Research article

Effect of Temperature on the Cohort Life Table of Brown Planthopper (*Nilaparvata lugens* Stål) (Homoptera: Delphacidae)

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Abstract We investigated the effect of constant temperatures (24, 28, 32, and 36 °C) and room temperature on brown planthopper (BPH), *Nilaparvata lugens*, population dynamics; these data are useful for forecasting BPH outbreaks. Eggs laid by gravid females were incubated in test tubes at the treatment temperatures and observed for egg hatching. After hatching, first instar nymphs were collected using a camel-hair brush and incubated individually in new test tubes, each with a rice plant. The number of hatched and unhatched eggs were recorded. Nymphs were monitored daily for life table parameters until adult emergence; the longevity of adults were also recorded. From life table analysis, the greatest mortality occurred in the first nymphal instar, which resulted in type III survivorship curves. Moreover, at 36 °C, 100% mortality occurred at the egg stage. Brachypterous and Macropterous forms achieved high net reproductive rates at lower temperature regimes. The growth parameters of BPH decreased at 36 °C; temperatures above 32 °C were detrimental to the development of BPH. Results indicate that egg and nymphal stages were significantly affected by temperature. Egg hatch also decreased drastically with increased temperatures, especially at 36 °C.

Keywords constant temperature, *Nilaparvata lugens*, life table parameters, rice

INTRODUCTION

Rice is an essential food crop and more than 90% of global production occurs in tropical and semi-tropical Asia (Food and Agriculture Organization, 2012). Each year, an additional 50 million rice consumers will be added to the world population, meaning that rice production must increase markedly (Heong and Hardy, 2009). In Myanmar, rice is the single most important crop, both as a staple and as a foreign exchange earner (Ministry of Agriculture and Irrigation, 2003).

Rice is susceptible to pests and diseases. From sowing to harvest, all parts of the plant are vulnerable to insect-feeding (Grist and Lever, 1969). Eight hundred species of insects attack rice crops, either in the field or during storage. Amongst these, one of the most economically important is the brown planthopper (BPH), *Nilaparvata lugens* (Stal.) (Homoptera: Delphacidae). BPH has become more problematic, posing a threat to rice production throughout South and South East Asia (Rao, 1950). In Myanmar, the first outbreak of BPH happened in 1970 at the Kyaukse Central Farm (Mandalay Division) and in Upper Myanmar (Myint, 1975). The BPH has since become a major pest of rice in Myanmar (Win et al., 2011).

BPH is present on rice during both dry and wet seasons. Biotic and abiotic factors affect survival, growth, development and multiplication of BPH; amongst these, temperature plays a significant role (abiotic factor). As a result of climate change, global mean temperatures are predicted to increase by 1.5 - 6.0 ºC by the end of the 21st century (IPCC, 2001). This significant temperature increase will affect insect physiology, behavior and development as well as species distribution and abundance; there is already evidence for this in the increase in number of generations a year, increasing survival rates in winter, and the earlier appearance of some insects (Huang, et al., 2010).

OBJECTIVE

This study aimed to investigate the effect of temperature on BPH life table parameters to provide the data needed for forecasting BPH outbreaks.

METHODOLOGY

Study site:
The experiments have been done at the JICA – ELB 1 Laboratory, Department of Entomology and Zoology, Yezin Agricultural University, Myanmar between August 2018 and January 2020.

Brown planthopper (BPH) rearing:
The initial population of BPH was collected from rice fields at Yezin Agricultural University. To establish a colony adult was confined on 30-day old potted rice plants (susceptible variety Manaw thukha) in aluminum rearing cages in a screen house.

Life table study:
There were four constant temperature treatments (24, 28, 32 and 36 °C), and a control maintained at room temperature (26.8-30.7 °C) which was recorded daily. Individual rice plants (tillering stage) were placed in test tubes with four gravid female BPH for the collection of eggs and sealed with a cotton wool plug. Replicate test tubes (n=5) were placed at each of the treatment, control temperatures and oviposition allowed to proceed for 24 h. After this time adult females were removed and the groups of eggs incubated at their allocated temperatures. Eggs were observed daily and, when they hatched, a camel-hair brush was used to transfer each first instar nymph individually into new test tubes, each with a new rice plant. Eggs continued to be observed and hatching first instars transferred into new test tubes until hatching stopped; the number of hatched and unhatched eggs were recorded at this point. The later instars were collected and transferred as the same way. Nymphs were monitored daily and the time to moult to each life stage recorded; they were provided with fresh plant materials as required. We recorded mortality (d_x) daily until their death. As adults emerged, one male and one female were paired and moved to a new rice plant. The total numbers of laid eggs were recorded daily until females died.

Age specific life table construction:
The life table was built by partitioning the life-cycle into distinct development stages (i.e. eggs, nymphs and adults) and recording the developmental time and survival or mortality of each stage. We calculated the pivotal age for the age class in units of time (days) (X), number of alive at each life stage (n_x), proportion of individuals surviving to the start of age interval x (l_x), mean number of individuals alive during the age interval x to x+1 (L_x), number dying during the age interval x to x+1 (d_x), percent apparent mortality (100 q_x), total number of age X units beyond the age (T_x), mean expectation of life for individuals alive at the start of age x (e_x), age-specific fertility, the number of living females born per female in each interval class (m_x), net reproductive rate (R_o), the innate capacity for an increase in numbers (r_m), and the mean length of a generation (G) from these data.

Data analysis:
ANOVA and comparison of means was done using LSD in the software program (SAS 9.1).

RESULTS AND DISCUSSION

Life Table

Life table analysis showed that a mean of 26.4% of 139.4 BPH eggs survived to adulthood when incubated at room temperature (control); this was 45.2% (of 143.0 eggs) at 24 °C, and 49.2% (of 113.8 eggs) at 28 °C. Win et al. (2011) found that 37.26% of 365 BPH eggs successfully emerged as adults in a field experiment where the temperature ranged between 23 °C and 33 °C.

Table 1 Mean number and percentage of BPH alive at each life stage when reared at different constant temperatures

Stages	Mean ± SE									
	Control		24 °C		28 °C		32 °C		36 °C	
	n_x	%	n_x	%	n_x	%	n_x	%	n_x	%
Egg	139.4 ± 3.9	100.0	143.0 ± 3.2	100.0	113.8 ±1.1	100.0	132.4 ±1.6	100.0	135.8 ± 2.7	100.0
First instar nymph	102.4 ± 6.2	73.5	137.0 ± 3.2	95.8	96.8 ± 1.5	85.1	107.4 ± 2.5	81.1	0.0 ± 0.0	0.0
Second instar nymph	77.6 ± 4.8	55.7	112.2 ± 3.1	78.5	77.4 ± 1.1	68.0	76.6 ± 1.8	57.9	0.0 ± 0.0	0.0
Third instar nymph	67.4 ± 3.8	48.4	99.0 ± 2.6	69.2	72.8 ± 0.9	64.0	56.4 ± 1.8	42.6	0.0 ± 0.0	0.0
Fourth instar nymph	57.2 ± 3.1	41.0	90.4 ± 2.6	63.2	67.2 ± 0.9	59.1	44.8 ± 1.3	33.8	0.0 ± 0.0	0.0
Fifth instar nymph	48.0 ± 2.7	34.4	80.0 ± 2.4	55.9	64.0 ± 0.8	56.2	22.6 ± 1.1	17.1	0.0 ± 0.0	0.0
Adult	36.8 ± 2.4	26.4	64.6 ± 2.2	45.2	56.0 ± 0.8	49.2	0.0 ± 0.0	0.0	0.0 ± 0.0	0.0

In our study high mortality occurred during the early immature stages and at 32 °C and 36 °C there was no survival to adulthood (Table 1). Begon and Mortimer (1981) reported that this low survivorship at higher temperatures is common in most insect species.

The highest mortality of any life stage (135.8±2.7) was observed at 36 °C in the egg stage. Greatest mortality in first, second, third, fourth and fifth instar nymph were found at 32°C. At 36 °C, none of the nymphal instars survived (Table 2). Krishnaiah et al. (2005) reported that temperatures ranging between 25 and 30 °C were most favorable for BPH multiplication, and that the insect could not tolerate constant temperatures of 35 °C and higher. Rout and Jena (2012) found that BPH thrived and multiplied well at a temperature of 30 ± 3 ºC, and that 33ºC and 35 ºC were unfavorable for insect survival.

Table 2 Mean number of BPH dying between age interval x and age interval x+1 (d_x) when reared at different constant temperatures

Stages	Mean ± SE				
	Control	24°C	28°C	32°C	36°C
	d_x	d_x	d_x	d_x	d_x
Egg	37.0±2.4	6.0±0.7	17.0±0.9	25.0±1.7	135.8±2.7
First instar nymph	24.8±1.5	24.8±0.8	19.4±0.7	30.8±0.8	0.0±0.0
Second instar nymph	10.2±1.1	13.2±0.5	4.6±0.3	20.2±0.6	0.0±0.0
Third instar nymph	10.2±0.8	8.6±0.3	5.6±0.2	11.6±0.6	0.0±0.0
Fourth instar nymph	9.2±0.5	10.4±0.5	3.2±0.2	22.2±0.5	0.0±0.0
Fifth instar nymph	11.2±0.4	15.4±0.2	8.0±0.1	22.6±1.1	0.0±0.0

The highest net reproductive rate (175.6) of the brachypterous form was observed at room temperature (control), followed by (168.2) at 24 °C, (166.8) at 28 °C and (74.6) at 32 °C, respectively. The lowest net reproductive rate (32.6) was found at 36 °C. The intrinsic rate of natural increase (r_m) was 0.6, 0.5, 0.7, 0.9 and 0.8 for control, 24 °C, 28 °C, 32 °C and 36°C, respectively (Table 3). The net reproductive rate of BPH was higher at lower temperature regimes. Manikandan et al. (2015) found that the net reproductive rate of BPH was greater at 30 °C (39.95) than at 36 °C (8.84).

Table 3 Life table parameters of brachypterous forms at different temperature

Parameter	Formula	Brachypterous forms				
		Control	24 °C	28 °C	32 °C	36 °C
Mean length of a generation (G)	$G = \sum l_x m_x X / \sum l_x m_x$	8.5	9.8	7.4	4.7	4.4
Instantaneous rate	$r_m = \log_e(R_o)/G$	0.6	0.5	0.7	0.9	0.8
Net reproductive rate	$R_o = \sum l_x m_x$	175.6	168.2	166.8	74.6	32.6
Gross reproductive rate	$\sum m_x$	175.6	168.2	166.8	74.6	32.6

The highest net reproductive rate (204.0) of macropterous forms was found at room temperature (control), followed by 142.6 at 28 °C, 102.4 at 24 °C and 93.6 at 32 °C. The lowest net reproductive rate (29.2) was found at 36°C. The intrinsic rate of natural increase (r_m) was 0.6 in both the control and at 24 °C, 0.6 at 28 °C, 0.8 at 32 °C and 0.9 at 36 °C (Table 4). Similar results were reported for BPH by Manikandan et al. (2015) who reported that the net reproductive rate was greater at lower temperature regimes (30.0 °C) than at higher temperature regimes (36.0 °C).

Developmental stages of BPH varied in length and time at different temperatures. The mean number of first instar nymph was highest at 24 °C with the value of (137.0 ± 3.2) and lowest at 28 °C (96.8 ± 1.5). The second instar nymph was highest at 24 °C (112.2 ± 3.1) and lowest at 32 °C (76.6 ± 1.8). The third instar nymph was highest at 24 °C (99.0 ± 2.6) and lowest at 32 °C (56.4 ± 1.8). The fourth instar nymph was highest at 24 °C (90.4 ± 2.6) and lowest at 32 °C (44.8 ± 1.3). The fifth instar nymph was highest at 24 °C (80.0 ± 2.4) and lowest at 32 °C (22.6 ± 1.1). Adults had the highest at 24 °C (64.6 ± 2.2) and no adults emerged adult at 32 °C. All eggs died at 36 °C (Table 5). This shows that, overall, 24 °C is the most favorable temperature for development of each life stage. Bae and

Pathak (1970) reported that there was no apparent difference in rate of growth of nymphs when reared at 25 °C or 29 °C but at 33 °C no nymphs survived beyond second instar.

Table 4 Life table parameters of macropterous forms at different temperature

Parameter	Formula	Macropterous forms				
		Control	24 °C	28 °C	32 °C	36 °C
Mean length of a generation (G)	$G = \sum l_x m_x X / \sum l_x m_x$	8.8	7.5	8.9	6.0	3.8
Instantaneous rate	$r_m = \log_e(R_o) / G$	0.6	0.6	0.6	0.8	0.9
Net reproductive rate	$R_o = \sum l_x m_x$	204.0	102.4	142.6	93.6	29.2
Gross reproductive rate	$\sum m_x$	204.0	102.4	142.6	93.6	29.2

Table 5 Life table of developmental stages of BPH at different temperature

Stages	Mean ± SE					P- value
	control	24 °C	28 °C	32 °C	36 °C	
Egg	139.4 ± 3.9	143.0 ± 3.2	113.8 ± 1.1	132.4 ± 1.6	135.8 ± 2.7	<.0001
First instar nymph	102.4 ± 6.2	137.0 ± 3.2	96.8 ± 1.5	107.4 ± 2.5	0.0 ± 0.00	<.0001
Second instar nymph	77.6 ± 4.8	112.2 ± 3.1	77.4 ± 1.1	76.6 ± 1.8	0.0 ± 0.00	<.0001
Third instar nymph	67.4 ± 3.8	99.0 ± 2.6	72.8 ± 0.9	56.4 ± 1.8	0.0 ± 0.00	<.0001
Fourth instar nymph	57.2 ± 3.1	90.4 ± 2.6	67.2 ± 0.9	44.8± 1.3	0.0 ± 0.00	<.0001
Fifth instar nymph	48.0 ± 2.7	80.0 ± 2.4	64.0 ± 0.8	22.6 ± 1.1	0.0 ± 0.00	<.0001
Adult	36.8 ± 2.4	64.6 ± 2.2	56.0 ± 0.8	0.0 ± 0.0	0.0 ± 0.00	<.0001

CONCLUSION

This study showed that population growth parameters were positively correlated with temperature up to 28 °C but negatively correlated at 32 °C and above. At 36 °C, survival of all growth stages decreased. Thus, temperatures above 32°C are detrimental to the development of BPH and no adults emerged at 32 °C and 36 °C. The most favorable temperature for BPH development was 24 °C for every life stage. According to results, BPH's net reproductive rate was greater at lower temperature regimes (control, 24 and 28 °C) than at higher temperature regimes (32 °C and 36 °C). No eggs hatched into nymph at 36 °C. BPH development was good at control, 24 °C and 28 °C although fitness was reduced at 32 and 36 °C. In the life table analysis, the highest mortality occurred in the first nymphal instar. The survivorship curve indicated a modest rate of mortality during the early life stages that gradually decreased as individuals reached adulthood; this followed a type III survivorship curve. Temperature had a direct effect on development, survival and reproduction of BPH.

Brown planthopper have high reproductive rate, so critical monitoring and forecasting of the brown planthopper is very necessary for timely control management. The research finding will provide valuable information to take monitoring program for control of BPH population outbreak according to the climate change.

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