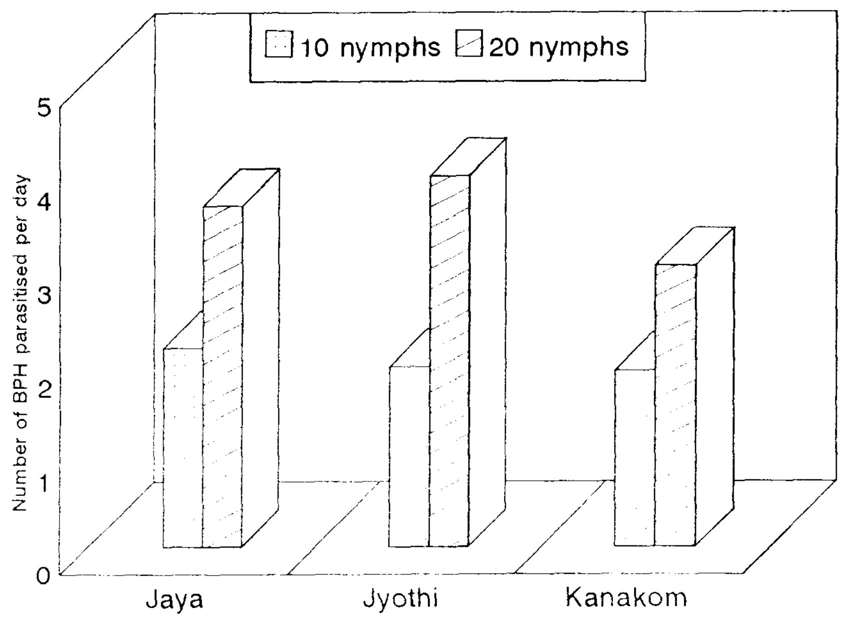

Fig.12 Rate of parasitism of BPH by Pseudogonatopus sp. at two host densities as influenced by varieties

varieties and highest on Kanakom. The number of hosts parasitised each day was also high at higher host densities. At higher host densities, the dryinid wasp, *Dicondylus indianus* Olmi was also reported to have fed upon and parasitised more *N. lugens* hoppers per day than at lower host densities (Sahragard *et al.*, 1991). This can be explained as due to higher efficiency of the dryinid parasitoid at the higher prey density. Probably at the lower host densities the energy of the dryinid is wasted in finding out the sparse number of prey that are available in the ecosystem. Most of the energy is lost in the host searching itself.

Though the rate of parasitism did not vary among the varieties at the host density of 10 hoppers, there was significant difference in the number of hosts parasitised at the host density of 20 hoppers. Results obtained on barley (Starks *et al.*, 1972) showed a higher predation of the green bug, *Shizaphis graminum* (Rondani) on resistant variety and were prevented from population build up by the parasite *Lysiphlebus testaceipes* (Cresson), but was ineffective in doing so on susceptible variety. But our results deviate from this observation. It is in the resistant variety that parasitism was lower at the higher prey density. This is because the very same dryinid is both a predator and a parasite. It has been reported that the dryinid does not oviposit on the prey it consumes as a predator (Chandra, 1980b). It is only, on the left over BPH nymphs that it oviposit. Since there is increased level of predation on the resistant variety at the higher prey density, it is only the remaining prey that is parasitised which explains the lower rate of parasitism.

5.5.4 Predatory potential of *Microvelia douglasi atrolineata*

The predatory potential of the veliid bug is given in Table 26 & Fig 9. The bugs predated significantly more hoppers on the resistant variety Kanakom at prey density of 40 *N. lugens* nymphs. While at the lower prey density (20 nymphs) there was no significant difference in their predation among the varieties. *M. d. atrolineata* being an aquatic predator feeds on those nymphs that fall off the plants on to water surface. It was shown that the number of *N. lugens* that fall off the plants was related to density and that the fall off was significantly higher in resistant variety than in susceptible ones (Almazan and Heong, 1992). Hence more predation observed on resistant Kanakom at higher prey density might be due to the more number of hoppers that fell off the plants which were fed upon by the bugs. This explanation is also true for the higher host density since when the number of BPH are more per hill there is a possibility of more numbers falling off on to the water level.

5.5.5 Predatory potential of *Micraspis* sp.

It was seen that the coccinellid beetle *Micraspis* sp. fed more hoppers when reared on Kanakom (Table 27 & Fig 10). Higher predation of *N. lugens* hopper on the resistant variety by the beetle may be due to the greater mobility of the hoppers on it in search of feeding site.

But in general, the percentage predation by both *Micraspis* sp. and *M.d.atrolineata* were of a low order.

5.6 Influence of varieties on the biology of *C. lividipennis*

5.6.1 Nymphal duration and adult longevity

Influence of varieties on the nymphal duration and adult longevity of *C. lividipennis* is presented in Table 28. Adult longevity of the mirid was significantly low when fed on *N. lugens* eggs reared on resistant variety Kanakom. Nymphal duration and adult longevity of mirid did not vary between the varieties Jaya and Jyothi. Low fecundity of *N. lugens* on Kanakom relates to the less availability of food to *C. lividipennis* nymphs which determines the amount of eggs consumed. This must have resulted in the increased nymphal period and reduced adult longevity on the resistant variety. Chua and Mikil (1989) also reports that when 20 or fewer eggs of *N. lugens* were given daily as food, nymphal duration increased and the adult longevity decreased.

5.6.2 Fecundity, incubation, pre-oviposition and oviposition period

The fecundity, incubation period, pre-oviposition period and oviposition period of *C. lividipennis* on different varieties is presented in Table 29. Fecundity and oviposition period were significantly high on the susceptible variety Jaya. Kanakom recorded the least fecundity and oviposition period. Pre-oviposition period was longer in Kanakom followed by Jyothi. However there was no significant difference in the incubation period of the mirid among the varieties. Reduced fecundity of *C. lividipennis* on the resistant variety could well be due to food shortage. The pre-oviposition period is more on the resistant variety probably because of antixenotic properties. The increased oviposition period on the susceptible variety might again be only due to increased prey availability. Such results have been obtained by Chua and Mikil (1989) also.

5.7 Anatomy of the culm of the rice varieties

Anatomical features of the rice culm namely the cuticle thickness, air column size and cell size are given in Table 30. An examination of the anatomy of the three rice varieties showed cuticle thickness to be an important factor governing resistance to *N. lugens* attack. The variety that is susceptible had a thin cuticle with a thickness of 31.19μ and resistant variety a cuticle thickness of 35.5μ, while the moderately resistant variety had an intermediate position. *N. lugens* is a phloem feeder (Sogawa, 1982; Khan and Saxena, 1984) which pierces the epidermis and sucks sap from the phloem. Hence a higher thickness naturally resists the penetration of the stylets of the insect to the phloem tissue. There is also a possibility that the thicker cuticle does not allow the stylet or the stylet sheaths to reach the phloem bundles so that the insect is deprived of food in the resistant variety.

Examination of the size of the air column shows that the resistant variety has smaller sized air column than the susceptible varieties. This means that the tissues are more compact in the resistant varieties rendering them difficult for the hoppers to pierce. Smaller size of the cells act to the compactness of the tissues in the resistant varieties. When the size of the cells are smaller, more number of cells are packed in unit area which is likely to enhance compactness and subsequently resistance to *N. lugens*.

Development of mechanical tissues namely the amount of schlerenchyma and degree of development of vascular bundles have been known to contribute to the resistance to the sucking pests (Thomas, 1977). The resistant variety Kanakom has a very well developed and thick bundle sheath which makes the hopper's stylet difficult to reach the phloem whereas in the susceptible and moderately susceptible varieties the degree of development of bundle sheath is less. Further, distribution of schlerenchyma at regular intervals above the vascular bundles gives an added advantage to the resistant variety. Thomas (1977) also recorded that in varieties highly resistant to *N. lugens*, distribution of schlerenchyma was more in the peripheral region compared to susceptible varieties.

5.8 Chemical composition of rice stem

Higher amounts of Silica, Zn and Mn and lower amounts of N, K, Ca and Mg were recorded in the resistant variety Kanakom compared to the susceptible Jaya and moderately resistant Jyothi.

Silica is known to impart resistance to several pests in rice including *N. lugens* (Sujatha *et al.*, 1987; Chandramohan, 1991; Mishra and Misra, 1992 & 1993). Thomas (1977) reported that in resistant variety PTB 33, the parenchymatous cells were more silicified compared to the susceptible varieties. Higher concentrations of Zn and Mn in varieties resistant to *Sogatella furcifera* has been reported by Mishra and Misra (1993). *S. furcifera* is also a phloem feeder like *N. lugens* feeding on the base of the rice plants.

There is evidence in the literature on the importance of minerals in plants as they relate to resistance. Plants deficient in essential minerals needed by insects may in addition contain atypical concentrations of organic compounds that can affect the growth or reproductive capacity of the insects feeding on them (Maxwell, 1972). Barker and Tauber (1954) reported that the pea aphid exhibits lower growth rate on plants deficient in N, K, Ca and Mg. Lower concentration of these elements were reported in rice varieties resistant to *S. furcifera* (Mishra and Misra, 1993).

Summary

SUMMARY

An investigation was carried out on the population dynamics of BPH, *Nilaparvata lugens* (Stal) and its natural enemies in three rice varieties Jaya (susceptible to BPH), Jyothi (moderately resistant) and Kanakom (resistant) at the rice fields of the Rice Research Station, Moncompu during 1997-98. The influence of the varieties on the biology of *N. lugens* and on the efficiency of its major natural enemies, *Cyrtorhinus lividipennis* Reuter, *Lycosa pseudoannulata* Boesenberg and Strand, *Pseudogonatopus* sp., *Microvelia douglasi atrolineata* Bergoth and *Micraspis* sp. was studied in the laboratory. Biology of the most predominant predator, *C. lividipennis* was studied on the egg of *N. lugens* reared on the three rice varieties. Anatomy of the rice culm and the composition of the various nutrients in it were also investigated. The results obtained are summarised below.

N. lugens population peaked from January to March in the field and steadily declined thereafter. Population of the hopper was significantly more on the susceptible variety Jaya, intermediate on moderately resistant Jyothi and low on resistant Kanakom. Major predators recorded were the mirid, *C. lividipennis*, wolf spider *L. pseudoannulata*, long jawed spider *Tetragnatha maxillosa*, Thorell, dwarf spider *Atypena formosana* (Oi), the veliid bug *M. d. atrolineata*, the dryinid parasitoid, *Pseudogonatopus* sp. and *Ophionea nigrofasciata* (Schmidt-Goebel).

The populations of *C. lividipennis*, *L. pseudoannulata*, *T. maxillosa* and *Pseudogonatopus* sp. showed a significant positive correlation and those of *A. formosana*, *M. douglasi*, *Micraspis* sp. and *O. nigrofasciata* a significant negative correlation with the population of *N. lugens* in the three varieties. Among the varieties, Jaya recorded more population of *C. lividipennis* followed by Kanakom, while the populations of *L. pseudoannulata*, *T. maxillosa* and *Pseudogonatopus* sp. were similar in the three varieties.

In all the varieties studied, the populations of *N. lugens*, *L. pseudoannulata*, *T. maxillosa* and *Pseudogonatopus* sp. showed a significant negative correlation with the minimum temperature, while the population of *C. lividipennis* showed a similar correlation in only Jaya.

Low fecundity, adult longevity, nymphal survival and population growth was recorded on resistant variety Kanakom compared to the susceptible Jaya. The nymphs took longer time on Kanakom than Jyothi and Jaya to develop into adults. Pre-oviposition period was also longer on Kanakom.

Percentage predation of eggs and nymphs of *N. lugens* by *C. lividipennis* was more when reared on the resistant variety than on moderately resistant and susceptible varieties. More predation of *N. lugens* nymphs by *L. pseudoannulata* and *M. d. atrolineata* was recorded on resistant variety Kanakom at higher prey densities only. Similarly at higher host density, *Pseudogonatopus* sp. parasitised and predated more hoppers on Kanakom. The coccinellid beetle, *Micraspis* sp. also predated more hoppers when reared on resistant Kanakom.

On Kanakom, *C. lividipennis* recorded longer nymphal duration, shorter adult longevity and low fecundity compared to those on Jaya and Jyothi.

A well developed bundle sheath with patches of schlerenchyma tissue distributed above it at regular intervals occurred in the stems of the resistant variety. Smaller size of air column and thicker cuticle were also associated with Kanakom.

Higher amounts of Silica, Zn and Mn and lower amounts of N, K, Ca and Mg were recorded in the resistant variety compared to moderately resistant and susceptible varieties.

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Appendix

APPENDIX-I

Weather parameters in Moncompu during 1998

Month	Week	Temperature Maximum °C	Temperature Minimum °C	TRF mm	RH %	Sun shine hours
January	1	35.8	30.5	0	92.3	7.7
	2	36.1	23.0	0	85.0	8.3
	3	35.1	22.1	0	87.6	6.3
	4	35.2	21.5	28.0	92.0	8.3
February	1	30.2	21.6	0	88.0	9.7
	2	35.3	21.7	0	91.0	9.2
	3	35.2	22.8	0	90.0	9.8
	4	33.8	24.6	0	89.0	9.4
March	1	34.8	23.4	0	88.2	9.5
	2	35.7	24.1	0	90.4	9.7
	3	33.2	24.8	0	91.5	9.8
	4	35.8	25.6	0	91.8	8.9
April	1	36.2	25.7	0	75.0	9.5
	2	36.9	26.4	0	74.0	9.6
	3	36.8	26.4	0	74.0	9.7
	4	36.3	26.2	8.3	74.2	6.3
May	1	35.2	24.2	12.3	76.9	9.0
	2	34.9	24.1	3.1	76.5	5.2
	3	34.4	24.1	7.6	75.3	5.1
	4	35.2	24.1	2.6	86.4	8.2
June	1	33.6	23.7	16.1	76.5	2.9
	2	32.8	24.1	16.1	80.3	1.9
	3	31.4	23.5	17.6	81.2	3.9
	4	29.2	22.5	41.3	86.8	1.6
July	1	28.1	24.3	13.6	90.6	2.2
	2	28.4	23.8	8.1	90.5	2.5
	3	28.5	23.1	15.5	86.4	2.9
	4	28.3	23.1	14.6	91.6	4.4

Contd.

Appendix-1. Continued

Month	Week	Temperature		TRF mm	RH %	Sun shine hours
		Maximum °C	Minimum °C			
August	1	28.5	23.1	1.7	92.1	2.5
	2	28.6	23.1	5.8	92.9	4.8
	3	28.3	23.0	10.5	92.5	2.6
	4	27.9	22.9	66.3	92.8	3.8
September	1	29.1	25.6	29.2	89.7	1.6
	2	29.0	23.0	32.0	88.1	2.1
	3	28.7	23.0	11.5	92.5	5.4
	4	27.1	23.0	17.6	91.7	1.6
October	1	28.5	22.2	10.4	91.2	-
	2	27.6	21.2	36.5	91.9	-
	3	29.7	23.3	7.9	91.1	-
	4	30.1	23.7	1.6	92.5	-
November	1	29.4	23.9	3.4	91.6	-
	2	29.9	23.1	2.9	91.4	-
	3	28.9	24.0	1.6	91.9	-
	4	28.5	24.2	0	91.4	-
December	1	28.5	23.7	13.9	90.9	-
	2	28.4	23.6	2.7	89.6	-
	3	28.5	24.0	0.42	91.4	-
	4	29.8	23.9	4.4	91.3	-

INSECT PEST - NATURAL ENEMY - HOST PLANT INTERACTION STUDIES WITH SPECIAL REFERENCE TO THE BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal).

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Field surveys were conducted in Kole land and Kuttanad to assess the population of rice BPH, *Nilaparvata lugens* (Stal) and its natural enemies. Field investigations on the population dynamics of BPH and its natural enemies were carried out on susceptible (Jaya), moderately resistant (Jyothi) and resistant (Kanakom) rice varieties at the rice fields of Rice Research Station, Moncompu during 1997-98. The influence of these varieties on the biology of the pest, the biocontrol efficiency of the major natural enemies and the biology of the mirid predator *Cyrtorhinus lividipennis* Reuter was studied in the laboratory. Histological and chemical investigations were undertaken to evaluate the factors that contribute to the resistance/susceptibility in them.

Results of field survey in Kole land revealed that the population of BPH was far below the economic threshold level (ETL). In Kuttanad, in kayal area during Rabi season and in karappadam tract during Kharif season outbreaks of BPH occurred in some localities due to the indiscriminate use of insecticides resulting in the mortality of natural enemies.

The results of the study on population dynamics revealed that the BPH population was significantly high on the susceptible Jaya and low on the resistant Kanakom with the population reaching a peak from February to March. The predatory complex of the BPH comprised of the mirid *Cyrtorhinus lividipennis*, *Lycosa pseudoannulata*, *Tetragnatha maxillosa*, *Atypena formosana*, *Microvelia douglasi atrolineata*, *Pseudogonatopus* sp. and *Ophionea nigrofasciata*. *C. lividipennis* was the most predominant predator regulating the hopper population and there exists a density dependent host-predator relationship.

The population of the mirid predator on Jaya and Kanakom did not differ significantly. The prey-predator ratio was lowest on the resistant variety and highest on the susceptible variety. Of the weather parameters studied, the minimum

temperature showed a highly significant negative correlation with the population of *N. lugens* in all the varieties.

BPH reared on the resistant variety recorded longer nymphal duration, decreased nymphal survival and shorter adult longevity indicating the prevalence of antibiosis in the variety. Lesser number of eggs laid, longer pre-oviposition period and shorter oviposition period recorded on Kanakom indicate the antixenosis factor in it. Macrpterous forms of BPH did not develop on the variety .

The predator *C. lividipennis* and *Micraspis* sp. fed more BPH when reared on the resistant variety. The veliid bug *M. d. atrolineata,* the spider *L. pseudoannulata* and the dryinid *Pseudogonatopus* sp. predated significantly more BPH nymphs on resistant variety at a higher prey density only. However, the dryinid parasitoid consumed significantly fewer number of hoppers on Kanakom at the higher host density.

C. lividipennis recorded longer nymphal duration, shorter adult longevity and low fecundity when fed on BPH reared on Kanakom which can be attributed to the low fecundity of *N. lugens* on Kanakom leading to less availability of food to the mirid. Nymphal duration and adult longevity of *C. lividipennis* did not vary between the varieties Jaya and Jyothi.

Well developed bundle sheath with more frequently distributed schlerenchyma tissue in the culm of the resistant variety seemed to impart resistance in Kanakom along with thicker cuticle.

Higher amounts of silica, Zn and Mn and lower amounts of N, K, Ca and Mg were recorded in the culm of the resistant variety compared to moderately resistant and susceptible varieties.

The findings strongly suggest the mechanism of antibiosis and antixenosis in the resistant variety Kanakom.