STUDIES ON BIOLOGY AND SEASONAL INCIDENCE OF RICE PLANTHOPPERS IN TUNGA-BHADHRA PROJECT (TBP) AREAS OF KARNATAKA

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STUDIES ON BIOLOGY AND SEASONAL INCIDENCE OF RICE PLANTHOPPERS IN TUNGA-BHADHRA PROJECT (TBP) AREAS OF KARNATAKA

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CERTIFICATE

This is to certify that the thesis entitled **STUDIES ON BIOLOGY AND SEASONAL INCIDENCE OF RICE PLANTHOPPERS IN TUNGA-BHADRA PROJECT (TBP) AREAS OF KARNATAKA** submitted by **Mr. MALLIKARJUN** for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **AGRICULTURAL ENTOMOLOGY** to the University of Agricultural Sciences, Raichur is a record of research work done by him during the period of his study in this University under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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(B. G. MASTHAN RADDY)

Affectionately Dedicated

To

My Parents

Sidramappa and Jagadevi

Brother and Sister

Ishwar and Jyothi

School friends

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LIST OF ABBREVIATIONS

%	:	per cent
/	:	Per
Anon.,	:	Anonymous
BPH	:	Brown planthopper
DAT	:	Days after transplanting
et al.,	:	And other people
ETL	:	Economic threshold level
Fig.	:	Figure
Ha	:	Hectare
i.e.,	:	That is
Kg	:	Kilo gram
NS	:	Non-significant
^{o}C	:	Degree Celsius
RH	:	Relative humidity
S	:	Significant
Sl. No.	:	Serial number
viz.,	:	Namely
WAT	:	Weeks after transplanting
WBPH	:	White backed planthopper
χ^2	:	Chi-square value

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INTRODUCTION…

I. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of more than half of the world's population is grown in a wide range of environments like uplands, deep water, shallow lowlands and irrigated conditions. The total rice growing area in the world is 160.8 million hectares with a production of 746 million tonnes of rough rice and more than 90 per cent of the world's rice is grown and consumed in Asia alone (Anon., 2016). Among the rice producing countries, India occupies the number one position with respect to area with 43.39 million hectares with total production of 104.32 million tones and productivity of 2404 kg/ha followed by China (29.3 million ha). However, with regard to the productivity, India occupies 15^{th} position with 3.01 tonnes/ha of rough rice, compared to Japan (6.65 tonnes/ha), North and South Korea (6.57 tonnes/ha), China (6.26 tonnes/ha) and Indonesia (4.57 tonnes/ha) (Anon., 2015). In Karnataka rice is cultivated in an area of 1.06 million hectare with annual production of 2.70 million tonnes and an average yield of 2547 kg/ha (Anon., 2016).

Low productivity of rice has been attributed to various biotic and abiotic factors. Among biotic factors loss caused by insect pests are considered as one of the prime factor. Over one thousand four hundred insect species are known to attack standing crop and stored rice in the world (Grist and Lever, 1969). More than 100 species of insects are known as important pests of this crop, out of which 20 are of major national economic significance and causes about 24% of damage (Pathak and Dhaliwal, 1981). Among them, yellow stem borer (*Scirpophaga incertulas* Walker.), leafolder (*Cnaphalocrosis spp*, Guenee.), brown planthopper (*Nilaparvata lugens* Stål.), white backed planthopper (*Sogotella furcifera* Horvath.), Green leafhoppers (*Nephotettix nigropictus* Motsch. and *Nephotettix cincticeps* Distant.) and paddy hispa (*Dicladispa armigera* Oliver) are predominant. These pests infest the crop from seedling to maturity in overlapping generations and vary in nature of damage being plant tissue borers, foliage feeders and sap suckers.

Brown planthopper, *N. lugens* and white backed planthopper, *S. furcifera* are known as pest of rice in South Asia and South-East Asia (Dyck and Morn 1979). Though, BPH is associated with rice since 1900, large scale field damage was reported for the first time in India during 1972 from Kuttanad area of Kerala (Kalode, 1974). From 1973 onwards, its occurrence and damage in vast areas in farmers fields was reported form

Krishna-Godavari belt of Andhra Pradesh, Cauvery belt of Tamil Nadu, Tunga-Bhadra belt of Karnataka, Mahanadi belt of Orissa and in West Bengal particularly Chinsurah region. Almost during the same period, WBPH was noticed in North-Western part of the country mainly Punjab, Haryana and Western Uttar Pradesh, although the area of occurrence and intensity of damage was low compared to BPH (Kalode, 1974).

It was recorded as Asia worst rice pest in the 1970's, causing heavy losses and economic desperation for thousands of farmers. In Karnataka this was not been reported previously as a pest but during May 1975, its outbreaks caused hopper burn on rice in the field near Mandya. The pest was reported from many widely scattered parts of the state. Based on the incidence, it was predicted that infestation would become severe in all rice growing areas of Karnataka (Channabasavanna *et al*., 1976). Later this prediction came true as it becomes one of the major limiting factors for rice production in Karnataka. Severe outbreak of this pest was noticed in Chamarajanagar district during 2007 and in Haveri, Shimoga, Mandya, Mysore and Chamarajanagar districts during 2009 (Siddegowda and Gubbaiah, 2011). Planthopper populations were severe at Gangavathi (30,000ha), Kampli (25,000ha) and Koppal (10,000ha) areas and only 2000 ha in Mandya regions of Karnataka covering Tunga bhadra and Cauvery commands during 2005 (Krishnaiah *et al.*, 2012). Based on production oriented survey conducted by scientists of Agricultural Research Station, Gangavathi during 2012-13, revealed that BPH and WBPH, were causing more than 40 per cent of damage and stem borer and leaf folder damage was 25 per cent in spite of regular plant protection measures (Anon., 2013).

Brown planthopper damages plants directly by sucking the sap and by ovipositing in plant tissues, causing plant wilting and 'hopperburn'. When the crop is 'Hopper burned' they migrate to healthy crop in large numbers. It also causes economic damage to the rice crop indirectly by transmitting 'grassy stunt' and 'ragged stunt' virus diseases (Cheng, 1989). The 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 (Bae and Pathak, 1970). Newly hatched about 400 nymphs infesting plants could cause complete drying in 3 to 15 days at 25 to 50 DAT, respectively (Pathak and Khan, 2002).

Planthopper complex in rice fields is important factor which needs to be investigated (Zhao, 1991). The white-backed planthopper (WBPH), *S. furcifera* and brown planthopper (BPH) *N. lugens* often co-occur on the same plant and feed on the phloem sap of paddy. Each species has the traits of congregating in large numbers and rapid population growth (Denno, *et al.*, 1994).

The complexity of planthoppers exists between BPH and WBPH. WBPH which attacks during initial cropping period later BPH overtakes the population in later stages (Matsumura, 1996)

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. However, systematic work on the species complexity, population competition between BPH and WBPH, biology, seasonal incidence and morphological identification of these insect-pests has not been done in northern region of the Karnataka so these studies were conducted with the following objectives:

Objectives:

1. To study the occurrence of morpho-species of rice planthoppers in Tunga-Bhadra Project (TBP) areas of Karnataka
2. To study the seasonal incidence of rice planthoppers in Tunga-Bhadra Project (TBP) areas of Karnataka
3. To study the biology of brown and black morphs of brown planthopper *N. lugens*

REVIEWS OF LITERATURE...

II. REVIEWS OF LITERATURE

The comprehensive review of literature pertaining to the various aspects on occurrence of morpho-species, seasonal incidence and biology of rice planthoppers are presented in this chapter.

2.1 To study the occurrence of morpho-species of rice planthoppers in Tunga-Bhadra Project (TPB) areas of Karnataka

Singh *et al.* (1977) observed 16 species of rice pests including *Nephotettix nigropictus* Motsch. and *N. virescense* which were caught in a light trap at Agricultural Research Farm, Dholi (Bihar) during June to November, 1976.

However, Claridge *et al.* (1980) reported the four BPH biotypes in rice ecosystem. Biotypes 1 and 2 are widely distributed in South-East Asia, biotype 3 is a laboratory biotype produced in Philippines and biotype 4 is the most destructive biotype and occurs predominantly in Indian sub-continent and thus referred it as the South Asian biotype.

Claridge *et al.* (1985) identified three different species from major tropical regions of the world have been attributed to the genus *Nilaparvata* on rice and other related weed hosts, particularly species of Leersia. *Nilaparvata lugens* (Stål.) is a major pest of rice in Asia and other two were identified as *Nilaparvata meander* (Feannah) from Nigeria associated with rice, *N. bakeri* and *N. muiri* from China associated with Leersia.

Kamala *et al*. (2002) noticed planthoppers and leafhoppers associated with rice ecosystems of Andhra Pradesh, India. Two planthoppers *viz., N. lugens*, *S. furcifera* and seven leafhoppers, *viz*., *Austroagallia bifurcata*, *Cofana unimaculata*, *Deltocephalus pruthii.*, *Balclutha rubrostriata*, *Orosius orientalis* and *Scaphoideus sabourensis* were reported for the first time to be associated with rice ecosystem in Andhra Pradesh.

Lakshmi Narayana *et al.* (2005) identified different planthopper species (Delphacidae: Homoptera) associated with different rice ecosystem for the first time in Andhra Pradesh *viz., N. lugens, S. furcifera,* and *Toya* sp.

Biodiversity of planthoppers of family Delphacidae associated with graminacious crops like rice and sugarcane from five states of South India *viz*., Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Kerala were studied by Rao and Chalam, 2007 and identified 24 planthoppers species of 17 genera. Species like *N. lugens, S. furcifera*, *S. kolophon* , *Cemus sp.*, *Sardia sp.* and *Tagosodes pusanus, Coronacella sinhalana, Euidella sp., Harmalia sp., Latistria sp., Opiconsiva sp., Perkinsiella sp., P. sinensis, Stenocranus sp., Toya bridwelli, T. propinqua and Tropidocephala sp.* were noticed.

However, the delphacid distant genus *Nilaparvata* consists of 18 species, with most occurring in the Oriental, Australian and Afro-tropical regions. *Nilaparvata* is an extremely important genus economically, with one of its members, *N. lugens*, a major pest of rice and other two important species identified were *N. bakeri* and *N. muiri* in China, on rice (Bartlett and Deitz, 2007).

Christopher and Mammen (2009) recognized the twenty families comprising approximately 1400 genera and 12,000 species. Fulgoroid families are distinguished from each other based mainly on the shape of the head, the spination of the hind tarsi, and the veination of the forewing.

Similarly Kunz (2010) investigated the biodiversity of plant and leaf hopper in vineyards of Austria and 56 Auchenorrhyncha species were identified. The most numerous being *Psammotettix confines* (Dahbom.), *Laodelphax straitella* (Fallen), *Dicranotropis hamate* (Boheman), *Psammotettix alienus* (Dahlbom), *Laodelphax striatella* (Fallen), *Dicranotropis hamate* (Boheman), *Psammotettix alienus* (Dahlbom), *Falcotoya minuscuula* (Horvath), *Macrosteles cristatus* (Ribaui), *Dictyophara europaea* (Linnaeus), *Philaenus spumarius* (L.), and *Anaceratagallia ribauti* (Ossiannilson).

Similarly, Shao-ji *et al.* (2010) collected about 441 adult planthopper specimens from the winter rice agro ecosystems from southern Yunnan, China, of which 22 species belonging to two subfamilies (one species belongs to Stenocraninae and 21 species to Delphacidae). Mainly *S. furcifera*, *S. vibix, S. colophon, N. lugens*, *N. bakeri, N. castanea. N. muiri*, *Nycheuma cognatum*, *Peregrinus maidis* (Ashmead), Laodelphax *striatellus* (Fallén), *Nycheuma cognatum* (Muir), and *Pseudosoga tavatrenus* (Fennah) *Toya terri, T, pasanus, Cemus punctatus, C. nigromaculocus, C. nigropuntatus, Maidis propinqua. Tropidocephala flaviceps,* and *T. brunnipennis.*

The biodiversity of planthoppers under delphacidae from four agro climatic zones of Maharashtra *viz.*, Western Vidarbha plains (Akola), Wet South Konkan (Karjat), Northern hills Maharashtra (Dhule), Moist Eastern Vidarbhan hills (Gadchiroli) were studied by Damdal *et al.* during 2013. A total of six delphacids were recorded on different hosts plants collected manually and through light traps.

Biodiversity of jassids from agro ecosystems of Kolhapur district, Maharashtra was studied and results revealed that 22 species of jassids belonging to the genera *Deltocephalus*, *Empoasca*, *Nilaparvata*, *Nephotettix*, *Recilia*, *Cofta* and *Typhlocyba* which have been found damaging various crops of Kolhapur region. These species were brown plant hopper *N. lugens*, white black plant hopper, *S. furcifera*, green leaf hopper, *Nephotettix nigropictus*, *N. virescens*, white leaf hopper, *Cotta spectra*, zigzag leaf hopper, *Recilia dorsalis* (Mots.), blue leaf hopper, *Typhlocyba maculifrons* (Mots.), *Laodephax striatella* (Fall.), grapevine leaf hopper, *Erythroneura sp*., *Idioscopus clypealis* (Lethi.), *I. atkinsoni,* potato jassid, *Hishimonus phycitus*, cotton jassid, *Empoasca devastan*, *E. notata, E. flarescens*, *E. kerri*, *E. parathea*, *Deltocephalus vulgaris*, *D. trisuli*, *D. truncates* and *D. brevis*.(Sathe *et al.* 2014).

Kumaresan *et al.* (2015) identified 22 planthopper species of 16 genera from Kolli hills of Tamilnadu. Which were mainly, *Cemus levicula, Euidella horvathi, Harmalia anacharsis, Latistria testacea, Nilaparvata lugens, Opiconsiva balteata, Peregrinus maidis, Perkinsiella saccharicida, P. sinensis, Purohita cervina, Sardia rostrata, Sogatella furcifera, S. vibix, S. kolophon, Stenocranus distinct, Tagosodes pusanus, Terthronal bovittatum, Toya attenuate, Toya bridwelli, T. propinqua, Tropidocephala flaviceps* and *T. serendiba.*

The experiment was conducted to analyze the occurrence of rice planthoppers in diversified farming on Chongming Eco-Island in China from 2006 to 2014 in rice agro ecosystem and identified three species like *N. lugens, S. furcifera* and *L. striatella* which were more predominant in those regions (Nianfeng and Ming, 2015).

Noor and Mubashar (2016) showed that the diversity of insect pest of major rice growing areas from China, Bangladesh, India, Philippines, Thailand and Sri Lanka found 9 different homopteran species in that 2 were delphacidae (*N. lugens, S. furcifera* and 5 were cicadellidae (*R. dorsalis, N. nigropictus, C. spectra, Thaia oryzivora, T. rubigenosa*).

2.2 To study the seasonal incidence of rice planthoppers in Tunga-Bhadra Project (TBP) areas of Karnataka

Nasu (1967) recorded increased population of *N. lugens* during September-October in Veitnam and also observed extensive incidence during June-September at Hunan region of China. Similarly, incidence of BPH was more during Aug-September with peak during October-November but then onwards declined.

However, two peak populations of BPH occurred during April-May in summer and October- November in *kharif* with higher population occurred during December and July on grasses in the absence of paddy crop (Prabhuswamy, 1972).

Meanwhile, the extensive damage due to the outbreak of planthopper was observed on rice which was grown during July to September in Thanjavur district of Tamil Nadu (Velusamy *et al.* 1975).

The Delphacids populations were most abundant from October-November on rice (Ammar *et al.* 1978) whereas, Chatterjee (1978) reported hopper burn during April on rice and the disappearance of pest during May, when the crop was harvested.

Varadharajan *et al.* (1979) opined that the most favorable period required for BPH was during second week of August and the second week of October with peak activity in the beginning to the end of the September in Aduthurai of Tamil Nadu.

The crop harvested during October-November was infested with greater number of *N. lugens* compared to those harvested earlier. Crop sown in July were severely infested which resulted in hopperburn (Mancharan and Jayaraj, 1979).

Inception of adult planthopper was occurred during the last week of August and first week of September then reached the peak during October and first week of November and afterwards declined (Misra, 1980).

The seasonal abundance of delphacid, *S. furcifera* on rice in eastern Uttar Pradesh, India, was studied in the *kharif* season of 1976-77 by light trapping at two sites. Maximum population of the pest occurred in the second week of October (Mishra and Prasad, 1985).

The phototropic response and field population of two planthoppers of rice were studied during wet season, in Madhya Pradesh during 1986-87 (Khan and Kushwaha 1991). The light trap data showed that *N. 1ugens* and *S. furcifera* were prevalent from September to December with peak activities in 39^{th}, 42^{nd} and 45^{th} SMW.

Similarly, Shivamurthappa (1993) observed the occurrence of maximum population of planthoppers during September to October and April to May and minimum during December to February and July to August in Mandya district.

Jeyrani *et al.* (2000) correlated the field incidence of BPH and light trap catches and found positive correlation between two factors. Further observed the more incidence of BPH during September with peak activity during October-November.

The incidence of *S. furcifera* was usually more common during early crop stage while *N. lugens* was usually prevalent during later stages of the crop growth as opined by Pathak and Khan, 2002. Further, they recorded the increased population of WBPH during July to Aug and it was declined during September to October while BPH population was increased during September to October in Punjab.

The inception of BPH was appeared during 2nd week of August and persists till middle of November with two peaks at 3rd and 4th of October in *kharif* rice of West Bengal as observed by Satphati and Mukhopadyaya, 2002.

Vijaykumar and Patil (2004) carried out field survey during *kharif* and observed the inception of BPH in the month of October and continued till the harvest of the crop with peak population during second fortnight of November in Raichur, Manvi and Sindhanoor whereas, It was during first fortnight of November in Sirguppa and Gangavathi of Karnataka.

The experiment on migration of brown planthopper in China from 1977-2007 with an incandescent light, was conducted by Yan and Wang (2008) and found initial population build in late April-May and the initial outbreak was in June-July. There were two peaks in the population in one year, the first peak was (early rice peak) appeared in late July- late August and second peak (late rice peak) appeared in September to October.

Dupo and Barrion (2009) conducted research on population fluctuations of brown planthoppers in six different sites of India (Aduthurai, Coimbatore, Maruteru, Sambalpur, Kaul, and Pattambi) and observed declining trend of BPH during 1998-2003, while it was revert trend during 2003-2005 and again population was decreased during 2005-2007.

The incidence of BPH in the rice fields of Chamarajnagar district was more in the first fortnight and second fortnight of November during 2009 as studied by Prashant *et al*. (2010). Further observed 40 per cent of damage caused by BPH alone.

The experiment on population dynamics in relation to temperature was carried out by Firake *et al.* (2010) in Tamil Nadu, and opined that the favorable period required for *N. lugens* for perpetuation was last week of August up to third week of September with the minimum temperature ranges from 24.8 $^{\circ}$C to 26.8 $^{\circ}$C.

Chander and Palta (2010) stated that the peak population of BPH was more during the June to August with favorable environmental conditions like cloudy weather and well distributed intermittent rains with high humidity.

Rajendra Prasad (2010) studied occurrence of BPH. It was found that the pest was noticed only during reproductive stage i.e. second fortnight of October and increased steadily reaching a peak population of 22.80 and 16.20 nymphs and adults per hill in Mundgod and Banavasi, respectively, thereafter the population declined at harvest. The mean population in this ecosystem was 19.50 nymphs and adults per hill at reproductive stage.

Chaudhary *et al*. (2014) conducted an experiment during the *kharif* season of 2011-12, at the Agricultural Research Farm, BHU Varanasi to evaluate the seasonal abundance of brown planthopper. It was evident that BPH appeared on the crop after 40-50 days after transplanting i.e. around last week of August. The incidence of BPH in the beginning was very low. As soon as the rain stopped in last week of September then the population increased with the vegetative stage of crop and reached highest in third week of October. The incidence of the pest was severe in the last week of September to last week of October. The population of BPH was positively correlated to temperature and relative humidity, whereas, a negative correlation was found to rainfall.

2.3 To study the biology of brown and black morphs of brown planthopper *N. lugens*

2.3.1 Site of oviposition and eggs

Brown planthopper lay eggs in small groups inside the air cavities of leaf sheath and midrib by making an incision with ovipositor and inserting the egg batches inside the tissues. The adult macropterous female laid about 100 eggs in their life span, while brachypterous female lay about 300-700 eggs. Eggs hatched in 4-8 days (Nasu, 1967).

The laided eggs were more or fewer crescent shaped, and were constricted near the caps which are flat, one end of the egg was united near the egg caps and the other one remained free. The eggs were cream to whitish in color when freshly deposited (Misra and Prasad, 1985).

Nalinakumari and Mammen (1975) reported that the eggs of BPH were thrusted within the mid region of the outer leaf sheath in the rows of 2 to 12 eggs. Fecundity rate of female ranges from 151 to 195, average being 172.40 eggs. Egg laying period varied from 10 to 28 days. Number of eggs laid by brachypterous female was 83. BPH prefers to feed in leaf sheath and leaf blade at the base of the plant near the water portion where it gets the microclimate for their growth and development.

Macropterous females migrate into rice fields shortly after transplanting, laying groups of 5-15 eggs into the sheaths or midribs of leaves. The eggs were covered with a dome-shaped egg plug secreted by the accessory glands of the female (Mochida and Okada, 1979).

Laboratory study in Maharashtra on the bionomics of BPH on rice seedlings stated 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. (Khaire and Dumbre, 1981).

The experiment on number of eggs laid by the brachypterous (B-form) and macropterous (M-form) females and their pre-ovipositional period under different prevailing environmental conditions were carried out by Zeng *et al.* (1989). The results revealed 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 17 to 32 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.

Heinrichs and Mochida (1994) opined that when the adult WBPH population was high, eggs were found in the upper parts of rice plant. The egg laying sites appear as brownish streaks and red eye spots appear at one end of the egg before hatching.

The egg stage of BPH lasted about 7 to 11 days in the tropics. Brachypterous form began to oviposit earlier than macropterous form (Dupo and Barrion, 2009).

2.3.2 Incubation period and hatchability

Similarly, Mochida and Okada (1979) recorded an incubation period of BPH as 7.9 and 8.5 days at constant temperature of 28 ºC and 29 ºC, respectively.

Misra (1980) noticed the increase in incubation period with decrease in temperature. Further he also reported that the period of incubation ranged from 6-8 days with an average of 6.5 days during the month of June-October, 11-14 days with an average of 12.6 days during the month of November-January and 6-8 days with an average of 7.6 during the month of February-April.

Nair (1986) reported that egg hatched in 4-9 days also 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 lay on an average 232.40 eggs.

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.

2.3.3 Nymphal period

Mochida (1964) noticed that the temperature conditions in the nymphal stage affect the longevity and oviposition of adult hoppers. The maximum growth of nymphs occurs at a temperature range of 28 ºC to 30 ºC. The final instar 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.

Nair (1986) reported that the nymph undergo 5 instars during nymphal period of 10-18 days, also reported that the total life-cycle from egg to adult took 19-23 days for completion.

There were totally five instars before nymph attains into adults. The total 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).

Heinrichs (1994) observed that nymphs were creamy white with a pale brown tinge, later becoming dark brown and there were four to five moults.

Dupo and Barrion (2009) observed 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 developments were influenced considerably by temperature. The nymphal period of planthoppers varied widely depending on food conditions, density during development, and other environmental factors.

2.3.4 Adult and its longevity

The total longevity of females varied from 14 to 30 days with an average of 21 days and that of males from 14 to 21 days with an average of 18.40 days (Nalinakumari and Mammen, 1975).

The dimorphic adults with two wing forms may be in *N. lugens*, where in the male is shorter (4.5 mm) than the female (5.0 mm), Male *N. lugens* can mate with a maximum of nine females in 24 hours and an individual female can copulate more than twice during its life time (Mochida and Okada, 1979).

Khaire and Dumbre (1981) reported that adult life span of male and female were16.5 and 27 days, respectively, while the longevity of males varied from 14 to 21 days with an average of 18.4 days and that of females from 14 to 30 days.

The survival rate was the highest at around 25°C. Adult BPH lived for 18 to 20 days while, it took three to four weeks to complete a generation and the adult longevity of BPH differed considerably between laboratory and field conditions, the maximum values being 36.6 and 9 days, respectively (Dupo and Barrion, 2009).

Kaur (2014) studied 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 2010.

2.3.5 Pre-oviposition, oviposition and post-oviposition period

The pre-oviposition period of planthoppers was about one day in the month of June-October and also during Feb-April but it took 2-3days during November-January with an average of 2.3days during November-January it takes of about 2-3 days averagely 2.30 days (Misra, 1980).

However, the effective oviposition period varied between 38-40 days in the month of June-October, 40-42 days during November-January and 35-37 days during February-April (Misra, 1980).

The amount of eggs laid by the brachypterous and macropterous females of the BPH and their pre-oviposition period were studied under different environmental conditions. The result revealed that the pre-ovipositional period of the macropterous form was distinctly longer than that of the brachypterous form under temperature ranging from 22 ºC to 31 ºC (Zeng *et al.*, 1989).

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 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).

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 2010 (Kaur, 2014).

MATERIAL AND METHODS…

III. MATERIAL AND METHODS

Studies were carried out on “morpho-species, seasonal incidence and biology of planthopper on rice” at Agricultural Research Station (ARS), Gangavathi, Koppal district, Karnataka during *Kharif* and rabi 2017-18. The ARS, Gangavathi is situated at 76º 32’ E longitude and 15º 15’ N latitude with an altitude of 419 m above mean sea level. The average rainfall received during the period of crop growth was 243.5 mm. Agricultural Research station Dhadhesugur, Bellary district. It is situated in northern dry zone (Zone-3) of Karnataka at 15º 46″ E latitude and 76º 45″ E longitudes with an altitude of 358 m above mean sea level. The details of the material and methods employed during the course of study are given in this chapter.

3.1 To study the occurrence of morpho-species of rice planthoppers in Tunga-Bhadra Project (TBP) areas of Karnataka

3.1.1 Study area

Experimental studies were carried out in intensive crop growing regions like Gangavathi and Siraguppa taluk. In Gangavathi taluk two locations *viz.,* ARS, Gangavathi and Kesaratti which is about five kilo meter away from ARS, Ganagavathi. In Siraguppa taluk two loctions *viz.*, ARS, Dhadhesugur and a farmer’s field in Dhadhesugur which was adjacent to the farm field were selected for experimental purpose. The crop was transplanted on 8th September in ARS, Gangavathi, 16th September in Kesaratti, 14th September in ARS, Dhadhesugur and 17th September in farmer’s field in Dhadhesugur during *kharif* 2017. In second season crop was transplanted on 19th January in ARS, Gangavathi, 16th January in Kesaratti, 17th January in ARS, Dhadhesugur and on 22nd January in farmer’s field in Dhadhesugur during rabi-summer 2017-18.

3.1.2 Light trap studies

In each location, crop was raised in ten gunta area with all agronomic practices except plant protection in ARS, Gangavathi and ARS, Dhadhesugur with plant protection measures in Kesaratti and farmer’s field in Dhadhesugur using popular variety BPT-5204. The selected paddy field was divided into two equal parts, with one part to record planthopper density and another part for light trap collections of macropteran adults. The light trap was designed in such a way that the light intensity was covered within a radius of five gunta area. Rechargeable LED light of 220V was used for the collection of planthoppers in the paddy field (Art No. L6010) (Plate 1). This trap covers a radius of about 4-5 m. Observations were started 3-4 Weeks after transplanting (WAT) up to 12-13 WAT in each location at 10 days interval. Light trap was kept in field between 6.30 and 8.30 pm. Further, only planthoppers were grouped based on morphological characters and the observation on population of BPH and WBPH was taken. The observations were subjected to chi-square test to know the significant variation within populations of BPH and WBPH individualy. Further, student t-test was carried out to know the significant variation between BPH and WBPH populations.

3.1.3 Processing of the specimens for study

The field collected specimens of planthoppers were mounted singly on triangular card points by using Fevicol R to have both visible and physical access to the head, wings and abdomen on which identification is based. The data label with information regarding locality, date of collection, was transfixed separately to the respective specimen for the morphometric studies under NIKON SMZ 25 microscope (Plate 2).

Further only planthoppers was grouped and they were preserved in 75% Ethyl alcohol. Further studies like structural variation of paramere, anal tube and aedeagus were carried out. Finally, to confirm the exact nomenclature of the collected specimen, experts Dr. C. A. Virakthamath Professor (Emeritus) GKVK, UAS, Bangaluru and Dr. Shobha Rani, Assistant professor (Entomology), Agriculture Research Station, Bidar were consulted.

3.1.4 Preparation of genitalia

For the study of male genitalia the procedure advocated by Oman (1949) and Knight (1965) for the leafhoppers was followed. The male specimen was gently supported on a cork piece on its back, and with the help of a fine needle the abdomen was detached from the thorax at the junction of the two. The abdomen was then transferred to a test tube containing a few milliliters of 10% caustic potash. This was warmed gently in a water bath till the convection currents were observed in the solution (about five minutes).The abdomen was removed to a glass cavity dish containing water and the macerated soft tissues were removed with the help of bent needles. After washing the traces of KOH in water, the abdomen was transferred to glycerin in a glass cavity dish for further dissection (separation of genitalial parts from the genital capsule) and the observations were made under a stereoscopic microscope. After study the dissected parts were placed in the abdomen of the specimen and preserved in a drop of glycerin held in microvial.

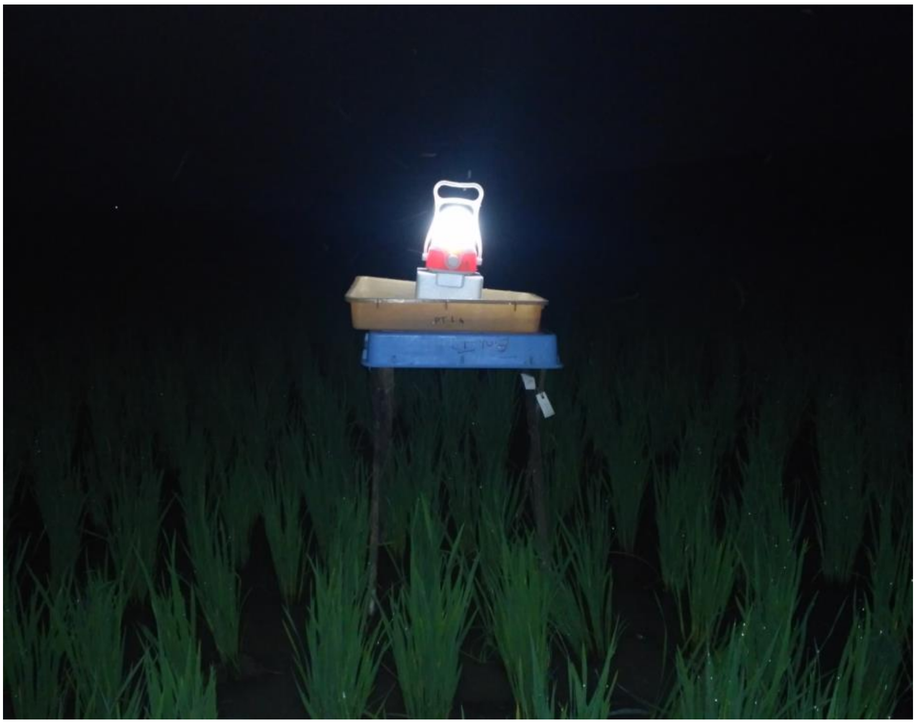


Plate 1: Setup of light trap in the field for the collection of planthoppers

Plate 2: NIKON SMZ 25 microscope used for morphometric studies.

3.1.5 Measurements

Twenty each male and female specimens of each species *viz.*, brown morph, black morph of brown planthoppers and white backed planthoppers were used for the measurement. The measurements of various body parts were made with the help of a standardized ocular micrometer placed in one of the eyepieces of stereoscopic microscope. All the measurements are expressed in millimeters. Various measurements taken on described in table 1.

Table 1. Measurements of different body parts of planthoppers

Name of the body region	Description
Total length	Distance between the anterior most point of head and the posterior tip of the folded forewings along the middorsal line or tip of the abdomen.
Clavus	Length along the claval suture from the articulatory point of forewing (with mesothorax).
Forewing	Distance between the articulatory point of forewing (with mesothorax) and its apical tip.
Frons	Distance between the anterior and the posterior margin of the frons along the mid ventral line.
Postclypeus	Distance between frontoclypeal suture and the posterior margin of post clypeus.
Pronotum	Distance between the anterior and posterior margins of the pronotum along the middorsal line.
Scutellum	Distance between posterior margin of pronotum and caudal apex of scutellum along the middorsal line.
Distance between eyes	Distance between the outer margins of eyes dorsally, towards anterior margin of head.
Vertex	Distance between the anterior and the posterior margins of vertex along the middorsal line.

Width of forewing	Distance measured in middle line of forewing where it is having maximum width.
Width of frons	Distance between the lateral carinae of frons at its maximum width.
Width of head	Distance between the lateral margins of the eyes where the width is maximum.
Width of postclypeus	Distance between the lateral margins of clypeus at the anterior margin at its maximum width.
Width of pronotum	Distance measured across the posterior angles where the pronotum is with maximum width.
Width of vertex	Distance between the lateral carina of vertex at the basal margin.

3.1.6 Measurements of different parts of planthoppers

1. Dorsal view

A. Total length of body

B. Length of clavus of forewing

C. Total length of forewing

2. Head and thorax

D. Distance between eyes

E. Length of vertex

F. Width of vertex

G. Width of head

H. Width of pronotum

I. Length of scutellum

J. Length of pronotum

3. Forewing

K. Width of forewing

4. Face

P. Length of frons

Q. Width of frons

R. Length of postclypeus

S. Width of postclypeus

3.2 To study the seasonal incidence of rice planthopper in Tunga-Bhadra Project areas of Karnataka

The studies on seasonal incidence of rice planthoppers were carried out in ARS, Gangavathi, Kesaratti, ARS, Dhadhesugur and in farmers field at Dhadhesugur during 2017-2018. In each location five gunta area was selected for the study.

The five gunta area was equally divided into subplots of 5m X 5m for recording observations. Systematic field investigations were conducted to explore the population dynamics of planthoppers both by light trap and field observation studies (Plate 3). The observation were started in *kharif*-2017 (from September to December) from 3-4 WAT and continued up to crop maturity stage (12-13 WAT). In each plot, 10 hills were selected randomly. From each hill, the planthoppers (Plate 4) were collected with the help of aspirator and transferred to vails (Plate 4) with at most care to avoid escape of any fauna. Later, only planthoppers were grouped based on morphology and the observation on population of BPH and WBPH was taken. Same procedure was carried out for all 10 hills in five subplots. Finally, collected insects were preserved in 75% ethyl alcohol. Same procedure was fallowed during rabi-summer 2017-18 (January-April). The observations were subjected to chi-square test to know the significant variation within populations of BPH and WBPH individually. Further, student t-test was carried out to know the significant variation between BPH and WBPH populations.

Plate 3: Destructive sampling technique for collection of samples

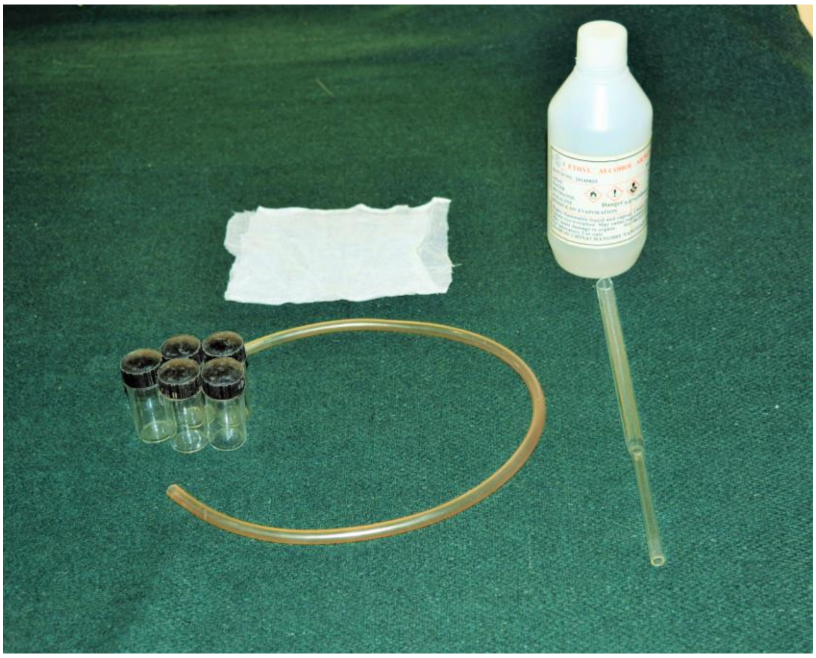


Plate 4: Materials used to collect the planthopper specimens from field

Plate 5: Population of BPH in field condition

3.3 To study the biology of brown and black morphs of brown planthopper, *N. lugens*

The biology of brown planthoppers (BPH), *N. lugens* was conducted on variety BPT-5204 during October-November 2017-2018 under the laboratory conditions at Department of Entomology, ARS Gangavathi.

3.3.1 Materials required

Test plants

The paddy cultivar BPT-5204 was collected from ARS, Gangavathi and raised in the cement rings (for nursery) for various biological studies of planthoppers.

3.3.2 Rearing and maintaining the pure culture

The nymphs and adults populations were collected from a farmer's field (Plate 5) adjoining the research farm. These were released on 40-45 days old potted plants of variety BPT-5204 kept in the cage to initiate the planthoppers culture (Plate 6).

Substantial population was maintained throughout the study period to get sufficient supply of different growth stages of hopper for conducting various experiments on biology of the planthoppers. The plants that died owing to insect feeding in the rearing cage were replaced with the fresh potted plants of the same age. The cage was cleaned as and when required.

3.3.3 Raising of test plants

The seed of cultivar BPT-5204 was sown in cement rings containing puddle soil and farm yard manure (FYM) in the ratio of 1:1. The rings were watered as and when needed. The 25 days old seedlings were transplanted in plastic pots (15 cm height and 8 cm diameter) containing puddled soil as per requirement of experiments.

3.3.4 Oviposition period

For these studies plants were raised in plastic cups. One pair of fresh adults (male and female) were released on 30 days, 20 old rice plants of BPT-5204 raised in plastic cups covered with OHP sheets (Plate 7). Each cup represents a replication. Plants were replaced daily by a fresh plant of the same age. The plants were observed for eggs every

Plate 6: Potted plants in cages used for obtaining the pure culture

Plate 7: Experimental setup for biological studies

day in the morning. The pairs were serially transferred daily to new rice plants under mylar cages until the death of female. Microscopic observations were made at every 24 hr interval. 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 continued was taken as oviposition period.

3.3.5 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 20 rice plants of BPT-5204 for oviposition. The time between the release of the female and appearance of the nymphs was considered as incubation period.

3.3.6 Nymphal period

The cupped plants were filled with water and covered with OHP sheets (15cm height and 8cm diameter). The newly emerged nymphs in batches of 5 each were released on 35 days old plants. Twenty such replications were maintained. The observation on number of nymphal period was taken periodically until all the nymphs become adult.

The interval between two moultings was taken as duration of the nymphal instar and the period between the time of release of freshly hatched nymph and the adult emergence was taken as the total nymphal period. Nymphal instar observations were taken at 12 hrs of interval.

3.3.7 Adult longevity

Five pairs of newly emerged macropterous adults were introduced on each of the five potted plants covered with OHP sheets. The longevity was taken as the period from the adult emergence till the death of the adults (both males and females, separately).

3.3.8 Comparative studies on biology of different morphs of brown planthopper

Comparative biological studies on different morphs like brown and black morphs of *N. lugens* was conducted on variety BPT-5204 during Feb-March 2018, using the same procedure fallowed for brown morph of brown planthopper under the laboratory conditions at Department of Entomology, ARS Gangavathi.

EXPERIMENTAL RESULTS…

IV. EXPERIMENTAL RESULTS

The results of the investigations carried out during the period June 2017- May 2018 on occurrence of morpho-species, seasonal incidence and biology of planthopper on rice are presented here under.

4.1 To study the occurrence of morpho-species of rice planthoppers in Tunga-Bhadra project (TBP) areas of Karnataka

Brown planthopper, *Nilaparvata lugens* (Stal.) and white backed planthopper *Sogatella furcifera* (Horvath) were collected from two locations of Tunga-Bhadra Project (TBP) areas *viz.*, Gangavathi and Dhadhesugur. The collected specimens were dried and carefully separated as brown planthopper and white backed planthopper. Among brown planthopper, two forms were found which are phenotypically different in their colouration and they are brown morph (Plate 8 and Plate 10) and black forms (Plate 9 and Plate 10).

4.1.1 Study of genital structures and morphometrics of different body regions of brown and black morph of *N. lugens*

The male genitalia of brown planthopper of both the colour forms were dissected to study the structural variation of paramere, anal tube and aedeagus ((Plate 11) of all the insects of two locations. All these structures were observed under NIKON SMZ 25 microscope. It was observed that there were no variations in the genital structures of brown and black forms and hence, these two forms are mere colour variants and are not different species or subspecies in both the locations. In morphometric studies like variation with respect to the length of clavus, clypeus, forewing, frons, pronotum, scutellum, vertex, total length and width of clypeus, forewing, frons, head, pronotum, vertex and distance between eyes of both the forms also revealed that there were no observed variations (Table 2). Hence, it was concluded that these belong to a single species as *Nilaparvata lugens* (Stal.). This colour variation is more pronounced in nymphs and less pronounced in adults. Within the nymphs also only later instars shows remarkable variations in colour.

Macropterous adult male (lateral view) of brown planthopper *N. lugens* (brown morph)

Macropterous adult female (lateral view) of brown planthopper *N. lugens* (brown morph)

Plate 8: Male and female (lateral view) of brown morphs of brown planthopper

Macropterous adult male (lateral view) of brown planthopper *N. lugens* (black morph)

Macropterous adult female (lateral view) of brown planthopper *N. lugens* (black morph)

Plate 9: Male and female (lateral view) of black morphs of brown planthopper

Macropterous adult female and male (dorsal view) of brown planthopper *N. lugens* (brown morph)

Macropterous adult female and male (dorsal view) of brown planthopper *N. lugens* (black morph)

Plate 10: Female and male (dorsal view) of Different morphs of brown planthopper

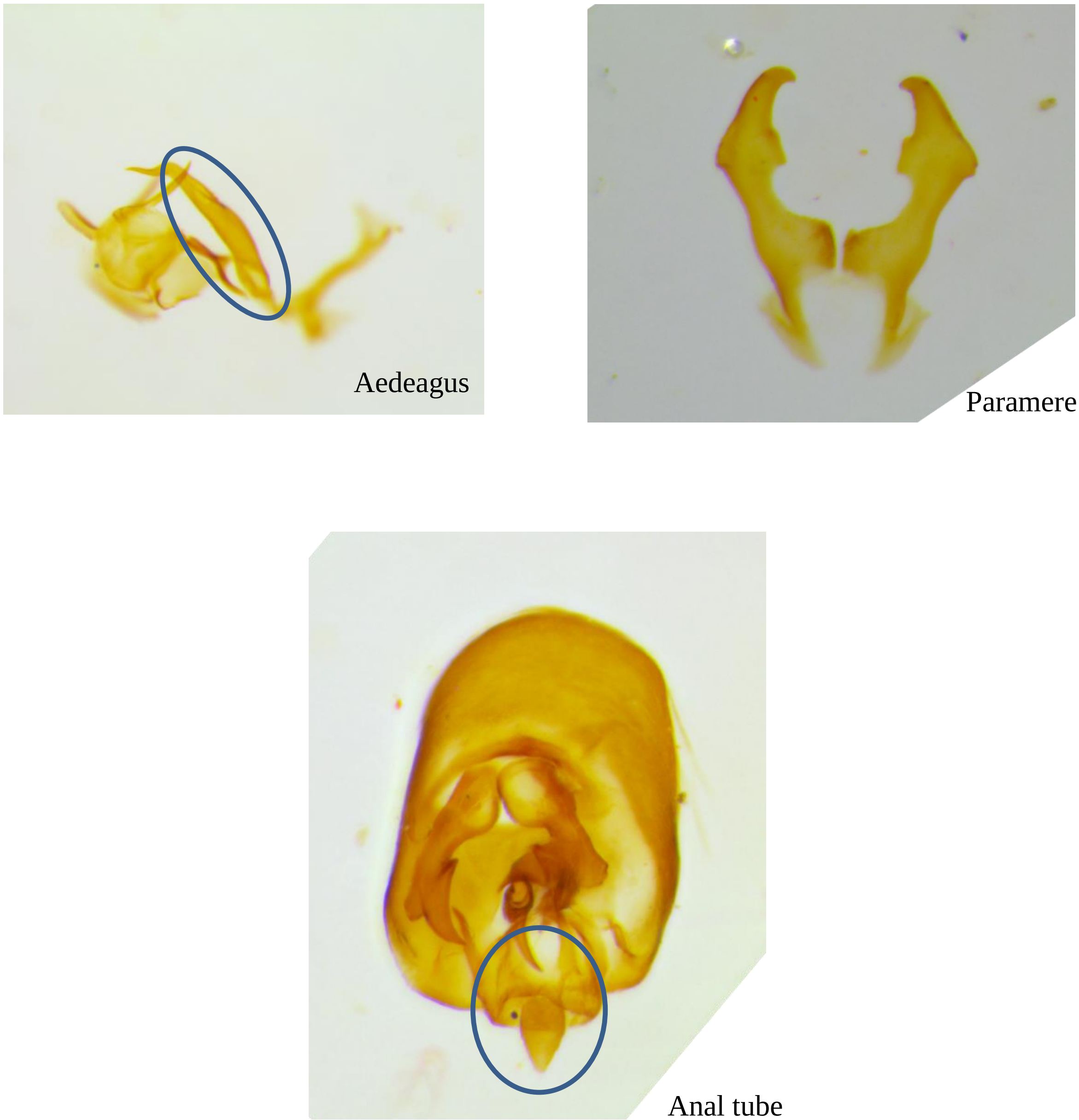


Plate 11: Genital structures of brown plant hopper, *N. lugens*

Table 2: Morphometrics of different body regions of brown and black morph of *N. lugens*

Species body regions	***N. lugens* (Stål) (Brown morph)**		***N. lugens* (Stål) (Black morph)**	
	Male	**Female**	**Male**	**Female**
Length	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**
Clavus	1.40±0.15	1.49±0.11	1.35±0.06	1.53±0.11
Clypeus	0.21±0.03	0.21±0.01	0.21±0.05	0.24±0.05
Forewing	2.31±0.01	2.53±0.13	2.33±0.15	2.63±0.16
Frons	0.38±0.05	0.42±0.06	0.39±0.05	0.45±0.09
Pronotum	0.16±0.01	0.19±0.01	0.16±0.02	0.24±0.02
Scutellum	0.22±0.04	0.26±0.02	0.25±0.04	0.26±0.02
Vertex	0.17±0.02	0.19±0.01	0.18±0.02	0.21±0.03
Total length	2.41±0.11	3.04±0.17	2.65±0.13	3.24±0.21
Width	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**
Clypeus	0.18±0.01	0.20±0.02	0.18±0.03	0.18±0.01
Forewing	0.68±0.06	0.77±0.06	0.71±0.03	0.80±0.06
Frons	0.18±0.01	0.22±0.02	0.20±0.02	0.24±0.02
Head	0.46±0.10	0.56±0.03	0.58±0.09	0.59±0.04
Pronotum	0.59±0.10	0.79±0.03	0.76±0.09	0.78±0.08
Vertex	0.19±0.02	0.22±0.02	0.18±0.02	0.23±0.02
Distance between Eyes	0.18±0.03	0.20±0.02	0.19±0.02	0.24±0.12

Mean of 20 observations

4.1.2 Light trap collection of brown and black morph of *N. lugens* in different locations (*kharif*-2017)

Paired t-test analysis was carried out to identify the level of significance among the populations of brown and black morphs of BPH during the light trap collection (*kharif*). The results revealed that populations of both morphs did not show any significant variations during the observation period in all locations *viz.*, ARS, Gangavathi ($t=1.05$; $P>0.05^{NS}$), Kesaratti ($t=0.067$; $P>0.05^{NS}$), ARS, Dhadhesugur ($t=0.08$; $P>0.05^{NS}$) and farmer's field in Dhadhesugur ($t=0.53$; $P>0.05^{NS}$) (Table 3).

4.1.3 Light trap collection of brown and black morph of *N. lugens* in different locations (rabi-summer 2017-18)

Similarly, in second season (rabi-summer) also the populations of both morphs did not show any significant during the observation period in all locations *viz.*, ARS, Gangavathi ($t=1.68$; $P>0.05^{NS}$), Kesaratti ($t=2.28$; $P>0.05^{NS}$), ARS, Dhadhesugur ($t=0.71$; $P>0.05^{NS}$) and farmer's field in Dhadhesugur ($t=1.35$; $P>0.05^{NS}$) (Table 4).

4.2 To study the seasonal incidence of planthoppers in Tunga-Bhadra project (TBP) area of Karnataka

4.2.1 Light trap Studies (*Kharif*-2017)

4.2.1.1 Light trap collection of *N. lugens* and *S. furcifera* in ARS, Gangavathi (*kharif*-2017)

Light trap collections of BPH and WBPH when subjected to Chi square test revealed significant differences across different dates of observations (χ^2_{cal}= 36.48** and χ^2_{cal}=18.35**). Number of BPH adults trapped increased gradually from 25 DAT (χ^2=7.54; n=9) and reached maximum at 75 DAT (χ^2= 18.63; n=42). However, in WBPH population, the number of adults trapped increased initially from 13 (χ^2= 0.87) to 32 (χ^2= 13.67) from 25 DAT to 45 DAT but, started decreasing significantly thereof reaching a minimum population of 9 at the end of the observation period of 75 DAT (χ^2= 2.6) (Table 5a).

Populations of BPH and WBPH did not vary significantly when subjected to student t-test ($t= 0.81$; $P>0.05^{NS}$). The lowest BPH population of 9 adults/trap was recorded on 25 DAT, whereas, WBPH recorded 13 adults/trap during 25 DAT. The highest number of BPH (42) was recorded at 75 DAT compared to 32 WBPH observed during 45 DAT (Table 5b).

Table 3: Light trap collection of brown and black morph of *N. lugens* in different locations (*kharif*-2017)

a) ARS, Gangavathi

DAT	Brown morphs/trap	Black morphs/trap
25	8	1
35	11	0
45	14	7
55	9	8
65	14	17
75	18	24
t-value =1.05 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

b) Kesaratti

DAT	Brown morphs/trap	Black morphs/trap
25	13	3
35	17	2
45	16	8
55	21	12
65	16	33
75	16	41
t-value=0.067 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

c) ARS, Dhadesugur

DAT	Brown morphs/trap	Black morphs/trap
25	11	0
35	8	5
45	5	2
55	11	5
65	14	20
75	12	27
t-value =0.08 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

d) farmer's field in Dhadesugur

DAT	Brown morph/trap	Black morphs/trap
25	9	0
35	11	2
45	11	6
55	13	11
65	15	21
75	17	26
t-value =0.53 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

Table 4: Light trap collection of brown and black morph of *N. lugens* in different locations (rabi-summer 2017-18)

a) ARS, Gangavathi

DAT	Brown morphs/trap	Black morphs/trap
25	12	9
35	11	25
45	9	22
55	11	18
65	9	12
75	8	5
t-value =1.68 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

b) Kesaratti

DAT	Brown morphs/trap	Black morphs/trap
25	7	12
35	28	29
45	14	22
55	11	19
65	14	11
75	7	12
t-value =2.28 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

c) ARS, Dhadesugur

DAT	Brown morphs/trap	Black morphs/trap
25	17	9
35	13	24
45	11	17
55	12	13
65	9	14
75	7	4
t-value =0.71 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

d) Dhadesugur

DAT	Brown morph/trap	Black morph/trap
25	26	15
35	13	20
45	17	22
55	9	26
65	11	18
75	6	11
t-value =1.35 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

Table 5a: Light trap collection of *N. lugens* and *S. furcifera* in ARS, Gangavathi (*kharif*-2017)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	9	21.83	7.54	13	16.83	0.87
35	11	21.83	5.37	14	16.83	0.47
45	21	21.83	0.031	32	16.83	13.67
55	17	21.83	1.06	19	16.83	0.27
65	31	21.83	3.85	14	16.83	0.47
75	42	21.83	18.63	9	16.83	2.6
			36.481			**18.35**
	χ^2_{cal}= 36.48** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=18.35**** **$\chi^2_{5\%}$ = 11.07** **$\chi^2_{1\%}$ =15.086**		

Table 5b: Student t-test

DAT	BPH/trap	WBPH/trap
25	9	13
35	11	14
45	21	32
55	17	19
65	31	14
75	42	9
t-value= 0.81 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

*Significance at (p=0.05) ** Significance at (p=0.01)

4.2.1.2 Light trap collection of *N. lugens* and *S. furcifera* in Kesaratti (*kharif*-2017)

There was a significant difference in BPH population (χ^2=42.33**) but non-significant difference in WBPH population collected from Kesaratti (χ^2=10.46) across different days of observations. The number of BPH adults trapped increased significantly from 25 DAT (χ^2=8.75; n=16) and reached maximum at 75 DAT (χ^2= 17.45;n=57). Whereas, in WBPH population, the number of adults trapped increased initially from 9 (χ^2= 2.5) to 24 (χ^2= 5.15) from 25 DAT to 45 DAT but later, started decreasing significantly reaching a population of 16 at the end of the observation period of 75 DAT (χ^2= 0.046) (Table 6a).

However, populations of BPH and WBPH did not vary significantly among themselves (t= 2.47; P>0.05^{NS}). The lowest BPH population of 16 adults/trap was recorded on 25 DAT, whereas, WBPH recorded 9 adults/trap during the same observation time. The highest number of BPH (57) was recorded at 75 DAT compared to 24 WBPH observed during 45 DAT (Table 6b).

4.2.1.3 Light trap collection of *N. lugens* and *S. furcifera* in ARS, Dhadhesugur (*kharif*-2017)

Observation was recorded that of previous location wherein, significant difference was observed in BPH population (χ^2=46.79**) but non-significant difference in WBPH population of ARS, Dhadhesugur (χ^2=10.56) during different periods of observations. Less number of BPH adults trapped initially from 25, 35 and 45 DAT and more from 55, 65 and 75 DAT with lowest population of 7 (χ^2=8.74) and highest of 41(χ^2=21.02). Whereas, in WBPH population, the number of adults trapped increased initially from 13 (χ^2= 0.23) to 24 (χ^2= 5.67) from 25 to 35 DAT but later, started decreasing significantly thereof reaching a minimum population of 9 at the end of the observation period of 75 DAT (χ^2= 2.29)(Table 7a)

With respect to student t-test, populations of BPH and WBPH did not vary significantly among themselves (t=0.88; P>0.05^{NS}). The lowest population of BPH (7 adults/trap) and WBPH (9 adults/trap) recorded on 45 and 75 DAT, respectively. The highest number of BPH (41) was recorded at 75 DAT compared to 24 WBPH observed during 35 DAT (Table 7b).

Table 6a: Light trap collection of *N. lugens* and *S. furcifera* in Kesaratti (*kharif*-2017)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	16	33	8.75	9	15.16	2.5
35	19	33	5.93	11	15.16	1.14
45	24	33	2.45	24	15.16	5.15
55	33	33	0	19	15.16	0.97
65	49	33	7.75	12	15.16	0.658
75	57	33	17.45	16	15.16	0.046
			42.33			**10.464**
	χ^2_{cal}= 42.33 $\chi^2_{5\%}$ =11.07 $\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=10.46 $\chi^2_{5\%}$ = 11.07 $\chi^2_{1\%}$ =15.086**		

Table 6b: Student t-test

DAT	BPH/trap	WBPH/trap
25	16	09
35	19	11
45	24	24
55	33	19
65	49	12
75	57	16
t-value= 2.47 P>0.05^{NS} P<0.05^{S}		

DAT: Days after transplanting

*Significance at (p=0.05)   ** Significance at (p=0.01)

Table 7a: Light trap collection of *N. lugens* and *S. furcifera* in ARS, Dhadesugur (*kharif*-2017)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	11	20.33	4.28	13	14.83	0.225
35	13	20.33	2.64	24	14.83	5.67
45	7	20.33	8.74	19	14.83	1.17
55	16	20.33	0.92	13	14.83	0.225
65	34	20.33	9.19	11	14.83	0.98
75	41	20.33	21.02	9	14.83	2.29
			46.79			**10.56**
	χ^2_{cal}= 46.79** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}= 10.56** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**		

Table 7b: Student t-test

DAT	BPH/trap	WBPH/trap
25	11	13
35	13	24
45	7	19
55	16	13
65	34	11
75	41	9
t-value= 0.88 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

*Significance at (p=0.05)   ** Significance at (p=0.01)

4.2.1.4 Light trap collection of *N. lugens* and *S. furcifera* from farmer's field in Dhadhesugur (*kharif*-2017)

Similarly, a significant difference in BPH population (χ^2=37.99**) and non-significant difference in WBPH population (χ^2=9.03) was observed in the samples collected from Dhadhesugur. Number of BPH adults trapped were increased gradually from the 25 DAT (χ^2=9.08; n=9) and reached maximum at the end 75 DAT (χ^2= 15.8; n=43). However, in WBPH population a fluctuation with a maximum population of 15 (χ^2=2.95) was observed on 45 DAT (Table 8a).

Similarly, populations of BPH and WBPH did not vary significantly among themselves when subjected to student t-test (t= 2.44; P >0.05^{NS}). The lowest BPH population of 9 adults/trap was recorded on 25 DAT crop, whereas, WBPH recorded 4 adults/trap during the 35 DAT. The highest number of BPH (43) was recorded at 75 DAT compared to 15 WBPH observed during 45 DAT (Table 8b).

4.2.2 Light trap studies (rabi-summer 2017-18)

4.2.2.1 Light trap collection of *N. lugens* and *S. furcifera* in ARS, Gangavathi (rabi-summer 2017-18)

The data on light trap collections of BPH and WBPH revealed a significant differences across different dates of observations (χ^2_{cal}= 13.84* and χ^2_{cal}=12.51*). Number of BPH adults trapped increased from 25 DAT (χ^2_{cal}=0.687; n=21) to 35 DAT (χ^2_{cal}=4.67; n=36) but later started decreasing significantly thereof reaching a minimum population of 13 at the end of the observation period of 75 DAT day of the crop (χ^2= 5.87). However, in WBPH population, the number of adults trapped increased initially from 12 (χ^2= 0.43) to 23 (χ^2= 4.98) from 25 DAT to 45 DAT but later, decreased significantly with a minimum population of 6 at the end of the observation period of 75 DAT (χ^2= 4.98) (Table 9a).

Similarly, populations of BPH and WBPH did not vary significantly among themselves when subjected to student t-test (t= 2.53; P>0.05^{NS}). The lowest BPH population of 13 adults/trap was recorded on 75 DAT, whereas, WBPH recorded 6 adults/trap during the same crop age. The highest number of BPH (36) was recorded at 33 DAT compared to 23 WBPH observed during 45 DAT (Table 9b).

Table 8a: Light trap collection of *N. lugens* and *S. furcifera* from farmer's field in Dhadesugur (*kharif*-2017)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	9	23.66	9.08	6	9.66	1.386
35	13	23.66	4.8	4	9.66	3.31
45	17	23.66	1.87	15	9.66	2.95
55	24	23.66	0.0048	13	9.66	1.15
65	36	23.66	6.44	11	9.66	0.185
75	43	23.66	15.8	9	9.66	0.045
			37.9948			**9.026**
	χ^2_{cal}= 37.99 $\chi^2_{5\%}$ =11.07 $\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=9.026 $\chi^2_{5\%}$ = 11.07 $\chi^2_{1\%}$ =15.086**		

Table 8b: Student t-test

DAT	BPH/trap	WBPH/trap
25	9	6
35	13	4
45	17	15
55	24	13
65	36	11
75	43	9
t-value= 2.44 $P>0.05^{NS}$ $P<0.05^{S}$		

DAT: Days after transplanting

*Significance at (p=0.05) ** Significance at (p=0.01)

Table 9a: Light trap collection of *N. lugens* and *S. furcifera* in ARS, Gangavathi (rabi-summer 2017-18)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	21	25.16	0.687	12	14.5	0.43
35	36	25.16	4.67	17	14.5	0.43
45	31	25.16	1.355	23	14.5	4.98
55	29	25.16	0.586	18	14.5	0.845
65	21	25.16	0.68	11	14.5	0.845
75	13	25.16	5.87	6	14.5	4.98
			13.848			**12.51**
	χ^2_{cal}= 13.848* $\chi^2_{5\%}$ =11.07 $\chi^2_{1\%}$ = 15.086			**χ^2_{cal}=12.51* $\chi^2_{5\%}$ = 11.07 $\chi^2_{1\%}$ =15.086**		

Table 9b: Student t-test

DAT	BPH/trap	WBPH/trap
25	21	12
35	36	17
45	31	23
55	29	18
65	21	11
75	13	6
t-value= 2.53 $P>0.05^{NS}$ $P<0.05^{S}$		

DAT: Days after transplanting

*Significance at (p=0.05)   ** Significance at (p=0.01)

4.2.2.2 Light trap collection of *N. lugens* and *S. furcifera* in Kesaratti (rabi-summer 2017-18)

There was a significant difference in BPH population (χ^2=20.09**) and non-significant difference in WBPH population collected from Kesaratti (χ^2=7.46). There was a sudden increase in number of BPH adults trapped from 25 DAT (χ^2_{cal}=3.64; n=19) to 35 DAT (χ^2_{cal}=10.64; n=47) but later started decreasing significantly thereof reaching a minimum population of 19 at the end of the observation period of 75 DAT (χ^2= 3.64). Similarly, in WBPH population, the number of adults trapped increased initially from 11 (χ^2= 2.01) to 24 (χ^2= 3.05) from 25 to 35 DAT but later, showed variations from 21(χ^2= 1.03) to 16 (χ^2= 0.04) (Table 10a).

Similarly, a non-significant variation was observed within the populations of BPH and WBPH (t= 2.55; P>0.05^{NS}). The lowest BPH population of 19 adults/trap was recorded on 25 DAT, whereas, WBPH recorded 11 adults/trap during the same observation time. The highest number of BPH (47) was recorded at 35 DAT as compared to 24 WBPH observed during same age crop (Table 10b)

4.2.2.3 Light trap collection of *N. lugens* and *S. furcifera* in ARS, Dhadhesugur (rabi-summer 2017-18)

Significant differences across different dates of observations was recorded in BPH (χ^2_{cal}= 14.79*) and WBPH (χ^2_{cal}=15.64**). Number of BPH adults trapped increased from 25 DAT (χ^2_{cal}=0.07; n=26) to 35 DAT (χ^2_{cal}=6.17; n=37) but later started decreasing significantly thereof reaching a minimum population of 11 at the end of the observation period of 75 DAT day of the crop (χ^2= 7.56). Similarly, in WBPH population, the number of adults trapped increased initially from 14 (χ^2= 0.029) to 26 (χ^2= 5.77) from 25 DAT to 45 DAT but later, decreased significantly with a minimum population of 7 at 65 DAT (χ^2=4.0) (Table 11a)

Similarly, populations of BPH and WBPH did not vary significantly among themselves when subjected to student t-test (t= 2.16; P>0.05^{NS}). The lowest BPH population of 11 adults/trap was recorded on 75 DAT whereas, WBPH recorded 7 adults/trap during the 65 DAT. The highest number of BPH (37) was recorded at 35 DAT as compared to 26 WBPH observed during 45 DAT (Table 11b).

Table 10a: Light trap collection of *N. lugens* and *S. furcifera* in Kesaratti (rabi-summer 2017-18)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	19	29.33	3.64	11	16.83	2.019
35	47	29.33	10.64	24	16.83	3.05
45	36	29.33	1.52	21	16.83	1.03
55	30	29.33	0.015	17	16.83	0.0017
65	25	29.33	0.639	12	16.83	1.329
75	19	29.33	3.64	16	16.83	0.04
			20.094			**7.46**
	χ^2_{cal}= 20.094** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=7.46** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**		

Table 10b: Student t-test

DAT	BPH/trap	WBPH/trap
25	19	11
35	47	24
45	36	21
55	30	17
65	25	12
75	19	16
t-value= 2.55 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

*Significance at (p=0.05)   ** Significance at (p=0.01)

Table 11a: Light trap collection of *N. lugens* and *S. furcifera* in ARS, Dhadesugur (rabi-summer 2017-18)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	26	24.66	0.07	14	14.66	0.029
35	37	24.66	6.17	21	14.66	2.75
45	28	24.66	0.45	26	14.66	5.77
55	25	24.66	0.0045	11	14.66	0.913
65	21	24.66	0.543	7	14.66	4.002
75	11	24.66	7.56	9	14.66	2.18
			14.7975			**15.644**
	χ^2_{cal}= 14.79* **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=15.644**** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**		

Table 11b: Student t-test

DAT	BPH/trap	WBPH/trap
25	26	14
35	37	21
45	28	26
55	25	11
65	21	7
75	11	9
t-value= 2.16 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

*Significance at (p=0.05) ** Significance at (p=0.01)

4.2.2.4 Light trap collection of *N. lugens* and *S. furcifera* from farmer's field Dhadhesugur (rabi-summer 2017-18)

A non-significant difference in BPH population (χ^2=9.38) and significant difference in WBPH population (χ^2=13.99*) in farmer's field in Dhadesugur was observed. Number of BPH adults trapped increased from 25 DAT (χ^2_{cal}=0.05; n=29) to 45 DAT (χ^2_{cal}=2.48; n=39) but later started decreasing significantly thereof reaching a minimum population of 17 at the end of the observation period of 75 DAT (χ^2= 5.85). However, there was a sudden increase in WBPH population (χ^2=6.75; n=21) on 45 DAT and later decreased reaching a minimum population of 75 DAT (χ^2=2.08) (Table 12a).

Similarly, a non-significant variation was observed within the populations of BPH and WBPH (t= 4.71; $P>0.05^{NS}$). The lowest population of BPH (17 adults/trap) and WBPH (6 adults/trap) recorded on 75 & 35 DAT, respectively. The highest number of BPH (39) was recorded at 45 DAT compared to 21 WBPH observed during same age crop (Table 12b).

4.2.3 Seasonal incidence studies (field collection studies during *kharif*-2017)

4.2.3.1 Number of *N. lugens* and *S. furcifera* in paddy at ARS, Gangavathi (*kharif*-2017)

Seasonal incidence of BPH and WBPH when subjected to Chi square test revealed non-significant differences across different dates of observations (χ^2_{cal}= 15.18 and χ^2_{cal}=5.24). The mean population (per hill) of BPH adults collected were increased gradually from three Weeks After Transplanting (WAT) (χ^2=1.38; mean=0.04) and reached maximum at 12 WAT (χ^2= 5.16; mean=4.46). However, in WBPH, the mean population increased initially from 0.66 (χ^2= 0.14) to 2.44 (χ^2= 1.84) from 3 WAT to 6 WAT but later, started decreasing significantly thereof reaching a minimum mean population of 0.23 at the end of the observation period of 13 WAT (χ^2= 0.64) (Table 13a).

Similarly, mean populations of BPH and WBPH did not vary significantly among themselves when subjected to student t-test (t= 0.79; $P>0.05^{NS}$). The lowest BPH mean population of 0.04 was recorded on 3 WAT whereas, WBPH recorded 0.23 during the 13 WAT. The highest mean population of BPH (4.46) was recorded at 12 WAT compared to mean population of WBPH (2.44) observed during 6 WAT (Table 13b).

Table 12a: Light trap collection of *N. lugens* and *S. furcifera* from farmer's field Dhadesugur (rabi-summer 2017-18)

DAT	Observed BPH/trap	Expected BPH/trap	χ^2	Observed WBPH/trap	Expected WBPH/trap	χ^2
25	29	30.33	0.05	9	12	0.75
35	33	30.33	0.23	6	12	3
45	39	30.33	2.48	21	12	6.75
55	35	30.33	0.719	16	12	1.33
65	29	30.33	0.05	13	12	0.08
75	17	30.33	5.85	7	12	2.083
			9.379			**13.99**
	χ^2_{cal}= 9.37 **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**			**χ^2_{cal}=13.99*** **$\chi^2_{5\%}$ =11.07** **$\chi^2_{1\%}$ = 15.086**		

Table 12b: Student t-test

DAT	BPH/trap	WBPH/trap
25	29	9
35	33	6
45	39	21
55	35	16
65	29	13
75	17	7
t-value= 4.71 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

DAT: Days after transplanting

*Significance at (p=0.05) ** Significance at (p=0.01)

Table 13a: Number of *N. lugens* and *S. furcifera* in paddy at ARS, Gangavathi (*kharif*-2017)

WAT	Observed BPH/hill	Expected BPH /hill	χ^2	Observed WBPH /hill	Expected WBPH/hill	χ^2
3rd week	0.04	1.46	1.38	0.66	1.05	0.144
4th week	0.06	1.46	1.34	1.28	1.46	0.05
5th week	0.15	1.46	1.17	2.16	1.46	1.17
6th week	0.28	1.46	0.95	2.44	1.46	1.84
7th week	0.48	1.46	0.65	1.74	1.46	0.44
8th week	0.82	1.46	0.28	0.68	1.46	0.13
9th week	2.26	1.46	0.44	0.54	1.46	0.24
10th week	3.04	1.46	1.71	0.7	1.46	0.11
11th week	3.22	1.46	2.07	0.62	1.46	0.17
12th week	4.46	1.46	5.16	0.48	1.46	0.31
13th week	1.23	1.46	0.036	0.23	1.46	0.64
			15.186			**5.244**
	χ^2_{cal}= 15.186 **$\chi^2_{5\%}$ = 18.31** **$\chi^2_{1\%}$ = 23.21**			**χ^2_{cal}= 5.244** **$\chi^2_{5\%}$ = 18.31** **$\chi^2_{1\%}$ = 23.21**		

Table 13b: Student t-test

WAT	BPH/hill	WBPH/hill
3rd week	0.04	0.66
4th week	0.06	1.28
5th week	0.15	2.16
6th week	0.28	2.44
7th week	0.48	1.74
8th week	0.82	0.68
9th week	2.26	0.54
10th week	3.04	0.7
11th week	3.22	0.62
12th week	4.46	0.48
13th week	1.23	0.23
t-value= 0.79 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

4.2.3.2 Number of *N. lugens* and *S. furcifera* in paddy at Kesaratti (*kharif*-2017)

There was a significant difference in BPH population (χ^2=105.59**) and non-significant difference in WBPH population collected from Kesaratti (χ^2=4.35). Where, the mean population (per hill) of BPH increased significantly from 4 WAT (χ^2=9.04; mean=0.03) and reached maximum at 12 WAT (χ^2= 32.88; mean=26.4). Whereas, in WBPH the mean population increased initially from mean population 0.34 (χ^2= 0.4) to 2.32 (χ^2= 1.93) from 4 WAT to 6 WAT but later, started decreasing significantly thereof reaching a mean population of 0.24 at the end of the observation period on 13 WAT (χ^2= 0.54) (Table 14a)

Similarly, populations of BPH and WBPH did not vary significantly among themselves (t= 2.79; $P>0.05^{NS}$). The lowest BPH population 0.03 was recorded on 4 WAT, whereas, WBPH population of 0.24 was recorded during 13 WAT. The highest BPH population of 26.4 was recorded at 12 WAT compared to 2.32 WBPH observed during 6 WAT (Table 14b).

4.2.3.3 Number of *N. lugens* and *S. furcifera* in paddy at ARS, Dhadhesugur (*kharif*-2017)

A non-significant difference in BPH population (χ^2=6.92) and WBPH population (χ^2=2.37) of Dhadhesugur was observed. The mean population (per hill) of BPH increased significantly from 4 WAT (χ^2_{cal}=1.07; mean=0.2) and reached maximum at 12 WAT (χ^2_{cal}=2.62; mean=3.4) but later decreased significantly thereof reaching a minimum mean population of 1.23 at the end of 13 WAT (χ^2= 1.07). However, there was a gradual increase in WBPH mean population from 4 WAT (χ^2=0.16; mean=0.56) to 8 WAT (χ^2=0.59; mean=1.7) and later varied, finally reached a minimum mean population of 0.2 at 13 WAT (χ^2=0.59) (Table 15a).

Similarly, a non significant variation was observed within the mean populations of BPH and WBPH (t= 1.41; $P>0.05^{NS}$). The lowest mean population of BPH (0.2/hill) and WBPH (0.2/hill) recorded on 4 and 13 WAT, respectively. The highest mean population of BPH (3.4/hill) was recorded at 12 WAT compared to WBPH (1.7/hill) observed during 8 WAT (Table 15b).

Table 14a: Number incidence of *N. lugens* and *S. furcifera* in paddy at Kesaratti (*kharif*-2017)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected BPH/hill	χ^2
4th week	0.03	9.1	9.04	0.34	0.96	0.4
5th week	0.14	9.1	8.82	1.8	0.96	0.73
6th week	0.86	9.1	7.55	2.32	0.96	1.93
7th week	3.12	9.1	5.86	0.76	0.96	0.14
8th week	6.44	9.1	0.76	0.48	0.96	0.46
9th week	7.9	9.1	0.15	0.9	0.96	0.0037
10th week	21.08	9.1	15.77	0.76	0.96	0.041
11th week	22.6	9.1	20.02	1.24	0.96	0.08
12th week	26.4	9.1	32.88	0.8	0.96	0.027
13th week	2.53	9.1	4.74	0.24	0.96	0.54
			105.59			**4.3517**
	χ^2_{cal}= 105.59** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 4.35** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**		

Table 14b: Student t-test

WAT	BPH/hill	WBPH /hill
4th week	0.03	0.34
5th week	0.14	1.8
6th week	0.86	2.32
7th week	3.12	0.76
8th week	6.44	0.48
9th week	7.9	0.9
10th week	21.08	0.76
11th week	22.6	1.24
12th week	26.4	0.8
13th week	2.53	0.24
t-value= 2.79 **P>0.05^{NS}** **P<0.05^{S}**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

Table 15a: Number of *N. lugens* and *S. furcifera* in paddy at ARS, Dhadesugur (*kharif*-2017)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected BPH/hill	χ^2
4th week	0.2	1.45	1.07	0.56	0.95	0.16
5th week	0.34	1.45	0.83	0.92	0.95	0.0009
6th week	0.78	1.45	0.31	1	0.95	0.0026
7th week	1.18	1.45	0.05	1.7	0.95	0.59
8th week	1.26	1.45	0.025	1.7	0.95	0.59
9th week	1.28	1.45	0.56	1.36	0.95	0.18
10th week	2.58	1.45	0.88	0.9	0.95	0.0026
11th week	2.34	1.45	0.54	0.64	0.95	0.1
12th week	3.4	1.45	2.62	0.56	0.95	0.16
13th week	1.23	1.45	1.07	0.2	0.95	0.59
			6.92			**2.3761**
	χ^2_{cal}= 6.92 **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 2.37** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 15b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.2	0.56
5th week	0.34	0.92
6th week	0.78	1
7th week	1.18	1.7
8th week	1.26	1.7
9th week	1.28	1.36
10th week	2.58	0.9
11th week	2.34	0.64
12th week	3.4	0.56
13th week	1.23	0.2
t-value= 1.41 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

4.2.3.4 Number of *N. lugens* and *S. furcifera* in paddy from farmer's field at Dhadhesugur (*kharif*-2017)

There was a significant difference in BPH population (χ^2=91.19**) and non-significant difference in WBPH population collected from farmer's field of Dhadhesugur (χ^2=7.70). Where, the mean population (per hill) of BPH increased significantly from 4 WAT (χ^2=7.14; mean=0.6) and reached maximum at 12 WAT (χ^2= 32.8; mean=24.8), after reached a minimum mean population of 9.7/hill (χ^2=0.24). Whereas, in WBPH the mean population increased initially from mean population 0.94/hill (χ^2= 0.07) to 3.2 (χ^2= 3.09) from 4 WAT to 6 WAT but later, started decreasing significantly thereof reaching a mean population of 0.26 at the end of the observation period on 13 WAT (χ^2= 0.77) (Table 16a).

Similarly, populations of BPH and WBPH did not vary significantly among themselves (t= 2.42; $P>0.05^{NS}$). The lowest mean population of BPH 0.6/hill was recorded on 4 WAT whereas, WBPH recorded 0.26/hill during the 12 WAT. The highest number of BPH (24.8/hill) was recorded at 12 WAT compared to WBPH (3.2/hill) observed during 6 WAT (Table 16b).

4.2.4 Seasonal incidence studies (field collection studies during rabi-summer 2017-18)

4.2.4.1 Number of *N. lugens* and *S. furcifera* in paddy at ARS, Gangavathi (rabi-summer 2017-2018)

A non-significant difference was observed in mean population of both BPH (χ^2=0.198) and WBPH (χ^2=0.11) from ARS, Gangavathi. The mean population (per hill) of BPH increased significantly from 4 WAT (χ^2_{cal}=0.016; mean=0.52) and reached maximum at 7 WAT (χ^2_{cal}=0.07; mean=0.84/hill) but later decreased significantly thereof reaching a minimum mean population of 0.38 at the end of 12 WAT (χ^2= 0.09). However, initially increase in WBPH mean population during 4 WAT (χ^2=0.065; mean=0.44) and varied gradually with reaching a minimum mean population of 0.24 on 12 WAT (χ^2=0.012) (Table 17a).

Similarly, a non-significant variation was observed within the mean populations of BPH and WBPH (t= 6.61; $P>0.05^{NS}$). The lowest mean population of BPH (0.52/hill) and WBPH (0.24/hill) recorded on 4 and 9 WAT, respectively. The highest mean population of BPH (0.84/hill) was recorded at 7 WAT compared to WBPH (0.44/hill) observed during 4 WAT (Table 17b).

Table 16a: Number of *N. lugens* and *S. furcifera* in paddy from farmer's filed at Dhadesugur (*kharif*-2017)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected WBPH/hill	χ^2
4th week	0.6	8.3	7.14	0.94	1.24	0.07
5th week	0.94	8.3	6.52	3.04	1.24	2.61
6th week	1.18	8.3	6.12	3.2	1.24	3.09
7th week	2.8	8.3	3.64	0.96	1.24	0.06
8th week	2.56	8.3	3.96	1.28	1.24	0.0013
9th week	3.44	8.3	2.85	0.88	1.24	0.11
10th week	15.14	8.3	5.64	0.56	1.24	0.37
11th week	21.9	8.3	22.28	0.56	1.24	0.37
12th week	24.8	8.3	32.8	0.68	1.24	0.25
13th week	9.7	8.3	0.24	0.26	1.24	0.77
			91.19			**7.70**
	χ^2_{cal}= 91.19** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 7.70** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 15b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.6	0.94
5th week	0.94	3.04
6th week	1.18	3.2
7th week	2.8	0.96
8th week	2.56	1.28
9th week	3.44	0.88
10th week	15.14	0.56
11th week	21.9	0.56
12th week	24.8	0.68
13th week	9.7	0.26
t-value= 2.42 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

Table 17a: Number of *N. lugens* and *S. furcifera* in paddy at ARS, Gangavathi (rabi-summer 2017-2018)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected WBPH/hill	χ^2
4th week	0.52	0.62	0.016	0.44	0.3	0.065
5th week	0.56	0.62	0.005	0.34	0.3	0.005
6th week	0.7	0.62	0.01	0.3	0.3	0
7th week	0.84	0.62	0.07	0.32	0.3	0.0013
8th week	0.68	0.62	0.0058	0.26	0.3	0.005
9th week	0.64	0.62	0.0006	0.22	0.3	0.021
10th week	0.62	0.62	0	0.32	0.3	0.0013
11th week	0.64	0.62	0.0006	0.3	0.3	0
12th week	0.38	0.62	0.09	0.24	0.3	0.012
			0.198			0.11
	χ^2_{cal}= 0.198 **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 0.11** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 17b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.52	0.44
5th week	0.56	0.34
6th week	0.7	0.3
7th week	0.84	0.32
8th week	0.68	0.26
9th week	0.64	0.22
10th week	0.62	0.32
11th week	0.64	0.3
12th week	0.38	0.24
t-value= 6.61 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

4.2.4.2 Number of *N. lugens* and *S. furcifera* in paddy at Kesaratti (rabi- summer 2017-18)

Similarly, a non-significant difference in BPH (χ^2=4.37) and WBPH mean population (χ^2=0.58) was observed in the samples collected from Kesaratti. The mean population BPH increased initially from the 4 WAT (χ^2=1.01; mean=0.18/hill) to 7 WAT (χ^2=2.76 mean=0.69/hill) and gradually decreased in their population. However, the mean population of WBPH increased gradually from 4 WAT (χ^2=0.03; mean=0.34/hill) to 6 WAT (χ^2=0.19; mean=0.76/hill), later decreased gradually (Table 18a).

The populations of BPH and WBPH did not vary significantly among themselves when subjected to student t-test (t=2.76; $P>0.05^{NS}$). The lowest BPH population of 0.18/hill was recorded on 4 WAT crop whereas, WBPH recorded 0.22/hill during the 12 WAT. The highest number of BPH (2.76/hill) was recorded at 7 WAT compared to WBPH (0.76/hill) observed during 6 WAT (Table 18b)

4.2.4.3 Number of *N. lugens* and *S. furcifera* in paddy at ARS, Dhadhesugur (rabi- summer 2017-18)

Similarly, a non-significant difference was observed in mean population of both BPH (χ^2=4.92) and WBPH (χ^2=0.18). The mean population BPH increased initially from the 4 WAT (χ^2=0.81; mean=0.52/hill) to 7 WAT (χ^2=2.58 mean=3.78/hill) and gradually decreased. However, in WBPH increased gradually from 4 WAT (χ^2=0.03; mean=0.17/hill) to 6 WAT (χ^2=0.03; mean=0.36/hill) and later varied gradually (Table 19a).

Populations of BPH and WBPH varied non-significantly among themselves (t=4.16; $P>0.05^{NS}$). The lowest BPH population of 0.52/hill was recorded on 4 WAT crop whereas, WBPH recorded 0.13/hill during the 12 WAT. The highest number of BPH (3.78/hill) was recorded at 7 WAT compared to WBPH (0.36/hill) observed during 6 WAT (Table 19b).

Table 18a: Number of *N. lugens* and *S. furcifera* in paddy at Kesaratti (rabi-summer 2017-18)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected WBPH/hill	χ^2
4th week	0.18	1.35	1.01	0.34	0.46	0.03
5th week	0.86	1.35	0.54	0.72	0.46	0.14
6th week	2.24	1.35	0.58	0.76	0.46	0.19
7th week	2.76	1.35	0.69	0.62	0.46	0.05
8th week	2.2	1.35	0.17	0.4	0.46	0.007
9th week	1.9	1.35	0.22	0.42	0.46	0.003
10th week	0.92	1.35	0.14	0.38	0.46	0.014
11th week	0.64	1.35	0.37	0.36	0.46	0.023
12th week	0.42	1.35	0.65	0.22	0.46	0.125
			4.37			0.58
	χ^2_{cal}= 4.37 **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 0.58** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 18b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.18	0.34
5th week	0.86	0.72
6th week	2.24	0.76
7th week	2.76	0.62
8th week	2.2	0.4
9th week	1.9	0.42
10th week	0.92	0.38
11th week	0.64	0.36
12th week	0.42	0.22
t-value= 2.76 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

Table 19a: Number of *N. lugens* and *S. furcifera* in paddy at ARS, Dhadesugur (rabi-summer 2017-18)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected WBPH/hill	χ^2
4th week	0.52	1.69	0.81	0.17	0.26	0.03
5th week	1.26	1.69	0.095	0.33	0.26	0.019
6th week	1.74	1.69	0.0015	0.36	0.26	0.03
7th week	3.78	1.69	2.58	0.3	0.26	0.006
8th week	2.58	1.69	0.46	0.35	0.26	0.03
9th week	2.22	1.69	0.16	0.26	0.26	0
10th week	1.2	1.69	0.14	0.25	0.26	0.004
11th week	1.12	1.69	0.19	0.23	0.26	0.003
12th week	0.78	1.69	0.49	0.13	0.26	0.065
			4.92			**0.18**
	χ^2_{cal}= 4.92 **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 0.18** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 19b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.52	0.17
5th week	1.26	0.33
6th week	1.74	0.36
7th week	3.78	0.3
8th week	2.58	0.35
9th week	2.22	0.26
10th week	1.2	0.25
11th week	1.12	0.23
12th week	0.78	0.13
t-value= 4.16 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

4.2.4.4 Number of *N. lugens* and *S. furcifera* in paddy in farmer's field at Dhadhesugur (rabi-summer 2017-18)

A non-significant difference in BPH (χ^2=9.83) and WBPH mean population (χ^2=0.35) was observed in the samples collected from Dhadhesugur. The mean population BPH increased initially from the 4 WAT (χ^2=0.88; mean=0.72/hill) to 6 WAT (χ^2=3.14 mean=4.62/hill) and later gradual fluctuations in their populations. However, in WBPH population gradual increase from 4 WAT (χ^2=0.04; mean=0.24/hill) to 5 WAT (χ^2=0.07; mean=0.52/hill) later the population reaches to 0.5/hill during 8 WAT. After that variation was observed in the mean population (Table 20a).

Similarly, populations of BPH and WBPH did not vary significantly among themselves (t= 3.21; $P>0.05^{NS}$). The lowest BPH population of 0.42/hill was recorded on 12 WAT crop whereas, WBPH recorded 0.22/hill during same crop age. The highest number of BPH (4.62/hill) was recorded at 7 WAT compared to WBPH (0.52/hill) observed during 5 WAT (Table 20b).

4.3 To study the biology of brown and black morphs of brown planthopper *N. lugens*

A biological study on brown planthopper, *N. lugens* was conducted during November and December, 2017, on paddy variety BPT-5204 under laboratory conditions. The results obtained during the study are presented in table 21.

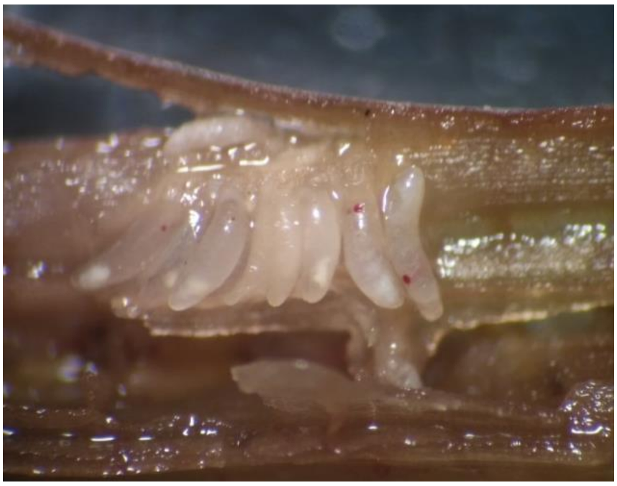
4.3.1 Biological parameters of brown morphs

4.3.1.1 Site of oviposition

The females laid their eggs in batches inside the leaf sheath (Plate 12), midrib and stem tissues. The eggs were not visible from outside. However, the tissues around the oviposition turned light brown to dark brown colour in 3-4 days. The maximum percentage of oviposition was found mainly inside leaf sheath.

4.3.1.2 Eggs

The eggs are arranged in groups varied from 3-12 and were white in colour when fresh but red eye spot developed gradually at the anterior ends (Plate 13) and their tips were flat. Maximum hatching of eggs were observed in the early morning. The eggs were hatched in 7-9 days with an average of 8.025±0.69 days.



Immature eggs of BPH, *N. lugens*

Eggs of brown planthopper *N. lugens*

Plate 13: Eggs of brown planthopper

Table 20a: Number of *N. lugens* and *S. furcifera* in paddy from farmer's field at Dhadesugur (rabi-summer 2017-18)

WAT	Observed BPH/hill	Expected BPH/hill	χ^2	Observed WBPH/hill	Expected WBPH/hill	χ^2
4th week	0.72	2.07	0.88	0.24	0.36	0.04
5th week	2.1	2.07	0.0004	0.52	0.36	0.07
6th week	2.22	2.07	0.11	0.4	0.36	0.004
7th week	4.62	2.07	3.14	0.48	0.36	0.04
8th week	4.55	2.07	2.97	0.5	0.36	0.05
9th week	2.24	2.07	0.013	0.44	0.36	0.017
10th week	1.12	2.07	0.44	0.28	0.36	0.017
11th week	0.66	2.07	0.96	0.21	0.36	0.063
12th week	0.42	2.07	1.32	0.22	0.36	0.05
			9.833			**0.351**
	χ^2_{cal}= 9.83 **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ =21.67**			**χ^2_{cal}= 0.351** **$\chi^2_{5\%}$ =16.92** **$\chi^2_{1\%}$ = 21.67**		

Table 20b: Student t-test

WAT	BPH/hill	WBPH/hill
4th week	0.72	0.24
5th week	2.1	0.52
6th week	2.22	0.4
7th week	4.62	0.48
8th week	4.55	0.5
9th week	2.24	0.44
10th week	1.12	0.28
11th week	0.66	0.21
12th week	0.42	0.22
t-value= 3.21 **$P>0.05^{NS}$** **$P<0.05^{S}$**		

WAT: Weeks after transplanting *Significance at (p=0.05) ** Significance at (p=0.01)

4.3.2 Duration of various nymphal instars

The nymphs can be distinguished by their colour and characters. The data revealed that the nymphs passed through five instars to reach adult stage. The characters of different instars (Plate 14) are given below.

4.3.2.1 First instar

The freshly hatched nymphs were cottony white. Abdomen was clear and segments were not so distinct. The duration of first instar nymphs ranged from 1-1.5 days with an average of 1.45±0.36 days. The length of first instar nymph was ranged from 0.5-0.62 mm with an average of 0.57±0.02 mm length and the breadth of first instar ranged from 0.17-0.19 with an average of 0.18±0.02 mm (Table 21 and 22).

4.3.2.2 Second instar

The eyes were slightly red in colour. The body segments were brown and slightly divided with brown coloured legs. The duration of second instars nymphs ranged from 2-2.5 days with an average of 3.13±0.83 days. The length of second instar nymph was ranged from 0.9-1.1 mm with an average of 0.97±0.13 mm length and the breadth of second instar ranged from 0.5-0.6 mm with an average of 0.57±0.08 mm (Table 21 and 22).

4.3.2.3 Third instar

The third instar nymphs were oval, brownish in colour with dull red colourd eyes and rudimentary wings. The duration of third nymphal instar ranged from 2.5-4 days with the average of 3.8±1.11 days. The length of third instar nymph was ranged from 1.15-1.3 mm with an average of 1.20±0.07 mm length and the breadth of third instar ranged from 0.6-0.65 with an average of 0.64±0.07 mm (Table 21 and 22).

4.3.2.4 Fourth instar

The head was enlarged with a brown vertex. The abdomen was swollen with irregular brown patches from first to seventh segments. The duration of this instar ranged from 3-4 days with an average of about 3.9±1.43 days. The length of fourth instar nymph was ranged from 1.4-1.5 mm with an average of 1.44±0.13 mm length and the breadth of fourth instar ranged from 0.7-0.9 with an average of 0.73±0.04 mm (Table 21 and 22).

Table 21: Biological parameters of brown planthopper *N. lugens* (brown morph) on paddy in laboratory condition.

SI. No.	Stage of development	Range (days)	Mean
1	Pre-oviposition period	1.50-3.00	2.11±0.41
2	Oviposition period	13.00-15.00	14.2±1.03
3	Post-oviposition period	5.00-7.00	6.3±0.64
4	Fecundity(eggs)	140-170	158±8.27
5	Incubation period	7.00-9.00	8.025±0.69
6	Nymphal period		
	1st instar	1.00-1.50	1.45±0.36
	2nd instar	2.00-2.50	2.13±0.83
	3rd instar	2.50-4.00	3.8±1.11
	4th instar	3.00-4.00	3.9±1.43
	5th instar	4.00-5.00	3.95±1.76
	Total nymphal period	13.50-18.00	16.85±2.79
7	Adult longevity		
	Longevity of Female	20.00-23.00	22.65± 0.48
	Longevity of Male	17.00-19.00	18.2±2.25
8	Total life cycle		
	Female	36.00-39.00	38±0.49
	Male	33.00-35.00	34.4±0.19

Mean of 20 observations

Table 22: Morphometric studies of brown planthopper (Brown morph)

Life stages	Length (mm)		Breadth (mm)	
	Range	Mean ±SD	Range	Mean ± SD
1st Instar	0.50-0.62	0.57±0.02	0.17-0.19	0.18±0.02
2nd Instar	0.90-1.10	0.97±0.13	0.50-0.60	0.57±0.08
3rd Instar	1.15-1.30	1.20±0.07	0.60-0.65	0.64±0.07
4th Instar	1.40-1.50	1.44±0.13	0.70-0.90	0.73±0.04
5th Instar	1.90-2.15	2.13±0.18	0.90-1.05	0.76±0.07
Female	3.00-3.20	3.04±0.16	0.70-0.90	0.79±0.03
Male	2.50-2.60	2.58±0.29	0.50-0.70	0.59±0.10

Mean of 10 observations

4.3.2.5 Fifth instar

The entire body was dark-brown and robust. The eyes were grayish-blue. On mesothorax three brown stripes were present on most of the adults. The wing rudiments fully covered the first three abdominal segments. The duration of fifth instar ranged from 3-5days with an average of 3.95±1.76 days. The length of fifth instar nymph was ranged from 1.9-2.15 mm with an average of 2.13±0.18 mm length and the breadth of fifth instar ranged from 0.9-0.1.05 with an average of 0.97±0.07 mm (Table 21 and 22).

4.3.3 Reproductive studies

The pre-oviposition period was 1.5-3days with a mean value of 2.11±0.41days. The oviposition period was 13-15 days with a mean value of 14.2±1.03 days. The post oviposition period was 5-7 days with a mean value of 6.3±0.64 days. The observations regarding fecundity of *N. lugens* was found to be of about 140-160 eggs with a mean value of 158±8.27 eggs.

4.3.4 Adult longevity

It was found that the longevity of males (Plate 15) was 17-19 days with a mean value of 18.20 ± 2.25 days. The average length and breadth of male BPH was 2.58±0.29 mm and 0.59±0.10 mm, respectively. The female (Plate 15) longevity was 21-23 days with a mean value of 22.65± 0.48 days. The average length and breadth of female BPH was 3.04±0.16 mm and 0.76±0.07 mm, respectively (Table 21 and 22).

4.3.5 Biology of black morph of BPH (Table 23)

4.3.5.1 Site of oviposition

The site of oviposition was same as that of the brown morphs. They also laid most of their eggs inside the leaf sheath

4.3.5.2 Eggs

The eggs were arranged in groups varied from 3-12 and were white in colour when fresh but red eye spot developed gradually at the anterior ends and we can’t differentiate the eggs of brown morph and black morph separately. Maximum hatching of eggs were observed in the early morning. The eggs were hatched in 8.0-8.5 days with an average of 8.2±0.54 days.

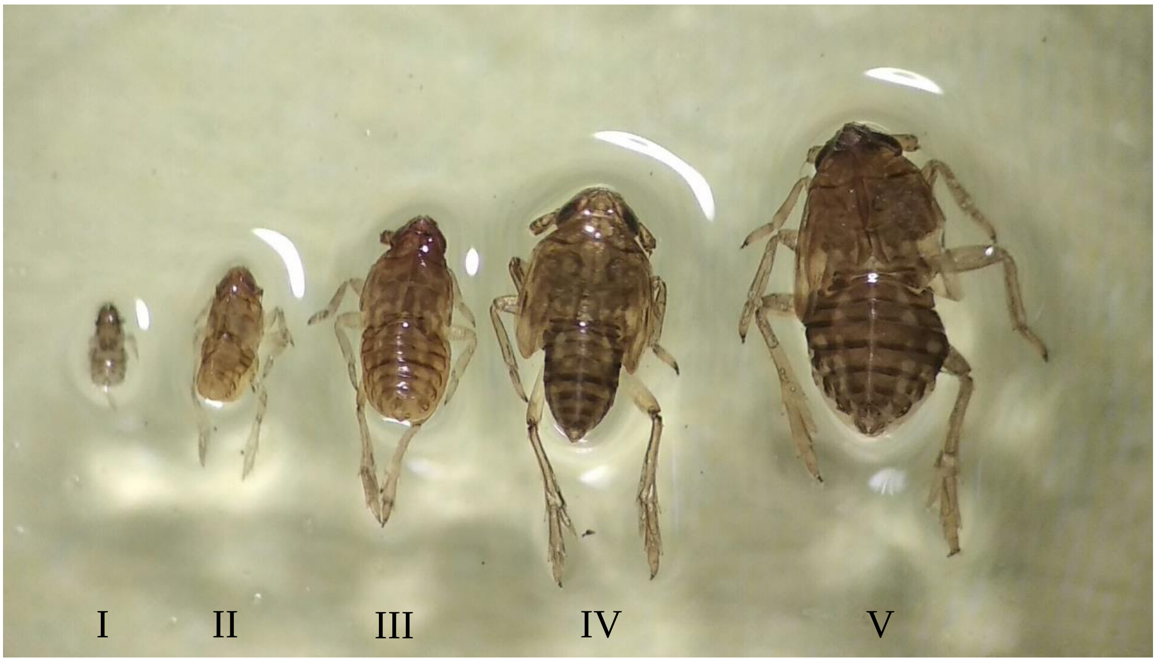


Plate 14: Different nymphal instars of brown planthopper (brown morph)

Plate 15: Macropterous adult female and male (dorsal view) of brown planthopper (brown morph)

4.3.5.3 Duration of various nymphal instars

The nymphs can be distinguished by their colour and characters. The data revealed that the nymphs passed through five instars to become adult. The characters of different instars (Plate 16) are given below.

4.3.5.3.1 First instar

The freshly hatched nymphs were brownish white. Abdomen was clear and segments were not so distinct. The duration of first instar nymphs ranged from 1.5-2.0 days with an average of 1.93±0.46 days. The length of first instar nymph was ranged from 0.4-0.6 mm with an average of 0.56±0.04 mm length and the breadth of first instar ranged from 0.2-0.25 mm with an average of 0.21±0.02 mm (Table 23 and 24).

4.3.5.3.2 Second instar

The eyes were slightly red in colour. The body segments were brownish and slightly divided with brown coloured legs. The duration of second instars nymphs ranged from 2.5-3.5 days with an average of 2.83±0.49 days. The length of second instar nymph was ranged from 0.8-1.02 mm with an average of 0.99±0.05 mm length and the breadth of second instar ranged from 0.5-0.6 mm with an average of 0.55±0.03 mm (Table 23 and 24).

4.3.5.3.3 Third instar

The third instar nymphs were brownish to dark brown in colour with red coloured eyes and rudimentary wings. The duration of third nymphal instar ranged from 2.5-3.5 days with the average of 3.1±0.5 days. The length of third instar nymph was ranged from 1.10-1.30 mm with an average of 1.27±0.04 mm length and the breadth of third instar ranged from 0.6-0.7 mm with an average of 0.69±0.035 mm (Table 23 and 24).

4.3.5.3.4 Fourth instar

The head was enlarged with a black vertex. The abdomen was swollen with irregular black patches from first to seventh segments. The duration of this instar ranged from 4-4.5 days with an average of about 4.0±0.54 days. The length of fourth instar nymph was ranged from 1.8-2.0 mm with an average of 1.89±0.17 mm length and the breadth of fourth instar ranged from 0.9-1 mm with an average of 0.95±0.06 mm (Table 23 and 24).

Table 23: Biological parameters of brown planthopper *N. lugens* (Black morph) on paddy in laboratory condition

SI. No.	Stage of development	Range (days)	Mean±SD
1	Pre-oviposition period	2.00-2.50	2.17±0.49
2	Oviposition period	13.00-14.50	14.8±0.67
3	Post-oviposition period	6.00-7.00	6.15±0.81
4	Fecundity(Eggs)	150-180	169.2±6.37
5	Incubation period	8.00-8.50	8.20±0.54
6	Nymphal period		
	1st instar	1.50-2.00	1.93±0.46
	2nd instar	2.50-3.50	2.83±0.49
	3rd instar	2.50-3.50	3.1±0.5
	4th instar	4.00-4.50	4±0.54
	5th instar	4.00-5.00	4.8±0.56
	Total nymphal period	15.00-18.00	16.65±2.25
7	Adult longevity		
	Longevity of Female	21.00-23.00	23.12±0.16
	Longevity of Male	17.00-20.00	18.50 ± 2.88
8	Total life cycle		
	Female	36.00-39.00	38.77±0.11
	Male	34.00-37.00	35.15±0.21

Mean of 20 observations

Table 24: Morphometric studies of Brown planthopper (Black morph)

Life stages	Length (mm)		Breadth (mm)	
	Range	Mean ±SD	Range	Mean ± SD
1st Instar	0.40-0.60	0.56±0.04	0.20-0.25	0.21±0.02
2nd Instar	0.80-1.02	0.99±0.05	0.50-0.60	0.55±0.03
3rd Instar	1.10-1.30	1.27±0.04	0.60-0.70	0.69±0.035
4th Instar	1.80-2.00	1.89±0.17	0.90-1.00	0.95±0.06
5th Instar	2.20-2.50	2.30±0.08	1.00-1.25	1.05±0.07
Female	3.00-3.20	3.14±0.21	0.70-0.90	0.78±0.08
Male	2.50-2.70	2.65±0.13	0.65-0.80	0.72±0.09

Mean of 10 observations

4.3.5.3.5 Fifth instar

The entire body was dark-black and robust. The eyes were grayish-blue. On mesothorax three black stripes were present on most of the adults. The wing rudiments fully covered the first three abdominal segments. The duration of fifth instar ranged from 4-6days with an average of 4.8±0.56. The length of fifth instar nymph was ranged from 2.2-2.5 mm with an average of 2.3±0.08 mm length and the breadth of fifth instar ranged from 1-1.25 mm with an average of 1.05±0.07 mm (Table 23 and 24).

4.3.5.4 Reproductive studies

The pre-oviposition period was 2.0-2.5 days with a mean value of 2.17±0.49 days. The oviposition period was 13.0-14.5 days with a mean value of 14.8±0.67 days. The post oviposition period was 6-7days with a mean value of 6.15±0.81 days. The observations regarding fecundity of *N. lugens* was found to be of about 150-180 eggs with a mean value of 169.2±6.37 eggs.

4.3.5.5 Adult longevity

It was found that the longevity of males (Plate 17) was 17-20 days with a mean value of 18.50±2.88 days. The average length and breadth of male BPH was 2.65±0.13 mm and 0.72±0.09 mm, respectively. The female (Plate 17) longevity was 21-23 days with a mean value of 23.12±0.16 days. The average length and breadth of female BPH was 3.14±0.21 mm and 0.78±0.08 mm, respectively (Table 23 and 24).

4.3.6 Comparison of various biological parameters between brown and black morphs of *N. lugens* (Stal.)

Paired ‘t’ test analysis was carried out to identify the level of significance among the various biological parameters between brown and black morph of BPH. The results revealed that, both the morphs did not show any significant difference in almost all biological parameters (Table 25).

Table 25: Comparison of various biological parameters between brown and black morphs of *N. lugens*.

Si. No.	Biological parameters	Significance
1	Pre-oviposition period	**NS (t=2.53)**
2	Oviposition period	**NS (t=2.04)**
3	Post-oviposition period	**NS (t=0.27)**
4	Fecundity	**NS (t=7.40)**
5	Incubation period	**NS (t=1.81)**
	Nymphal period	
6	1st instar	**NS (t=0.36)**
7	2nd instar	**NS (t=2.99)**
8	3rd instar	**NS (t=0.87)**
9	4th instar	**NS (t=0.12)**
10	5th instar	**NS (t=2.4)**
	Adult longevity	
11	Longevity of Female	**NS (t=0.89)**
12	Longevity of Male	**NS (t=0.46)**
	Total life cycle	
13	Female	**NS (t=0.82)**
14	Male	**NS (t=0.50)**
	$P>0.05^{NS}$ **$P<0.05^{S}$**	

NS= Non significance

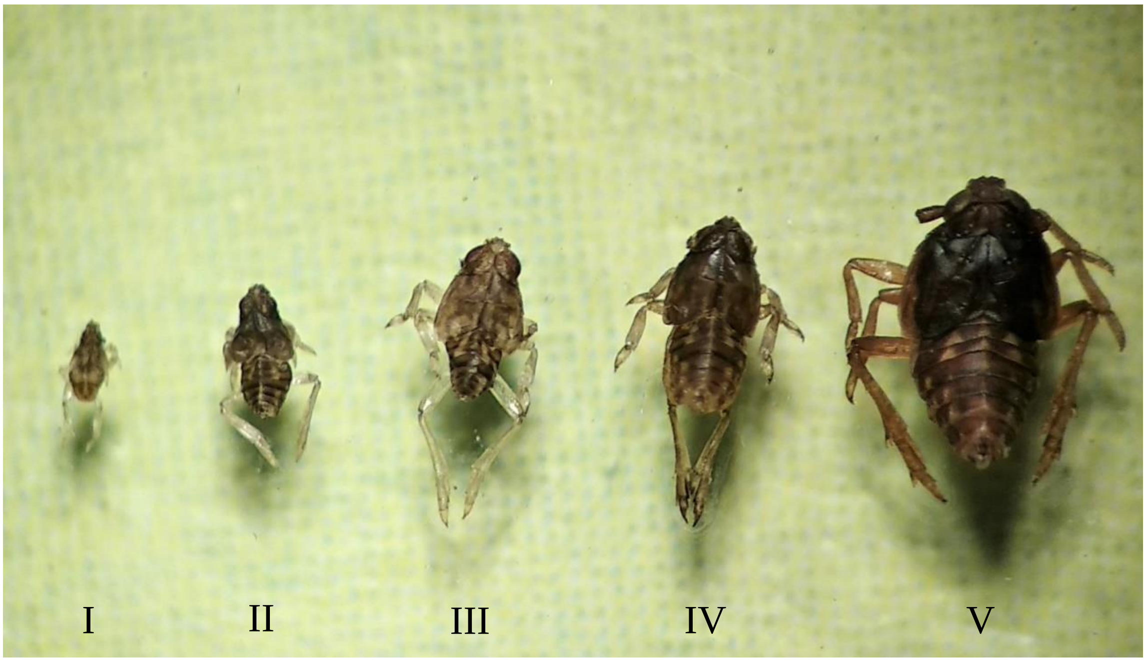


Plate 16: Different nymphal instars of brown planthopper (black morph)

Plate 17: Macropterous adult female and male (dorsal view) of brown planthopper (black morph)

DISCUSSION…

V. DISCUSSION

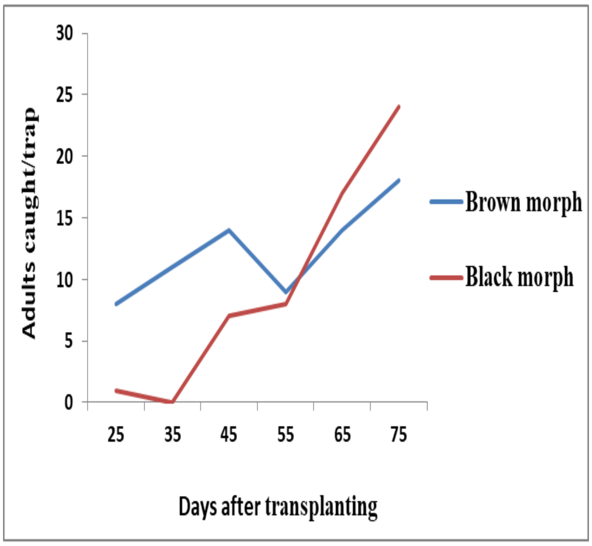
The results obtained on occurrence of morpho-species, seasonal incidence and biology of planthopper studied under laboratory conditions are discussed here.

5.1 To study the occurrence of morpho-species of rice planthoppers in Tunga-Bhadra regions of Karnataka

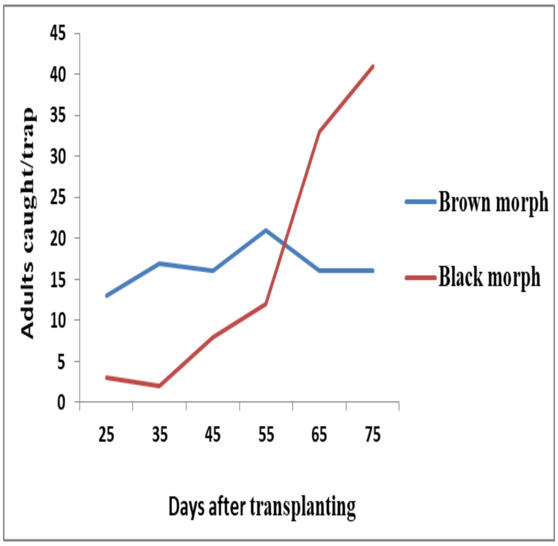
The male genital structures of both colour forms of brown planthoppers were observed under NIKON SMZ 25 microscope. It was observed that there were no variations in the genital structures of brown and black forms. In morphometric study also revealed that there were no much variations in the measurements of different body parts of brown and black morphs. This confirms that these forms are mere colour variants and are not different species or subspecies in both the locations. Hence, it was concluded that these belong to a single species as *Nilaparvata lugens* (Stal). The present findings are in line with the earlier reports of Rao (2006), who reported that there are no variations in genital structures of both brown and black forms of brown planthopper, representing only one species *i.e., N. lugens*.

5.1.1 Light trap collection of brown and black morph of *N. lugens* in different locations (*kharif*-2017)

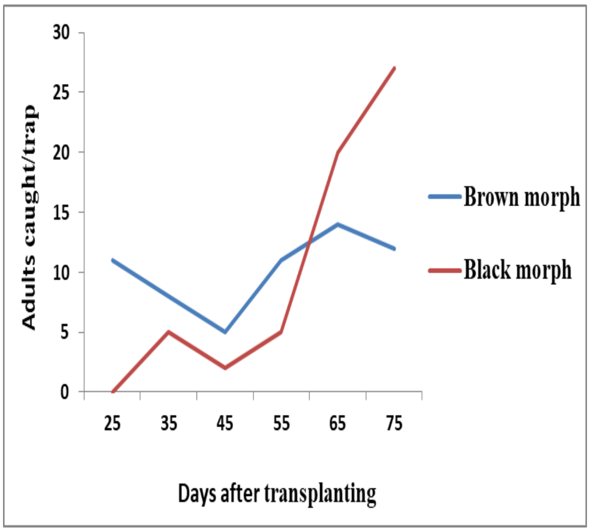
The population dynamics of brown and black morphs of BPH *N. lugens* remains constant in all the locations. The brown morph population was more on initial light trap catches. Started with a population of 8 (brown) and 1(black) per trap in ARS, Gangavathi, 13 (brown) and 3 (black) per trap in Kesaratti, 11 (brown) and zero (black) per trap in ARS, Dhadhesugur and 9 (brown) and zero (black) per trap in farmer's field in Dhadhesugur during 25 DAT. Later brown morph displaced by black morph with peak light trap collection of 18 (brown) and 24 (black) adults per trap in ARS, Gangavathi, 16 (brown) and 41 (black) adults per trap in Kesaratti, 12 (brown) and 27 (black) per trap ARS, Dhadhesugur and 17 (brown) and 26 (black) adults per trap in farmer's field in Dhadhesugur during 75 DAT (Fig. 1). The black morphs development might be because of the melanization process in the later instars of BPH after the loss of the succulency in the crop. They have to overcome the unavailability of food and harsh abiotic conditions.



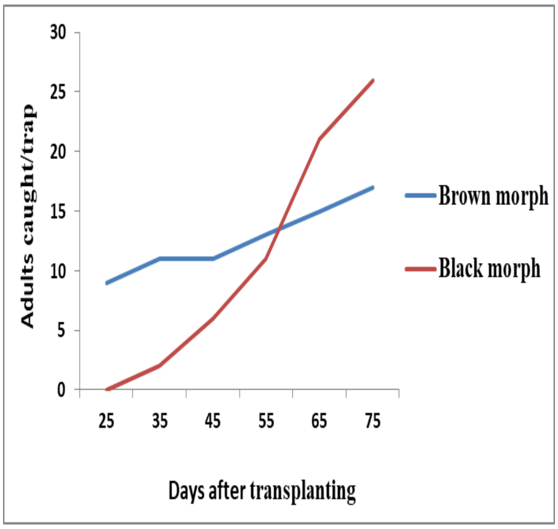
a) ARS, Gangavathi



b) Kesaratti



c) ARS, Dhadesugur



d) Farmer’s field in Dhadesugur

Fig. 1. Light trap collection of brown and black morph of *N. lugens* in different locations (*kharif*-2017)

5.1.2 Light trap collection of brown and black morph of *N. lugens* in different locations (rabi-summer 2017-18)

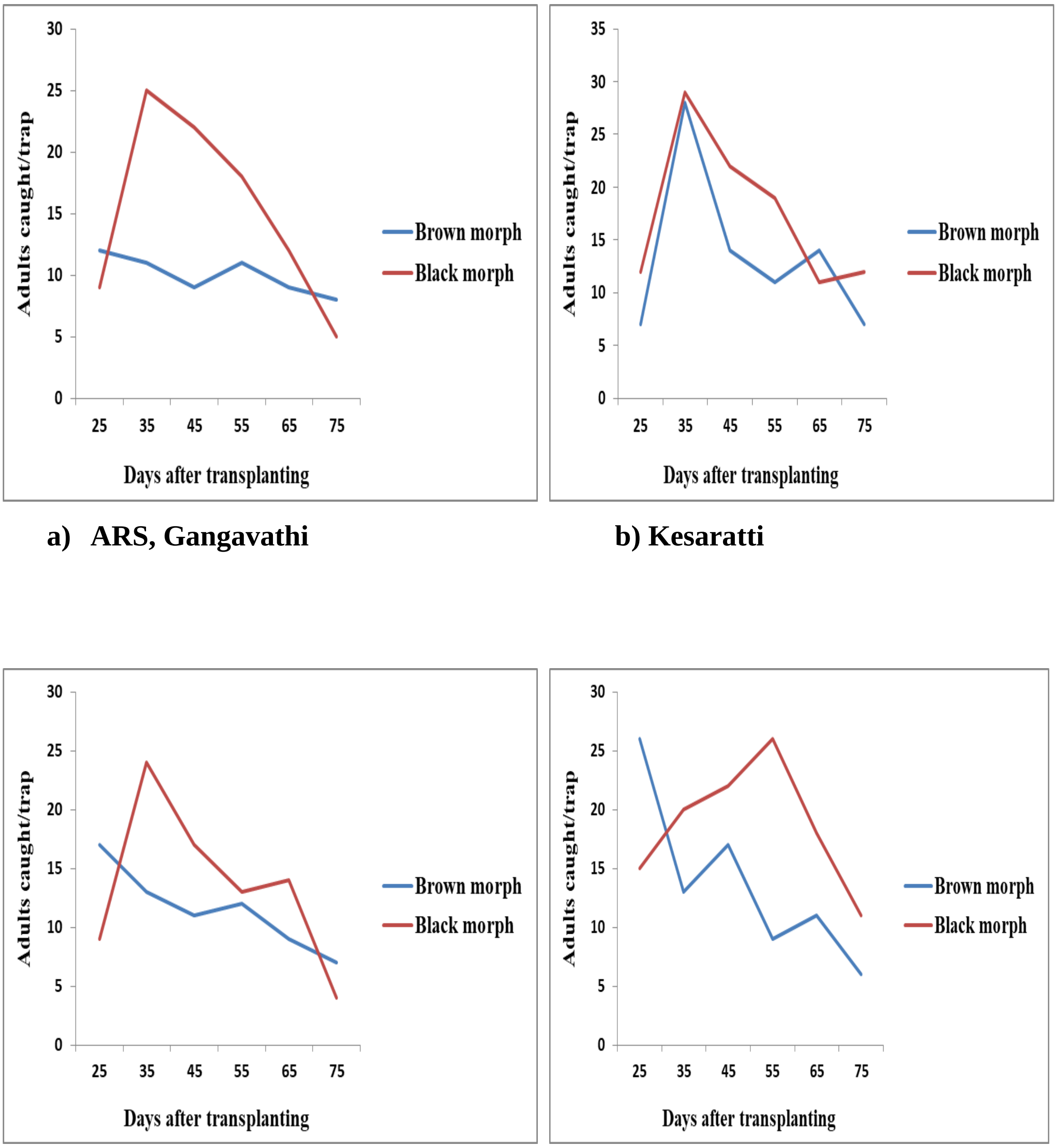
In the second season also the trend remains same in all locations. Initially, the BPH, *N. lugens* population trapped was more on early stage of the crop. In which particularly the black morph population trapped was more than brown morph reaching a peak population of 11 (brown) and 25 (black) adults per trap in ARS, Gangavathi, 28 (brown) and 29 (black) adults per trap in Kesaratti, 13 (brown) and 24 (black) adults per trap in ARS, Dhadhesugur and 13 (brown) and 20 (black) adults per trap in farmer's field in Dhadhesugur during early 35 DAT (Fig. 2). The increase in black morph population might be because of later instar nymphs or adults tend to attack the initial stage of the crop of next season because of unavailability of food resources. Later, the population trapped per trap goes on decreasing in both the morphs. This might be due to the unfavorable environmental conditions and unavailability of microclimate. There are no reports regarding light trap collections of brown and black morphs so, this forms the first report.

5.2 To study seasonal incidence of rice planthoppers in Tunga-Bhadra regions of Karnataka

5.2.1 Light trap collection of *N. lugens* and *S. furcifera* from all locations during *kharif*-2017

Adults of *N. lugens* started appearing in the first observation itself (3-4 WAT) in all the location. Later, the number of *N. lugens* collections. Increased gradually reached peak on penultimate observation periods 65-75 DAT in ARS, Gangavathi (42/trap), Kesaratti (57/trap), ARS, Dhadhesugur (41/trap) and farmer field in Dhadhesugur (43/trap) (Fig. 3). The present findings are in close agreement with the observation made by Yang *et al.* (2011) who reported that *N. lugens* adults trapped were more at later stages of the crop around 70-80 DAT.

The population dynamics of *S. furcifera* also fallowed same trend in all the locations. It was recorded that initially there was less catches of WBPH and later started increasing gradually from 25 DAT reaching highest peak during observation period in ARS Gangavathi (32/trap), Kesaratti (24/trap), ARS, Dhadhesugur (24/trap) and farmer's field in Dhadhesugur (15/trap) at 45 DAT during *Kharif*-2017 (Fig. 4). However the population did not sustain till the harvest of the crop. There was a sudden and steep decrease in the adult population. Similar observation was recorded by Wang *et al.* (1997), Cheng (1989), who reported a sudden decline in the WBPH population and attributed to competitive displacement (inter specific) by *N. lugens* population.



a) ARS, Gangavathi

b) Kesaratti

c) ARS, Dhadesugur

d) Farmer’s field in Dhadesugur

Fig. 2. Light trap collection of brown and black morph of *N. lugens* in different locations (rabi-summer 2017-18)

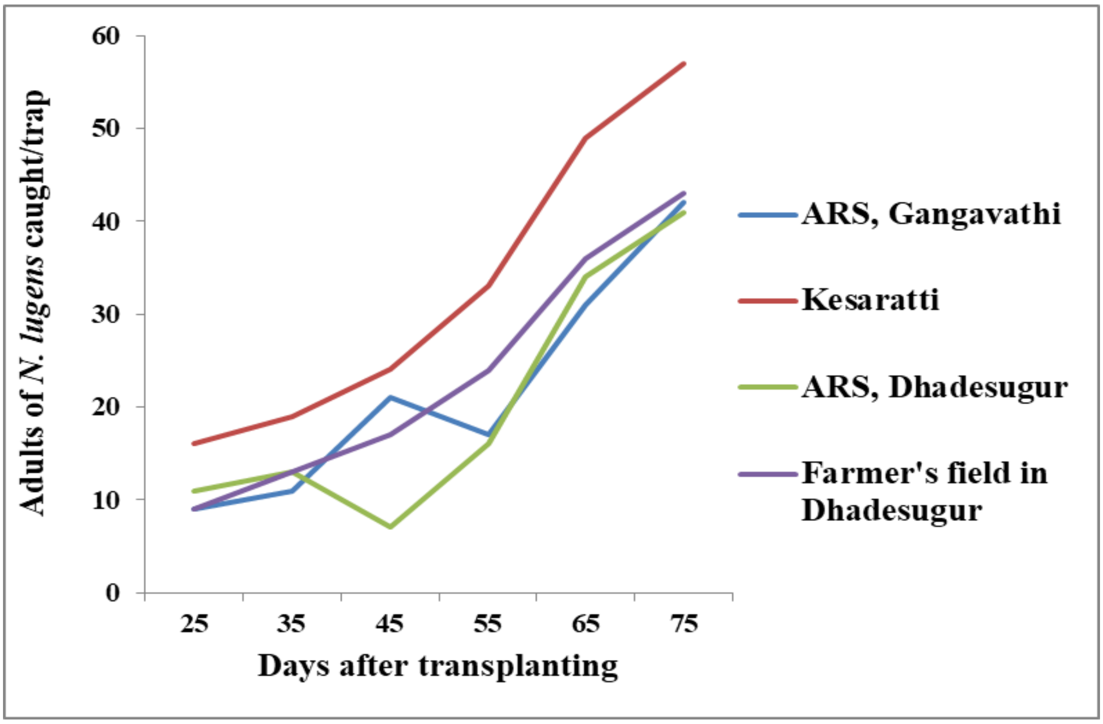


Fig. 3. Light trap collection of brown planthopper, *N. lugens* from all locations during *kharif*-2017

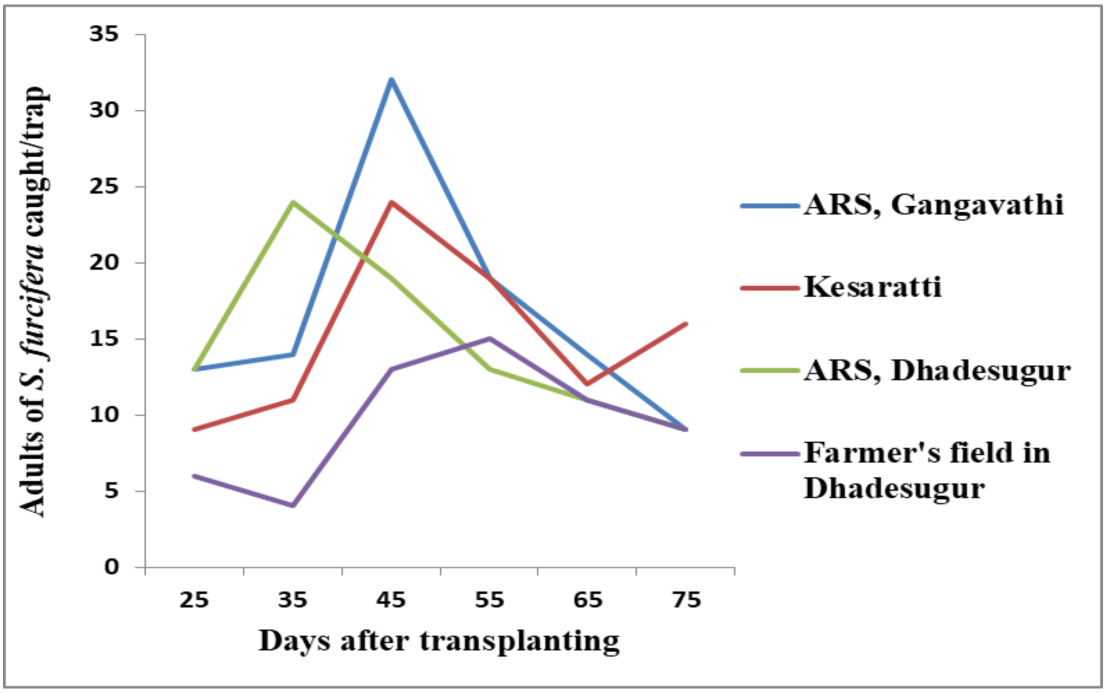


Fig. 4. Light trap collections of white backed planthopper, *S. furcifera* from all locations during *kharif*-2017

The overall trap catches observed during *Kharif*-2017 in all four locations indicated distinct trends in the *N. lugens* and *S. furcifera*. Both the planthopper population appeared simultaneously at the initial stage (*S. furcifera* catches was more than *N. lugens*) of the crop as indicated by the trap collections. However, BPH population after colonization maintained, extended till the end of the cropping period as shown from the trap collection. Whereas, WBPH population could be able to maintain early up to peak vegetative stage and later crashed. The trend perfectly coincides with the several incidence studies (Matsumura, 1996).

5.2.2 Light trap collection of *N. lugens* and *S. furcifera* from all locations during rabi-summer (2017-18)

The population dynamics of *N. lugens* remained same in all the locations. The adult trap catches started appearing at the initial stage of the crop *i. e.,* 20-25 DAT and reached maximum catches of 36 adults/trap in ARS, Gangavathi, 47 adults/trap Kesaratti, 37 adults/trap in ARS, Dhadhesugur and 39 adults/trap in farmer's field in Dhadhesugur at 35-40 DAT. Results were in line with the report of Hu *et al.* (2010) who attributed to the immigration of previous population (previous season's population). However present observations are in contrast with the reports of Phan *et. al.* (2009) who recorded maximum trap catches of BPH adults at 55-60 DAT during late April. This might be due to change in the cropping season, crop stage and other abiotic factors (Fig. 5).

In the second cropping season (rabi-summer) the population dynamics of *S. furcifera* recorded similar trend in all locations. The number of WBPH adults caught per trap was more during initial stage of the crop up to tillering stage and reached maximum of 23 adults/trap in ARS, Gangavathi, 24 adults/trap in Kesaratti, 26 adults/trap in ARS, Dhadhesugur and 21 adults/trap in farmer's field in Dhadhesugur at 35-40 DAT. Thereafter a sudden decline in the WBPH population was observed. The present findings are in line with the study made by Alam and Alam (1997) who reported that the WBPH adults trapped was more during early March and later declined. This might be because of massive adults/nymphs die off due to hot weather conditions (Fig. 6).

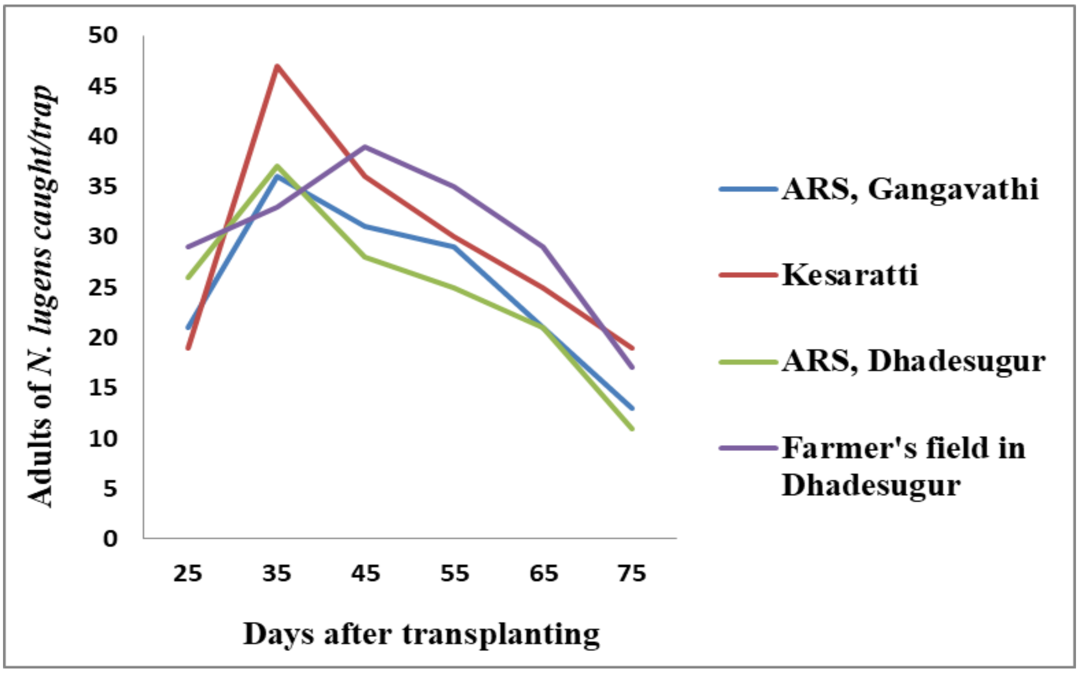


Fig. 5. Light trap collection of brown planthopper, *N. lugens* from all locations during rabi-summer 2017-18

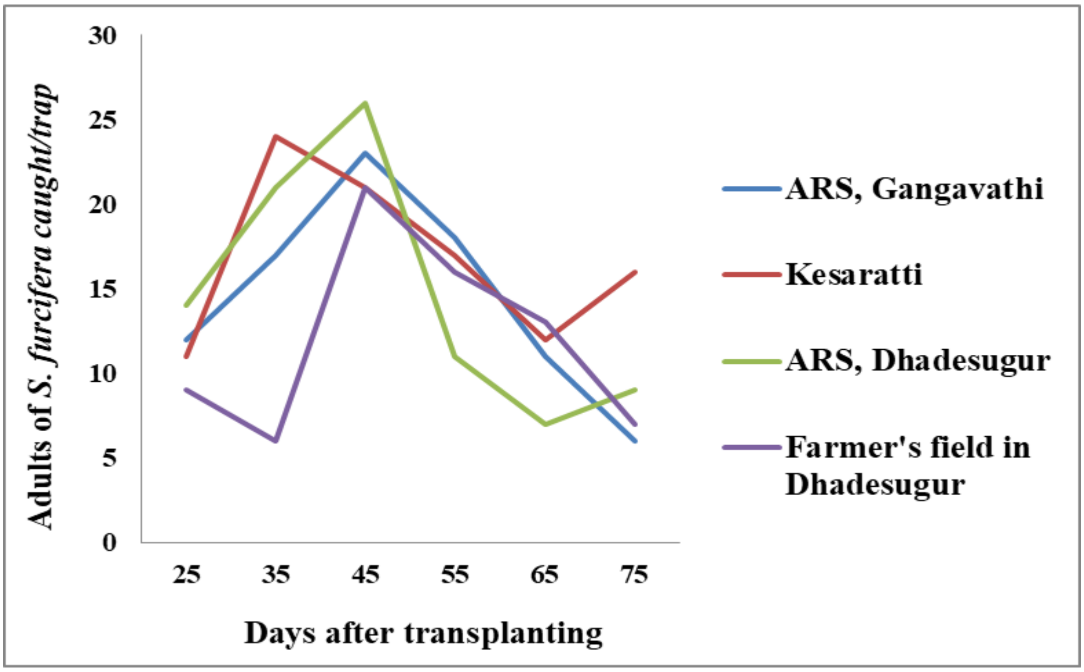


Fig. 6. Light trap collection of white backed planthopper, *S. furcifera* from all locations during rabi-summer 2017-18

5.2.3 Number of *N. lugens* and *S. furcifera* in paddy from all locations during *Kharif*-2017

The population trend of *N. lugens* was similar in all the location. It was observed that the initial occurrence of BPH was started at 8-9 WAT later the population increased sustainably and continuously reaching a peak of 4.46/hill in ARS Gangavathi, 26.4/hill in Kesaratti, 3.4/hill in ARS, Dhadhesugur and 24.8/hill in farmer's field in Dhadhesugur at penultimate observations at 11-12 WAT (Fig. 7). The peak population was coincided with the crop maturity. The present finding is in close agreement with the observation made by Nagangouda (1999) who reported the occurrence of BPH at 8-9 WAT. Further Prashant *et. al.* (2010) and Vijay Kumar and patil (2004) also recorded peak population of BPH during second fortnight of November *i.e.*, 12-13 WAT. However present finding differed from Thans *et al.* (1985) and Kittur *et al.* (1984) who recorded that peak population of BPH during December-January. This variation might be due to the change in the time of transplanting, duration of crop and variety grown.

The population dynamics of *S. furcifera* fallowed similar in all four locations though the actual number varies from field to field. It was observed that WBPH infested the paddy in the initial stage of the crop in all locations. Later the population started increasing gradually from 4 WAT reaching highest peak of 2.4/hill in ARS, Gangavathi, 2.32/hill in Kesaratti, 1.7/hill in ARS, Dhadhesugur and 3.2/hill in farmer's field in Dhadhesugur at 6-7 WAT(43rd SMW) during *kharif* 2017. However the peak population was not sustained till the harvest of the crop. The population started decreasing drastically reaching 0.48/hill in ARS, Gangavathi, 0.24/hill in Kesaratti, 0.2/hill in ARS, Dhadhesugur and 0.26/hill in farmer's filed in Dhadhesugur at 12-13 WAT. The results clearly indicate that the WBPH populations were more on tillering stage of the crop (4-5 WAT). Similar observations were recorded by Hirao (1972) and Noda (1987) who opined that the population of WBPH would be highest on young rice plants. Heong *et. al.* (1992), Ngoan (1972) also recorded a steep and sudden decline in the WBPH population as the crop age increases. Similarly Matsmura (1996) observed increased population growth at the initial stage of the crop fallowed by steep decline as age of the crop increases. Further as reports of initial increases the WBPH population and sudden and steep decline in the population at later stages was in close agreement with wang *et. al.*(1997) and cheng *et. al.* (1989) this might be because of fact that when both the species of BPH and WBPH established in the same habitat WBPH is at a competitive displacement. Therefore it seems likely that primitive migration of *S. furcifera* before *N. lugens* to new habitat is to compensate for later interspecific competition. (Fig. 8)

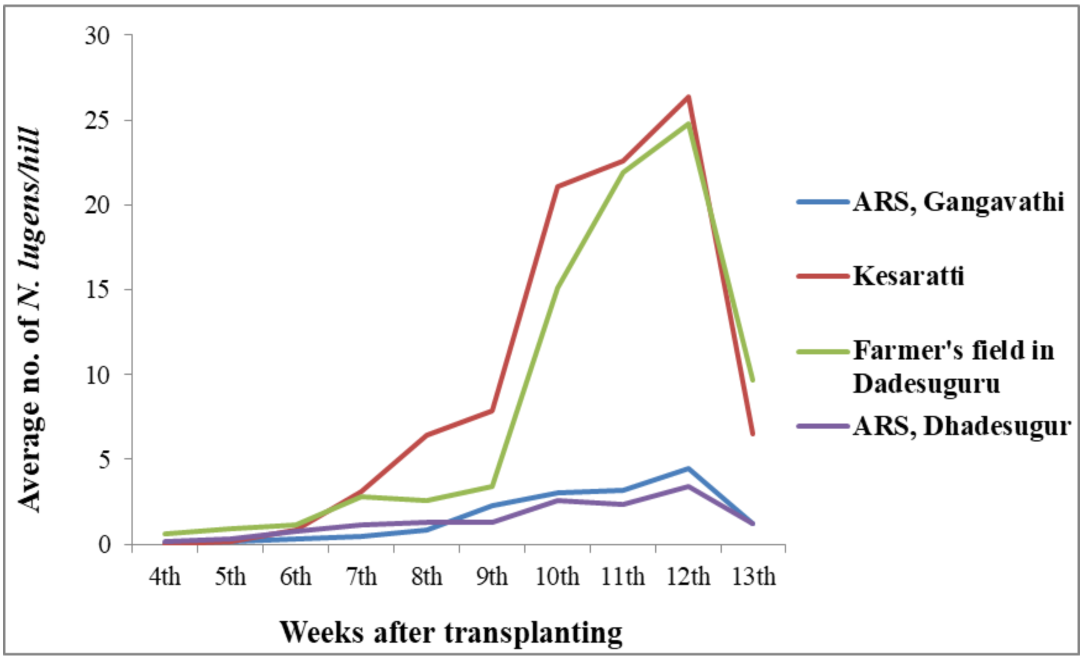


Fig. 7. Number of brown planthopper, *N. lugens* in paddy from all locations (*kharif*-2017)

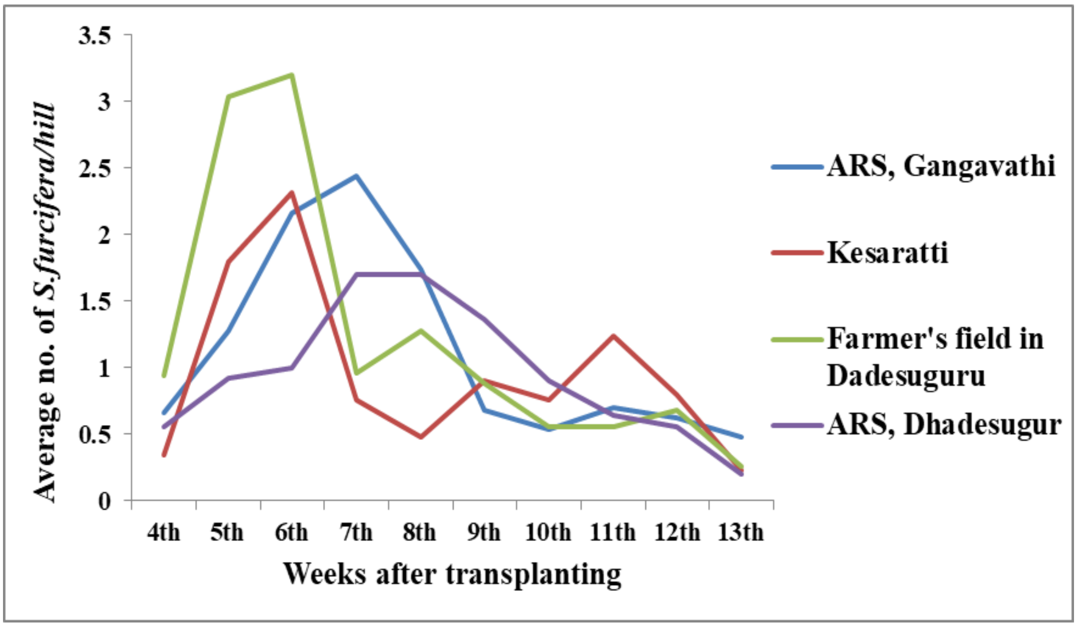


Fig. 8. Number of white backed planthopper, *S. furcifera* in paddy from all locations (*kharif*-2017)

The overall study on the seasonal incidence of *N. lugens* and *S. furcifera* during *kharif*-2017 indicated interesting observations. The initial colonization of WBPH was much before (4-5 WAT) the colonization of BPH (7-8 WAT). As the crop age increases the WBPH population started declining and was overtaken by BPH population. It appears that, WBPH would not be a threat in the observed location as it will be eliminated due to competitive displacement by BPH coupled with crop age.

5.2.4 Number of *N. lugens* and *S. furcifera* in paddy from all locations during rabi-summer 2017-18

The population dynamics of *N. lugens* remained same in all locations. The population started appearing at the initial stage *i. e.,* 4 DAT rather than attacking after 8-9 WAT as observed in the *kharif* season and reached maximum population of 0.84/hill in ARS, Ganavathi, 2.76/hill in Kesaratti, 3.78/hill ARS, Dhadhesugur and 4.62/hill in farmer's field in Dhadhesugur at 7-8 WAT. Later population started declining. Present findings are in line with Dale (1994) who reported the same trend in Kerala during February-March. Whereas maximum population was noticed at 7-8 WAT. This may be due to the infestation of the first season as immigrants to the subsequent crop. Later the population declined due to high temperature, low humidity. However our findings are in contrast with the reports of Channabasavanna (1976), Chatterjee (1978), who reported that the maximum BPH population during late March-April(10-11 WAT). This might be due to the late transplanting of the crop, duration of the crop and favourable environmental condition/microclimate prevailing in that area/field (Fig. 9).

In the second cropping season (rabi-summer) the population trend of *N. lugens* and *S. furcifera* remained same in all the locations. WBPH population occurred at initial stage of the crop as observed in the previous season. However the population remained negligible during throughout cropping period, reaching a peak of 0.4/hill in ARS, Gangavathi, 0.76/hill in Kesaratti, 0.74/hill in ARS, Dhadhesugur and 0.52/hill in farmer's field in Dhadhesugur at 6-7 WAT. Our results are in line with the Win *et. al.* (2011) who recorded that the population of WBPH reaches peak of 7-8/hill during early February-March (6 WAT). The population was less in our results but trend of population remains similar (Fig. 10).

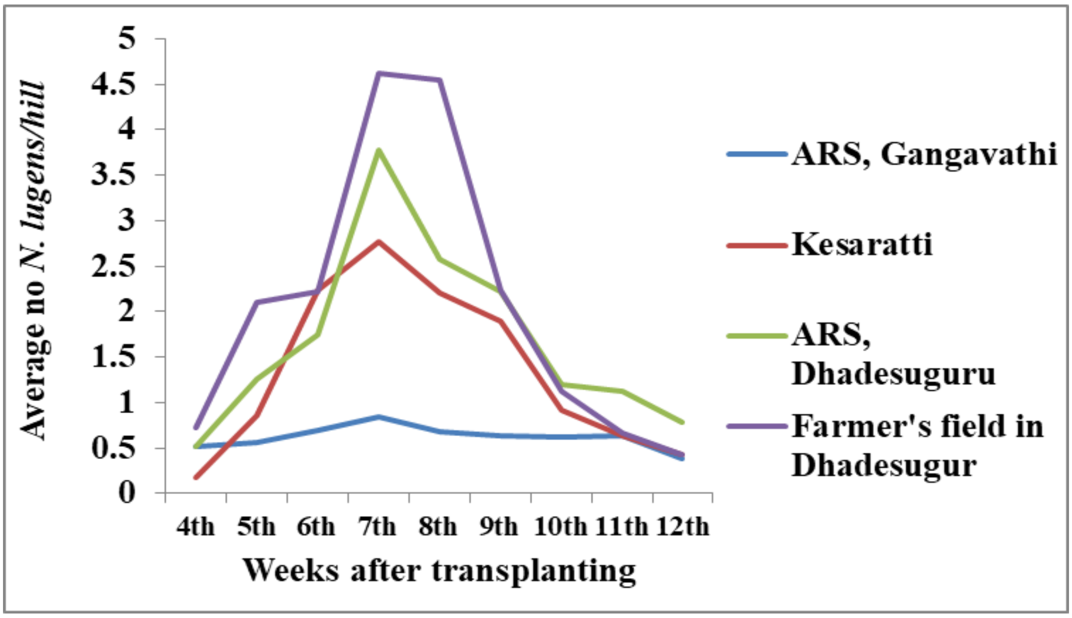


Fig. 9. Number of brown planthopper, *N. lugens* in paddy from all the locations (rabi-summer 2017-18)

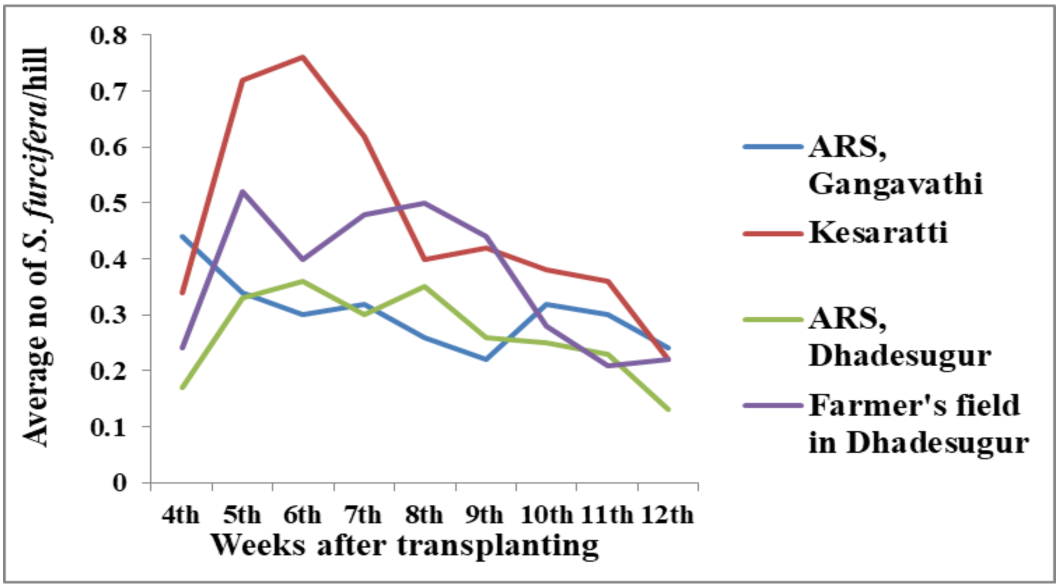


Fig. 10. Number of white backed planthopper, *S. furcifera* in paddy from all locations (rabi-summer 2017-18)

5.3 To study the biology of brown and black morphs of brown planthopper

5.3.1 To study the biology of paddy brown planthopper (brown morph)

5.3.1.1 Planthopper egg and incubation period

The female laid eggs in batches inside the leaf sheath, midrib and stem tissues. The eggs were not visible from outside. However, the tissues around the oviposition turned light brown to dark brown colour in 3-4 days. The maximum percentage of oviposition was found mainly inside leaf sheath. The eggs are arranged in groups varied from 3-12 and were white in colour when fresh but red eye spot developed gradually at the anterior ends and their tips were flat. Maximum hatching of eggs were observed in the early morning. The eggs were hatched in 7-9 days with an average of 8.025±0.69. Results are in accordance with the report of 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. Similarly incubation period of 4-8 days was reported by 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.

5.3.1.2 Nymphal period and morphometry

The freshly hatched nymphs were cottony white with clear abdomen and indistinct segments. The mean duration of first instar nymph was 1.45±0.36 days, with the average length and breadth of 0.57±0.02 mm and 0.18±0.02 mm, respectively, while the second instar nymph had slightly red coloured eyes with an average duration of 3.13±0.83 days and average length and breadth of 0.97±0.13 mm and 0.57±0.08 mm respectively. Whereas, the third instar nymphs were oval to brownish in colour with dull red coloured eyes and rudimentary wings. The duration of third nymphal instar ranged from 2.5-4 days with the average of 3.8±1.11 days with the average length and breadth of 1.20±0.07 mm and 0.64±0.07 mm, respectively. The fourth instar nymph had enlarged head with a brown vertex and the abdomen was swollen with irregular brown patches from first to seventh segments with the duration of about 3.9±1.43 days with the average length and breadth of 1.44±0.13 mm and 0.73±0.04 mm, respectively. The fully developed fifth instar nymph was dark-brown and robust with grayish-blue eyes, having three brown stripes on mesothorax and the wing rudiments fully covered the first three abdominal segments. The duration was of 3.95±1.76 days and the average length and breadth of about 2.13±0.18 and 0.97±0.07 mm, respectively. The present results are supported by the findings of Khaire and Dumbre (1981) who described that five nymphal instars lasted for 1.50, 2.50, 2.50, 3.50 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 14.50 days.

5.3.1.3 Pre-oviposition, oviposition, fecundity and post oviposition periods

The pre-oviposition period, oviposition period and post oviposition period were observed as 2.075±0.4, 14.2±1.03 and 6.3±0.64 days, respectively. The present findings are in line with the earlier reports of Nalinakumari and Mammen (1975) and Khaire and Dumbre (1981) who recorded *N. lugens* pre-oviposition period as 1-2 days and Nair (1986) who reported similar results about the average total oviposition period as 13.70 days. However, the findings are in contradictory with the reports of 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 due to variety of the crop, varied abiotic factors during different cropping period. Fecundity ranged from 140-170 eggs with a mean of 158±8.27 eggs. These findings are in close agreement with findings of Nalinakumari and Mammen (1975), who reported that fecundity rate of female ranges from 151 to 195.

5.3.1.4 Adult longevity

The longevity of males was reported as 18-21 days with a mean value of 18.20 ± 2.25 days and that of females was 23-25 days with a mean value of 22.65±0.48 days. These findings are in close association with the report of Nalinakumari and Mammen (1975), who reported that the total longevity of females varied from 14 to 30 days with an average of 21 days and that of males from 14 to 21 days with an average of 18.40 days.

5.3.2 To study the biology of paddy brown planthopper (black morph)

5.3.2.1 Planthopper egg and incubation period

The female laid their eggs in batches inside the leaf sheath, midrib and stem tissues. We can’t differentiate the eggs of brown and black morph which were white in colour when fresh but red eye spot was developed gradually at the anterior ends and their tips were flat. The eggs were hatched in 8-8.5 days with an average of 8.2±0.54 days.

5.3.2.2 Nymphal period and morphometry

The freshly hatched nymphs were brownish white. Abdomen was clear and segments were not so distinct. Mean duration of first instar nymph was 1.93±0.46 days with average length and breadth of 0.56±0.04 and 0.21±0.02 mm, respectively, the second instar nymph had slightly red coloured eyes with average duration of 2.83±0.49 days average length and breadth of 0.99±0.05 and 0.55±0.03 mm, respectively, whereas third instar nymphs had brownish to dark brown in colour with red coloured eyes the duration of third nymphal instar ranged from 3.1±0.5 days with the average length and breadth of 1.27±0.04 and 0.69±0.035 respectively. The fourth instar nymph had enlarged head with a black vertex with average duration of 4±0.54 days with the average length and breadth of 1.89±0.17 and 0.95±0.06, respectively. The fifth instar nymph was dark-black and robust, the wing rudiments fully covered the first three abdominal segments with average duration of 4.8±0.56 days with average length and breadth of 2.3±0.08 and 1.05±0.07 mm, respectively.

5.3.2.3 Pre-oviposition, oviposition, fecundity and post oviposition periods

The pre-oviposition period, oviposition period and post oviposition period were observed as 2.17±0.49, 14.8±0.67 and 6.15±0.81 days, respectively.

5.3.2.4 Adult longevity

The longevity of males was reported as 17-20 days with mean value of 18.50 ± 2.8 days and that of females was 21-23 days with a mean value of 23.12±0.16 days.

5.3.6 Comparison of various biological parameters between brown and black morphs of *N. lugens* (Stal.)

In comparison with the biology of brown and black morphs of BPH, there were no such significant variations observed with respect to the different biological parameters (Fig. 17). There are no report findings regarding the biology of black morph and brown morphs of BPH so, this forms the first result. The morphometry of both the morphs revealed that there was no difference except the total body length of the female and male (black morph) was 3.24±0.21 mm and 2.65±0.13 mm that of brown morph female (3.04±0.17 mm) and male (2.41±0.11 mm) (Table 2). This was due to initially the brown morphs population was more than the black morph up to the nearly panicle initiation stage later the black morph population was more and it continues up to the harvest of the crop. It is just assumption that the formation of black morphs was due to the melanization because of unavailability of food after the harvest of the crop so, they malanize themselves and coverts brown to black, to migrate for larger area they has to increase the length of forewing in search of the food to overcome the harsh environmental condition (Fig. 11).

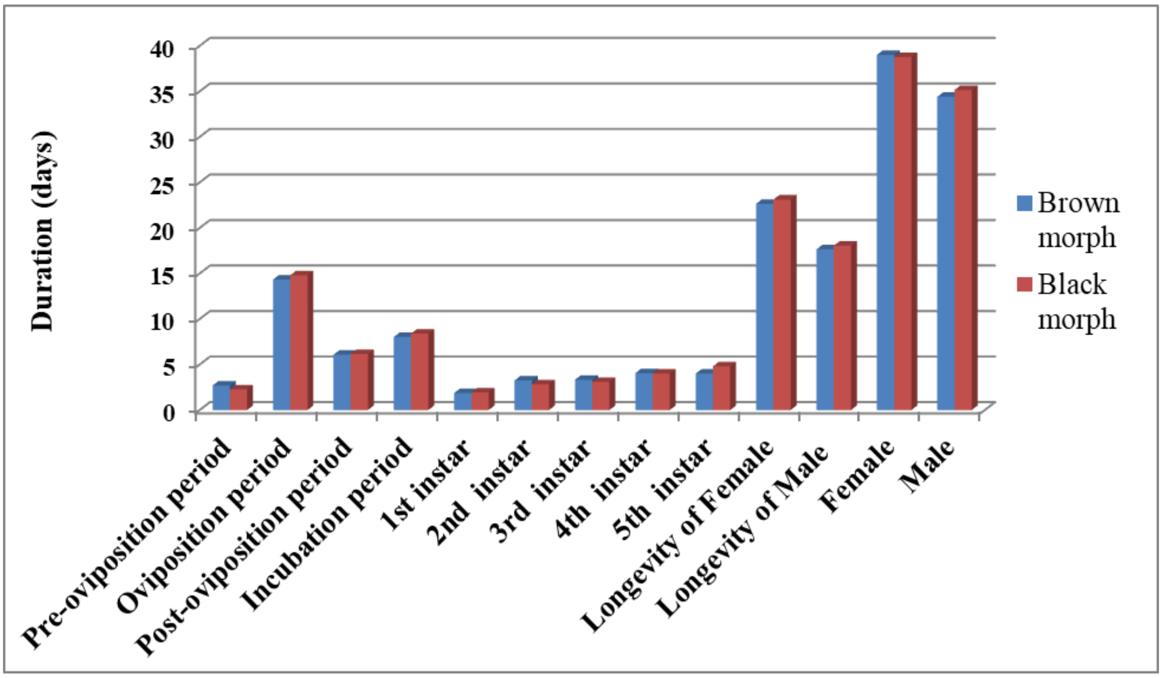


Fig. 11. Comparison of biological studies on different morphs of brown planthopper *N. lugens*

SUMMARY AND CONCLUSION…

VI. SUMMARY AND CONCLUSION

The present investigation was pursued to study the occurrence of morpho-species, seasonal incidence/population and biology of planthopper. The studies were conducted in research farms, farmer's field and laboratory (Entomology) of Agricultural Research Station, Gangavathi, during *kharif* and rabi-summer 2017-18.

The planthoppers *viz.,* brown planthopper, *N. lugens* and white backed planthopper, *S. furcifera* were collected from rice fields from four locations of two taluk *viz.,* Gangavathi and Siraguppa. In Gangavathi, ARS, Gangavathi and Kesaratti, in Siraguppa ARS, Dhadhesugur and farmer's field in Dhadhesugur were selected for experiment purpose. During collection it was observed that the existence of two different morphs in brown planthopper *N. lugens.* The genital study revealed that both the morphs belong to same species *i.e., N. lugens*. In morphometric studies of different parts of these two morphs also revealed that there are no such variations with respect to the body size of the morphs. There were no morphs variation occurred in WBPH population also.

The light trap observations during 2017-18 revealed that WBPH catches were started during early stages of the crop *i.e.,* 3-4 WAT reached the maximum at 6-7 WAT (mid-October). In case of BPH, the population catches were started at 4-5 WAT and reaches maximum population during 12-13 WAT (last week of November) during *kharif*-2017. In rabi-summer, the WBPH and BPH adult population trap catches started during 3-4 WAT, but WBPH population caught was maximum during mid-February and BPH population caught was maximum during 6-7 WAT (last week of February)

The observation on seasonal incidence during 2017-18 revealed the maximum population of WBPH, *S. furcifera* attack the paddy at initial stage of the crop *i. e.,* 3-4 WAT and reached maximum during 6-7 WAT (mid-October). The BPH population started appearing during later stages of the crop and reached maximum at 12-13 WAT (last week of November- early December) during *kharif*-2017 in all locations. In rabi-summer maximum population of WBPH was started appearing during initial stage of the crop 3-4 WAT (Early February) but population was negligible but in BPH population started along with WBPH and reached a minimum population during 6-7 WAT (last week of February – early march) in all location.

The biology of BPH, *N. lugens* was studied on cultivar BPT-5204 under laboratory conditions during November to December 2017. The eggs were laid inside the leaf sheath and midrib in groups. The numbers in an egg group were 3-12 eggs. The eggs were white in colour when fresh but red eye spot developed at the anterior end before hatching. Egg period lasted for 8.02±0.69 days with a range of 7-9 days, mean duration of 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} nymphal instars were 1.5-2, 2.5-3, 2.5-4, 3-4 and 4-5 days, respectively. The total nymphal period was 16.85 days with range of 16-20 days. The pre-oviposition, oviposition period and post oviposition periods were 2.11±0.41 (1.5-3), 14.2±1.03 (13-15) and 6.3±0.64 (5-7) days, respectively. Female on an average laid 158 (140-170) eggs during its life span. Longevity of males and females ranged from17-19 days and 20-23 days with an average of 18.2±2.25 and 22.65±0.48 days, respectively. Total life cycle of female and male ranged from 36-39 days and 33-35 days with an average of 38±0.49 and 34.4±0.19 days, respectively.

The biology of brown morphs was compared with the biology of black morphs and results showed that there were no such significant variations observed with respect to the biological parameters of both the morphs except a little high fecundity in black morph (150-180) compare to brown morphs (140-165). With respect to the morphometry of both the morphs, the black morphs female (3.24±0.21) and male (2.65±0.13) showed larger total body length than brown morph's female (3.04±0.17) and male (2.41±0.11).

From the present investigation the fallowing conclusions can be drawn

- The two different morphs which are existing in paddy ecosystem are not different species/sub-species. They belongs to a single species *N. lugens* (from the confirmation of genital and morphometric studies).

- BPH, *N. lugens* developed two distinct peaks, one during last week of November to first week of December during *kharif*-2017 and second during last week of February to first week of March during rabi-summer 2017-18. But, WBPH *S. furcifera* reaches a peak during last week of October in *kharif* with negligible population during rabi-summer 2017-18.

- ❖ The incidence of WBPH *S. furcifera* reaches maximum population during 6-7 WAT, later the steep decline in the population of WBPH was observed. Which was over taken by BPH, *N. lugens* in later stages of the crop. The reason behind this was inter-specific competitive displacement between the populations of BPH and WBPH, which displaces the WBPH population by BPH population.
- ❖ Comparative study with respect to the biological parameters of different morphs revealed no variation in the biological studies of these morphs.

Future line of work:

- ❖ Interaction of both BPH and WBPH has to be studied with respect to the biological aspects for better understanding of the population abundance and depletion.
- ❖ Detailed study on the co-existence and competitive displacement in the BPH and WBPH need to be explored.

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"Studies on biology and seasonal incidence of rice planthoppers in Tunga-Bhadra Project (TBP) areas of Karnataka"

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ABSTRACT

Investigations were carried out on the occurrence of morpho-species of brown planthopper(BPH), their biology and seasonal incidence in the Tunga-Bhadra Project areas of Karnataka (ARS, Gangavathi, Kesaratti, ARS, Dhadesugur and farmer's field in Dhadesugur) during June 2017 to May 2018. It was found that the existence of two different morphs in the rice ecosystem and were studied for morphometric and genital variability. In morpho-species study there were no such variations in morphometrics including genital structures. These are just mere colour variants of brown planthopper (BPH), *Nilaparvata lugens* (Stal) and are not different species or subspecies in all the locations. In biological studies of brown and black morphs of BPH, brown morph showed ovipositional period (14.5-19 days), fecundity (140-170 days), incubation period (7-9 days), nymphal period (13.5-18 days) adult female and male longevity (20-23 and 17-19 days). The black morphs also showed the similar biological parameters as that of brown morph. So, there were no such variations in the biological parameters of both the morphs. The incidence of white backed planthopper (WBPH) and BPH was observed during *kharif* and *rabi-summer* season. The population of WBPH attacks the paddy at initial stage of the crop and reached maximum during 40-45 DAT with a population of 0.34, 0.76, 0.36, 0.52 per hill in ARS, Gangavathi, Kesaratti, ARS, Dhadesugur and farmer's field in Dhadesugur. The BPH population started appearing during later stages of the crop and reached maximum at 75-85 DAT with a maximum population of 4.46, 26.4, 3.4, 24.8 per hill in ARS, Gangavathi, Kesaratti, ARS, Dhadesugur and farmer's field in Dhadesugur during last week of December during *kharif*. In *rabi-summer* WBPH population was negligible but BPH population reached a maximum population of 0.84, 2.76, 3.78, 4.62 per hill during last week of February (45-50 DAT).