BIODIVERSITAS
Volume 24, Number 8, August 2023
Pages: 4690-4698

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240851

Beneficial interaction between rice stunt virus and its insect vector *Nilaparvata lugens* Stal based on life table

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Manuscript received: 15 July 2023. Revision accepted: 29 August 2023.

Abstract. *Listihani L, Yuniti IGAD, Ariati PEP, Pandawani NP, Selangga DGW, Temaja IGRM, Wirya GNAS, Sudiarta IP. 2023. Beneficial interaction between rice stunt virus and its insect vector* Nilaparvata lugens *Stal based on life table. Biodiversitas 24: 4690-4698.* The brown planthopper (*Nilaparvata lugens)* causes direct and indirect damage as a stunting virus vector in rice. Insect vectors and viruses are closely related with respect to disease transmission to host plants. Thus, this research aimed to determine the specific relationship between a virus and its insect vector on the biology and demography statistics of viruliferous brown planthopper (BPH). Research method included the propagation of *N. lugens* and stunt virus inoculum, the observation of cohort, stadia duration and egg survival rates, imago life span, and *N. lugens* life table. The BPH life table was arranged with the jackknife method for two treatments: plants infected by stunt virus and healthy plants. The research result showed that plants infected by stunt virus can shorten the BPH nymphal development stage from instar 2 to instar 5, life cycle, preoviposition period, and double time. Plants infected by stunt virus did not influence the BPH hatching pattern but influenced the total number of hatching eggs. The next BPH generation of stunt virus inflected plants increased 29.51 times more from the previous generation, while on healthy plants, the next BPH generation only increased 27.51 times. Virus-infected plants generally appeared to be superior quality hosts for vectors compared to uninfected plants, thus enhancing vector life table and virus spread.

Keywords: Brown planthopper, life table, *Nilaparvata lugens,* rice, stunt virus, vector

INTRODUCTION

Indonesia is the world's third largest rice consumer and producer after China and India. Insect pest which often incur a loss on rice plants in Indonesia is the brown planthopper (*Nilaparvata lugens* Stal.) or BPH. BPH has spread over Bali Province with the most damage found in Badung Regency as hopperburn symptoms (Listihani et al. 2022a). BPH causes severe damage called hoppernburn (Nguyen et al. 2019; Quais et al. 2020; Horgan and Penalver-Cruz 2022). In addition to being a pest, it is also a virus vector, so its presence around plantations poses a risk of even larger loss. BPH is a vector for rice ragged stunt disease caused by *Rice ragged stunt virus* (RRSV) and for rice grassy stunt disease caused by *Rice grassy stunt virus* (RGSV) (Nguyen et al. 2015; Nguyen et al. 2019; Phatthalung and Tangkananond 2022).

The rice ragged stunt disease in rice was first reported in Indonesia in 1976 in di West Java, Central Java, East Java, Bali, North Sumatera, South Sumatera, Lombok, South Kalimantan, and South Sulawesi (Suprihanto et al. 2015). The rice plants infected with ragged stunt disease show stunted growth, darkening of leaves with ragged sides or spiraling tips, swelling of leaf stalk, and bumps at the underside of the leaves or the outer side of leaf (Zheng et al. 2014; Helina et al. 2020). It was reported by Suprihanto et al. (2015) that endemic regions of BPH infestations in West Java province are Cirebon Regency, Bekasi, Majalengka, Sukabumi, Tasikmalaya, Garut, Cianjur, Subang, Karawang and Indramayu; moreover, incidences of stunting disease have been reported in Java and Bali (Kusuma et al. 2018; Listihani et al. 2022a).

Research by Sianipar et al. (2015) showed different BPH population dynamics. During the BPH population outbreak in 2010, which damaged to 4874 ha rice plantation, the planthopper population outbreak also caused stunting disease incidence to appear in the field. This showed that every insect vector has a different capability in transmitting and spreading the virus.

Insect vectors and viruses are closely related in regard to virus transmission into the host plant. So far, the relationship between vector BPH and stunt viruses in rice plants in the form of viruliferous BPH life table has not been reported. The influence of stunt virus viruliferous BPH on BPH survival rate and fecundity can be determined by constructing a life table. The life table is a table of survival and fecundity data of every individual in a population (Chen et al. 2017; Ning et al. 2017; Triwidodo and Listihani 2020; Wang et al. 2021; Khan et al. 2022). Lifetable can provide detailed information on the birth, development, reproduction, and mortality of every individual within a population. This information is the basic needed to study various aspects and behaviors of a population (Ning et al. 2017; Khan et al. 2022).

An age-specific life table is used to manage mortality and natality data, providing a more detailed description of the cohort properties. The life table can provide a simple statistical summary, including the individual life expectancy and natality rate. In addition, the life table has a modifiable basic form that can be used for various data analyses such as mortality caused by various factors (Chen et al. 2017; Naranjo and Ellsworth 2017; Herrero et al. 2018; Janssen et al. 2022).

Thus, this research aimed to determine the specific relationship between viruses and their vectors on the biology and demography statistics of viruliferous BPH. The information obtained from this research may not be beneficial in understanding viruliferous BPH population dynamics but also useful for designing BPH and stunt viruses control strategies in rice.

MATERIALS AND METHODS

Propagation of *Nilaparvata lugens*

The brown planthopper population used in the greenhouse research was obtained from Badung Regency. Twenty imagoes of each planthopper in the field were put inside separate gauze hoods, which contained rice plants of IR64 cultivar is susceptible cultivar to BPH aged 10 days after sowing (DAS) as their feed and egg-laying media. The rice plants were taken out of the lid after 1 day and then transferred into a different hood in a greenhouse to obtain virus-free planthopper imagoes.

Propagation of stunt virus inoculum

Rice plant samples with stunt disease symptoms from Badung Regency were used as a virus inoculum source. Stunt virus inoculum was propagated by providing instar 3-4 nymph of brown planthopper infestation with an acquisition feeding period of 2 days, a latent period of 4 days, and an inoculation feeding period of one day. The inoculation feeding period occurred in a tube, in which every tube contained one healthy plant with two viruliferous vectors. After the inoculation feeding period, insects were euthanized by treating them with the insecticide butylphenyl methyl carbonate.

Nilaparvata lugens cohort observations

Nilaparvata lugens cohort observations were a group of individuals born in almost the same time interval. BPH cohort observation was performed in three steps, including observation of stadia duration, survivability of *N. lugens* eggs, nymphs, and imagoes. *Nilaparvata lugens* cohort observation was conducted with two treatments: on healthy plants and on plants infected by the stunting virus, 20 repetitions were taken on each treatment.

Nilaparvata lugens stadia duration and egg survivability observations

The observation was conducted everything by recording the number of instar I nymphs that appeared in every glass. The plants were then dissected on day 17 to record the number of unhatched eggs. Rice tiller dissection and BPH eggs were counted under a stereo microscope.

Nilaparvata lugens stadia duration and nymph survivability observation

Five instar I nymphs that emerged on the same day were put inside a plastic glass containing a rice plant aged 21 DAS. The number of nymphs alive, dead, and shed were observed and recorded as development every day until they reached imago. The sex of the imagoes was also recorded.

Nilaparvata lugens imago life span observation

Male imagoes were put inside a reaction tube filled with healthy tiller and infected by stunting virus aged 21 DAS. The observation was conducted every day until the last male imago died. The result of the observation was data on the life cycle and lifespan of male BPH.

The observation for female BPH started by putting one female imago into a reaction tube which had been filled by rice tillers aged 21 DAS and two male BPH imagoes. The female and male imagoes were transferred into a new reaction tube 24 hours after being placed. The transfer was performed every day until the last female imago was dead. Every plant infested with BPH was dissected under a stereo microscope for egg counting. This observation provided data on the female life cycle, lifespan, female age during first egg laying, pre-oviposition period, oviposition period, and fecundity (Triwidodo and Listihani 2020).

Nilaparvata lugens life table

BPH cohort observation data for one generation was arranged into a life table. The net reproduction rate (Ro) was only based on the female population, and it was assumed that enough male was available in the surrounding. The data required for the calculation were as follows:

x = the cohort age class (day),
lx =the life expectancy of each individual in age x,
mx = the fecundity of each individual in age x
lxmx = the number of offspring born within age x

From the life table obtained, the calculation was utilized to determine other demographic parameters:

Gross reproductive rate (GRR) = Σm_x

Net reproductive rate (Ro) = $\Sigma l_x m_x$

Mean generation time, $T = \frac{\sum xlxmx}{\sum lxmx}$

Intrinsic growth rate (r) = $\frac{(\ln Ro)}{T}$

Population doubling time, DT= $\frac{\ln(2)}{r}$

Correction on r value was adjusted according to the Euler equation, which was Growth rate (r_m), $\sum l_x m_x e^{-mx}=1$

The BPH life table for both treatments was arranged using the jackknife method to estimate the variance of intrinsic growth rate (r_m).

Data analysis

Experimental data in this study were analyzed by ANOVA, followed by checking of assumptions and then

further tested with t-test at a significance level of 5% using Minitab application version 17.

RESULTS AND DISCUSSION

Brown planthopper is part of insect groups with paurometabolous type metamorphosis (gradual metamorphosis), so insect goes through three developmental phases: egg, nymph, and imago. The results showed that the number of eggs laid by female insects ranged from 2 to 13 eggs per egg group for both treatments. Moreover, stunt virus infected rice plants did not affect BPH egg stadium period. The period of egg stadium for both treatments ranged between 7 to 17 days (Table 1). BPH egg is generally inserted into plant tissues around the base of the stem (± 5 cm from the base) up to the middle area of the stem (Vongpa et al. 2016). Shentu et al. (2020) and Penalver-Cruz and Horgan (2022) reported that every egg group consists of two to 32 eggs. BPH nymph undergoes four sheddings (instar I to V). Instar I BPH nymph was greyish-white in color and ± 1.3 mm in length. Instar II BPH was pale brown color. On every shedding, BPH color became progressively brown. There was little difference in morphology from instar II to instar IV except for body size. When the planthopper reaches the last instar nymph, which was instar V, the BPH nymph turns bright brown in color and ± 2.9 mm in length. BPH last instar had similar morphology with imago, and the difference lay in the sexual organ not yet developed.

The time required to finish every development phase during instar II nymph was shorter in plants infected by the virus compared to the nymphs living on healthy plants (Table 1). The results also showed that other than accelerating BPH nymph growth, virus infected plants also accelerated the stadia time in BPH instar II nymph. According to Triwidodo and Listihani (2020) and Triwidodo et al. (2020), instar I insect is in the phase of searching for a place to live and still not actively looking for food because the nutrition obtained from its parent is still enough to live through instar I. When the insect is in instar II phase, it is in a plant fluid sucking adaptation phase which makes the plant fluid sucking instar II nymph in virus-infected plants get significantly influenced. In instar III, IV, and V, the insect has adapted to the environment and its feed, so nymphs that absorb nutrition from infected plants get significantly influenced. BPH nymphs that absorbed nutrition from stunting virus infected plants have their growth phase and stadia time shortened.

BPH imago has two body morphology (dimorphism), which are long-winged (macropterous) and short-winged (brachypterous) (Shah et al. 2019; Listihani et al. 2022a; Listihani et al. 2023). The development of the wing form is influenced by nymph density, food quality, and environmental conditions when BPH is in the pre-adult phase (Quais et al. 2020; Horgan and Penalver-Cruz 2022). The increase in the BPH population is directly proportional to the emergence of macropterous imago. Both morphological forms have its own role in developing the BPH population. The macropterous form functions in migration with the objective of searching for food sources whereas the brachypterous form's main function is to reproduce (Listihani et al. 2023).

The imagoes used at the beginning of the research were in the brachypterous form. The imagoes originated from BPH endemic region with an abundant population from Badung Regency (Listihani et al. 2022a). The life cycle is the interval from the oviposition process (egg laying) until when the imago appeared for the first time. In this research, the BPH life cycle also changed with the presence of plants infected with the stunting virus, for both female imago (Figure 1A) and male imago (Figure 1B). The female imago life cycle ranged between 26 to 34 days (healthy plants) and 26 to 32 days (plants infected by stunting virus). The female imago age distribution for the two treatments showed a normal distribution pattern.

Table 1. Interval and average length of stadia of *N. lugens* on healthy rice plants and plants infected with stunt virus

Stadia	Interval (n)		Average ± error*	
	Healthy plants	Stunt virus infected plants	Healthy plants	Stunt virus infected plants
Egg	7-17 (252)	7- 17 (238)	12.14 ± 0.16a	12.94 ± 0.10a
1st Instar	2-4 (85)	2-4 (100)	3.23 ± 0.01a	3.27 ± 0.01a
2nd Instar	2-5 (90)	2-4 (92)	3.36 ± 0.08a	3.11 ± 0.09b
3rd Instar	2-4 (68)	2-4 (78)	3.45 ± 0.01a	3.14 ± 0.04b
4th Instar	2-4 (60)	2-4 (68)	3.43 ± 0.03a	3.15 ± 0.04b
5 th Instar	3-5 (55)	3-5 (59)	3.63 ± 0.04a	3.22 ± 0.07b
Male				
Life cycle	25-33 (23)	25-32 (24)	28.53 ± 0.13a	26.88 ± 0.85b
Longevity	8-19 (23)	9-18 (24)	16.33 ± 0.16a	16.42 ± 0.25a
Female				
Life cycle	26-34 (32)	26-32 (35)	29.29 ± 0.31a	27.78 ± 0.38b
Longevity	10-20 (32)	10-18 (35)	16.47 ± 0.41a	16.58 ± 0.32a
Age at first reproduction	28-37 (32)	27-36 (35)	32.25 ± 0.14a	30.23 ± 0.42b
Preoviposition period	3-5 (32)	3-4 (35)	3.43 ± 0.10a	2.74 ± 0.23b
Oviposition period	7-17 (32)	7-17 (35)	12.84 ± 0.02a	13.45 ± 0.03b
Fecundity	20-90 (32)	20-89 (35)	51.64 ± 2.84a	50.24 ± 2.52a

Note: numbers in the same row followed by the same letter are not significantly different based on the results of the t test

A similar result was also obtained for the male BPH cycle. This could be seen from the time required for male imagoes in virus-infected plants to finish their life cycle (Table 1). The male life cycle in healthy plants ranged from 25 to 33 days. Meanwhile, the life cycle of male imago living on virus-infected plants ranged from 25 to 32 days. The male BPH life cycle was longer compared to the female life cycle. This condition applies to the stunting virus infected plants treatment.

Life span was the interval from when the imago first appeared until when the imago died. The influence of stunting virus infected plants on BPH imago life span was not same as that of nymph. The presence virus infected plants showed no significant effect on the life span of female and male imago of *N. lugens*. The average life span of *N. lugens* female imago was 16.47 ± 0.41 days (healthy plants) and 16.58 ± 0.32 days (virus infected plants) with a range of 10 to 20 days (healthy plants) and 10 to 18 days (virus infected plants) (Table 1). Meanwhile, the mean lifespan of male imago was 16.33 ± 0.16 days (healthy plants) and 16.42 ± 0.25 days (virus infected plants) with a range of 8 to 19 days (healthy plants) and 9 to 18 days (virus infected plants). The lifespan of the female imago was longer compared to the male imago.

The distribution pattern for the time required by the planthopper to finish the adult phase (Figure 2) was different from the age distribution pattern in the pre-adult phase. During the pre-adult phase, virus infected plants treatment always showed an acceleration of development time.

The female BPH imago kept with stunting virus infected plants had shorter pre-oviposition period compared to female kept with healthy plants (Figure 3). The acceleration of the pre-oviposition period caused earlier egg laying (Figure 4). In this research, stunting viruses infected plants did not affect female BPH fecundity (Table 1). This ability was one of the limiting factors of BPH control in the field. Fecundity is the potential reproductive ability of the female imago. Brown planthopper is known to have high fecundity (Mawan 2013).

The emerging percentages for female and male imago are shown in Table 1 and Figure 4. Plants infected with stunting virus showed an acceleration in the emergence of female imago, which occured on day 27th after egg laying (early generation oviposition), a day earlier than the imago living on healthy plants. Similar tendency was found in male BPH imago. Male imago kept on plants infected by stunting virus first emerged on day 28 after egg laying, two days earlier from the BPH kept in healthy plants. The female BPH imago on stunting virus infected plants started to emerge before the emergence of the female imago in healthy plants. In healthy plants, the female imago appeared later, while in virus infected plants the female imago emerged earlier.

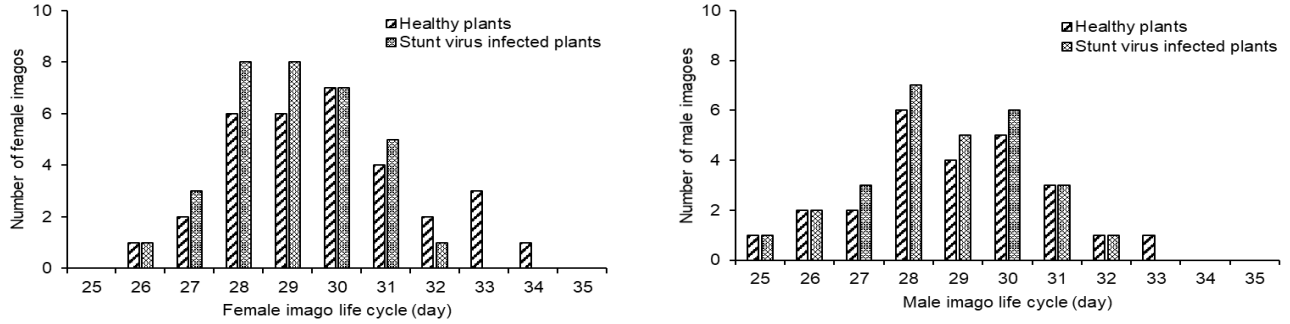
The sex ratio for *N. lugens* can be seen in Table 2. The sex ratio analysis was performed by the chi-square method. The analysis result of the two treatments showed that the calculated chi-square value was lower than the table chi-square value so, Fisher theory determined that the sex ratio of male and female being 1:1 was acceptable (Table 2). The sex ratio is the relative number of male and female in a population which is shown by the comparison of the number of male with 100 female (Compton and Tu 2022). BPH age distribution from the first egg hatched until the end of observation was calculated based on the total number of hatched eggs and the total number of eggs placed, which can be seen in Figure 5. Figure 5A and 5B showed similar hatching pattern with the highest number of hatching eggs occured on day 12 and 13 for both healthy and stunting virus infected plants. However, the same pattern did not mean the same number of eggs. The dissection result showed that the plants infected by stunting virus had a higher number of hatched eggs compared to healthy plants (Figure 5B). Plants infected by the stunting virus did not influence the BPH hatching pattern but did affect the number of hatching eggs.

Plants infected with stunting virus, show an increase in the number of hatching eggs (Figure 5B). This condition occured because lowering egg mortality may be often related to the response of species with low stress level. The total number of hatching eggs in plants infected by the stunting virus was ± 21% from 1594 eggs per 100 female BPH. This result was higher than that of healthy plants, which was ± 19% from 1502 eggs per 100 female BPH. This shows that plants infected by the stunting virus had a positive effect on the mortality of BPH eggs. The damaging BPH development phases were the pre-adult (nymph) and adult (imago), so control effort during the egg phase was more effective as no damage had yet occurred on the rice plant. The survival rate (l_x) *N. lugens* in healthy plant and stunting virus infected plant cohorts are shown in Figure 6. The survival rate curve showed a similar pattern, with lower BPH survivorship occurring during nymph development, especially in early instar phases (instat I to III) that ranged from 5-22 days (healthy plants) and 5-21 days (plants infected by stunting virus). The significant decrease in survival rate was due to increas mortality happening gradually along with BPH development. The observed survivability pattern showed that BPH pre-adult phase was more vulnerable to food quality suitability.

The life table for both treatments showed that from 100 BPH instar I as the initial cohort population, around 32% (healthy plants) and 35% (virus infected plants) successfully grew into female imago with the highest mortality occuring during the early planthopper development. Based on the observation, the BPH population for both treatments was categorized as type III survival curve.

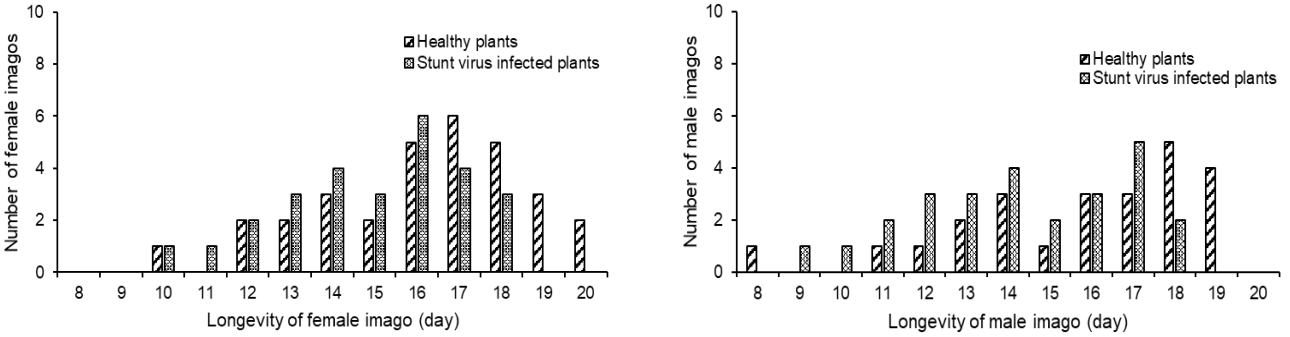
Table 2. Sex ratio of *Nilaparvata lugens* on healthy rice plants and plants infected with stunt virus

Treatment	Male	Female
Healthy plants	1	1.29
Stunt virus infected plants	1	1.34



A **B**

Figure 1. Life cycle of female (A) and male (B) *Nilaparvata lugens* imago on healthy rice plants and plants infected with stunt virus



A **B**

Figure 2. Distribution of longevity of female (A) and male (B) imago of *Nilaparvata lugens* on healthy rice plants and plants infected with stunt virus

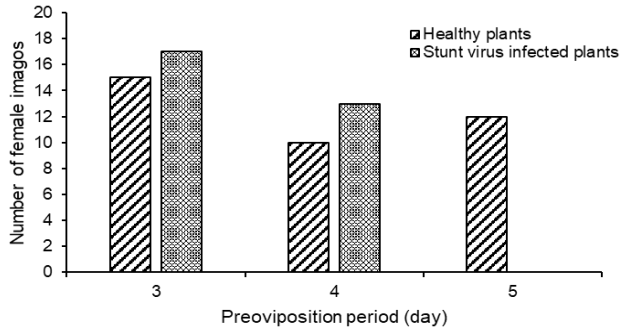
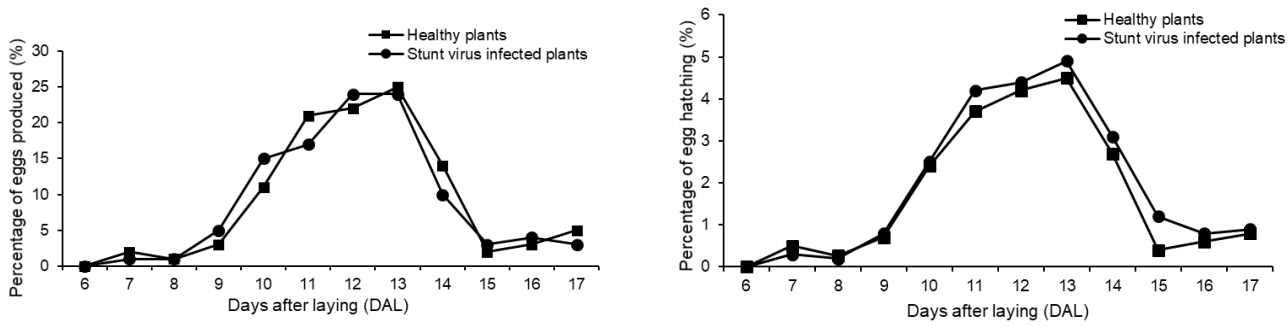


Figure 3. Preovipositional distribution of *Nilaparvata lugens* on healthy rice plants and plants infected with stunt virus

Figure 4. Age at first reproduction of female imago *Nilaparvata lugens* on healthy rice plants and plants infected with stunt virus



A **B**

Figure 5. Age distribution of *Nilaparvata lugens* during observation. This percentage is based on (A) the number of eggs laid and (B) the number of eggs hatched on healthy rice plants and plants infected with stunt virus

The BPH survivability and fecundity based on lx and mx data are shown on Figure 7. Female BPH imago laid a small number of eggs in the early imago phase, and the number increased as imago aged and decreased when the imago was about to die. The highest number of eggs laid by female BPH was 8 eggs (healthy plants) and 9 eggs (virus infected plants). This condition occured on day 31 (healthy plants) and day 32 (virus infected plants) after egg hatching.

The BPH population and reproduction parameters are presented in Table 3. The BPH Ro was higher in virus infected plants compared to healthy plants with values of 29.51 ± 0.03 and 27.51 ± 0.09, respectively. This result showed that next generation of BPH kept in stunting virus infected plants multiply 29.51 times from the previous generation, while on healthy plants the next BPH generation only multiply 27.51 times.The net reproductive rate (Ro) is the average number of offspring (from the first phase of a life cycle) produced by every individual at the end of cohort (Wang et al. 2021).

The average generation time (T) is the average time required since the eggs are placed until they turned into imagoes and placed eggs for the first time (Russianzi et al. 2021). BPH kept in stunting virus infected plants required shorter generation development time compared to healthy plants.

Results revealed that the BPH population rm on healthy plants was higher from the stunting virus infected plants. This showed that in helathy plants there was no other factor limiting its growth rate. This result strengthen the hypothesis that stunting virus infected plants can suppress the BPH growth rate. The intrinsic growth rate (rm) illustrates the rate of population increase in a growing population with unlimited resources (Janssen et al. 2022). The life table with rm data can provide a deeper understanding on the life pattern characteristic of the observed species (Ahn et al. 2020).

Doubling time or the time required for BPH population to double (DT) was 8.103 days (healthy plants) and 7.806 days (stunting virus infected plants). The rm and DT are useful to show population growth in a constant growing environment with unlimited resources (Janssen et al. 2022). The BPH DT value in stunting virus infected plants requires shorter time for the population to double compared to healthy plants.

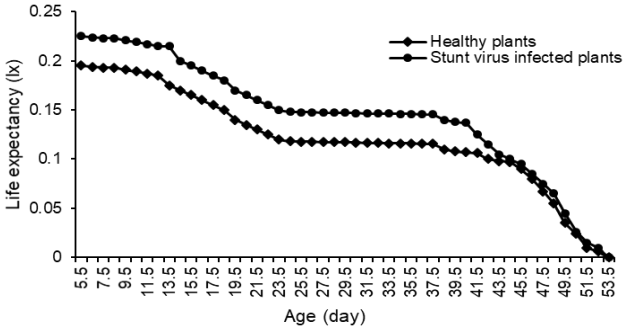


Figure 6. Survival curve for *Nilaparvata lugens* in the cohort on healthy rice plants and plants infected with stunt virus

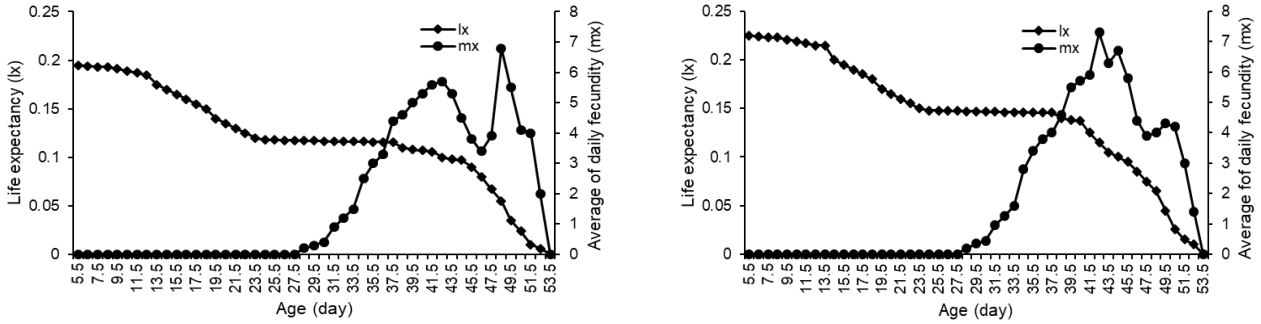


Figure 7. Life expectancy and daily fecundity of *Nilaparvata lugens* reared on healthy rice plants (A) and plants infected with stunt virus (B)

Table 3. Demographic statistics of *Nilaparvata lugens* ± error on healthy rice plants and plants infected with stunt virus

Parameters	Healthy plants	Stunt virus infected plants
Gross reproduction rate (GRR)	82.32 ± 0.02a	98.27 ± 0.05b
Net reproduction rate (R_o)	27.51 ± 0.09a	29.51 ± 0.03b
Generation time average (T) (day)	37.900 ± 0.008a	35.406 ± 0.006b
Intrinsic increase rate (r_m)	0.083682 ± 0.000036a	0.082074 ± 0.000043b
Doubling time (DT) (day)	8.103 ± 0.001a	7.806 ± 0.005b

Note: Numbers on the same line that are followed by the same letter indicates does not significantly different based on t-test, α = 0.05

Nilaparvata lugens is a main pest as well as stunt virus vector on rice plants in South Asia and South East Asia, including in Indonesia. The stunting viruses transmitted by *N. lugens* are *Rice ragged stunt virus* (RRSV) and *Rice grassy stunt virus* (RGSV). RRSV and RGSV are transmitted by brown planthopper in a persistent propagative manner (Phatthalung and Tangkananond 2022). Zheng et al. (2014) explained that viruses transmitted in a persistent propagative manner multiply inside the vector before being transmitted to the host plant and the time required is called the latent period. Persistent virus gets into the vector through the digestive system, moves through the midgut lumen, translocate by passing the epithelial cell wall into the hemolymph, and finally moved into the salivary glands. From there the virion is inoculated into uninfected plants during feeding (Dietzgen et al. 2016).

During this research it was observed in virus infected plant the increase in BPH population in the following generation cause a higher incidence of stunting disease in the field. Other than the macropterous imago, the nymph was also important in spreading and transmitting stunt viruses to rice plants in a given field. This may be because a nymph is an insect actively consuming rice plant fluid since it requires enough nutrition for its development into an imago. When nymphs feed on plants infected by stunt viruses, they can transmit the viruses just like macropterous or brachypterous imago. Tyagi et al. (2022) reported short distance distribution of brown planthopper in a plantation is performed by the nymphs, brachypterous, or macropterous imago. Short-distance distribution between plantation and long-distance distribution are performed by the macropterous imago. According to Phatthalung and Tangkananond (2022), the brown planthopper nymph is more efficient compared to the imago in transmitting the ragged stunt virus. Successful transmission of plant viruses depends on the manner of interaction between the plant virus, vector, and host plant (Listihani et al. 2018a, b; Listihani et al. 2019; Listihani et al. 2020; Listihani et al. 2022a, b; Listihani et al. 2023; Selangga and Listihani 2021; Selangga et al. 2021; Selangga and Listihani 2022; Selangga et al. 2022; Selangga et al. 2023; Temaja et al. 2022).

On one side of the spectrum, persistent viruses, such as RGSV and RRSV, enable virus acquisition and inoculation by keeping the BPH vectors for longer periods (Dietzgen et al. 2016). Improved plant host quality in virus-infected host plants is related to the prolonged feeding by vectors of persistently transmitted viruses (Mauck et al. 2012). Vector insect host preference has been found to be influenced by virus-induced biochemical and physiological changes in the host plant (Mauck et al. 2012). Virus-infected plants may produce volatiles to become more attractive to feeding insects (Rajabaskar et al. 2014).

In this research, virus infected plants can hasten the life cycle of BPH and make the doubling time (DT) shorter which was 7.806 days compared to health plants with 8.103 days. Virus-infected plants generally present themselves as superior quality hosts for vectors compared to uninfected plants, thus enhancing the vector's life cycle and virus distribution (Bosque-Perez and Eigenbrode 2011).

In this research, virus-infected plants can multiply the next BPH generation 29.51 times from the previous generation, while in healthy plants the next BPH generation only multiply 27.51 times. This is due to the mutualism symbiosis between the virus and the vector. The virus benefits from having its transmission supported by the vector. The virus helps the vector by inducing the plant to produce good quality food for the vector which improves the vector's reproduction. Insect vectors may also benefit from plant virus transmission by having expanding host range. For example, whitefly performance improves greatly on begomovirus-infected tobacco (*Nicotiana tabacum*), which is usually a poor host for some whitefly biotypes (Zhang et al. 2012). These results suggest that vector would also benefit by selectively feeding on virus-infected tissue, such as by releasing effectors to promote virus uptake and release, or by targeting virus-infected cells during feeding.

To conclude, from the results of the present study it was concluded that stunt virus infected plants caused the BPH development phase instar II to instar V nymph, life cycle, pre-oviposition period, and double time value to be shorter and the net reproductive rate higher than in healthy plants. In stunt virus infected plants, the number of BPH eggs which managed to hatch is higher than in healthy plants. The next BPH generation of stunt virus inflected plants increased 29.51 times more from the previous generation, while on healthy plants the next BPH generation only increased 27.51 times.

ACKNOWLEDGEMENTS

This research was funded by the PDKN program provided by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for Listihani and the team with contract no. 078/E5/PG.02.00.PL/2023.

REFERENCES

Ahn JJ, Cho JR, Kim JH, Seo BY. 2020. Thermal effects on the population parameters and growth of *Acyrthosiphon pisum* (Harris) (Hemiptera: Aphididae). Insects 11 (8): 481. DOI: 10.3390/insects11080481.

Bosque-Perez NA, Eigenbrode SD. 2011. The influence of virus-induced changes in plants on aphid vectors: Insights from luteovirus pathosystems. Virus Res 159: 201-205. DOI: 10.1016/j.virusres.2011.04.020.

Chen Q, Li N, Wang X, Ma L, Huang JB, Huang GH. 2017. Age-stage, two-sex life table of *Parapoynx crisonalis* (Lepidoptera: Pyralidae) at different temperatures. Plos One 12 (3): e0173380. DOI: 10.1371/journal.pone.0173380.

Compton A, Tu Z. 2022. Natural and engineered sex ratio distortion in insects. Front Ecol Evol 10: 884159. DOI: 10.3389/fevo.2022.884159.

Dietzgen RG, Mann KS, Johnson KN. 2016. Plant virus–insect vector interactions: current and potential future research directions. Viruses 8: 303. DOI: 10.3390/v8110303.

Helina S, Sulandari S, Trisyono YA, Hartono S. 2020. Assessments of yield losses due to double infection of Rice ragged stunt virus and Rice grassy stunt virus at different severity in the field, Yogyakarta, Indonesia. Pak J Phytopathol 32 (2): 129-136. DOI: 10.33866/phytopathol.030.02.0578.

Herrero MI, Dami LC, Fogliata SV, Casmuz AS, Gomez DRS, Gastaminza GA, Murua MG. 2018. Fertility life table, population parameters and biotic potential of *Helicoverpa gelotopoeon* (Dyar)

(Lepidoptera: Noctuidae). An Acad Bras Cienc 90 (4): 3831-3838. DOI: 10.1590/0001-3765201820180318.
Horgan FG, Penalver-Cruz A. 2022. Compatibility of insecticides with rice resistance to planthoppers as influenced by the timing and frequency of applications. Insects 13 (2): 106. DOI: 10.3390/insects13020106.
Janssen A, Fonseca MM, Marcossi I, Kalile MO, Cardodo AC, Walerius AH, Hanel A, Marques V, Ferla JJ, Farias V, Carbajal PAF, Pallini A, Nachman G. 2022. Estimating intrinsic growth rates of arthropods from partial life tables using predatory mites as examples. Exp Appl Acarol 86: 327-342. DOI: 10.1007/s10493-022-00701-2.
Khan J, Khan A, Ahmed N, Alhag SK, Almadiy AA, Sayed S, Alam P, Ullah F. 2022. Age and stage-specific life table parameters of *Harmonia dimidiata* (Coleoptera: Coccinellidae) fed on Rhopalosiphum padi (Hemiptera: Aphididae) at different temperatures. Egypt J Biol Pest Control 32: 113. DOI: 10.1186/s41938-022-00610-x.
Listihani L, Ariati PEP, Yuniti IGAD, Selangga DGW. 2022a. The brown planthopper (*Nilaparvata lugens*) attack and its genetic diversity on rice in Bali, Indonesia. Biodiversitas 23 (9): 4696-4704. DOI: 10.13057/biodiv/d230936.
Listihani L, Ariati PEP, Yuniti IGAD, Wijaya LGAS, Yuliadhi KA, Selangga DGW, Wirya GNAS, Sudiarta IP, Sutrawati M, Triwidodo H. 2023. Relationship study between the brown planthopper population and the intensity of Rice ragged stunt virus and Rice grassy stunt virus, as well as the inoculum sources. Intl J Agric Technol 19 (3): 1055-1068.
Listihani L, Damayanti TA, Hidayat SH, Wiyono S. 2018a. Moleculer characterization of Papaya ringspot virus type P on Cucumber in Java. J Fitopatol Indones 14 (3): 75. DOI: 10.14692/jfi.14.3.75. [Indonesian]
Listihani L, Damayanti TA, Hidayat SH, Wiyono S. 2020. First report of cucurbit aphid-borne yellows virus on cucumber in Java, Indonesia. J Gen Plant Pathol 86: 219-223. DOI: 10.1007/s10327-019-00905-2.
Listihani L, Yuniti IGAD, Lestari PF, Ariati PEP. 2022b. First report of Sweet potato leaf curl virus (SPLCV) on *Ipomoea batatas* in Bali, Indonesia. Indian Phytopathol 75 (2): 595-598. DOI: 10.1007/s42360-022-00489-6.
Listihani, Hidayat SH, Wiyono S, Damayanti TA. 2018b. First report of tobacco mosaic virus on cucumber [*Cucumis sativus* (L.)] in Java, Indonesia. IOP Conf Ser: Earth Environ Sci 197: 012043. DOI: 10.1088/1755-1315/197/1/012043.
Listihani, Hidayat SH, Wiyono S, Damayanti TA. 2019. Characteristic of Tobacco mosaic virus isolated from cucumber and tobacco collected from East Java, Indonesia. Biodiversitas 20: 2937-2942. DOI: 10.13057/biodiv/d201023.
Mauck K, Bosque-Perez NA, Eigenbrode SD, De Moraes CM, Mescher MC, Fox C. 2012. Transmission mechanisms shape pathogen effects on host-vector interactions: Evidence from plant viruses. Funct Ecol 26: 1162-1175. DOI: 10.1111/j.1365-2435.2012.02026.x.
Mawan A. 2013. Effects of Endophytic Fungi on The Biology and the Demographic Statistics of Brown Planthopper. [Thesis]. IPB University, Bogor. [Indonesia]
Naranjo SE, Ellsworth PC. 2017. Methodology for developing life tables for sessile insects in the field using the whitefly, *Bemisia tabaci*, in cotton as a model system. J Vis Exp 129: e56150. DOI: 10.3791/56150.
Nguyen CD, Verdeprado H, Zita D, Sanada-Morimura S, Matsumura M, Virk PS, Brar DS, Horgan FG, Yasui H, Fujita D. 2019. The development and characterization of near-isogenic and pyramided lines carrying resistance genes to brown planthopper with the genetic background of japonica rice (*Oryza sativa* L.). Plants 8: 498. DOI: 10.3390/plants8110498.
Nguyen TD, Lacombe S, Bangratz M, Ta HA, Vinh do N, Gantet P, Brugidou C. 2015. P2 of Rice grassy stunt virus (RGSV) and p6 and p9 of Rice ragged stunt virus (RRSV) isolates from Vietnam exert suppressor activity on the RNA silencing pathway. Virus Genes 51 (2): 267-275. DOI: 10.1007/s11262-015-1229-2.
Ning S, Zhang W, Sun Y, Feng J. 2017. Development of insect life tables: comparison of two demographic methods of *Delia antiqua* (Diptera: Anthomyiidae) on different hosts. Sci Rep 7: 4821. DOI: 10.1038/s41598-017-05041-5.
Penalver-Cruz A, Horgan FG. 2022. Interactions between rice resistance to planthoppers and honeydew-related egg parasitism under varying levels of nitrogenous fertilizer. Insects 13: 251. DOI: 10.3390/ insects13030251.
Phatthalung TN, Tangkananond W. 2022. The infectivity survival and transmissibility of Rice ragged stunt virus from the frozen-infected rice leaves by the brown planthopper, *Nilaparvata lugens* Stal. Trends Sci 19 (14): 5097. DOI: 10.48048/tis.2022.5097.
Quais MK, Munawar A, Ansari NA, Zhow WW, Zhu ZR. 2020. Interactions between brown planthopper (*Nilaparvata lugens*) and salinity stressed rice (*Oryza sativa*) plant are cultivar-specific. Sci Rep 10: 8051. DOI: 10.1038/s41598-020-64925-1.
Rajabaskar D, Bosque-Perez NA, Eigenbrode SD. 2014. Preference by a virus vector for infected plants is reversed after virus acquisition. Virus Res 186: 32-37. DOI: 10.1016/j.virusres.2013.11.005.
Russianzi W, Anwar R, Triwidodo H. 2021. Biostatistics of fall armyworm *Spodoptera frugiperda* in maize plants in Bogor, West Java, Indonesia. Biodiversitas 22: 3463-3469. DOI: 10.13057/biodiv/d220655.
Selangga DGW, Listihani L. 2021. Molecular identification of Pepper yellow leaf curl Indonesia virus on chili pepper in Nusa Penida Island. J Trop Plant Pests Dis 21 (2): 97-102. DOI: 10.23960/jhptt.22197-102.
Selangga DGW, Wiyono S, Susila AD, Hidayat SH. 2021. Distribution and identification of Pepper yellow leaf curl Indonesia virus infecting chili pepper in Bali Island. J Fitopatol Indones 17 (6): 217-224. DOI: 10.14692/jfi.17.6.217-224. [Indonesian]
Selangga DGW, Listihani L, Temaja IGRM, Wirya GNAS, Sudiarta IP, Yuliadhi KA. 2023. Determinants of symptom variation of Pepper yellow leaf curl Indonesia virus in bell pepper and its spread by *Bemisia tabaci*. Biodiversitas 24: 869-877. DOI: 10.13057/biodiv/d240224.
Selangga DGW, Listihani L. 2022. Squash leaf curl virus: Species of begomovirus as the cause of butternut squash yield losses in Indonesia. Hayati J Biosci 29 (6): 806-813. DOI: 10.4308/hjb.29.6.806-813.
Selangga DGW, Temaja IGRM, Wirya GNAS, Sudiarta IP, Listihani L. 2022. First report of Papaya ringspot virus-watermelon strain on melon (*Cucumis melo* L.) in Bali, Indonesia. Indian Phytopathol 75 (3): 911-914. DOI: 10.1007/s42360-022-00519-3.
Shah NAN, Osman MK, Othman NA, Ahmad F, Ahmad AR. 2019. Identification and counting of brown planthopper in paddy field using image processing techniques. Procedia Comput Sci 163: 580-590. DOI: 10.1016/j.procs.2019.12.140.
Shentu X, Xiao Y, Song Y, Cao Z, Fan J, Yu X. 2020. Comparative analysis of the diversity of the microbial communities between non-fertilized and fertilized eggs of brown planthopper, *Nilaparvata lugens* Stal. Insects 11 (1): 49. DOI: 10.3390/insects11010049.
Sianipar MS, Djaya L, Santosa E, Soesilohadi RCH, Natawigena WD, Ardiansyah M. 2015. Population of brown plant hopper (*Nilaparvata lugens* Stal.) and the diversity of its natural enemy in highland paddy rice field in the village of Panyocokan, Ciwidey District, Bandung Regency. Agric J 26 (2): 111-121. DOI: 10.24198/agrikultura.v26i2.8469. [Indonesian]
Suprihanto, Somowiyarjo S, Hartono S, Trisyono YA. 2015. Identification and molecular diversity of Rice ragged stunt virus and Rice grassy stunt virus in Java, Indonesia. Intl J Sci: Basic Appl Res 24 (5): 374-386.
Temaja IGRM, Selangga DGW, Phabiola TA, Khalimi K, Listihani L. 2022. Relationship between viruliferous *Bemisia tabaci* population and disease incidence of Pepper yellow leaf curl Indonesia virus in chili pepper. Biodiversitas 23 (10): 5360-5366. DOI: 10.13057/biodiv/d231046.
Triwidodo H, Agustini A, Listihani L. 2020. Biology and the statistic demographic of *Aphis glycines* Matsumura (Hemiptera: Aphididae) on the soybean with plant growth promoting rhizobacteria (PGPR) treatment. J Perlindungan Tanaman Indones 24 (1): 54-60. DOI: 10.22146/jpti.68694. [Indonesian]
Triwidodo H, Listihani. 2020. High impact of PGPR on biostatistic of *Aphis craccivora* (Hemiptera: Aphididae) on yardlong bean. Biodiversitas 21: 4016-4021. DOI: 10.13057/biodiv/d210912.
Tyagi S, Narayana S, Singh RN, Srivastava CP, Twinkle S, Das SK, Jeer M. 2022. Migratory behaviour of brown planthopper, *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae), in India as inferred from genetic diversity and reverse trajectory analysis. 3 Biotech 12: 266. DOI: 10.1007/s13205-022-03337-6.
Vongpa V, Amornsak W, Gordh G. 2016. Development, reproduction and longevity of *Aprostocetus* sp. (Hymenoptera: Eulophidae), an egg parasitoid of the Brown planthopper, *Nilaparvata lugens* (Stal)

(Hemiptera: Delphacidae). Agric Nat Resour 50: 291-294. DOI: 10.1016/j.anres.2016.10.001.

Wang T, Ren YL, Tian TA, Li ZT, Wang XN, Wu ZY, Tang J, Liu JF. 2021. Determining the effect of temperature on the growth and reproduction of *Lasioderma serricorne* using two-sex life table analysis. Insects 12 (12): 1103. DOI: 10.3390/insects12121103.

Zhang T, Luan JB, Qi JF, Huang CJ, Li M, Zhou XP, Liu SS. 2012. Begomovirus-whitefly mutualism is achieved through repression of plant defences by a virus pathogenicity factor. Mol Ecol 21: 1294-1304. DOI: 10.1111/j.1365-294X.2012.05457.x.

Zheng L, Mao Q, Xie L, Wei T. 2014. Infection route of Rice grassy stunt virus, a tenuivirus, in the body of its brown planthopper vector, *Nilaparvata lugens* (Hemiptera: Delphacidae) after ingestion of virus. Virus Res 188: 170-173. DOI: 10.1016/j.virusres.2014.04.008.