BIOLOGY OF BROWN PLANTHOPPER, *Nilaparvata lugens* (Stal) ON RICE

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
ENTOMOLOGY
(Minor Subject: Plant Pathology)

By

Gavneet Kaur
(L-2009-A-29-M)

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CERTIFICATE-I

This is to certify that the thesis entitled, **"Biology of Brown Planthopper *Nilaparvata lugens* (Stal) on rice"** submitted for the degree of **Master of Science,** in the subject of **Entomology** (Minor subject: **Plant Pathology**) to the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ms. Gavneet Kaur (L-2009-A-29-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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Major Advisor
(Dr Preetinder Singh Sarao)
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CERTIFICATE-II

This is to certify that the thesis entitled, **"Biology of Brown Planthopper *Nilaparvata lugens* (Stal) on rice"** submitted by **Ms. Gavneet Kaur (L-2009-A-29-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Entomology** (Minor subject: **Plant Pathology**) has been approved by the Student's Advisory Committee along with Head of the Department after an oral examination on the same.

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(Dr Balwinder Singh)

Major Advisor
(Dr. Preetinder Singh Sarao)

Dean Post-Graduate Studies
(Dr Gursharan Singh)

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ABSTRACT

The biology of Brown Planthopper (BPH), *Nilaparvata lugens* (Stal) was studied during 2010-2011 on rice cultivar PR114 under screen house conditions at the Department of Plant Breeding & Genetics, PAU, Ludhiana. The oviposition occurred mostly from 19:30 to 21:30 hours into the leaf sheath near the base of the plant. The mating period lasted for 56 -113 seconds and one male copulated with a maximum of three females. Fecundity-cum-fertility varied from 98.40 to 136.70 eggs during different periods of study with range of 3-17 eggs per egg mass. Pre-oviposition, oviposition, incubation, total nymphal period, post-oviposition, male longevity and female longevity varied from 1.70 to 2.70, 21.00 to 14.10, 5.13 to 7.40, 17.40 to 22.73, 2.30 to 6.70, 17.40 to 21.50, and 23.50 to 25.00 days during May 22-June 20, 2010 (mean temperature 30.01±3.65˚C, mean RH 74.80±7.92%) to September 4 - 30 (mean temperature 26.82±1.72˚C, mean RH 82.00±7.97%), respectively. BPH passed through eight overlapping generations during the period from June 12, 2010 - July 4, 2011. The sex ratio (male:female), wing form ratio (macropterous: brachypterous) and survival percentage varied from 1:1.09 to 1:2.07, 1:1.17 to 1:1.87 and 85.53 to 94.16 per cent, respectively during the three periods of study from May to September 2010. In host range studies, BPH oviposited on *Lolium temulentum* and *Eleusine indica* and the adults survived for a short period on nine other weed species and three crop plants. During, August- October, 2010, 29-38 adult brown planthoppers per ten sweep net were recorded on rice crop. In light trap BPH started appearing in the month of June, 2010 and it was found maximum in the months of September-October and afterwards its population declined rapidly.

Keywords: *Nilaparvata lugens*, rice, Pre-oviposition, oviposition, incubation, total nymphal period, longevity, fecundity-cum-fertility, host range, light trap

Signature of Major Advisor

Signature of the Student

ਖੋਜ ਗ੍ਰੰਥ ਦਾ ਸਿਰਲੇਖ	:	**ਝੋਨੇ ਉਪਰ ਭੂਰੇ ਟਿੱਡੇ, *ਨੀਲਾਪਰਵਤਾ ਲੁਗਨਜ਼* (ਸਟਾਲ) ਦਾ ਜੀਵਨ ਚੱਕਰ**
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ਨਿਚੋੜ

ਭੂਰਾ ਟਿੱਡਾ, *ਨੀਲਾਪਰਵਤਾ ਲੁਗਨਜ਼* (ਸਟਾਲ) ਦੇ ਜੀਵਨ ਚੱਕਰ ਨੂੰ 2010-2011 ਦੌਰਾਨ ਝੋਨੇ ਦੀ ਕਿਸਮ ਪੀ.ਆਰ. 114 ਉੱਤੇ ਸਕਰੀਨ ਘਰ ਤਹਿਤ ਪਲਾਂਟ ਬ੍ਰੀਡਿੰਗ ਅਤੇ ਜਨੈਟਿਕਸ ਵਿਭਾਗ, ਪੀ.ਏ.ਯੂ., ਲੁਧਿਆਣਾ ਵਿਖੇ ਜਾਂਚਿਆ ਗਿਆ। ਮਾਦਾ ਕੀੜੇ ਨੇ ਸਭ ਤੋਂ ਵਧੇਰੇ ਅੰਡੇ ਲੀਫ਼ ਸ਼ੀਥ (ਤਣੇ ਦੇ ਦੁਆਲੇ, ਪੱਤੇ ਦੇ ਖੋਲ) ਵਿੱਚ 19:30 ਤੋਂ 21:30 ਘੰਟੇ ਵਿੱਚ ਦਿੱਤੇ। ਸੰਭੋਗ ਦੀ ਮਿਆਦ 56-113 ਸੈਕਿੰਡ ਸੀ ਅਤੇ ਇੱਕ ਨਰ ਕੀੜਾ ਅਧਿਕਤਮ ਤਿੰਨ ਮਾਦਾ ਕੀੜਿਆਂ ਨਾਲ ਸੰਭੋਗ ਕਰਨ ਵਿੱਚ ਸਮਰੱਥ ਹੋਇਆ। ਜਾਂਚ ਪ੍ਰਕਿਰਿਆ ਦੇ ਵੱਖੋ-ਵੱਖੀ ਮਿਆਦ ਦੌਰਾਨ ਉਪਜਾਉਪਨ-ਕਮ-ਪ੍ਰਜਨਨ ਸ਼ਕਤੀ 98.40 ਤੋਂ 136.70 ਅੰਡੇ ਦੇਖੀ ਗਈ ਜਿਹਨਾਂ ਦੀ ਸੀਮਾ 3-17 ਅੰਡੇ ਪ੍ਰਤੀ ਅੰਡਾ ਸਮੂਹ ਸੀ। ਪੂਰਵ-ਓਵੀਪੋਜੀਸ਼ਨ, ਓਵੀਪੋਜੀਸ਼ਨ, ਉਸ਼ਮਾਇਨ, ਕੁੱਲ ਨਿੰਫਲ ਮਿਆਦ, ਪੋਸਟ ਓਵੀਪੋਜੀਸ਼ਨ, ਨਰ ਕੀੜੇ ਦੀ ਉਮਰ ਅਤੇ ਮਾਦਾ ਕੀੜੇ ਦੇ ਉਮਰ 1.70 ਤੋਂ 2.70, 21.00 ਤੋਂ 14.14, 5.13 ਤੋਂ 7.40, 17.40 ਤੋਂ 22.73, 2.30 ਤੋਂ 6.70, 17.40 ਤੋਂ 21.50 ਅਤੇ 23.50 ਤੋਂ 25.00 ਦਿਨ ਕ੍ਰਮਵਾਰ ਮਈ 22 ਤੋਂ ਜੂਨ 20, 2010 (ਔਸਤ ਤਾਪਮਾਨ 30.01 ± 3.65^{0}C, ਔਸਤ ਨਮੀ 74.80 ± 7.92%) ਸੰਤਬਰ 4-30, 2010 (ਔਸਤ ਤਾਪਮਾਨ 26.82 ± 1.72^{0}C, ਔਸਤ ਨਮੀ 82.00 ± 7.97%) ਰਹੀ। ਭੂਰੇ ਟਿੱਡੇ ਵਲੋਂ ਜੂਨ 12, 2010 ਤੋਂ ਜੁਲਾਈ 4, 2011 ਦੀ ਮਿਆਦ ਦੌਰਾਨ 8 ਅਤਿ ਵਿਆਪੀ ਪੀੜੀਆਂ ਦਰਜੀਆਂ ਗਈਆਂ। ਮਈ ਤੋਂ ਸਤੰਬਰ 2010 ਦੇ ਤਿੰਨ ਅੰਤਰਾਲਾਂ ਦੌਰਾਨ ਸੈਕਸ ਅਨੁਪਾਤ (ਨਰ:ਮਾਦਾ), ਵਿੰਗ ਫਾਰਮ ਅਨੁਪਾਤ (ਮੈਕਰੋਪਟੈਰਸ:ਬਰੈਕੀਪਟੈਰਸ) ਅਤੇ ਅਸਤਿਤਵ ਫੀਸਦੀ 1:1.09 ਤੋਂ 1:2.07, 1:1.17 ਤੋਂ 1:1.87 ਅਤੇ 85.53 ਤੋਂ 94.16 ਪ੍ਰਤੀਸ਼ਤ, ਕ੍ਰਮਵਾਰ ਵੇਖੀ ਗਈ। ਮੇਜ਼ਬਾਨ ਰੇਂਜ ਅਧਿਐਨ ਵਿੱਚ ਭੂਰੇ ਟਿੱਡੇ ਨੇ ਲੋਲੀਅਮ ਟੈਮੂਲੈਂਟਮ ਅਤੇ ਇਲਉਸਿਨ ਇੰਡੀਕਾ ਤੇ ਅੰਡੇ ਦਿੱਤੇ ਅਤੇ ਬਾਲਗਾਂ ਨੇ 9 ਹੋਰ ਖਤਪਤਵਾਰ ਪ੍ਰਜਾਤੀਆਂ ਅਤੇ ਤਿੰਨ ਪ੍ਰਕਾਰ ਦੀਆਂ ਫਸਲਾਂ ਉਪਰ ਛੋਟੀ ਮਿਆਦ ਲਈ ਜਿੰਦਾ ਰਹੇ। ਅਗਸਤ-ਅਕਤੂਬਰ 2010 ਦੌਰਾਨ 29-38 ਪ੍ਰਤੀ 10 ਮਹਾਂਜਾਲ ਬਾਲਗ ਭੂਰੇ ਟਿੱਡੇ ਨੂੰ ਝੋਨੇ ਦੀ ਫਸਲ ਉਪਰ ਦੇਖਿਆ ਗਿਆ। ਪ੍ਰਕਾਸ਼ ਜਾਲ ਯੰਤਰ ਵਿੱਚ ਭੂਰਾ ਟਿੱਡਾ ਜੂਨ 2010 ਵਿੱਚ ਦਿਖਨਾ ਸ਼ੁਰੂ ਹੋਇਆ ਅਤੇ ਇਸਨੂੰ ਸਤੰਬਰ-ਅਕਤੂਬਰ ਵਿੱਚ ਅਧਿਕਤਮ ਪਾਇਆ ਗਿਆ ਮਗਰੋਂ ਇਸਦੀ ਜੰਨਸੰਖਿਆ ਘੱਟਦੀ ਗਈ।

ਸ਼ਬਦ ਕੁੰਜੀ: ਝੋਨਾ, ਭੂਰਾ ਟਿੱਡਾ, *ਨੀਲਾਪਰਵਤਾ ਲੁਗਨਜ਼*, ਪੂਰਵ ਓਵੀਪੋਜੀਸ਼ਨ, ਓਵੀਪੋਜੀਸ਼ਨ, ਪੋਸਟ ਓਵੀਪੋਜੀਸ਼ਨ, ਉਪਜਾਉਪਨ ਕਮ ਪ੍ਰਜਨਨ, ਲੰਮਾ ਜੀਵਨ, ਪ੍ਰਕਾਸ਼ ਯੰਤਰ

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ਪ੍ਰਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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ABBREVIATIONS

%	per cent
BPH	Brown Planthopper
cm	centimeter
ha	hectare
hr	hour
kg	kilograms
km	kilometer
min	minutes
mm	millimeters
^{o}C	Degree Celsius
q	quintal
r	correlation coefficient
RH	relative humidity
mt	million tonnes
WBPH	Whitebacked Planthopper

CHAPTER I

INTRODUCTION

Rice, *Oryza sativa* L. is one of the world's most important cereal crops. It is a dietary staple of more than half of the world's population and more than 90 per cent of the world's rice is grown and consumed in Asia alone (Rai 2004). India has the largest area among rice growing countries and it stands second in production. It produces 89.09 mt of rice on an area of 37.49 m ha with a productivity of 3.02 t per ha (Anonymous 2009). In Punjab, during 2010 rice was grown over an area of 28.02 lakh ha with total production and average yield of 112.36 lakh t and 60.33 q per ha, respectively (Anonymous 2011). Rice is a crop of warm humid environment which is also conducive for survival and proliferation of insect pests. More than 100 species of insects are known as pests of this crop, out of which 20 are of major economic significance (Pathak and Dhaliwal 1981). Among these brown planthopper, *Nilaparvata lugens* (Stal) (BPH); whitebacked planthopper, *Sogatella furcifera* (Horvath) (WBPH); yellow stem borer, *Scirpophaga incertulas* (Walker); leaf folder, *Cnaphalocrocis medinalis* (Guenee); rice thrip, *Stenchaetothrips biformis* (Bagnall); rice hispa, *Dicladispa armigera* (Oliver); root weevil, *Sitophilus oryzae* (Linnaeus) and rice-ear-cutting-caterpillar, *Mythimna separata* (Walker) are important insect-pests of rice in Punjab.

The overall losses due to insect-pest damage in rice were estimated at 25 per cent (Dhaliwal *et al* 2004) or varied from 31.5 to 86.0 per cent (Gunathilagaraj and Kumar 1997). Annual yield loss to rice caused by planthoppers alone was one mt during 1970 – 1990 (Cheng *et al* 2003). Bae and Pathak (1970) reported that rice plant suffered 40 to 70 per cent or 30 to 50 per cent yield loss if attacked by 100 to 200 first instar nymphs at 25 days or at 50 to 75 days after transplanting (DAT), respectively. Pathak and Khan (1994) observed that 400 newly hatched nymphs infesting plants could cause complete drying in 3 to 15 days at 25 to 50 DAT, respectively. Plants nearing maturity also develop hopper burn if infested with about 400- 500 nymphs and adults. It also causes economic damage to the rice crop indirectly by transmitting grassy stunt (Rivera *et al* 1966) and ragged stunt virus diseases (Ling *et al* 1978). In Punjab, *N. lugens* was first recorded in 1973 from Ludhiana, Patiala, Kapurthala and Ropar (Anonymous 1974); afterwards it appeared in 1975, 1983, 1988, 1997, 2007 and 2010 (Singh and Dhaliwal 1991 and Anonymous 1974, 1997, 2007, 2010). The BPH occurred on an epidemic scale and posed serious problems in irrigated paddy areas in the Philippines and Indonesia, where the rice intensification programs had been enforced by the governments due to cultivation of the high yielding varieties bred by IRRI in the years 1973 to 1977 (Dyck and Thomas 1979). In the early 1970s, devastating infestations by the BPH also prevailed in the eastern coastal tracts and southern parts of the Indian sub-

continent, including Sri Lanka (Kulshreshtha *et al* 1974, Fernando 1975, Kalode 1976 and Sogawa 1979).

Nilaparvata lugens (Homoptera: Delphacidae) is a small brownish, sap sucking insect-pest. Members of the genus *Nilaparvata* are characterized by several lateral spines on the hind basi-tarsus (Okada 1977). The adult shows density dependent wing dimorphism with macropterous and brachypterous forms (Hasegawa 1955). Macropterous adults have the ability to migrate over long distances. The BPH is endemic to the tropical oriental region, but its habitat can temporarily expand as far north as Japan and Korea every summer through long distance massive migrations from the tropics (Kisimoto 1971). Khaire and Dumbre (1981) reported that females laid an average of 568.40 eggs in masses on leaf sheaths or inside stems. Eggs hatched within 4-8 days. Life cycle was completed in 18-24 days, 38-44 days and 18-35 days during June-October, November-January and February-April, respectively in southern parts of India (Panwar 1995). There were five nymphal stages and nymphs resemble adults except in size and their lack of wings. Misra and Israel (1968) reported that the nymph size varied from 0.97 mm to 2.69 mm. Adult hoppers were brownish black measuring 3.5-4.5 mm in length. This insect has a high reproductive potential to multiply from ten to hundred fold in each generation. When suitable food is available, the next generation of adults is often brachypterous or short winged. Both nymph and adult suck sap primarily at the base of tillers from phloem tissues so their presence goes undetected, which leads to yellowing of lower leaves starting from leaf tip backwards, reduced vigour, stunting and ultimately drying of whole plant. Honey-dew excreted by the nymphs and adults at the base of the plant is covered with sooty mould which reduced the photosynthetic activity. In field, at early infestation, round yellow patches appear which soon turn brownish due to drying up of the plants. This condition is called “hopperburn”. The patches of infestation then may spread out and cover the entire field. Severely affected plants do not bear any grains. Crop loss is usually considerable and complete destruction of crop occurs in severe cases.

The BPH was considered a major rice pest before 1960 only in its temporary summer habitat, particularly in Japan and Korea (Miyashita 1963 and Paik 1977). In Japan, sporadic but catastrophic outbreaks of BPH have been recorded throughout the history of rice cultivation. The BPH had long been a minor paddy pest in its endemic habitat in the tropics. However, since the early 1970s, the BPH has dramatically risen as a key pest threatening rice production in tropical Asia (Dyck and Thomas 1979). Shepard *et al* (1995) reported that the populations of both the BPH and WBPH increased after insecticide applications. Kenmore *et al* (1984) submitted that due to the widespread misuse of insecticides natural enemies were killed which lead to the outbreaks of BPH. The promiscuous use of pesticides also promoted

resurgence of the insect pest (Heinrichs and Mochida 1984). Likewise, it was believed that excessive use of urea as a nitrogenous fertilizer could also lead to outbreak by increasing the fecundity of BPH (Preap *et al* 2002). BPH was phloem feeder that invades maturing rice crops from other rice areas, sometimes being displaced by wind over long distances (Otuka *et al* 2005). It had high survival rate, greater population build-up and a higher tendency for outbreaks (Li *et al* 1996 and Preap *et al* 2001).

Climatic factors such as temperature, rainfall and relative humidity greatly influences the insect population change (Way and Heong 1994, Zhu 1999 and Heong *et al* 2007). Temperatures between 25 and 30°C are considered optimal for egg and nymphal development whereas temperature above 30°C i.e., 33-35°C are unfavourable for insect survival (Ho and Liu 1969, Bae and Pathak 1970, Chiu 1970, Kulshreshtha *et al* 1974 and Kalode 1976). Eggs have greater tolerance for high temperatures than do nymphs or adults. High temperatures probably influence distribution or even seasonal abundance (Bae and Pathak, 1970). Low temperatures between 8-15°C are unsuitable for development (Ho and Liu 1969 and Kalode 1974). Regular intermittent rains right from summer months until September led to high humidity and optimal temperature, which resulted in rapid multiplication of rice planthoppers. A range of 70-85 per cent relative humidity was reported to be optimal for BPH development in India (Kulshreshtha *et al* 1974) and the relative humidity to be positively correlated with BPH incidence (Narayanasamy *et al* 1979 and Manoharan and Jayaraj 1979). Meteorological analyses, radar observations, and Mark and recapture field experiments have been conducted (Kisimoto 1976, Rosenberg and Magor 1983, Seino *et al* 1987, Watanabe and Seino 1991, Riley *et al* 1991, Sogawa 1995 and Turner *et al* 1999) and based on those studies, it is now believed that the species migrate for long distances ranging from northern Vietnam to China, Korea and Japan in a few generations.

Biology of the pest, cultural methods, regular monitoring and forecasting are very important steps around which both ecological understanding and integrated management of planthoppers can be done to achieve profitable and stable rice cultivation. Some work on biology of *N. lugens* has been reported by workers in different regions of India (Nalinakumari and Mammen 1975, Khaire and Dumbre 1981 and Zaherudeen and Prakasa Rao 1988). However, no systematic work on the biology, host-range and population abundance of this insect-pest has been done in northern region of the country so these studies were conducted with the following objectives :

1. To study the detailed biological parameters of *N. lugens* on rice
2. To study the host-range and population abundance of *N. lugens*

CHAPTER II

REVIEW OF LITERATURE

2.1 Taxonomy and distribution

Brown planthopper (BPH), *Nilaparvata lugens* was first described as *Delphax lugens* by Stal (1854). This species was transferred to the genus *Nilaparvata* by Muir and Giffard in 1924. In Sri Lanka, BPH was first known under the name *Nilaparvata greeni* Distant (Fernando *et al* 1979). In Taiwan, it was first recorded as *Liburnia oryzae* Matsumura (Fukuda 1934), this was later changed to *Nilaparvata oryzae* Matsumura (Anonymous 1944 and Wang 1957) and then to *Nilaparvata lugens* Stal (Lin 1958, Tao 1966, Ho and Liu 1969, Chou 1969 and Chiu1970).

The distribution of BPH is limited to Asia, Australia and the Pacific Islands. In Asia, it is found in Bangladesh, Brunei, Burma (Myanmar), China, Hong Kong, India, Indonesia, Japan, Cambodia, Korea, Laos, Malaysia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, and Vietnam. In Australia and the Pacific Islands, it is found on the Caroline Islands, Fiji, Mariana Islands, Papua New Guinea and Solomon Islands (CAB 1984) but not found in America and Africa. BPH is mainly a pest of irrigated rice, but can also be abundant in rainfed environments. It is rare in upland rice (Reissig *et al* 1986).

The average size of the eggs was 0.99 mm long and 0.20 mm wide as reported by Misra and Israel (1968). First instar nymphs were 0.97 mm long and 0.37 mm wide. The head was triangular with a narrow vertex, the compound eyes were small and brownish with a black centre and long vertex with demarcation between the thorax. The abdominal segments were not distinct. Legs were light-brown with a movable spur on hind tarsus. The body was creamy white with a pale brown tinge. Second instar nymphs were 1.29 mm long and 0.53 mm wide. The eyes were slightly red. The thoracic area was narrower than the abdomen. The abdomen was uniformly brownish-white and slightly swollen. The legs are brown, the body is oval and brownish-white in colour.

Third instar nymphs were 1.42 mm long and 0.67 mm wide. They were oval and brownish in colour. The eyes were dull red. There was a longitudinal midline from the base of the vertex to the tip of metathorax, wing rudiments became apparent. Fourth instar nymphs were 1.99 mm long and 1.00 mm wide. The compound eyes were bulged and dull-red in colour. The longitudinal midline runs from the base of vertex to the end of metathorax, wing rudiments covered the first two abdominal segments and almost covered the third. The abdomen was swollen with irregular brown patches which were clearly observed from the first to the seventh segments. Fifth instar nymphs were on average 2.69 mm long and 1.25 mm wide. The entire body was dark-brown and robust. The eyes were greyish-blue. The

wing rudiments fully covered the first three abdominal segments. Adult BPH had two wing-forms namely long-winged (macropterous) and short-winged (brachypterous). Macropterous males and females were about 3.9 and 4.6 mm in length, respectively.

2.2 Biological parameter studies

2.2.1 Environmental conditions required for the BPH development

The nymphal period varied widely depending on the food conditions, density during development and other environmental factors as recorded by Suenaga (1963). In the tropics, it took about 10–18 days from hatching until the first instar nymph reached adulthood. The threshold temperatures of embryonic and post-embryonic development were 10.8 and 9.8°C, respectively. Hatchability and survival rate were the highest around 25°C. He also reported that the reproductive capacity of the rice planthoppers was reduced by severe drought and high temperature. The temperature conditions in the nymphal stage also affected the longevity and oviposition of the adult hoppers (Mochida 1964).

The development of BPH was optimum at 25-29°C, but 33°C was detrimental to all life stages in Asia (Bae *et al* 1968). However, this effect was moderated considerably by rearing the insects at 12-hour alternations of 25°C and 33°C or 29°C and 33°C. Bae and Pathak (1970) reported that in most species, egg and nymph developed fastest at 25-30^{o}C and there were 4–5 moults and the nymphal period was 2-3 weeks. BPH hibernated as fifth instar nymph or as egg. The hibernating insects became active when the weather warmed up around March to April, and migrated to the grasses where they bred for one generation before migrating to rice fields shortly after transplanting in June or July.

The pest population increase was positively correlated to sunshine hours as suggested by Alam (1971). However excessive solar radiation was detrimental to population increase (Narayanasamy *et al* 1979). The adult usually lived for 10-20 days in summer and 30-50 days during autumn. Females kept at 20^{o}C have an oviposition period of 21 days which was reduced to 3 days if they were kept at 30^{o}C (Bae and Pathak 1970, Nasu 1967). In the case of BPH the minimum growth of nymphs was at a temperature range of 28 to 30°C in the daytime and at a slightly lower temperature at night. In warm humid climates, planthoppers remained active throughout the year and their population fluctuated according to the availability of host plants, activity of natural enemies, and other prevailing environmental factors. When fifth instar female nymphs were irradiated at 15 to 20 Krad Cobalt 60, egg formation was interrupted (Mochida 1973). Eggs are very sensitive to desiccation and soon shrivelled when the host plant started wilting (Kisimoto 1977).

Results obtained in all the catches made at Annamalainagar (Tamil Nadu), between July and December showed that BPH started appearing in small numbers in the second week

of July when the mean temperature was around 31°C with relative humidity of 88 per cent. During this period there was no rainfall and the sun was out for about 6 -7 hours a day. During the next four weeks time, mean temperature came down to 29°C with gradual reduction in sunshine hours with one or two showers. During the first week of September the catch went upto 48 when the mean temperature was between 27 and 29˚ C and at the same time relative humidity was around 90 per cent. From there on the population went upto a maximum of 2442 during the second week of October when the humidity was around 94 per cent. Throughout the month of October, the population was so high that it continued upto first week of December and from the second week onwards the insect disappeared. At Sathamangalam (Tamil Nadu), the maximum population was noticed during third week of October and throughout this month it was high (Narayanasamy *et al* 1979). According to Nair (1986), the most favourable temperature for the development and survival of nymphs was around 29°C and effective relative humidity was 60-80 or 90 per cent.

Canedo (1980) stated that an insect population always fluctuates according to the dynamic conditions of its environment. Both physical (abiotic) and biotic factors are believed to be the factors responsible for the change in a population. He stated four components that influenced BPH populations, namely extension of irrigation which allowed double cropping of rice, short duration photoperiod intensive rice varieties used, more nitrogenous fertilizers applied and intensive insecticide application. These factors can cause planthopper outbreaks. Severe hopperburn of *kharif* crop occurred during the years when the trap catches were more than 10000/day (Subramanian and Sathianandan 1981). Light traps are useful for catching immigrant insects and forecasting subsequent outbreaks of hopperburn, especially when the immigrant density is high (Hirao 1979). Uthamaswamy (1989) studied the effect of weather factors on light trap catches of BPH on rice during 1975-1985 at Aduthurai. A decrease of mean minimum temperature by 1°C significantly increased the trap catches by 2.59/day. An increase of 1 km/hr of wind velocity decreased the trap catches by 2.38/day. Other factors like maximum mean temperature, relative humidity and rainfall did not have significant effect on trap catches. The population of BPH varied in different months being the maximum in August. Normally its outbreak synchronized with the flowering of crop.

The survival of BPH nymphs at 31.35 and 38.00°C was significantly lower than that at 26°C as founded by Xiaoping and Guorvi (1992). The longer the time after infestation, the higher were the differences in survival at various temperatures. BPH females laid upto 140 eggs after 12 days at 26˚C. Fecundity decreased rapidly as temperature increased. Results indicated that average rice field temperatures of more than 31°C would have obvious inhibitory effects on the survival and fecundity of BPH. Averages of 31°C during mid July to

early August usually caused the highest BPH mortality in subtropical rice areas such as Hangzhou and Xiaoshan, China.

A direct assay method to evaluate high temperature tolerance of BPH populations was used by Domingo and Heong (1992). They found that macropterous females were most tolerant to high temperatures. The relative potency compared with that of the brachypterous females was estimated to be 2.53 ± 0.32. Tolerance of the nymphal stages was also higher than that of the brachypterous females. BPH populations maintained on rice cultivars TN1, Mudgo and ASD7 did not significantly differ in tolerance. High temperature tolerance in the macropterous BPH females was a clear advantage for range shifts. This intrinsic colonization ability, along with the species high fecundity, implies that BPH is extremely adaptable to global warming conditions. Zhu *et al* (1994) reported that under the optimum temperature of 24.2℃, the index of population trend was 295.50. But the index of population trend was 0.56 at 34℃. Brachypterous females and males were the most sensitive to high temperature, under the constant temperature of 40℃, mean life span of adults was only 21.40 to 23 hours. Macropterous females were tolerant to high temperature. However, the adult mortality was lower and the nymphal mortality was higher at low temperature of 16℃.

The effects of different temperatures (27.80-38.00^{o}C) on the duration of nymphal stages, egg laying, pre-oviposition period and longevity of BPH in the laboratory was studied by Dai *et al* (1997). The duration of developmental stages increased above 34^{o}C. The numbers of eggs reduced when fourth instar nymphs were treated with high temperatures and also when adult females were treated with high temperatures at different days, especially one day after the emergence of the brachypterous form and three days after the emergence of the macropterous form. High temperatures shortened the life span. A constant high temperature had little effect on the pre-oviposition period of brachypterous female adults, while the pre-oviposition period macropterous females was prolonged when fourth instar nymphs were reared under constant high temperatures. When treated with changing high temperatures, pre-oviposition periods of both brachypterous and macropterous females were prolonged. Changing high temperatures had greater effects on reproduction than constant high temperatures. Mating of females was more affected by high temperatures than that of males. The critical temperature for development and reproduction was recorded as 34˚C.

A laboratory study on the interactive effects of temperature (20˚C, 23˚C, 26˚C, 29˚C, and 32˚C) and nitrogen fertilization level (0 and 250 kg x hm^{-2}) on the survival, development, and reproduction of BPH was carried out by Zheng *et al* (2009). With increasing temperature from 20˚C to 29˚C, the egg hatchability, nymphal survival, and adult fecundity of BPH increased and the developmental duration of all stages shortened while at 32˚C, it was in

adverse. At all test temperatures, the BPH on rice plants treated with 250 kg N x hm^{-2} had higher egg hatchability, nymphal survival and adult fecundity, and shorter developmental duration of eggs and nymphs, compared with no nitrogen fertilization which suggested that high level nitrogen fertilization enhanced the ecological adaptability of BPH to stress conditions. There were significant interactive effects of temperature and nitrogen fertilizer on the egg hatchability, nymphal duration, and adult fecundity of BPH implying that global warming and long-term high level application of nitrogen fertilizer could be responsible for the outbreaks of BPH in recent years. Win *et al* (2011a) assessed the survival and fertility characteristics of the BPH in the laboratory and field. Life tables and population parameters of the BPH were constructed in an environment with unlimited food supply and that was free of natural enemies. The highest mortality occurred in the immature stage, especially in the first and second instars. Bao *et al* (1999) used a mesoscale dynamic and numerical prediction model - MM4 to analyse the factors which lead to serious infestation on rice in China during the midsummer of 1991. Among these factors air stream, temperature and potential height of the crop played key roles. Conditions were most suitable for migration when the atmosphere was convective.

2.2.2 Egg stage

The distribution pattern for the size of egg groups laid in the leaf blades and sheaths of rice plants as observed by Mochida (1964) was generally very skew, but in rice seedling it was not so skewed. The number of eggs in an egg group deposited in the rice seedlings was smaller than the blades and leaf sheaths. Nasu (1967) reported that BPH lays eggs in small groups inside the air cavities of leaf sheath and mid rib of rice by making an incision with ovipositor and inserting the egg batches inside the tissue. Eggs laid were normally not visible outside but the ovipositional sites were identified as brown patches with the passage of time. According to Misra and Israel (1968), eggs were more or less crescent shaped, and were constricted towards the egg caps which are flat. One end of the egg was united near the egg caps and the other remained free. The egg was whitish in colour when freshly deposited and the egg cap and eyes were not seen but red eye spots developed at the head end which became prominent prior to hatching.

Observations at IRRI showed that the females laid 300-350 eggs, brachypterous females laid more eggs than macropterous females. The eggs were usually cylindrical with their micropyle ends protruding from the leaf tissue. They were whitish when freshly laid, but later turned darker with two distinct spots. The incubation period was 4-8 days (Bae and Pathak 1970). Nalinakumari and Mammen (1975) described that eggs were thrusted within the tissue, generally in the mid region of the outer leaf sheath in the rows of 2 to 12 eggs.

Number of eggs laid by a female ranges from 151 to 305, average being 232.40 eggs. Egg laying period varied from 10 to 28 days. The fecundity of the brachypterous female was 83. The insect prefers to feed on leaf blades and leaf sheaths at the base of plants, where it is shaded and humidity is high. Damage is generally greater in the wet season than in the dry season. Macropterous females migrate into rice fields shortly after transplanting, laying groups of 5-15 eggs into the sheaths or midribs of leaves. During their adult lifespan of 10-30 days, macropterous females produced about 100 eggs, while brachypterous females laid 300 to more than 700 eggs. The eggs hatched in 4-8 days (Anonymous 1975).

The eggs were covered with a dome-shaped egg plug secreted by the accessory glands of the female as reported by Mochida and Okada (1979). Only the tips or minute operculum of eggs protrude from the plant surface. The number of eggs laid at a site varied in different countries. The egg of BPH consists of the chorion, vittelline membrane, protoplasm, nucleus, yolk, and mycetocyte. A pit or depression appears on the posterior pole at 28 to 32 hours after oviposition and then develops into a deep slender tube. The mycetocyte remains situated on top of the vagination as invagination progresses. By the second day, the invagination develops; the movement of the mycetocyte is toward the anterior pole. The third day allows observers to distinguish the head, thoracic, and abdominal parts. By the fourth and early fifth day, the invagination's top and tail are bent. At the same time, the mycetocyte movement is along the egg's ventral side specifically the posterior pole. With the original position of the embryo reversed, the mycetocyte goes back to its original position. At this point, blastokinesis is said to be complete. He also reported that hatching takes place in about 4 to 15 days.

The period of incubation ranged from 6-8 days with an average of 6.50 days during the months of June-October, 11-14 days with an average of 12.60 days during the months of November-January and 6-8 days with an average of 7.60 during the months of February-April (Misra 1980). He also reported that oviposition took place both near the mid rib of leaf sheath and leaf blade. The female mated and incisioned parallel to the mid-rib of leaf sheath and leaf blade and lays eggs like that of WBPH. The eggs touched each other at their anterior ends but they were free on the other end. The egg caps were protruded outside the leaf sheath when approaches towards hatching. A few eggs were also deposited at the point where the blade joins the ligule. The ovipositional sites were detected by the dirty brown colour of leaf sheath. It was observed that during the effective period of oviposition the female laid eggs daily. An average of 26 eggs were laid during the first week after pairing and 100 eggs were laid during the third week after pairing and then declined. A female can lay a maximum of 159 egg masses and minimum of 61. The maximum number of eggs laid was 749 and

minimum of 321. The number of eggs in an egg mass was observed to be the maximum of 11 and the minimum was one. The average number of egg masses laid by female was 124 and the average number of eggs laid was 531. He reported that the females laid an average of 568.4 eggs, which were laid in masses on leaf sheaths or inside stems, and percentage hatch was 78.66.

The BPH females laid 100 to 500 eggs depending on the stage of growth of the rice plant (Van Der Laan 1981). In the greenhouse, each female laid about 100 to 200 eggs. Khaire and Dumbre (1981) carried out laboratory studies in Maharashtra on the bionomics of BPH on rice seedling and reported that egg stage lasted for 10 days. Females laid an average of 568.40 eggs and these were laid in masses on leaf sheath or inside stem and percentage hatch was 78.66 per cent. Zeng *et al* (1989) studied the number of eggs laid by the brachypterous (B-form) and macropterous (M-form) females and their pre-ovipositional period under different environmental conditions. The results showed that there was no significant difference in the number of eggs laid by the two different wing-forms of females under constant temperature within the ranges of 16℃ to 33℃ and ambient temperature varying from 17.4℃ to 27℃. Also, the two wing-forms of females feeding on rice plants in the seedling, tillering and booting stages produced the same level of egg number. Although more eggs laid by B-form on the resistant variety 7105 were observed, there was no significant difference in the number of eggs laid by the two wing-forms on the moderately resistant and susceptible varieties.

One female laid on an average 124 egg masses comprising 2-11 eggs per mass. Eggs hatched within 4-8 days (Panwar 1995). Dupo and Barrion (2009) reported that the egg stage of BPH lasted about 7 to 11 days in the tropics. Brachypterous form began to oviposit earlier than macropterous form. More eggs (60 to 500) were laid as egg-groups by brachypterous females than the macropterous females. In most cases, the eggs were thrust in a straight line, generally on the lower part of the host plant along the mid-region of the leaf sheath, though sometimes eggs were laid in clusters of 4–10 in longitudinal rows within the leaf midribs. The number of eggs laid by female delphacids during their life span varied between 0 and 1,474. The number of eggs laid was correlated to life span and ovipositional period. Win *et al* (2011a) assessed that the highest number of eggs produced per female per day was 9.63. Nair (1986) reported that egg hatched in 4-9 days. He reported that the average number of eggs laid per day were 12.86 and 15.69 respectively. About 2-12 eggs were laid in one bunch and one female laid on an average 232.40 eggs.

2.2.3 Nymph stage

Kisimoto (1957) observed that in BPH, the nymphal period was shorter for the brachypterous form than for the macropterous form in both sexes and, even at high densities, the nymphal period of the brachypterous insect was fairly constant, whereas that of the macropterous insect was lengthened by greater density. The first instar nymphs hatched after 5-9 days. They moulted five times during a period of 2-3 weeks. Initially, most of them developed into brachypterous adults but as population density increases, or if food became scarce, the proportion developing into the macropterous form increased. Nymphs were creamy white with a pale brown tinge, later becoming dark brown. There were four to five moults. The final nymphs were nearly 3 mm long, with a line from the top of the head to the middle part of the body where it is widest (Anonymous 1975).

There were 5 instars before the just hatched nymph turned into adults. The nymphal period ranged from 10-16 days with an average of 13.50 during the month of June-October, 19-34 days with an average of 26.70 days during the month of November–January and 12-33 days with an average of 17.40 during the month of February-April (Misra 1980). Khaire and Dumbre (1981) described that five instars lasted for 2.50, 3.00, 4.50, 5.50 and 4.50 days, respectively. Nair (1986) reported that the nymph undergwent 5 instars during nymphal period of 10-18 days. He also reported that the total life-cycle from egg to adult took 19-23 days for completion.

Dupo and Barrion (2009) reported that after embryonic development, the eggs of planthoppers hatched into first instar nymphs. The shell was normally burst open by the muscular activity of the nymph, which may swallow air or amniotic fluid, and thus increased its volume as the pressure exerted. Planthoppers have five instar nymphs that actively feed on the host plant's phloem sap to become adults. Usually, the newly hatched first instar nymph was cottony white and turns purple-brown within an hour. The five nymphal stadia were distinguished by shapes of the mesonotum, and body size. Both embryonic and postembryonic development were influenced considerably by temperature. The nymphal period of planthoppers varied widely depending on food conditions, density during development, and other environmental factors. For example, BPH in the tropics took about 10 to 18 days from the hatching of the first instar nymph till adult stage.

2.2.4 Adult stage

Wing dimorphism of planthoppers has been studied by different scientists (Kisimoto 1956, Iwanaga *et al* 1985, Morooka *et al* 1988 and Matsumura 1996). Kisimoto (1965) reported the wing dimorphism in BPH as long-winged macropterous and short-winged

brachypterous adults. They reported that wing dimorphism was caused primarily by population density experienced during the nymphal stage. In females, crowding promoted macropterization, while in the males, a moderate nymphal density promoted brachypterization. BPH has an adult lifespan of 10-30 days. Adults are brownish black with a yellowish-brown body. There are two forms, long winged and short winged. In field infestations started with the arrival of the winged form, which then produce wingless types. Winged form develops when numbers are high; females are about 4.00 mm and males 4.50 mm and wingless forms are smaller. After harvest, the planthoppers migrate to grasses, or spread to new crops of rice. BPHs live for up to 20 days (Anonymous 1975).

The abundance of leafhoppers and planthoppers is attributed to high temperature and high humidity as observed by Bae and Pathak (1970). The macropterous forms are adapted to migration and develop with crowding and the shortage of host plants.They reported that the brachypterous forms were generally larger and had longer legs and ovipositors. Their pre-oviposition period was usually shorter than that of the macropterous forms. More brachypterous forms developed at low temperature. In males, short daylength and high temperature increased the percentage of brachypterous forms, but the daylength had no effect on the development of winged female forms. The macropterous forms were somewhat more tolerant to temperature then were the males.

The longevity of males varied from 14 to 21 days with an average of 18.40 days and that of females from 14 to 30 days with an average of 21 days as reported by Nalinakumari and Mammen (1975) and Nair (1986). Misra (1980) submitted that the period of longevity ranged from 30-32 days in male and 46-47 days in female during the month of June-October, 35-37 days in male and 45-47 days in female during the month of November–January and 26-30 days in male and 38-39 days in female during the month of February-April. It was observed that male:female ratio during August-September was 1:1, during November-December it was 1:1.1 and 1:1.2 in January-February. Khaire and Dumbre (1981) reported that adult life span for male and female was 16.50 and 27.00 days, respectively.

The density of BPH population effects the wing form (brachypterous and macropterous) ratio among the immigrant (Iwanaga *et al* 1985). Adult planthoppers lived for 18 to 20 days, while a generation took 3 to 4 weeks. The adult longevity of BPH differed considerably between laboratory and field conditions, the maximum values being 36.60 and 9.00 days, respectively (Dupo and Barrion 2009). Win *et al* (2011a) assessed the survival and fertility characteristics of the BPH in the laboratory and field. Life tables and population parameters of the BPH were constructed in an environment with unlimited food supply and that was free of natural enemies. The highest mortality occurred in the immature stage,

especially in the first and second instars. The life-table analysis showed that the population density of BPH decreased gradually. The survival ratio of male to female was 0.512:0.488. The females lived for a maximum of 20 days.

2.2.5 Pre-oviposition , Oviposition and Post-oviposition period

The pre-oviposition period of *N. lugens* was reported as one day by Nalinakumari and Mammen (1975). Misra (1980) reported that the pre-oviposition period was within one day during the month of June-October, 2-3 days with an average of 2.30 days during the month of November-January and about one day during February-April. He also described that oviposition started from the second day of emergence and extended upto 4.60 days. Misra (1980) reported that the effective oviposition period varied between 38-40 days during the month of June-October, 40-42 days during the month of November-January and 35-37 days during the month of February-April. He observed that females of this species lay eggs upto their death. The abdomens of these dead females were still found very much swollen and when dissected numerous different sized oocytes were present in the ovary. Khaire and Dumbre (1981) reported that the pre-oviposition period was 2 days and post-oviposition periods was 2.6 days. Nair (1986) studied the oviposition periods and found the duration as 18.2 and 13.7 days on an average in Kerala for the macro and brachypterous forms respectively and fecundity was 69-83 eggs per female.

The amount of eggs laid by the brachypterous and macropterous females of the BPH and their pre-ovipositional period were studied under different environmental conditions by Zeng *et al* (1989). The results showed that the pre-ovipositional period of the brachypterous form was distinctly shorter than that of the macropterous form under temperature ranging from 22℃ to 31℃. After emergence the female started egg laying within 3-10 days (Panwar 1995). The pre-oviposition period of planthoppers varied from 3 to 8 days. Brachypterous females have a shorter pre-oviposition period (3 to 4 days) than macropterous females (3 to 10 days) under cool conditions (Dupo and Barrion 2009). Win *et al* (2011a) assessed that the adults mated on the day of emergence and the female started laying eggs from the day next to mating. The trend of oviposition showed a peak at around the tenth day of the female life. The highest number of eggs produced per female per day was 9.63. The intrinsic rate of increase (rm) in egg production per female per day was 0.0677 and the daily finite rate of increase (λ) was 1.0688 females per female per day, with a mean generation time (T) of 34.05 days. The net reproductive rate (Ro) of the population was 10.02. The population doubling time (DT) was 10.42 days.

2.2.6 Life-cycle and number of generations

Nilaparvata lugens passed through five or six generations in the central part of China (Lei and Wang 1958) and five generations on single rice crop in southern Japan (Mochida 1964). Bae *et al* (1968) carried out studies in Korea to investigate the seasonal fluctuations in numbers of BPH by collecting them in light-traps and also to compare 15 different insecticides for their control on rice. It had 4 generations a year, adult numbers reaching peaks in early June, the end of July (the over-all maximum), the end of August and September for *S. furcifera* and in late July, late August (the over-all maximum) and early October.

In the tropics, BPH is active all year round, and produces 3-6 generations per crop. It is not able to overwinter in temperate regions, so it migrates into these areas in the spring, often after traveling long distances (Anonymous 1975). Das *et al* (1972) claimed that 4-5 generations were completed in a cropping season. Two population peaks occurred within one year (Anonymous 1975, Kalode 1974 and Diwakar 1975). Nalinakumari and Mammen (1975) reported that the total life cycle of the hopper from egg to adult was from 19 to 23 days, the average being 21.60 days. Mochida *et al* (1977) studied the total life cycle of planthoppers and it was about 9 to 26 days or 3 to 4 weeks and a new generation may appear monthly. In Java, four to five generations of hoppers developed in one rice crop. They also reported that BPH may have two to eight generations during one rice cropping season in tropical lowlands. Cook and Perfect (1989) have investigated the population characteristics of the BPH, over eight growing seasons on rainfed rice in the Philippines. Three nymphal generation peaks were observed in most seasons. The third peak was not always the largest and peaks varied considerably in size from season to season. Generation peaks were less distinct at a second sampling site within an irrigation system, possibly associated with increased asynchrony of planting and the consequent increased immigration potential. Mortality was highest for eggs and first instar nymphs. Egg to adult survivorship was estimated as 1–12 per cent.

The period for total life-cycle varied from 18-24 days with an average of 21.20 in case of female and 17-20 days with an average of 18.20 in male during the months of June-October, 34-48 days with an average of 41.30 in case of female and 32-45 days with an average of 37.70 days in male during the months of November-January and 14-23 days with an average of 19.70 days in female and 18-35 days with an average of 20.50 in male during the months of February-April in southern parts of India was reported by Panwar (1995).

2.3 Behavioural parameters

2.3.1 Mating behaviour

The pre-mating period of females ranged from 2-5 days in brachypterous form and 3-7 days in macropterous forms as reported by Takeda (1974). Many males became sexually mature within the first day after emergence and most by the second day. There was no apparent difference between the males of different wing forms in the frequency of copulation during the adult life. The male's ability to copulate increased for the first 5 days after emergence and then decreased. Nalinakumari and Mammen (1975) studied life-history of BPH in Kerala and reported that mating commenced from the day of emergence of the adults and it took place generally during night and rarely in the day time.

The female planthoppers initiated copulation by producing abdominal vibrations from a distance of 80 cm. Male BPH can mate with a maximum of nine females for 24 hours and an individual female can copulate more then twice during its life time (Mochida and Okada 1979). Mating of BPH, was investigated by Oh (1979) in relation to oviposition. Females became unreceptive immediately after mating and showed various types of repelling behaviour to courting males. As a result, females usually did not mate repeatedly in quick succession, but after ceasing to lay fertilized eggs they behaved as virgins and mated again before producing more fertilized eggs. Copulation, followed by deposition of fertilized eggs, occurred twice, or in a few cases three times, throughout the adult stage. Copulation lasted about 2 min at the first mating and about 1 min at the second or third mating. When the number of fertilized eggs began to decrease rapidly, oviposition rate also decreased, but it increased again immediately after re-mating. Repeated copulation was also related to the potential rate of population increase.

The adults did not mate immediately after the final moult. The pre-mating period ranged from 1-3 days with an average of 1.50 days during the months of June-October, 2-4 days with an average of 3.10 during November-January and 1-2 days with an average of 1.60 during the months of February-April (Misra 1980). Khaire and Dumbre (1981) carried out laboratory studies in Maharashtra on the bionomics of BPH on rice seedling and reported that mating occurred between 05:30 and 06:30 hr on the leaf sheaths or stems.

2.4 Host-range

Nilaparvata lugens fed and reproduced primarily on rice. Some wild *Oryza* species in Asia also served as field hosts for BPH as reported by Heinrichs and Medrano (1984). Field populations were also collected on the grassy weed *Leersia hexandra*. Claridge *et al* (1985) suggested that the BPH found on rice and that found on *L. hexandra* in the

Philippines represented closely related, but distinct, sympatric species on the basis of differences in acoustic mating signals. A new species name for the *Leersia* strain has not yet been erected, and the terms 'sibling species' and 'populations' (Sezer and Butlin 1998, Hemingway *et al* 1999) have both been used in recent publications to refer to BPH from the two host plants. Van Vreden and Ahmadzabidi (1986) listed the grasses *Arthroxon hisdipus, Digitaria adscendens*, *Echinochloa crusgalli* var. *oryzicola*, *Isachne globosa*, *Leersia japonica* and *Poa annua* as hosts of BPH in Peninsular Malaysia.

Similarly, Zaherudeen and Prakasa Rao (1988) studied the oviposition and hatchability of BPH in some common host plants and weeds. A set of 52 common weeds, from the rice based agro-ecosystem of Orissa, 17 wild species belong to genus *Oryza* and 21 crop plants were studied. Out of 90 plant species tested, 16 weeds and 2 crop plants showed no oviposition whereas others showed oviposition. Kim *et al* (1994) studied the feeding behaviour and survival of 3 delphacids, BPH, WBPH and *Laodelphax striatellus* [L. striatella], on some species of millets. Finger millet (*Eleusine coracana*) and Indian barnyard millet (*Echinochloa frumentacea*) are resistant to BPH and WBPH.

The biodiversity of planthoppers of the family Delphacidae (Fulgoroidea: Hemiptera) associated with graminaceous crops, Rice (*Oryza sativa* L) and Sugarcane (*Saccharam officinarum* L) from five states of South India viz., Andhra Pradesh, Tamilnadu, Karnataka, Maharastra and Kerala was studied by Rao *et al* (2007). About 23 planthoppers species of 17 genera were identified. Among these planthopper, BPH population was dominant in rice ecosystems of Karnataka and Kerala, whereas WBPH population was dominant in Andhra Pradesh, Maharastra and Tamilnadu. These two species were the major pests in all rice growing tracts of South India and the remaining species are not at pest status and may be casual visitors from the weeds of a particular crop ecosystem or from neighbouring crops.

A study at Raipur during 2006-2007 to assess the survival of BPH both nymphs and mature adults on different paddy field weeds, wild rice (*Oryza nivara*) and rice check variety TN1 was carried out by Ponnada *et al* (2010). The study revealed that BPH nymphal and adults survival was zero on all weeds. On wild rice there was prolonged nymphal development, slow growth and low survival as compared to the insects caged on susceptible check variety TN1. BPH is a monophagous insect restricted to cultivated rice and its allied forms like *Oryza perenie* and *Oryza spontanea*. Similar results were reported by Kisimoto (1985) that the BPH is monophagous insect, restricted to cultivated rice and its allied wild forms such as *Oryza perenie* and *Oryza spontanea.*

2.5 Population abundance

The population density of BPH in the rice field increased in September and October, causing damage to rice plants. The seasonal occurrence of the insect was similar to that of WBPH. However in the winter, it hibernated as the egg stage (Takezawa 1961 and Miyake and Fujiwara 1962). Misra (1980) reported that the adults made their first appearance during the last week of August and first week of September. They multiplied in the field when the seedlings were at vegetative stage and reached a peak during October and first week of November and then declined. In the second crop they appeared in the month of January, reach a peak in February and then declined in March. In the year 1974 and in subsequent years, the peak came in April and declined during May.

The seasonal changes in abundance of macropterous BPH and WBPH based on observed numbers of adults and presumptive macroptery in fifth instar nymphs occurring in rice crops in the Philippines were reported by Cook and Perfect (1985). Percentage presumptive macroptery in fifth instar nymphs was correlated with nymphal density over the range of 0–20 nymphs per hill for females of both species and 5–20 nymphs per hill for male BPH. Lunar phase had no effect on wingmorph expression in either species. Comparison of the percentage macroptery in fifth-instar nymphs with subsequent percentage macroptery in BPH adults for one season showed net emigration occurred from 60 days after transplanting to harvest except for a period of net immigration lasting 7–10 days at approximately 95 DAT for both sexes. Wada *et al* (1987) analysed the daily trap catches of the rice planthoppers, BPH and WBPH, and associated synoptic weather patterns in Kyushu, South-west Japan, in the autumns of 1980–85. These results strongly imply overseas immigration of the planthoppers from China to Kyushu in autumn, identical to invasions by the same species in early summer. However, such autumn migration was apparently non-adaptive because migrants or their progenies were soon killed by cold weather.

The population dynamics of BPH at nine study sites in the irrigated coastal lowland of West Java, Indonesia, where rice was cultivated under intensive modern agricultural practices was investigated by Sawada *et al* (1992). The BPH populations were definitely characterized by the low initial immigrants in a year, followed by the subsequent high population growth. In the wet cropping season in particular, populations multiplied about 2000 times in size in the period from initial to second, or peak, generations reaching quite often the destructive level despite their low initial densities. Seasonal changes of the BPH population in paddy fields showed that during the first 4-5 weeks after transplanting, macropterous adults that apparently immigrated from the neighbouring areas were dominant, though some brachypterous adults that probably originated from eggs oviposited in nursery

bed were also observed. After the small peak of the initial immigrants, three distinct peaks were observed at a 3-4 week interval, which correspond to a period of approximately one BPH generation in the tropics. This may suggest that the population peaks imply generation peaks. Macropterous adults may easily disappear from one field to another thereby they may cause overlapping generations in BPH population.

The investigations on field population densities of BPH in the Shinghai area of China in 1977-1991, together with the analysis of ovarian development in adult females were carried out by Huang *et al* (1992). The delphacids in single cropping late rice originated from the south, with immigration usually taking place from the last ten days of June to the first ten days of August, at which time adults developed. The process from immigration and formation of the population to its extinction covered three to four generations. Population dynamics in the field were related to such factors as the number of immigrant insects, temperature, diet and natural enemies. The latter two had a stable influence on the population in years. Temperature and the number of immigrants were the leading factors determining growth and reproduction. The number of brachypterous adults was closely related to the population size, and large number of brachypterous adults preceeded large population increases.

A 40-year light trap record and found three different types of growth pattern for planthoppers like low immigrant density and high population growth rate, low immigrant density and low population growth rate, and high immigrant density and low population growth rate was analyzed by Watanabe *et al* (1994). In the 1980s, immigrant density varied and population growth rates were lower than those in the other decades. After the mid-1990s to early 2000, the immigrant densities of both planthopper species were lower than those in the 1980s (Matsumura 2000). The links between light trap catches of migrant BPH and meteorological variables using data from east central China were analyzed by Crummay and Atkinson (1997). Three case studies revealed that distribution of catch was associated with synoptic-scale fronts and meso-scale atmospheric features, such as heavy precipitation and the sea breeze. Combination of analyses of meteorological and insect catch data, with knowledge of BPH behaviour and concentration and deposition mechanisms in the atmosphere, strongly suggested that meso-scale atmospheric structures influenced the distribution of catch. Jeyrani *et al* (2000) worked out seasonal trends of BPH population level and the interrelationship between light trap catches and field population at Tamil Nadu Rice Research Institute, Aduthurai for three seasons during 1997 – 1998. Correlation studies were made on the light trap catches and field population of BPH using mean weekly catches / counts as variables. Analysis indicated a positive correlation ($r = 0.512$) between field

population and light trap catches. It was also observed that light trap catches were significantly high during September, October 1997 and January 1988.

Srinivasa *et al* (2000) studied the effect of moon phases and some weather factors on the light trap catches of insect pests of rice in three different localities in the state of Karnataka, India. The study indicated that moon light effect was more pronounced than the effect of weather factors in all the species at all the three localities. BPH catches were significantly influenced by both maximum and minimum temperatures at Bangalore. BPH registered more catches around full moon at Bangalore and around new moon at Mandya. Dupo and Barrion (2009) reported that in six cities in India (Aduthurai, Coimbatore, Maruteru, Sambalpur, Kaul, and Pattambi), the trend in BPH catches was of a decreasing nature during 1998 to 2003, while it was increasing from 2003 to 2005. From 2005 to 2007, the BPH population tended to decrease. There were more BPH observed in the 1990s than in the 2000s. The yearly catches decreased by 2.30 per cent in 2006 and 4.50 per cent in 2007. There were only 39,699 BPH trapped in 2007, which was the second lowest sample observed in the past 10 years. Win *et al* (2011b) studied the population fluctuation of BPH in Myanmar for two seasons (rainy and summer). Population fluctuation study revealed that BPH population was high at 64 and 74 days after transplanting (in mid September 2007) associated with heavy rainfall, high temperature and high humidity. The BPH population was lowest (in mid October 2007) suggesting that low rainfall and low humidity were at least partially responsible for the decreased population of BPH. The fluctuation of plant hopper were correlated with temperature and showed higher correlation with rainfall patterns during the first cropping season. Second cropping season coincided with dry season, there was no rainfall and hopper population was observed to be correlated to temperature and relative humidity. Thus temperature, rainfall and relative humidity were observed to influence plant hopper population during the two different rice growing seasons.

CHAPTER III

MATERIALS AND METHODS

The biology of brown planthopper (BPH), *Nilaparvata lugens* (Stal) was studied on rice cultivar PR 114 from 2010 to 2011 under the screen house conditions at Department of Plant Breeding & Genetics, Punjab Agricultural University (PAU), Ludhiana.

A. Material

3.1 Test plants

The seeds of rice cultivar PR 114, wheat, maize, oats, pearl millet and sorghum were obtained from the Department of Plant Breeding and Genetics, PAU, Ludhiana and weed seeds were collected from fields for studying various biological and behavioural parameters, host-range and population abundance studies.

3.2 Screen house and glass house

The glass house (7.8 x 3.30 x 3.40 m) was used for the raising of potted plants of PR 114 to maintain the insect culture of BPH. The experiments were conducted in the insect-proof screen houses fitted with 30 mesh galvanized wire gauge.

3.3 Insect cages

3.3.1 Insect rearing cages

The rectangular cages of steel bar (0.68 x 0.50 x 0.50 m) were used for rearing the BPH. For making cages these frames were covered with nylon netting (40 mesh), stitched along the four sides of the frame with the open bottom and top. The top opening was quite large and nylon netting at the upper end was tied with rope everytime after transferring the test insects in or out of it.

3.3.2 Glass chimneys and Mylar film cages

The glass chimneys, each covered with a piece of muslin were used for studying various biological and behavioural parameters. A small hole in the muslin served the purpose of transferring insects to the test plants under the chimneys, which was plugged with cotton afterwards. For the host-range studies, mylar film cages were used which were about 30 inches long with a 15 x 15 cm windows. The upper end of cage was covered with muslin.

3.4 Earthen pots

The earthen pots (12 cm) were used for raising the test variety and other plant species for studying the biology, behaviour and host-range of the BPH.

3.5 Water trays

The test plants were kept in galvanized iron trays containing water. These not only irrigated the plants but also kept away the ants and other crawling insects.

3.6 Concrete troughs

The concrete troughs (410 x 60 x 15 cm) containing water were used for keeping insect rearing cages and potted plants for studying various biological parameters.

3.7 Aspirators

An aspirator was prepared by joining two pieces of glass tubes (16 x 0.8 cm) with plastic tube (34 x 0.9 cm) and one end of it was fixed with a piece of muslin with the help of a rubber band and the other end was kept free for sucking the insects. The glass tube (0.45 cm in diameter) was used for transferring the nymphs.

3.8 Insect collection hand net

The hand net having a steel ring (37.5 cm in diameter) supporting a collapsible nylon bag (55 cm long) and a handle (75 cm long) was used for collection of planthoppers.

3.9 Thermometers

The maximum and minimum and dry and wet bulb thermometers were used for recording the temperatures and relative humidity in the screen house during the study period.

3.10 Desert cooler

Two desert coolers were used to lower the temperature of the screen house to 29 ± 2˚C in summer months.

3.11 Electric heater

An electric heater was used to raise the temperature in the glass house in the winter for raising test plants and for providing proper environment to the insects.

B. Methods

3.1 Raising of test plants

The plants of rice cultivar PR 114 were used for rearing insect culture and conducting different experiments for biological studies. The test plants were raised in an insect-proof glass house by sowing the seeds in earthen pots containing puddled clay soil. During winter, the germination of the rice seed was obtained by covering earthen pots with polythene sheets and raising the temperature of screen house with an electric heater. The test plants for host-range experiments were raised similarly in earthen pots.

3.2 Raising colonies of test insects and their maintainence

The insects were released on 30-day-old-rice plants under cage. These plants were placed in a concrete trough and covered with insect rearing cage. The plants that died owing to insect feeding in the insect rearing cage were replaced with the potted plants of the same

age. Two such cages of insect culture were maintained throughout the studies to procure sufficient number of insects for conducting the experiments. For obtaining neonate nymphs, newly emerged male and female adults were paired and released on 20-day-old-potted plants under the glass chimney for oviposition up to the emergence of the nymphs. The fifth instar nymphs were released on potted plants covered with chimneys. The adults encountered on the next days were considered as the newly emerged ones.

3.3 Biological parameters

3.3.1 Pre-oviposition, oviposition and post-oviposition period

One pair of newly emerged adults (male and female) was released each on ten potted plants of 20-day-old-rice plants of PR 114 under glass chimneys. The pairs were serial transferred daily to new rice plants under glass chimneys until the death of female. Pre-oviposition period was considered from day of emergence of female to the day when it started laying eggs. The number of days for which egg laying continue was taken as oviposition period. The post-oviposition period was observed as number of days between the last day of oviposition till the death of female.

3.3.2 Fecundity-cum-fertility and adult longevity

The observations on this aspect were taken from the material of the previous experiment and the same methodology was followed. The potted rice plants were kept under observation daily for the emergence of the nymphs and survival of the adults. The nymphs from each pair were counted and removed daily at the time of observation. The total number of nymphs emerged from one pair represented the fecundity-cum-fertility of the female. The longevity was taken as the period from the adult emergence till the death of the adults (both males and females, separately).

3.3.3 Incubation period

Incubation period was studied by releasing ten gravid females picked up from insect rearing colony. These females were released singly on each of 10 rice plants of PR 114 under glass chimneys for oviposition. Serial transfers of these females were made daily for 5 consecutive days. The time between the release of the female and appearance of the nymphs was considered as incubation period.

3.3.4 Nymphal development and survival

Nymphs were observed daily to note the change of instar and the exuviae was removed with wet camel hair brush. This process was done till adult emergence. The interval between two moultings was taken as duration of the nymphal instar and the period between the time of release of a freshly hatched nymph and the adult emergence was taken as the total

nymphal period. The survival percentage was calculated from the number of adults developed from the number of nymphs released.

3.3.5 Sex ratio and wing type

The sex ratio and wing type was studied from the field collected population and the adults emerged from nymphal development studies on the basis of difference in colour, size and presence of ovipositor in case of female and difference in wing size in case of macropterous and brachypterous forms (Plate 1 and Plate 2).

3.3.6 Number of generations

Number of generations per year was computed by releasing ten pairs of freshly emerged adults on rice plant under split cage for egg laying and further development. The adults after the emergence of the nymphs of first generation were removed and released in another split cage for development of next generation. The time taken from one adult to the formation of another adult from its progeny was considered as one generation. This process was continued for whole of the year.

3.4 Behavioural studies

3.4.1 Time of oviposition

The time of oviposition i.e. diel oviposition activity was determined by confining ten gravid females on rice plant under the glass chimneys and serial transfer of these females to new rice plants were made at 4 hour interval for 24 hours. The nymphs emerged on different plants were counted and removed daily until the emergence stopped.

3.4.2 Site of oviposition

The site of oviposition was determined both by dissecting various parts of rice plants, under stereoscopic binocular microscope, with the help of fine needles and by taking visual observations on the emergence of the nymphs as well as by using staining technique (Gifford and Trahan 1969). In staining technique after completion of emergence of the nymphs, the rice seedlings were cut from their base just above the soil, blanched in boiling water for 5 min and placed in 95 per cent ethyl alcohol for 2 days. Thereafter these seedlings were taken out of the alcohol, washed under tap water, and placed in the stain (composed of 1 part each of phenol, lactic acid, and distilled water plus two parts of glycerine with enough fuchsin acid) for 24 hours to allow adequate colouring of the eggs. Finally, the stained seedlings were washed under tap water to remove excess stain and were placed in 3 per cent KOH solution for clearing/destaining the plant tissues. After the clearing was complete, the seedlings were washed under tap water and observed under stereoscopic binocular

microscope. The egg shells/unhatched eggs were easily seen through the plant tissues as dark red objects. The seedlings were then placed in a 2 per cent solution of acetic acid for storage.

3.4.3 Mating behaviour

One pair of newly emerged adults was released on 20-day old rice plant under glass chimney. Experiment was repeated five times. The duration of mating was recorded using a stop watch.

3.4.4 Polygamous behaviour

Polygamous behaviour was studied by releasing freshly emerged one male and ten females on 20 days old plants of PR 114 under glass chimneys. Females were transferred singly after 5^{th} day of release on 20-day-old-plant of PR 114 to observe nymphal emergence.

3.5 Population abundance

BPH population was observed from different crops and weeds at weekly interval by using sweep net. The BPH population was also recorded with light trap throughout the year.

3.6 Host-range studies

Thirty-day-old-plants of gramineae family i.e. *Triticum aestivum* (wheat), *Zea mays* (maize), *Sorghum vulgare* (sorghum), *Pennisetum typhoides* (pearl millet) and *Avena sativa* (oats) and different weeds like *Echinochloa crusgalli* (swank), *Digitaria sanguinalis* (takri ghas), *Eragrostis tenella and E. pilosa* (love grass), *Sorghum halepense* (baru), *Lolium temulentum* (kanki), *Eleusine indica* (makra), *Cyperus difformis* (rice motha), *Cynodon dactylon* (khabbal gha), and *Cyperus rotundus* (motha) were raised in pots in screen house. Experiment was replicated thrice. Two pairs of adults were released in potted plants of each of test species.

3.7 Temperature and relative humidity records

The dry and wet, maximum and minimum temperatures were recorded daily at any time between 8 to 8.30 a.m. The thermometers were installed in the screen houses where the present studies were undertaken.

3.8 Statistical analysis of data

The means and standard deviations of different biological parameters were calculated as follows:

$$\text{Mean } \left(\overline{X}\right) = \frac{\sum X}{N}$$

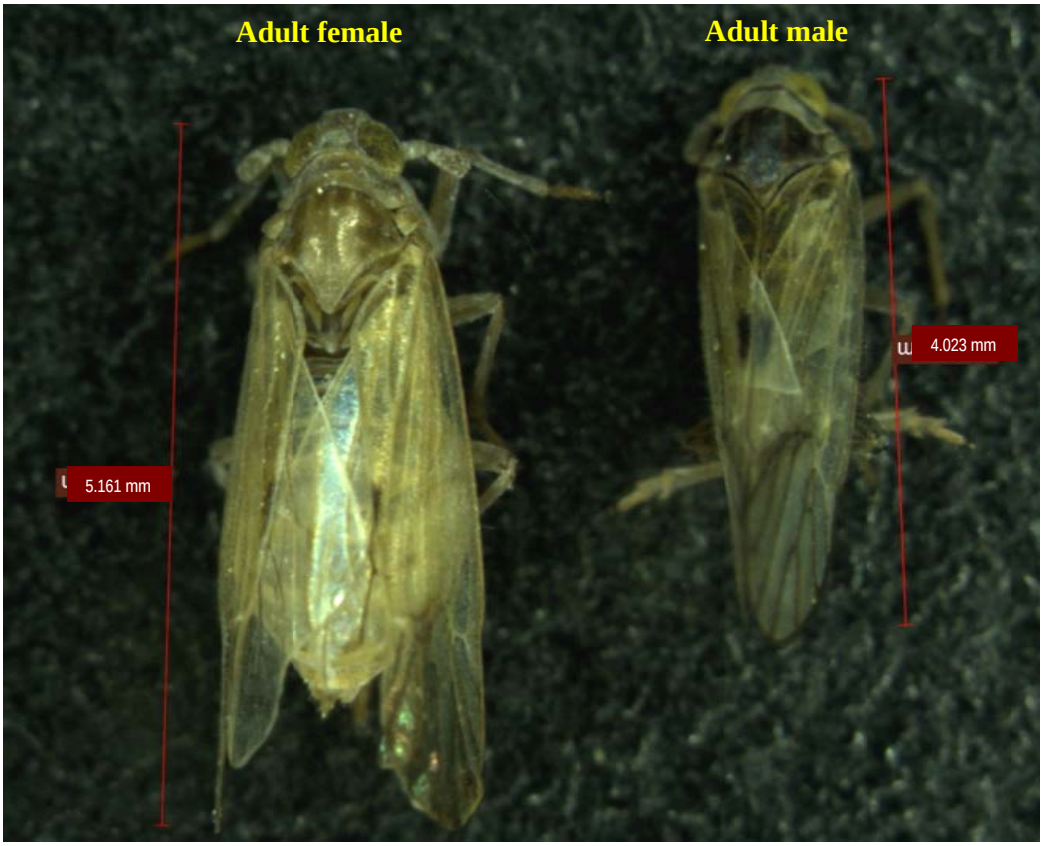

Plate 1. Adult stages of *N. lugens*

Plate 2. Brachypterous and Macropterous female of *N. lugens*

$$\text{Standard deviation (SD)} = \sqrt{\frac{\sum\left(X - \overline{X}\right)^2}{\left(N - 1\right)}}$$

Where,

ΣX = Sum of the observations

X = Mean of observations

N = Total number of observations

Data on host-range studies were statistically analyzed with analysis of variance (ANOVA). The different means were separated by critical difference (CD) at $p = 0.05$ (Gomez and Gomez 1984).

CHAPTER IV

RESULTS AND DISCUSSION

The biology of Brown Planthopper (BPH), *Nilaparvata lugens* (Stal) was studied on rice variety PR114 under the screen house condition at Department of Plant Breeding & Genetics, PAU, Ludhiana during the *kharif* season of 2010 and 2011. The results related to various biological parameters, behavioural studies, host range and population abundance are presented and discussed in various sections of this chapter as follows:

4.1 Biological parameters

4.1.1 Pre-oviposition, Oviposition and Post-oviposition period

The observations regarding the pre-oviposition, oviposition and post-oviposition period of *N. lugens* were made during the three different periods of year 2010. There was significant difference in pre-oviposition period during different periods of study in 2010. The pre-oviposition period was minimum i.e. 1-3 days with a mean value of 1.70 ± 0.67 days during May 22 - June 20; 1-3 days with a mean value of 2.20 ± 0.63 days during July 15 - August 11 and was maximum during September 4 - 30, 2010 i.e. 2-4 days with a mean value of 2.70 ± 0.67 days (Table 1). The pre-oviposition during May 22 – June 20 and July 15 – August 11and July 15 – August 11 and September 4-30 were at par with each other. The pre-oviposition period during May 22 – June 20 and September 4-30 differed significantly. It is evident from the studies that there is increase in pre-oviposition period with decrease in temperature i.e. 1.70 ± 0.67 days at 30.01 ± 3.65^{o}C to 2.70 ± 0.67 days at 26.82 ± 1.72 ˚C. The results of study substantiate the earlier findings of Nalinakumari and Mammen (1975) and Khaire and Dumbre (1981) who described *N. lugens* pre-oviposition period as 1-2 days. Mochida and Okada (1979) also reported an increase in preoviposition period in case of macropterous females when temperature declined in range between 33˚C and 20˚C. They also reported that the pre-oviposition period ranged from 3- 4 days for brachypterous females and 3-10 days for macropterous females at constant temperatures of 20 and 33˚C. The results of present findings are also supported by the findings of Misra (1980) who has reported similar trend of increase in pre-oviposition period with decrease in temperature as one day during the month of June - October to 2-3 days with an average of 2.30 days during the month of November - January and about one day during the month of February - April.

The difference in oviposition period among different periods of study was significant during 2010. The data presented showed that there was decrease in oviposition period with decrease in temperature (Table 1). The oviposition period was minimum 12-16 days with a mean value of 14.10 ± 1.45 days during September 4-30, 2010; 15-20 days with a mean value of 17.20 ± 1.55 days during July 15 - August 11, 2010 and was maximum during May 22- June 20 i.e. 17-25 days with a mean value of 21.00 ± 2.62 days. There was decrease in oviposition with a decrease in temperature from 30.01 ± 3.65^{o}C to 26.82 ± 1.72^{o}C and

Table 1. Pre-oviposition, oviposition, post-oviposition period, adult longevity and fecundity-cum-fertility of *N. lugens* during different periods in 2010

Period of study	Duration of different periods (days) (Mean ± SD)			Longevity (days) (Mean ± SD)		Fecundity cum fertility (Mean ± SD)	Temp.(˚C) (Mean ± SD)	RH (%) (Mean ± SD)
	Pre-oviposition	Oviposition	Post-oviposition	Males	Females			
May 22 - June 20	1.70 ± 0.67 (1 - 3)	21.00 ± 2.62 (17 - 25)	2.30 ± 0.67 (1 - 3)	21.50 ± 2.88 (17 - 26)	25.00 ± 3.33 (19 - 30)	136.70 ± 20.69 (93 - 168) (11.70)*	30.01 ± 3.65	74.80 ± 7.92
July 15 - August 11	2.20 ± 0.63 (1 - 3)	17.20 ± 1.55 (15 - 20)	4.80 ± 1.23 (3 - 7)	18.20 ± 2.25 (15 - 21)	24.20 ± 1.99 (21 - 28)	107.30 ± 13.74 (84 - 126) (10.39)*	28.98 ± 1.80	86.32 ± 7.09
September 4 - September 30	2.70 ± 0.67 (2 - 4)	14.10 ± 1.45 (12 - 16)	6.70 ± 1.57 (5 - 9)	17.40 ± 2.46 (14 - 22)	23.50 ± 2.17 (20 - 27)	98.40 ± 12.10 (76 - 115) (9.95)*	26.82 ± 1.72	82.00 ± 7.97
CD (p = 0.05)	0.56	1.79	1.11	2.33	NS	0.68	-	-

Figures in parentheses denote the range

*Figures in parentheses are square root transformed values

increase in relative humidity. The results are comparable to that of Nair (1986) who reported similar results about the average oviposition periods as 18.20 and 13.70 days in Kerala for the macro and brachypterous forms, respectively. However, Misra (1980) who reported that the effective oviposition period ranges from 38-40 days during the month of June - October, 40-42 days during the month of November - January and 35-37 days during the month of February – April.

There was significant difference between the post-oviposition period during the different periods of study in 2010. The post-oviposition period was significantly higher during May 22 - June 20 and significantly lower during September 4 – 30. There was increase in post-oviposition period from 2.30 ± 0.67 days to 6.70 ± 1.57 days with decrease in temperature from 30.01 ± 3.65°C to 26.82 ± 1.72°C. It was found that during May 22 - June 20 the post-oviposition period ranged from 1-3 days with a mean value of 2.30 ± 0.67 days and 3-7 days with a mean value of 4.80 ± 1.23 days during July 15 - August 11. The duration was found maximum during September 4-30, 2010 i.e. 5-9 days with a mean value of 6.70 ± 1.57 days. Misra (1980) has reported that females lay eggs upto their death. However, Khaire and Dumbre (1981) observed that post-oviposition period was 2.60 days.

4.1.2 Fecundity-cum-fertility

The fecundity-cum-fertility differed significantly during the different periods of study in 2010. The fecundity-cum-fertility was found to be 93-168 nymphs with a mean value of 136.70 ± 20.69 nymphs during May 22 - June 20; 84-126 nymphs with a mean value of 107.30 ± 13.74 during July 15 - August 11 and 76-115 nymphs with a mean value of 98.40 ± 12.10 nymphs during September 4 - 30. The fecundity-cum-fertility was observed significantly higher during May 22 - June 20. There was decrease in fecundity-cum-fertility from 136.70 ± 20.69 nymphs to 98.40 ± 12.10 nymphs as the temperature decreased from 30.01± 3.65°C during May 22 - June 20 to 26.82 ± 1.72°C during September 4-30 (Table 1). Similar results have been reported by Nalinakumari and Mammen (1975) who observed that the fecundity of the brachypterous female was 83. During their adult lifespan of 10-30 days, macropterous females produce about 100 eggs (Anonymous 1975). The results are comparable to Misra (1980) who has reported that an average of 26 eggs are laid during the first week after pairing and about 100 eggs are laid during the third week after pairing and then it declines. According to a study conducted by Bae and Pathak (1970), eggs were laid in masses ranging from 1 to 27 eggs per egg mass and the average number of eggs laid by a

female was recorded as 244.20. At 20˚C that average number of eggs declined to 86.80 and at 33˚C no oviposition occurred.

4.1.3 Adult longevity

There was significant difference in adult longevity during the different periods of study. During the three different periods of year 2010, longevity of adults was found to be more during May 22 - June 20 and minimum during month of September (Table 1). The longevity of males was found to be less than females. It was found that the longevity of males was 17-26 days with a mean value of 21.50 ± 2.88 days and that of females was 19-30 days with a mean value of 25.00 ± 3.33 days during May 22 - June 20. During July 15 - August 11, the longevity of males was 15-21 days with a mean value of 18.20 ± 2.25 days and that of females was 21-28 days with a mean value of 24.20 ± 1.99 days. Statistically there was no significant difference of female longevity of *N. lugens* during the three different periods of study whereas in case of males, significantly higher longevity was observed during May 22 - June 20 and longevity during the other two periods of study were at par with each other. The duration of adult longevity was 14-22 days with a mean value of 17.40 ± 2.46 days and 20-27 days with a mean value of 23.50 ± 2.17 days for males and females, respectively during September 4-30, 2010 (Table 1). There was decrease in adult longevity in case of both males and females with decrease in temperature from 30.01 ± 3.65^{o}C to 26.82 ± 1.72˚C (Table 1). Suenaga (1963) studied the temperature range for normal behaviour of *N. lugens* and observed that a range of 9 to 30˚C and 10 to 32˚C was suitable for macropterous male and macropterous female, respectively. The present studies are in conformation to the study conducted by Nalinakumari and Mammen (1975) who described that the longevity of males varied from 14 to 21 days with an average of 18.40 days and that of females from 14 to 30 days with an average of 21 days. Khaire and Dumbre (1981) reported that adult life span for male and female was 16.50 and 27.00 days. The range varied from 10-30 days.

The period of longevity ranged from 30-32, 35-37 and 26-30 days in males and 46-47, 45-47 and 38-39 days in females during the months of June-October, November - January and February – April, respectively (Misra 1980). Adult planthoppers live for 18 to 20 days, while a generation takes 3 to 4 weeks. The adult longevity of BPH differs considerably between laboratory and field conditions, the maximum values being 36.60 and 9.00 days, respectively (Dupo and Barrion 2009). However according to study conducted by Win *et al* (2011a), the females lived for a maximum of 20 days. According to a study conducted by Bae and Pathak (1970), both male and female planthoppers had the longest life spans at 25˚C, females living longer than males. At 25˚C the longevity for males and females was recorded as 11.6 and 18.6 days, respectively.

4.1.4 Incubation period

The incubation period differed significantly during the different periods of study in 2010. The incubation period of BPH increased as the temperature reduced from 30.01 ± 3.65 to 26.82 ± 1.72˚C (Table 2). The incubation period was significantly lower during May 22 – June 20. During May 22 - June 20 the duration of egg stage was 4-7 days with a mean value of 5.13 ± 0.83 days and it increased to 5-8 days with a mean value of 6.67 ± 0.98 days during July 15 - August 11 when the mean temperature was 28.98 ± 1.80˚C (Table 2). The duration further increased to 5-9 days with a mean value of 7.40 ± 0.99 days during the month of September when the mean temperature decreased to 26.82 ± 1.72˚C. Results are in accordance to that reported by Dupo and Barrion (2009) who observed the egg stage of BPH of about 7 to 11 days in the tropics. Khaire and Dumbre (1981) carried out laboratory studies in Maharashtra on the bionomics of BPH on rice seedling and reported that egg stage lasted for 10 days. The incubation period was 4-8 days (Bae and Pathak 1970). However, Mochida and Okada (1979) have reported an incubation period of 7.9 and 8.5 days at constant temperatures of 28˚C and 29˚C, respectively.

Incubation period of BPH varied from 4-9 days as reported by different scientists (Nair 1986 and Panwar 1995). Similar increase in length of incubation period with decrease in temperature was observed by Misra (1980). He reported that the period of incubation ranges from 6-8 days with an average of 6.50 days during the months of June-October, 11-14 days with an average of 12.60 days during the month of November - January and 6-8 days with an average of 7.60 during the month of February - April. Bae and Pathak (1970) reported that more than 90 per cent of eggs incubated at 25˚C or 29˚C, or their combinations, hatched in an average period of 7 days, but no eggs hatched when incubated at 33˚C. Exposure to 33˚C, even in combination with 25˚C or 29˚C , reduced hatching significantly and increased the incubation period. Mochida and Dyck (1977) reported that the period of egg stage varied according to temperature i.e., about 24, 15, 7 and 7 days at constant temperatures of 17.5, 20, 25 and 30˚C, respectively.

4.1.5 Nymphal development and survival

The difference in nymphal instars period among different periods of study was significant except second, fourth and fifth instar (Table 2). The nymphal duration was 1-3 days with a mean value of 2.00 ± 0.38 days, 2-4 days with a mean value of 3.07 ± 0.46 days, 3-5 days with a mean value of 4.00 ± 0.65 days, 3-5 days with a mean value of 4.33 ± 0.62 days, and 3-5 days with a mean value of 4.00 ± 0.38 days for first, second, third, fourth

Table 2. Incubation period and nymphal period of *N. lugens* during different periods in 2010

Period of study	Incubation period (days) (Mean ± SD)	Duration of different nymphal instars (days) (Mean ± SD)						Temp. (˚C) (Mean ± SD)	RH (%) (Mean ± SD)
		First	Second	Third	Fourth	Fifth	Total		
May 22 - June 20	5.13 ± 0.83 (4 - 7)	2.00 ± 0.38 (1 - 3)	3.07 ± 0.46 (2 - 4)	4.00 ± 0.65 (3 - 5)	4.33 ± 0.62 (3 - 5)	4.00 ± 0.38 (3 - 5)	17.40 ± 1.45 (13 - 19)	30.01 ± 3.65	74.80 ± 7.92
July 15 - August 11	6.67 ± 0.98 (5 - 8)	2.13 ± 0.52 (1 - 3)	3.13 ± 0.64 (2 - 4)	4.40 ± 0.51 (4 - 5)	4.60 ± 0.51 (4 - 5)	4.33 ± 0.49 (4 - 5)	18.60 ± 1.19 (16 - 21)	28.98 ± 1.80	86.32 ± 7.09
September 4 - September 30	7.40 ± 0.99 (5 - 9)	2.60 ± 0.51 (2 - 3)	3.20 ± 0.41 (3 - 4)	4.87 ± 0.83 (4 - 6)	4.67 ± 0.49 (4 - 5)	4.13 ± 0.83 (3 - 5)	22.73 ± 1.39 (21 - 25)	26.82 ± 1.72	82.00 ± 7.97
CD(p = 0.05)	0.69	0.33	NS	0.50	NS	NS	1.00		

Figures in parentheses denote the range

and fifth instar, respectively during May 22 - June 20, 2010 period of study (Table 2). When the temperature decreased to 28.98 ± 1.80˚C during July 15 - August 11, the nymphal duration of various instars increased i.e. 1-3 days with a mean value of 2.13 ± 0.52 days, 2-4 days with a mean value of 3.13 ± 0.64 days, 4-5 days with a mean value of 4.40 ± 0.51 days, 4-5 days with a mean value of 4.60 ± 0.51 days and 4-5 days with a mean value of 4.33 ± 0.49 days for first, second, third, fourth and fifth instar respectively. During the study period in the month of September 4-30, 2010 the duration of each instar was found maximum as compared to other two study periods i.e. 2-3 days with a mean value of 2.60 ± 0.51 days, 3-4 days with a mean value of 3.20 ± 0.41 days, 4-6 days with a mean value of 4.87 ± 0.83 days, 4-5 days with a mean value of 4.67 ± 0.49 days and 3-5 days with a mean value of 4.13 ± 0.83 days for first, second, third, fourth and fifth nymphal instar, respectively. There was difference in size of five nymphal instars (Plate 3).

The present results are supported by the findings of Khaire and Dumbre (1981) who described that five nymphal instars lasted for 2.50, 3.00, 4.50, 5.50 and 4.50 days. Similarly Misra (1980) also reported that there were 5 instars before the just hatched nymph turned into adult. The nymphal period ranged from 10-16 days with a mean value of 13.50 during the month of June - October, 19-34 days with a mean value of 26.70 days during the month of November - January and 12-33 days with a mean value of 17.40 during the month of February-April. BPH in the tropics took about 10 to 18 days from the hatching of the first instar nymph till adult stage (Dupo and Barrion 2009). According to Mochida and Dyck (1977), the period required for the completion of postembryonic development changed according to temperature i.e., 18, 13, 11 and 17 days at constant temperatures of 20, 25, 28 and 32˚C, respectively whereas Mochida and Okada (1979) reported a period of 17 and 18.2 days for the development of nymphs at constant temperatures of 33 and 35˚C, respectively. Suenaga (1963) observed that the fourth and fifth instar nymphs were normally active between 12 and 31˚C.

The difference in total nymphal period among different periods of study was significant. The total nymphal duration was longest during September 4-30 and was shortest during May 22 – June 20, period of study. With decrease in temperature the total nymphal period increased. The total nymphal period was 13-19 days with a mean value of 17.40 ± 1.45 days, 16-21 days with a mean value of 18.60 ± 1.19 days and 21-25 days with a mean value of 22.73 ± 1.39 days during May 22 - June 20, July 15 - August 11 and September 4-30, respectively. According to a study conducted by Bae and Pathak (1970), there was no apparent difference in rate of growth of nymphs when reared at 25˚C or 29˚C or their combinations. At these temperatures about 90 per cent of nymphs reached the adult stage in an average period of 2 weeks, but at 33˚C no nymphs survived beyond second instar. The

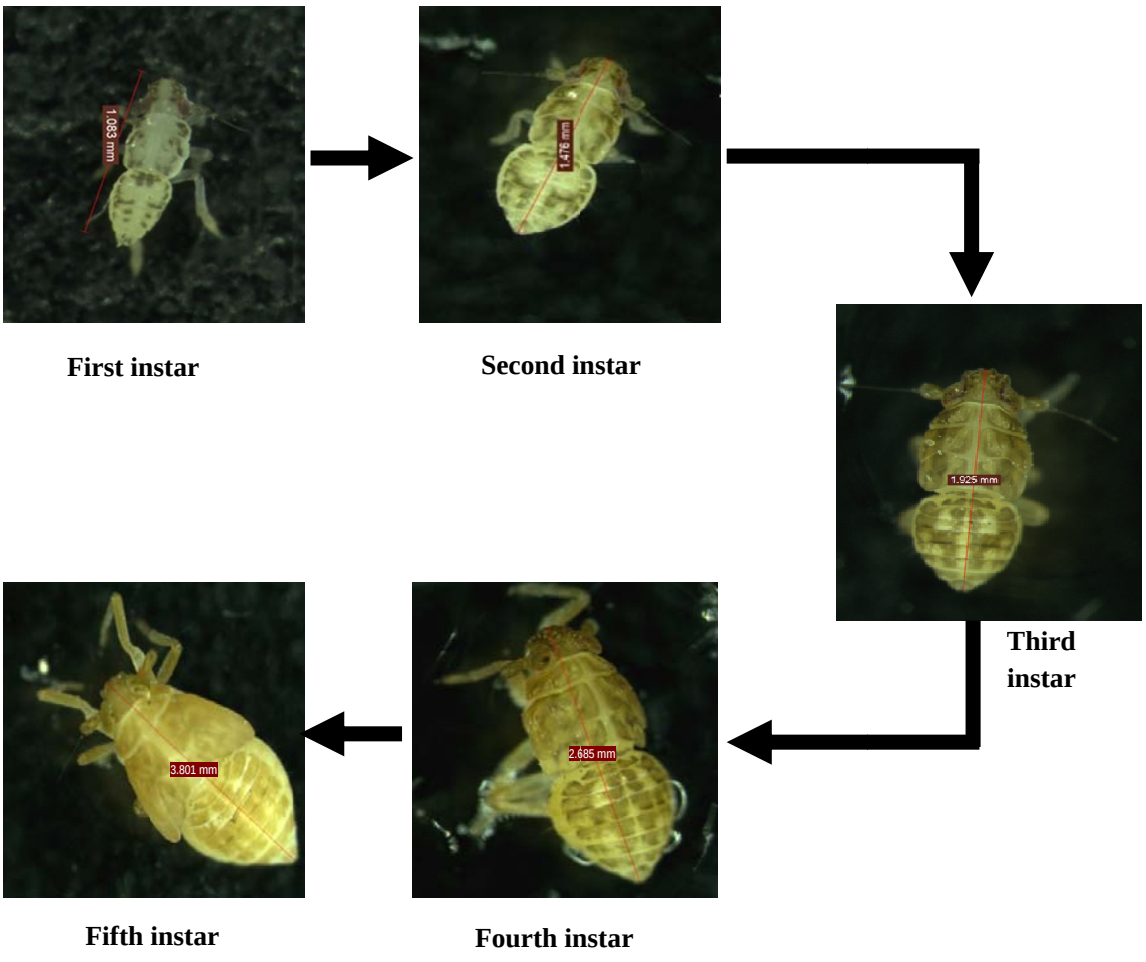

Plate 3. Different instars of *N. lugens*

nymphal period was prolonged when insects were subjected to alternating temperatures of 25˚C and 33˚C or 29˚C and 33˚C. Their survival was also greatly reduced at these temperature combinations.

The survival percentage of nymphs was found to be maximum during May 22 - June 20 i.e. 94.16 per cent and it decreased with decrease in temperature i.e. 88.46 per cent and 85.53 per cent during July 15 - August 11 and September 4-30, 2010 respectively (Table 3). Win *et al* (2011a) observed that the survival ratio of male to female was 0.512:0.488. Cook and Perfect (1989) have reported that mortality was highest for eggs and first instar nymphs while, egg to adult survivorship was estimated as 1-12 per cent.

Table 3. Survival percentage of *N. lugens* during different periods in 2010

Period of study	Number of nymphs released	Number of adults developed	Nymphal survival (%)	Temp.(˚C) (Mean ± SD)	RH (%) (Mean ± SD)
May 22 - June 20	137	129	94.16	30.01 ± 3.65	74.80 ± 7.92
July 15 - August 11	104	92	88.46	28.98 ± 1.80	86.32 ± 7.09
September 4 - September 30	76	65	85.53	26.82 ± 1.72	82.00 ± 7.97

4.1.6 Sex ratio and Wing type

Sex ratio and wing type ratio in case of *N. lugens* adults were calculated from field collected populations and adults emerged from nymphal development studies. The differentiation between two sexes were made on the basis of their colour, size difference and presence of ovipositor in case of female (Plate 2). In case of field collected population sex ratio (Male : Female) was observed as 1:2.05, 1:1.50, 1:1.18 during July 11 - August 8, 2010; August 15 - September 12, 2010 and September 19 -October 17, 2010 respectively (Table 4). Similar trend in sex ratio was observed in case of laboratory population of nymphal development studies. The ratio was found to be 1:2.07, 1:1.42 and 1:1.09 during May 22 - June 20, 2010; July 15 - August 11, 2010 and September 4 - 30, 2010 respectively. Females usually outnumbered males in all the three periods of study in both field collected and adult emerged from nymphal development studies. There were two wing forms of *N. lugens* i.e., macropterous form and brachypterous form. Macropterous form in more numbers with decrease in temperature was observed as 1.10:1, 1.35:1 and 1.85:1 during July 11 - August 8, 2010, August 15 - September 12, 2010 and September 19 - October 17, 2010 respectively in case of field collected population whereas, more brachypterous form of adults were observed from nymphal development studies in laboratory with decrease in temperature as 1:1.87, 1:1.30 and 1:1.17 during May 22 - June 20, July 15 - August 11 and September 4 -

October 17, respectively (Table 4). Misra (1980) reported that female : male ratio during August-September is 1:1, during November - December 1.1:1 and January-February 1.2 : 1. Win *et al* (2011a) assessed that the survival ratio of male to female was 0.512:0.488.

Table 4. Sex ratio and Wing type of *N. lugens* during different periods in 2010

Period of study	Sex ratio M : F	Wing type* M : B	Temp. (˚C) (Mean ± SD)	RH (%) (Mean ± SD)
Field collected population				
July 11- August 8	1 : 2.05	1.10 : 1	29.89 ± 2.01	81.25 ±7.77
August 15 - September 12	1 : 1.50	1.35 : 1	28.97 ± 1.56	84.31 ± 6.19
September 19 - October 17	1 : 1.18	1.85 : 1	26.55 ± 1.11	75.84 ± 7.30
Population from Nymphal development studies in laboratory				
May 22 - June 20	1 : 2.07	1 : 1.87	30.01 ± 3.65	74.80 ± 7.92
July 15 - August 11	1 : 1.42	1 : 1.30	28.98 ± 1.80	86.32 ± 7.09
September 4 - September 30	1 : 1.09	1 : 1.17	26.82 ± 1.72	82.00 ± 7.97

M = Male, F = Female, *M = Macropterous, B = Brachypterous

4.1.7 Number of generations

The BPH passed through 8 overlapping generations during the period of study from June 12, 2010 to July 4, 2011. The time taken to complete one generation ranged from 23 days (June 12 - August 3, 2010) to 106 days (November 16, 2010 - March 1, 2011) (Table 5). The duration of generation was prolonged during the winter months of study (Fig.1).

In the tropics, BPH is active all year round, and produces 3-6 generations per crop. It is not able to overwinter in temperate regions, so it migrates into these areas in the spring, often after travelling long distances (Anonymous 1975). Das *et al* (1972) claimed that 4- 5 generations were completed in a cropping season. Two population peaks occurred within one year (Anonymous 1975, Kalode 1974, Diwakar 1975). In Java, four to five generations of hoppers may develop in one rice crop. Mochida *et al* (1977) reported that BPH may have two to eight generations during one rice cropping season in tropical lowlands. In fact, BPH has five generations on a single rice crop in southern Japan (Mochida 1964), five or six generations in the central part of China (Lei and Wang 1958), and four or five generations in Java (Mochida *et al* 1977).

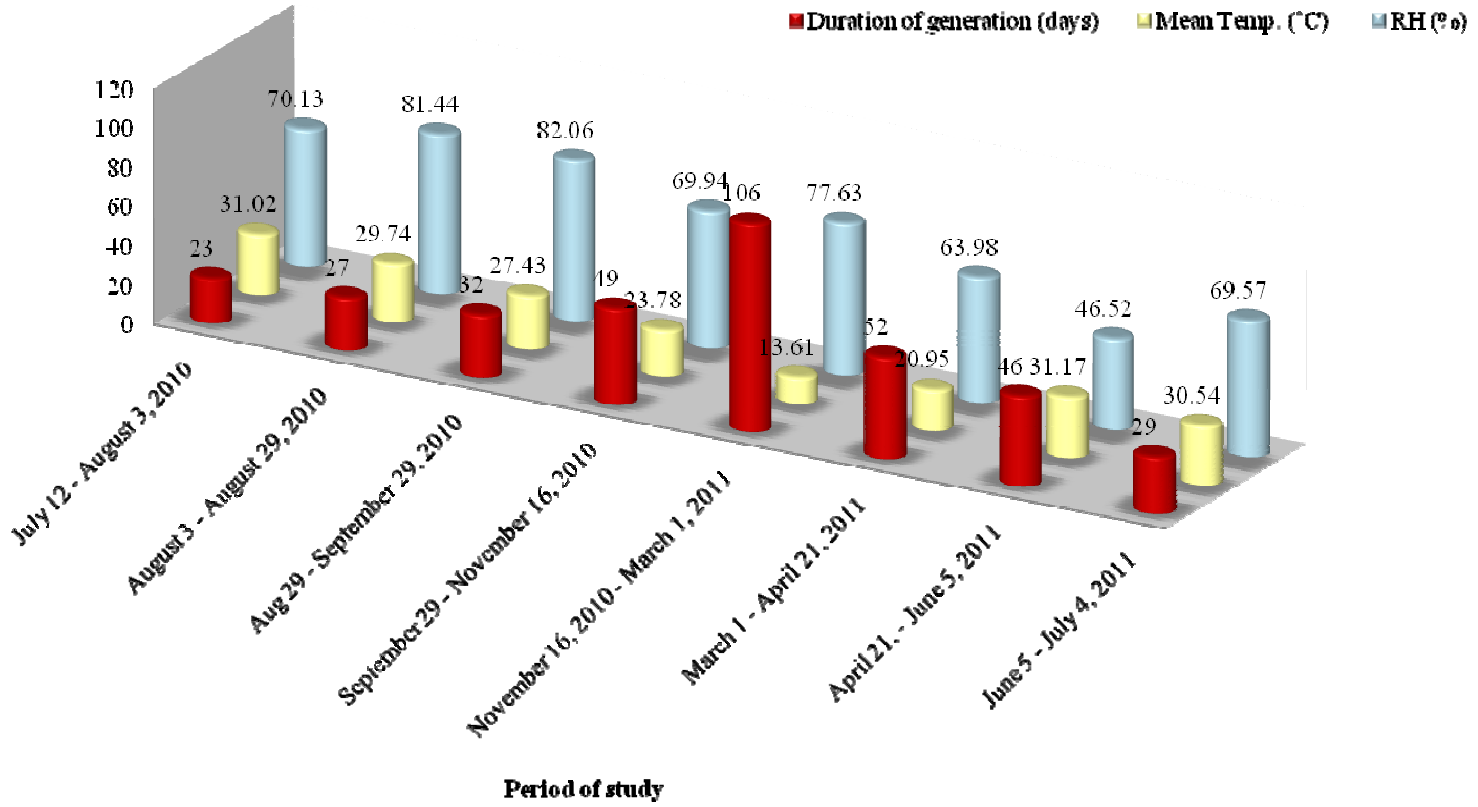

Fig. 1. Number of generations of *N. lugens* in screen house during 2010-2011

Table 5. Number of generations of *N. lugens* in screen house during 2010-2011

Generation	Period	Duration of generation (days)	Temp. (˚C) (Mean ± SD)	RH (%) (Mean ± SD)
1st	July 12 – Aug 3, 2010	23	31.02 ± 2.82	70.13 ± 16.82
2nd	Aug 3 - Aug 29, 2010	27	29.74 ± 1.29	81.44 ± 7.15
3rd	Aug 29 - Sept 29, 2010	32	27.43 ± 2.09	82.06 ± 7.65
4th	Sept 29 - Nov 16, 2010	49	23.78 ± 3.18	69.94 ± 6.46
5th	Nov 16, 2010 - Mar 1, 2011	106	13.61 ± 3.06	77.63 ± 7.71
6th	Mar 1 - Apr 21, 2011	52	20.95 ± 2.87	63.98 ± 12.62
7th	Apr 21 - June 5, 2011	46	31.17 ± 2.85	46.52 ± 10.33
8th	June 5 - July 4, 2011	29	30.54 ± 2.66	69.57 ± 15.15

4.2 Behavioural studies

4.2.1 Time of oviposition

The maximum oviposition i.e. 35 took place during 19:30 to 21:30 hours followed by 17 during 07:30 – 11:30 hours and 9 during 15:30 – 19:30 hours, while no oviposition occurred during 23:30 to 03:30 hours (Table 6). Khaire and Dumbre (1981) carried out laboratory studies in Maharashtra on the bionomics of BPH on rice seedling and reported that mating occurred during the dusk hours on the leaf sheaths or stems.

Table 6. Diel oviposition activity of *N. lugens* in 2010

Time of the day (hours)*	No. of eggs/ 5 females
15:30 – 19:30	9
19:30 – 23:30	35
23:30 – 03:30	0
03:30 – 07:30	2
07:30 – 11:30	17
11:30 – 15:30	3

*****Recorded on September 20-21, 2010

4.2.2 Site of oviposition

BPH laid eggs in small groups into the leaf sheath near the base of plant. Usually 3 - 17 eggs were laid in a row in each egg mass by the BPH (Plate 4) and the upper end of eggs were having a reddish spot. There were 4 – 6 egg masses on each plant. Eggs were white in

colour and slightly curved (Plate 5). Eggs laid were normally not visible from outside but the ovipositional sites were identified as reddish brown patches after staining (Plate 6).

Nair (1986) has also reported that 2 - 12 eggs are laid in one bunch. Khaire and Dumbre (1981) carried out laboratory studies in Maharashtra and found that eggs were laid in masses on leaf sheaths or inside stems. Nalinakumari and Mammen (1975) described that eggs were thrusted within the tissue, generally in the mid region of the outer leaf sheath in the rows of 2 to 12 eggs. Misra and Israel (1968) described that the egg was whitish in colour when freshly deposited and the egg cap and eyes were not seen but red eye spots developed at the head end which become prominent prior to hatching

4.2.3 Mating behaviour

Mating behaviour of *N. lugens* was studied by releasing one pair of adults on 20 days old rice plant under glass chimney. The duration of mating was recorded using a stopwatch and the maximum duration was observed 113 seconds and minimum as 56 seconds. The mean duration was recorded as 84.20 ± 18.90 seconds. Mating of BPH, was investigated by Oh (1979) in relation to oviposition. Mating period lasted for about 120 seconds at the first mating and about 60 seconds at the second or third mating.

Polygamous behaviour was studied by releasing freshly emerged one male and ten females in confinement for 5 days under screen house conditions. Only 1-3 females oviposited. Mochida and Okada (1979) have observed that one male BPH can mate with a maximum of nine females for 24 hours and an individual female can copulate more than twice during its lifetime.

4.3 Host-range and population abundance

4.3.1 Population abundance (Field studies)

The sweep net data on the population of BPH collected from rice and other graminaceous crops (wheat, maize, sorghum and bajra) from May 23, 2010 to May 22, 2011 at weekly interval are presented in Table 7. The adults of BPH were available from June 6, 2010 to November 14, 2011 under field conditions. The maximum adult population of 29-38 BPH per ten sweeps was recorded on rice crop in August - October, 2010 after which it gradually started declining and diminished in mid-November. Three to four peaks of *N. lugens* were observed from sweep net data in rice crop (Fig. 2).

Table 7. Population abundance of *N. lugens* recorded in sweep net on different crops

Study period	Wheat	Maize	Sorghum	Bajra	Rice
May 23, 2010	*	0	*	*	*
30	*	0	*	*	*
June 6, 2010	*	*	*	*	1
13	*	*	*	*	3
20	*	*	*	*	2
27	*	*	*	*	4
July 4, 2010	*	2	0	0	6
11	*	0	0	0	5
18	*	0	0	0	11
25	*	0	0	0	13
August 1, 2010	*	1	0	0	17
8	*	1	0	0	15
15	*	0	1	0	18
22	*	0	0	0	24
29	*	1	2	0	16
September 5, 2010	*	0	2	0	29
12	*	0	0	1	33
19	*	0	0	1	34
26	*	0	0	0	36
October 3, 2010	*	0	1	0	35
10	*	0	0	0	38
17	*	0	*	*	31
24	*	*	*	*	34
31	*	*	*	*	26
November 7, 2010	0	0	*	*	10
14	0	0	*	*	4
21	0	0	*	*	*
28	0	0	*	*	*
December 5, 2010	0	0	*	*	*
12	0	0	*	*	*
19	0	0	*	*	*
26	0	0	*	*	*
January 2, 2011	0	0	*	*	*
9	0	0	*	*	*
16	0	0	*	*	*
23	0	0	*	*	*
30	0	0	*	*	*

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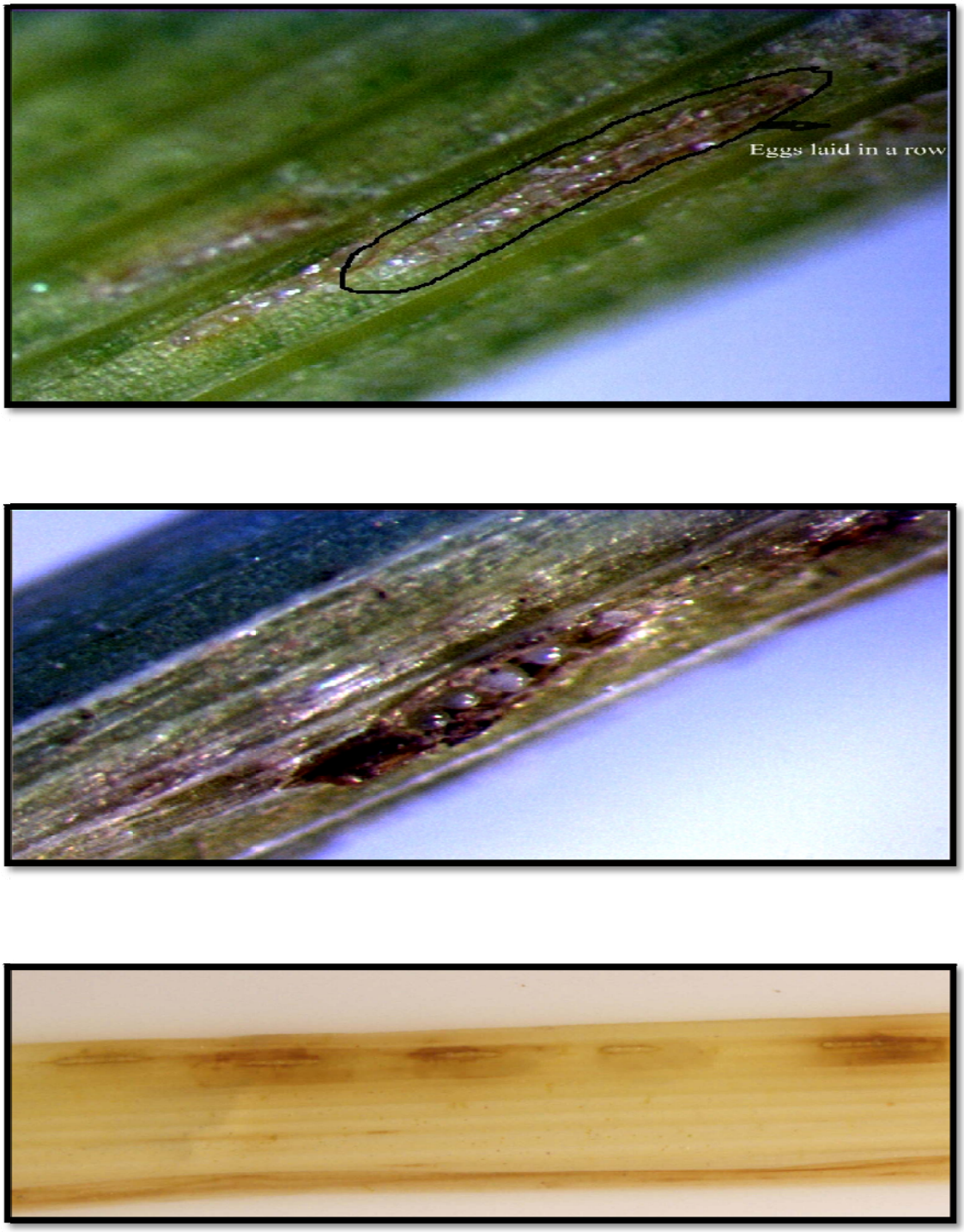

Plate 4. Oviposition site of *N. lugens*

Plate 5. Eggs of *N. lugens*

Before staining **After staining**

Plate 6. Oviposition site of *N. lugens* before and after staining

Study period	Wheat	Maize	Sorghum	Bajra	Rice
February 6, 2011	0	0	*	*	*
13	0	0	*	*	*
20	0	0	*	*	*
27	0	0	*	*	*
March 6, 2011	0	0	*	*	*
13	0	0	*	*	*
20	0	0	*	*	*
27	0	0	*	*	*
April 3, 2011	0	0	*	*	*
10	0	0	*	*	*
17	0	0	*	*	*
24	*	0	*	*	*
May 1, 2011	*	0	*	*	*
8	*	0	*	*	*
15	*	0	*	*	*
22	*	0	*	*	*
29	*	0	*	*	*

Based on 10 sweep net readings , *No crop

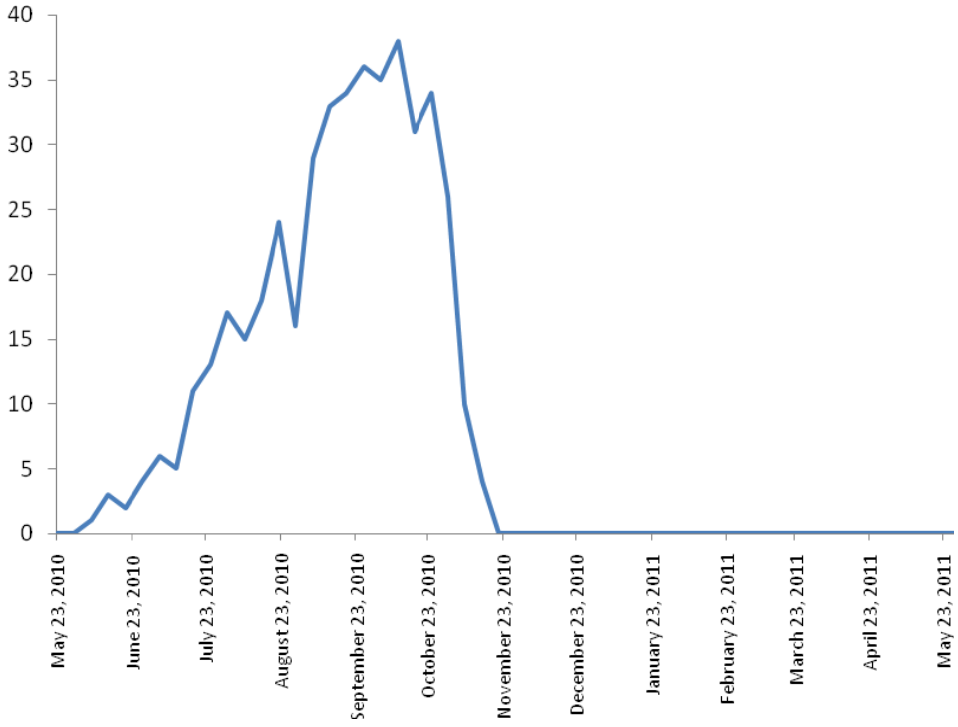

Fig. 2. Population abundance of *N. lugens* recorded in sweep net on rice crop

The results of present findings are supported by Win *et al* (2011b) who studied the population fluctuation of BPH in Myanmar for two seasons (rainy and summer). Population fluctuation study revealed that BPH population was high at 64 and 74 days after transplanting (in Mid September 2007) associated with heavy rainfall, high temperature and high humidity. Sawada *et al* (1992) investigated population dynamics of BPH at nine study sites in the irrigated coastal lowland of West Java, Indonesia, where rice was cultivated under intensive modern agricultural practices. The BPH populations were definitely characterized by the low initial immigrants in a year, followed by the subsequent high population growth.

4.3.2 Population abundance (Light trap studies)

Light trap was operated throughout the nights from June 2010 to May 2011 at Screen house, Department of Plant Breeding and Genetics at Ludhiana. The data on daily catches showed that the insect started appearing in the month of June, 2010 (Table 8) and its presence was found maximum in month of October 2010 and afterwards it started declining and almost diminished in the month of December, 2010 (Fig. 3 and Fig. 4). A positive correlation was found between number of BPH trapped in light trap and abiotic parameters like, temperature, relative humidity and rainfall i.e., r = 0.13, r = 0.16 and r = 0.05, respectively.

Table 8. Number of *N. lugens* trapped in light trap per month from June 2010 to May 2011

Month	No. of brown planthoppers per light trap	Temp.(^{o}C) (Mean ± SD)	RH (%) (Mean ± SD)
June, 2010	34	32.29 ± 3.01	53.80 ± 10.40
July, 2010	55	29.71 ± 2.38	81.16 ± 9.38
August, 2010	234	29.72 ± 1.26	80.84 ± 7.10
September, 2010	800	27.21 ± 2.02	82.40 ± 7.76
October, 2010	1359	25.22 ± 2.68	71.40 ± 7.19
November, 2010	110	19.25 ± 1.94	66.23 ± 3.45
December, 2010	0	13.06 ± 1.19	76.03 ± 4.42
January, 2011	0	10.57 ± 2.37	81.87 ± 7.97
February, 2011	0	15.25 ± 1.78	80.75 ± 3.99
March, 2011	0	20.05 ± 3.38	72.71 ± 7.41
April, 2011	0	24.46 ± 3.69	48.97 ± 5.99
May, 2011	0	32.20 ± 2.32	44.68 ± 9.61

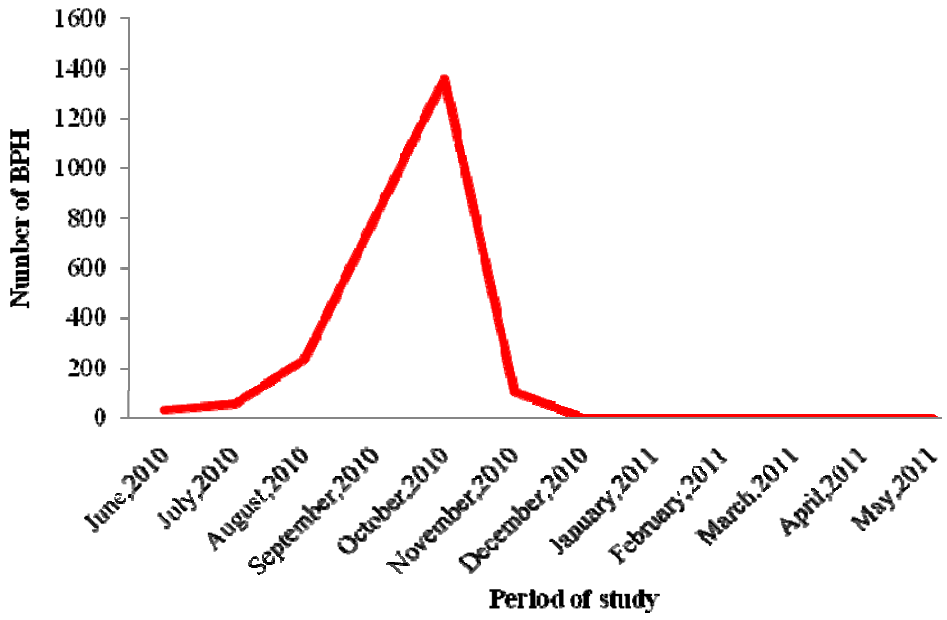

Fig. 3. Population of *N. lugens* recorded in light trap from June 2010 - May 2011

Jeyrani *et al* (2000) also worked out seasonal trends of BPH population level and the interrelationship between light trap catches and field population at Tamil Nadu Rice Research Institute, Aduthurai for three seasons during 1997–1998. Correlation studies were made on the light trap catches and field population of BPH using mean weekly catches/counts as variables. Analysis indicated a positive correlation (r = 0.512) between field population and light trap catches. He also observed that light trap catches were significantly high during September - October 1997.

4.3.3 Host-range

In host range studies, two pair of planthoppers per plant and three plants per species were tested. Oviposition was observed in case of *Lolium temulentum* L. (Plate 7) and *Eleusine indica* Gaertnet. But the nymphs died within one to two days of their emergence. There was no oviposition or adult survival on Maize (*Zea mays* L.). The plants that were found unsuitable for oviposition were *Echinochloa crusgalli* (L.), *Cyperus difformis* (L.), *Eragrostis pilosa* (L.), *Sorghum halepense* (L.), *Triticum aestivum* L. , *Sorghum vulgare* Pers., *Pennisetum typhoides* (Burm f.), *Avena sativa* L., *Cynodon dactylon* (L.), *Eragrostis tenella* (L.), *Digitaria sanguinalis* (L.), and *Cyperus rotundus* L.. The adult longevity varied from 2.00 ± 1.00 days on *T. aestivum* to a maximum duration of 5.67 ± 0.58 days in case of *D. sanguinalis* (Table 9). The adult longevity was statistically at par with each other in case of *Avena sativa, Echinochloa crusgalli*, *Eragrostis pilosa, Eleusine indica* and *Digitaria sanguinalis* but differed significantly from other plant species.

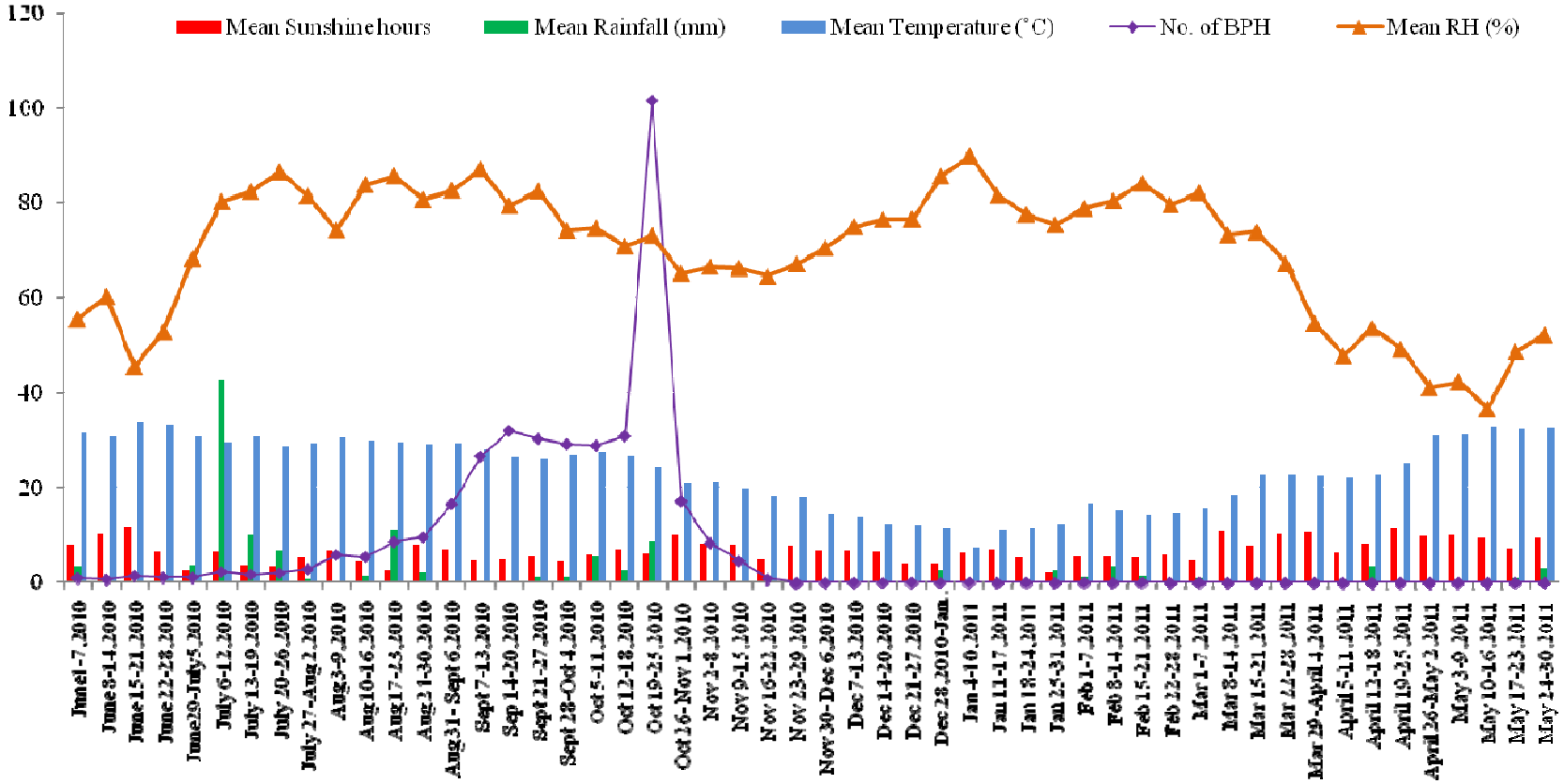

Fig. 4. Weekly mean number of *N. lugens* trapped in light trap from June 2010 - May 2011

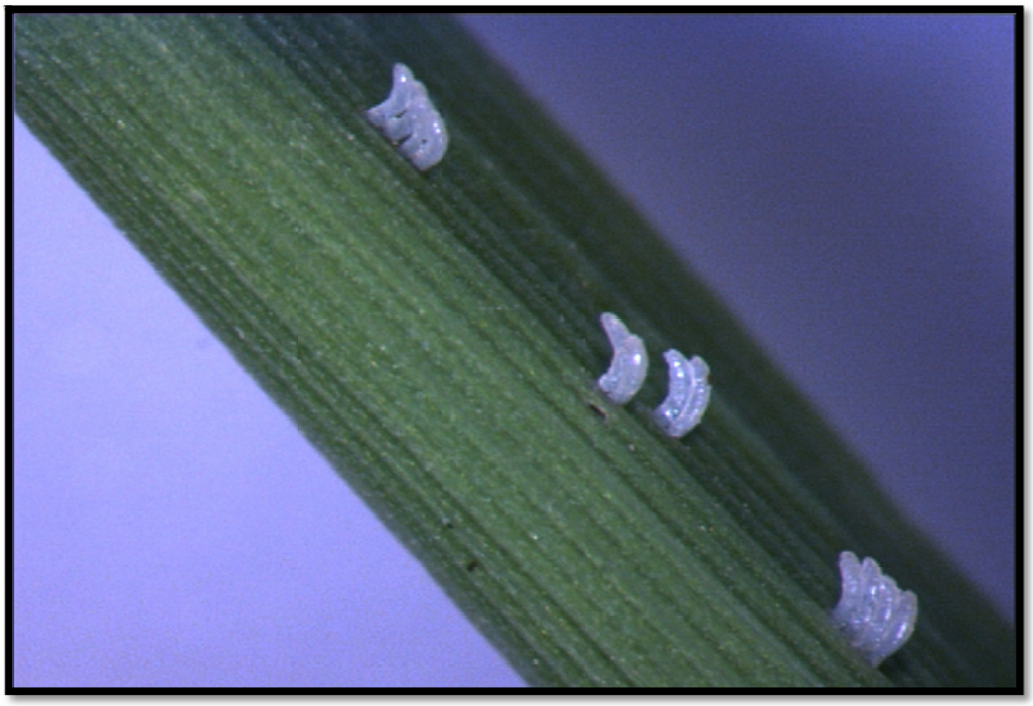

Plate 7. Eggs of *N. lugens* on leaf of *Lolium temulentum*

Table 9. Host-range studies of *N. lugens* during 2010 – 2011

A. Plants suitable for Oviposition but not for nymphal development

Common name	Botanical name	Incubation period (days) (Mean ± SD)	Nymphal period (Mean ± SD)
Kanki	*Lolium temulentum* L.	7.67 ± 1.53	Died within two days
Makra (Goose grass)	*Eleusine indica* Gaertnet	8.33 ± 1.53	Died within one day

B. Plants unsuitable for Oviposition

Common name	Botanical name	Adult longevity (days) (Mean ± SD)
Wheat	*Triticum aestivum* L.	2.00 ± 1.00
Khabbal ghas	*Cynodon dactylon* (L.)	2.33 ± 0.58
Love grass	*Eragrostis tenella* (L.)	2.33 ± 0.58
Motha	*Cyperus rotundus* L.	3.33 ± 0.58
Rice motha	*Cyperus difformis* (L.)	3.33 ± 1.15
Pearl millet	*Pennisetum typhoides* (Burm f.)	3.33 ± 0.58
Kanki	*Lolium temulentum* L.	3.33 ± 1.15
Baru	*Sorghum halepense* (L.)	3.33 ± 0.58
Sorghum	*Sorghum vulgare* Pers.	3.33 ± 0.58
Oats	*Avena sativa* L.	4.33 ± 0.58
Swank	*Echinochloa crusgalli* (L.)	4.33 ± 1.53
Love grass	*Eragrostis pilosa* (L.)	5.00 ± 1.00
Makra (Goose grass)	*Eleusine indica* Gaertnet	5.33 ± 1.15
Takri gha	*Digitaria sanguinalis* (L.)	5.67 ± 0.58
CD (p = 0.05)		1.48

Van Vreden and Ahmadzabidi (1986) have also listed certain grasses *Arthroxon hisdipus, Digitaria adscendens*, *Echinochloa crusgalli* var. oryzicola, *Isachne globosa*, *Leersia japonica* and *Poa annua* other than rice as hosts of BPH in Peninsular Malaysia. Similarly, Zaherudeen and Prakasa Rao (1988) studied the oviposition and hatchability of BPH in some common host plants and weeds. A set of 52 common weeds, from the rice based agro-ecosystem of Orissa, 17 wild species belong to genus *Oryza* and 21 crop plants were studied. Out of 90 plant species tested, 16 weeds and 2 crop plants showed no oviposition whereas others showed oviposition.

CHAPTER V

SUMMARY

The biology of Brown planthopper (BPH), *Nilaparvata lugens* (Stal) was studied during 2010-2011 on rice cultivar PR114 under the screen house conditions at the Department of Plant Breeding & Genetics, PAU, Ludhiana.

The biology of BPH varied during different months of study period. The pre-oviposition period was minimum i.e. 1-3 days with a mean value of 1.70 ± 0.67 days during May 22 - June 20; 1-3 days with a mean value of 2.20 ± 0.63 days during July 15 - August 11, 2010 and was maximum during September 4 - 30, 2010 i.e. 2-4 days with a mean value of 2.70 ± 0.67 days. The oviposition period was minimum i.e. 12-16 days with a mean value of 14.10 ± 1.45 days during September 4-30, 2010; 15-20 days with a mean value of 17.20 ± 1.55 days during July 15 - August 11, 2010 and was maximum during May 22- June 20, 2010 i.e. 17-25 days with a mean value of 21.00 ± 2.62 days. The post-oviposition period ranged from 1-3 days with a mean value of 2.30 ± 0.67 days during May 22 - June 20, 2010 and 3-7 days with a mean value of 4.80 ± 1.23 days during July 15 - August 11, 2010. The duration was observed maximum during September 4-30, 2010 i.e. 5-9 days with a mean value of 6.70 ± 1.57 days. The fecundity-cum-fertility was observed as 93-168 nymphs with a mean value of 136.70 ± 20.69 nymphs during May - June; 84-126 nymphs with a mean value of 107.30 ± 13.74 nymphs during July - August and 76-115 nymphs with a mean value of 98.40 ± 12.10 nymphs during the month of September. Females lived longer than males and the longevity of females and males decreased with decrease in temperature. The longevity of males was 17-26 days with a mean value of 21.50 ± 2.88 days and that of females was 19-30 days with a mean value of 25.00 ± 3.33 days during May 22 - June 20, 2010; 15-21 days with a mean value of 18.20 ± 2.25 days in case of males and 21-28 days with a mean value of 24.20 ± 1.99 days in case of females during July 15 - August 11, 2010 and 14-22 days with a mean value of 17.40 ± 2.46 days and 20-27 days with a mean value of 23.50 ± 2.17 days for males and females, respectively during September 4-30, 2010. Incubation period was observed as lowest during May-June as 4-7 days with a mean value of 5.13 ± 0.83 days; 5-8 days with a mean value of 6.67 ± 0.98 days during July – August and maximum during September as 5-9 days with a mean value of 7.40 ± 0.99 days. Eggs were laid in small groups into the leaf sheath near the base of the plant. Eggs were white in colour and developed eye shaped red spot prior to hatching. There were 3-17 eggs laid in one egg mass and there were 4-6 egg masses on each plant.

There were five nymphal instars and the duration of first, second, third, fourth and fifth nymphal instar varied between 1-3 days with a mean value of 2.00 ± 0.38 days to 2-3 days with a mean value of 2.60 ± 0.51 days, 2-4 days with a mean value of 3.07 ± 0.46 days to 3-4 days with a mean value of 3.20 ± 0.41 days, 3-5 days with a mean value of 4.00 ± 0.65 days to 4-6 days with a mean value of 4.87 ± 0.83 days, 3-5 days with a mean value of 4.33 ± 0.62 days to

4-5 days with a mean value of 4.67 ± 0.49 days and 3-5 days with a mean value of 4.00 ± 0.38 days to 3-5 days with a mean value of 4.13 ± 0.83 days, respectively. The total nymphal period varied from 13-19 days with a mean value of 17.40 ± 1.45 days to 21-25 days with a mean value of 22.73 ± 1.39 days. The total nymphal period increased with decrease in temperature. The survival percentage of nymphs was recorded as 85.53, 88.46 and 94.16 per cent during September, July-August and May-June period of study in 2010, respectively. Females usually outnumbered males and sex ratio (male : female) varied from 1: 1.18 to 1 : 2.05 among the field collected populations and 1: 1.09 to 1: 2.07 among the screen house reared insect population. Wing type ratio (macropterous : brachypterous) varied from 1.10 : 1 to 1.85 : 1 among the field collected populations and 1 : 1.17 to 1 : 1.87 among the screen house reared insect population. The planthopper passed through eight overlapping generations in a year. One generation was completed in 23 days at 31.02 ± 2.82^{o}C during July 12 –August 3, 2010 and 106 days at 13.61 ± 3.06^{o}C in November 16, 2010- March 1, 2011. The oviposition occurred mostly at dusk from 19:30 to 23:30 hours. The mating period lasted for 56-113 seconds. When one male was confined with ten females for five days, then out of ten only one-three females oviposited.

The plant species other than rice were found allowing oviposition and adult longevity for few days but did not supported its development and completion of life cycle. The oviposition occurred on *Lolium temulentum* L. (kanki) and *Eleusine indica* Gaertnet (makra) but the nymphs died within 1-2 days of the emergence. Fourteen plant species namely *Echinochloa crusgalli* (L.), *Cyperus difformis* (L.), *Eragrostis pilosa* (L.), *Sorghum halepense* (L.), *Triticum aestivum* L., *Sorghum vulgare* Pers., *Pennisetum typhoides* (Burm f.), *Avena sativa* L., *Cynodon dactylon* (L.), *Eragrostis tenella* (L.), *Digitaria sanguinalis* (L.), and *Cyperus rotundus* L. were found unsuitable for oviposition, however the mean duration of adult longevity on these plants ranged from 2.00 ± 1.00 to 5.67 ± 0.58 days.

No population of brown planthopper was recorded on wheat, bajra and maize whereas only few adults were observed on sorghum during August – September. During August - October, 2010, 29-38 brown planthopper adults per ten sweep net were recorded on rice crop after which it declined gradually. Data regarding number of brown planthopper from light trap was recorded and it showed that insect started appearing in month of June, 2010 and its presence was found maximum in month of October and afterwards it declined drastically.

Brown Planthopper appeared in the months of June and its population started increasing in the month of August-September when this pest was more serious as it damages the crop at grain formation stage. So critical monitoring of the brown planthopper is very necessary for timely management. The weed plants Kanki and Makra supports the oviposition of BPH so these weeds should be removed from the cropping areas.

REFERENCES

Alam S (1971) *Population dynamics of the common leafhopper and planthopper pests of rice.* Unpub. Ph. D. thesis. Cornell University, USA.

Anonymous (1944) *Insect pests of rice. Handbook for farmers in Taiwan. (Japanese).* Agricultural Research Institute, Government of Taiwan.

Anonymous (1974) *Annual report*. Pp 15-17. Rice Section, Department of Plant breeding, Punjab Agricultural University, Ludhiana.

Anonymous (1975) *Annual report of International Rice Research Institute*. Pp 384. Los Banos, Philippines.

Anonymous (1997) *Production Oriented Survey.* Pp 16-17. Directorate of Rice Research, All India Coordinated Rice Improvement Programme (ICAR), Hyderabad.

Anonymous (2007) *Production Oriented Survey.* Pp 21-26. Directorate of Rice Research, All India Coordinated Rice Improvement Programme (ICAR), Hyderabad.

Anonymous (2009) www.indiastat.com.

Anonymous (2010) *Production Oriented Survey.* Pp 131-132. Directorate of Rice Research, All India Coordinated Rice Improvement Programme (ICAR), Hyderabad.

Anonymous (2011) *Package of practices for crops of Punjab (Kharif 2011)*. Pp 3. Directorate of Extension Education, PAU.

*Bae S H, Choi K M, Lee Y I and Kim M S (1968) Seasonal fluctuations and control of white-back planthopper (*Sogatella furcifera* Horvath) and brown planthopper (*Nilaparvata lugens* Stal). Research Reports of the Office of Rural Development **3**: 59-65.

Bae S H and Pathak M D (1970) Life history of *Nilaparvata Lugens* (Homoptera: Delphacidae) and susceptibility of rice varieties to its attack. *Ann ent Soc Am* **63:** 149-53.

Bao Y X, Cheng J Y and Cheng X N (1999) Analysis on the meteorological backgrounds for the great events of *Nilaparvata lugens* long distance migration northward during mid summers in China. *J Nanjing agric Univ* **22**: 35-40.

CAB (Commonwealth Agricultural Bureaux) (1984) International distribution maps of plant pests. December, Map 199.

Canedo F M (1980) *Change agents perceived credibility and their influence in the innovation decision process of development program.* Ph.D. Thesis, University of the Philippines, Los Banos, Laguna, Philippines.

Cheng X N, Wu J C and Ma F (2003) *Research and prevention of the brown planthopper*. Pp 52-55. Chinese agricultural press, Beijing, China.

Chiu M (1970) Ecological studies on the rice brown planthopper. *Taiwan Agric* **6**: 143-52.

Chou W D (1969) Effectiveness of insecticides against brown planthopper on the second rice crop at Chiayi, Taiwan in 1967. *Taiwan Agric* **5**: 128-41.

Claridge M F, Hollander Den J and Morgan J C (1985) The status of weed-associated populations of the brown planthopper, *Nilaparvata lugens* (Stal) - host race or biological species. *Zool J Linn Soc* **84:** 77–90.

Cook A G and Perfect T J (1985) Seasonal abundance of macropterous *Nilaparvata lugens* and *Sogatella furcifera* based on presumptive macroptery in fifth-instar nymphs. *Ecol Ent* **10**: 249-58.

Cook A G and Perfect T J (1989) The population characteristics of the brown plant hopper, *Nilaparvata lugens*, in the Philippines. *Ecol Ent* **14**: 1–9.

Crummay F A and Atkinson B W (1997) Atmospheric influences on light trap catches of the brown planthopper rice pest. *Agric Forest Met* **88**: 181-97.

Dai H G, Song X L, Wu X Y, Ding Z Z, Li P Y (1997) The effects of high temperatures on development and reproduction of the brown planthopper, *Nilaparvata lugens* Stal. *Acta ent Sin* **22**: 159-64.

Das N M, Mammen K V and Christudas S P (1972) Occurrence of *Nilaparvata lugens* (Stal) (Delphacidae: Homoptera) as a serious pest of paddy in India. *Agric Res J Kerala* **10**: 191-92.

Dhaliwal G S, Arora R and Dhawan A K (2004) Crop losses due to insect pests in Indian Agriculture: An update. *Indian J Ecol* **31**: 1-7.

Diwakar M C (1975) Current entomological problems of paddy in new agricultural strategy. *Sci Cult* **41**: 19-22.

Domingo I and Heong K L (1992) Evaluating high temperature tolerance in brown planthopper (BPH). *Int Rice Res Newsl* **17**: 22.

Dupo A L B and Barrion A T (2009) Taxonomy and general biology of delphacid planthoppers in rice agrosystem. In: Heong K L and Hardy B (ed) *Planthoppers: new threats to the sustainability of intensive rice production systems in Asia*. Pp 3-157. International Rice Research Institute, Manila, Philippines.

Dyck V A and Thomas B (1979) The Brown Planthopper Problem. In: Dyck V A and Thomas B (ed) *Brown Planthopper: Threat to Rice Production in Asia.* Pp 3-17. International Rice Research Institute, Manila, Philippines.

Fernando H E (1975) The brown planthopper in Sri Lanka. *Rice Ent Newsl* No. 2.

Fernando H, Senadhera D, Elikawela Y, Alwis H M D and Kudagamage C (1979*)* Varietal resistance to the brown planthopper in Sri Lanka. In : Kalode M B and Khrishna T S (ed) *Brown Planthopper: Threat to Rice Production in Asia.* Pp 241-49. International Rice Research Institute, Los Banos, Philippines.

Fukuda K (1934) Investigation on the Brown planthopper. *Bull Agric Div Cent Res Inst* (Government of Formosa) **99**: 1-19.

Gifford J R and Trahan G B (1969) Staining technique for eggs of Rice Water Weevils ovipositioned intracellularly in the tissue of the leaf sheaths of rice. *J econ Ent* **64**: 740.

Gomez A K and Gomez A A (1984) Statistical procedures for Agricultural Research. John Wiley and Sons, New York, USA.

Gunathilagaraj K and Kumar M G (1997) Rice pest complex: An appraisal. *Madras agric J* **84**: 249-62.

Hasegawa H (1955) Some notes on the Japanese species of the genus *Nilaparvata* Distant (Homoptera: Delphacidae) (in Japanese, English summary). *Bull natl Inst agric Sci* **5**: 117-38.

Heinrichs E A and Medrano F G (1984) *Leersia hexandra* a weed host of the rice brown planthopper, *Nilaparvata lugens* (Stål). *Crop Prot* **3**: 77-85.

Heinrichs E A and Mochida O M (1984) From secondary to major pest status: the case of insecticide - induced rice brown planthopper, *Nilaparvata lugens*, resurgence. *Prot Ecol* **7**: 201-18.

Hemingway J, Karunaratne S H P P, Claridge M F (1999). Insecticide resistance spectrum and underlying resistance mechanisms in tropical populations of the brown planthopper (*Nilaparvata lugens*) collected from rice and the wild grass *Leersia hexandra*. *Int J Pest Mgmt* **45**: 215-23.

Heong K L, Manza A, Catindig J, Villareal S and Jacobsen T (2007) Changes in pesticide use and arthropod biodiversity in the IRRI research farm. *Outl Pest Mgmt* **18**: 229-33.

Hirao J (1979) Forecasting brown planthopper outbreaks in Japan. In: Hirao J (ed) *Brown planthopper: Threat to rice production in Asia.* Pp 101-12. International Rice Research Institute, Los Banos, Philippines.

Ho H S and Liu T H (1969) Ecological investigation on brown planthopper in Taichung District. *Pl Prot Bull* Taiwan **11:** 33-42.

Huang J Y, Li R D and Yang Z H (1992) A study of population dynamics of brown planthopper *Nilaparvata luegns* (Stal), on single cropping late rice in the Shanghai area. *J Shanghai Agric Coll* **10**: 226-33.

Iwanaga K, Tojo S and Nagata T (1985) Immigration of the brown planthopper, *Nilaparvata lugens*, exhibiting various responses to density in relation to wing morphism. *Ent Exp Appl* **38**: 101-08.

Jeyrani S, Sridhan S and Sadakatullah S (2000) Interrelationship between light trap catches and field population of brown plant hopper, *Nilaparvata lugens* Stal. *Insect Envir* **6**: 59-60.

Kalode M B (1974) *Recent changes in relative pest status of rice insects as influenced by cultural, ecological and genetic factors.* Pp 28. Paper presented at the International rice research conference held at International Rice Research Institute, Manos, Philippines.

Kalode M B (1976) Brown plant-hopper in rice and its control. *Indian Fmg* **27**:3-5.

Kenmore P E, Carino F O, Perez C A, Dyck V A and Gutierrez A P (1984) *Population regulation of the rice brown planthopper* (*Nilaparvata lugens* (Stal)) *within rice fields in the Philippines*. Pp 32-35.

Khaire V A and Dumbre R B (1981) Laboratory studies on bionomics of brown planthopper *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae). *J Maharashtra agric Univ* **6**: 102-5.

Kim C S, Koh H S and Fukami H (1994) Antifeedants of rice planthoppers in some millets. *Appl Ent Zool* **29**: 71-79.

Kisimoto R (1956) Factors determining the wing-form of adult, with special reference to the effect of crowding during the larval period of brown planthopper, *Nilaparvata lugens* Stål: studies on the polymorphism in the planthoppers (Homoptera, Araeopidae). *Appl Ent* **12**: 105-11.

*Kisimoto R (1957) Studies on the polymorphism in the planthoppers (Homoptera, Araeopidae) III. Differences in several morphological and physiological characters between two wing-forms of the planthoppers [in Japanese, English summary]. *Jpn J Appl Ent Zool* **1**:164-73.

*Kisimoto R (1965) Studies on the polymorphism and its role playing in the population growth of planthopper, *Nilaparvata lugens* (Stål.). *Bull Shikoku Agric Exp Stn* **13**: 100-06.

Kisimoto R (1971) Long distance migration of planthoppers, *Sogatella furcifera* and *Nilaparvata lugens. Trop Agric Res Ser* **5**: 201-16.

Kisimoto R (1976) Synoptic weather conditions inducing long-distance immigration of planthoppers, *Sogatella furcifera* Horvath and *Nilaparvata lugens* Stal. *Ecol Ent* **1**: 95-109.

Kisimoto R (1977) Bionomics, forecasting of outbreaks and injury caused by the rice brown planthopper. Pp 27-41. Food and Fertilizer Technology Center for Asian and Pacific Region, Taipei (Taiwan).

Kisimoto R (1985) Studies on polymorphism and its role playing in the population growth of brown planthopper *Nilaparvata lugens* (Stal.). *Bul Shikoku Agric Exp Stn* **13**: 1-106.

Kulshreshtha J P, Anjanelulu A and Padmanabhan S Y (1974) The disastrous brown planthopper attack in Kerala. *Indian Fmg* **24**: 5-7.

*Lei H C and Wang C H (1958) studies on *Nilaparvata lugens* (Stal) in Human (Chinese, English summary) *Acta Oce ent Sin* **1**: 283-313.

Li R D, Ding J H, Wu G W and Shu D M (1996) *The brown planthopper and its population management.* Pp 30-37. Fudan University Press, Shanghai China.

Lin K S (1958) Control of rice hoppers based on their behaviour and population changes. *Pl Prot Bull* **5**: 17-18.

Ling K C, Tiongco E R and Aguiero V M (1978) Rice ragged stunt, a new virus disease. *Pl Dis Reptr* **62**: 701-05

Manoharan M N and Jayaraj S (1979) Studies on the ecology of the rice brown planthopper, *Nilaparvata lugens* (Stal.). *Proc Workshop futurology on the use of chemicals in agriculture.* Pp 58. Tamil Nadu Agricultural University, Coimbatore.

Matsumura M (1996) Genetic analysis of a threshold trait: density-dependent wing dimorphism in *Sogatella furcifera* (Horváth) (Hemiptera: Delphacidae), the whitebacked planthopper. *Heredity* **76**: 229-37.

Matsumura M (2000) The current status of occurrence and forecasting system of rice planthoppers in Japan. *Proc 2nd Int Workshop on Inter-country Forecasting Sys and Mgmt for Brown Planthopper in East Asia*. Pp 123-131. Hangzhou, China.

Misra B C (1980) Ecology of the brown planthopper in the tropics In: Dyck V A, Misra B C, Alam S, Chen C N, Hsieh C Y and Rejesus R S (ed) *Brown planthopper: Threat to rice production in Asia.* Pp 61-98. International Rice Research Institute, Manila, Philippines.

Misra B C and Israel P (1968) Anatomical studies of the ovipositional site of plant hoppers and leaf hoppers of rice. *Indian J Genet Pl Breed* **34**: 440-42.

*Miyake T and Fujiwara A (1962) Studies on the hibernation and diapause of the white planthopper *Sogatella furcifera* Horvath and the brown planthopper, *Nilaparvata lugens* Stal. *Bull Hiroshima Pref Agric Exp Stn* **13**: 1-77.

Miyashita K (1963) Outbreaks and population fluctuation of insects, with special reference to agricultural insect pests in Japan. *Bull natl Inst agric Sci* **15:** 99-170.

Mochida O (1964) On the oviposition in the brown planthopper, *Nilaparvata Lugens* (Stal) (Homoptera: Auchenorrhyncha). *Jpn J Appl Ent Zool* **8**: 141-48.

Mochida O (1973) The characters of the two wing- forms of *Javesella pellucida* (F.) (Homoptera: Delphacidae), with special reference to reproduction. *Trans R ent Soc Lond* **125**: 177-225.

Mochida O and Dyck V A (1977) Bionomics of the brown planthopper, *Nilaparvata lugens.* Pp 192-198. *Proc. Int Seminar, Tokyo by FFTC (ASPAC, Taipei).*

Mochida O, Suryana T, and Wahyu A (1977) Recent outbreaks of the brown planthopper in Southeast Asia In: *The rice brown planthopper*. Pp 170-91. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei.

Mochida O and Okada T (1979) Taxonomy and biology of *Nilaparvata Lugens* (Homoptera: Delphacidae) In: Mochida O and Okada T (ed) *Brown planthopper: Threat to Rice production in Asia.* Pp 21-43. International Rice Research Institute, Los Banos, Philippines.

Morooka S, Ishibashi N and Tojo S (1988) Relationship between wing-form response to nymphal density and black colouration of adult body in the brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae). *Appl Ento Zool* **23**: 449-58.

Muir F and Gifford W M (1924) Studies in North American Delphacidae. *Bull Exp Stn Hawaiian Sugar Planters Ass* **15**: 1-53.

Nair M R G K (1986) *Insects and Mites of crops in India*. Pp 4-5. ICAR, New Delhi

Nalinakumari and Mammen K V (1975) Biology of brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae). *Agric Res J Kerala* **13**: 53-54.

Narayanasamy P, Balasubramanian M and Baskaran P (1979) Biological studies of population dynamics of rice brown planthopper and green leafhopper. *Int Rice Res Newsl* **4**: 21.

Nasu S (1967) *Rice leafhoppers : The major insect pests of the rice plant*. Pp 493-523. Johns Hopkins University Press, Baltimore, Md. (USA).

Oh J (1979) Repeated copulation in the brown planthopper, *Nilaparvata lugens* Stål (Homoptera: Delphacidae). *Ecol Ent* **4**: 345–53.

Okada T (1977) Taxonomic characters for identification of the rice brown planthopper (*Nilaparvata lugens*) and its related species in the Asian and Pacific region In: *The rice Brown planthopper*. Pp 1-25. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei, Taiwan.

Otuka A, Watanabe T, Suzuki Y and Matsumura M (2005) Long-distance migrations of brown planthopper *Nilaparvata lugens* (Homoptera: Delphacidae) across the border between the East Asian and Southeast Asian Population. *The 12th International Auchenorrhyncha Congress and concurrent 6th International Workshop on Leaf hoppers and Planthoppers of Economic Significance.* Pp 8-9. University of California, Berkeley.

Paik W H (1977) Historical review of the occurrence of the brown planthopper in Korea. In: *The rice brown planthopper*. Pp 230-47. Food and Fertilizer Technology Center for the Asian and Pacific Region, Taipei.

Panwar V P S (1995) *Agricultural Insect pests of crops and their Control*. Pp 7-8. Kalyani publishers, Noida.

Pathak M D and Dhaliwal G S (1981*) Trends and strategies for rice insect problems in tropical Asia.* IRRI Research paper Series No. 64, Pp 25-39. The International Rice Research Institute, Manila, Philippines.

Pathak M D and Khan Z R (1994) *Insect pests of rice*. Pp 89. International Rice Research Institute (IRRI), Manila, Philippines.

Ponnada U, Pophaly D J, Shaw S S and Ganguli J (2010) Survival of Brown planthopper (BPH) *Nilaparvata lugens* (Stal.) on paddy field weeds. *Int J Pl Prot* **2**: 293-94.

Preap V, Zalucki M P, Jahn G C and Nesbitt H J (2002) Establishment of *Nilaparvata lugens* Stål in rice crop nurseries: a possible source of outbreaks. *J Asia-Pacif Ent* **5**: 75-83.

Preap V, Zalucki M P, Nesbitt HJ and Jahn G C (2001). Effect of fertilizer, pesticide treatment, and plant variety on the realized fecundity and survival rates of brown planthopper, *Nilaparvata lugens*, generating outbreaks in Cambodia. *J Asia-Pacif Ent* **4**: 75-84.

Rai M (2004) International year of rice- An overview. *Indian Fmg* **54**: 3-6.

Rao V R S and Chalam M S V(2007) Biodiversity of planthopper fauna (Delphacidae: Hemiptera) associated with rice and sugarcane crop-ecosystems in South India. *Hexapoda* **14**: 129-41.

Reissig W H, Heinrichs E A, Litsinger J A, Moody K, Fiedler L, Mew T W and Barrion A T (1986) *Illustrated guide to integrated pest management in rice in tropical Asia*. Pp 411. International Rice Research Institute, Manila, Philippines.

Riley J R, Cheng X N, Zhang X X, Reynolds D R, Smith A D, Cheng J Y, Bao A P and Zhai B (1991) The long-distance migration of *Nilaparvata lugens* (Stal) (Delphacidae) in China: radar observations of mass return flight in the autumn. *Ecol Ent* **16**: 471-489

Rivera C T, Ou S H and Iida T T (1966) Grassy stunt disease of rice and its transmission by the brown planthopper, *Nilaparvata lugens* Stal. *Pl Dis Reptr* **50**: 453-56.

Rosenberg L J and Magor J I (1983) A technique for examining the long-distance spread of plant virus diseases transmitted by the brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae) and other wind-borne insect Vectors In: R.T. Plumb and J.M. Thresh (ed) *Plant virus epidemiology: The spread and control of insect-borne viruses.* Pp 229-38. Blackwell Scientific Publications, Oxford, London.

Sawada H, Craib S W, Suwardivijaya, Mustaghfirin E and Kusmayadi A (1992) Population dynamics of the Brown planthopper in the coastal lowland of West Java, Indonesia. *JARQ* **26**: 88-97.

Seino H, Shiotsuki Y, Oya S and Hirai Y (1987). Prediction of long-distance migration of rice planthoppers to northern Kyushu considering low-level jet stream. *J Agric Met* **43**: 203-8.

Sezer M and Butlin R K (1998) The genetic basis of host plant adaptation in the brown planthopper, *Nilaparvata lugens. Heredity* **80:** 499-508.

Shepard B M, Barrion A T and Litsinger J A (1995) *Rice-feeding insects of tropical Asia*. Pp 228. International Rice Research Institute, Manila, Philippines.

Singh J and Dhaliwal G S (1991) Ecological appraisal of changing scenario of rice insect pests in Punjab. *Indian J Ecol* **18**: 139-54.

*Sogawa K (1979) The brown planthopper in India and Sri Lanka. *Nekken Shiryo* **43**: 24.

*Sogawa K (1995) Windborn displacements of the rice planthoppers related to the seasonal weather patterns in Kyushu District. *Bull Kyushu natl Agric Exp Stn* **28**: 219-78.

Srinivasa N, Viraktamath C A and Thontadarya T S (2000) Influence of moon phase and weather on the light trap catches of insect pests of rice. *Oryza* **27**: 183-90.

*Stal C (1854) Nya Hemiptera. *Ofv Svanska Vet Alcad Forh* **11**: 231-55.

Subramanian A and Sathianandan V K R (1981) Unusual occurrence of brown planthopper at Aduthurai and insecticidal control. *Aduthurai Reptr* **5**: 6-7.

*Suenaga H (1963) Analytical studies on the ecology of two species of planthoppers, the whitebacked planthopper *Sogatella furcifera* Horvath and the brown planthopper *Nilaparvata lugens* Stal, with special reference to their outbreaks. *Bull Kyushu Agric Exp Stn* **8**: 1-152.

Takeda M (1974) Mating behavior of the brown planthopper, *Nilaparvata lugens* Stål [in Japanese. English summary]. *Jpn J Appl Ent Zool* **18**: 43-51.

Takezawa H (1961) Studies on the overwintering of the brown planthopper, *Nilaparvata lugens* Stal. *Jap J Appl Ent Zool* **5**: 40-45.

Tao C H (1966) Studies on biology of brown planthopper, *Nilaparvata lugens* Stal and its chemical control measures. *Annual Report* for 1965. Taiwan Agricultural Research Institute.

Turner R, Song Y H and Uhm K B (1999) Numerical model simulations of brown planthopper *Nilaparvata lugens* and white-backed planthopper *Sogatella furcifera* (Homoptera: Delphacidae) migration. *Bull Ent Res* **89**: 557-68.

Uthamaswamy S (1989) Influence of weather factors on light trap catches of green leafhopper (*Nephotettix virescens*) and brown planthopper (*Nilaparvata lugens*) on rice (*Oryza sativa*). *Indian J agric Sci* **59**: 319-21.

*Van Der Laan P A (1981) Pests of crops in Indonesia. *Schtran Baru Van Hoeve Jakarta*. **30**: 151-56.

*Van Vreden G and Ahmadzabidi A L (1986) *Pests of rice and their natural enemies in Penisular Malaysia*. Pp 230. Centre for Agricultural Publication and Documentation (PUDOC), Wageningen.

Wada T, Seino H, Ogawa Y and Nakasuga T (1987) Evidence of autumn overseas migration in the rice planthoppers, *Nilaparvata lugens* and *Sogatella furcifera*: analysis of light trap catches and associated weather patterns. *Ecol Ent* **12**: 321–330.

Wang T T (1957) Rice insect pest control after Taiwan restoration. *Pl Prot Bull* **4**: 1-5.

Watanabe T and Seino H (1991) Correlation between immigration area of rice planthoppers and the low-level jet stream in Japan. *Appl Ent Zool* **26**: 457-62.

Watanabe T, Sogawa K and Suzuki Y (1994) Analysis of yearly fluctuations in the occurrence of migratory rice planthoppers, *Nilaparvata lugens* Stål and *Sogatella furcifera* Horváth, based on light-trap data in northern Kyushu. *Jpn Appl Ent Zool* **38**: 7-15.

Way M J and Heong K L (1994) The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice-a review. *Bull Ent Res* **84**: 567-87.

Win S S, Muhamad R, Abidin Z, Ahmad M and Adam N A (2011a) Life table and population parameters of *Nilaparvata lugens* Stal.(Homoptera: Delphacidae) on rice. *Trop Life Sci Res* **22**: 27–39.

Win S S, Muhamad R, Ahmad Z A M and Adam N A (2011b) Population fluctuations of brown planthopper, *Nilaparvata lugens* (Stal) and whitebacked plant hopper, *Sogatella furcifera* (Horvath) on rice. *Trends Appl Sci Res* **8**: 183-90.

Xiaoping Y and Guorvi W (1992) Effect of high temperature on the survival and fecundity of brown planthopper (*Nilaparvata lugens* Stal). *Int Rice Res Newsl* **17**: 26.

Zaherudeen S M and Prakasa Rao P S (1988) Ovipositional host status of some weeds, wild rice (*Oryza* species) and cultivated crop plants for *Nilaparvata lugens. Indian J agric Sci* **58**: 659-61.

Zeng Z, Chen G and Xu H X (1989) A study of the development of wing dimorphism in the rice brown planthopper *Nilaparvata lugens* Stal. *Acta ent Sin* **26**: 260-67

Zheng X S, Chen G, Xu H X and Lu Z X (2009) Interactive effects of temperature and nitrogen fertilizer on the survival, development, and reproduction of brown planthopper *Nilaparvata lugens*. *Acta ent Sin* **20**: 1171-5.

Zhu Z R (1999) *Population ecology and management strategy of the whitebacked planthopper, S. furcifera* (Horvath) *in subtropical rice*. Ph.D. Thesis. Nanjing Agricultural University, China.

Zhu Z R, Cheng J, Jiang M X and Zheng X X (1994) Complex influence of rice variety, fertilization timing and insecticide on population dynamics of *Sogatella furcifera* (Horvath), *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae) and their natural enemies in rice in Hangzhou, China. *J Pest Sci* **77**: 65-74.

*Original not seen

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