

Article

## Life table parameters and development of *Neoseiulus longispinosus* (Acari: Phytoseiidae) reared on citrus red mite, *Panonychus citri* (Acari: Tetranychidae) at different temperatures

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### Abstract

Development time, survival, reproduction, and sex ratio were determined for the predatory mite *Neoseiulus longispinosus* (Evans) at six constant temperatures (20, 25, 27.5, 30, 32.5 and 35 °C) reared on citrus red spider mite *Panonychus citri* (McGregor). No predatory mite reached adulthood at 35°C. All female and male immature stages of *N. longispinosus* developed significantly faster as the temperature increased from 20 to 30 °C, but development slowed down as the temperature exceeded 30 °C. The mean total developmental time of females was longest at 20 °C (9.73 days), followed by 25°C (5.67 days), 27.5°C (4.46 days), and 32.5 °C (4.55 days) and was shortest at 30°C (3.69 days). The oviposition rate and lifetime fecundity were highest at 27.5 °C (2.80 eggs/female/day and 43.76 eggs/female, respectively) and lowest at 20°C (0.78 eggs/female/day and 21.64 eggs/female, respectively). However, temperature had no influence on the sex ratio of offspring with the proportion of females ranging from 0.62 to 0.65. The intrinsic rate of increase ( $r$ ) of *N. longispinosus* averaged 0.323, 0.303, 0.267, 0.189 and 0.107 females female<sup>-1</sup> day<sup>-1</sup> at 30, 27.5, 32.5, 25, and 20°C, respectively. These values suggested that the most optimal temperatures for the population growth of *N. longispinosus* were between 27.5 and 30°C.

**Key words:** Predatory mite, *Neoseiulus longispinosus*, Citrus red spider mite, *Panonychus citri*, intrinsic rate of increase

### Introduction

Citrus red spider mite, *Panonychus citri* (McGregor), is a major pest in different varieties of citrus (e.g. *Citrus × sinensis*, *Citrus limon*, *Citrus maxima* or *Citrus reticulata*) in many parts of the world, including South-East Asia (Dinh 2002). The mites feed on the chlorophyll of leaves causing bronzing of leaves and defoliation. Chemicals are often used to control this spider mite leading to the development of pesticide resistance in the pest, environmental contamination and residues on citrus fruits. In recent surveys in the citrus growing areas of North Vietnam, the predatory mite *Neoseiulus longispinosus* (Evans) was found to be the most dominant predator, feeding on all life stages of *P. citri* (Huyen *et al.* 2016).

*Neoseiulus longispinosus*, a type II phytoseiid predatory mite (McMurtry *et al.* 2013), has received increasing attention in Asia for the control of spider mites since 2010 (Nusartlert *et al.* 2011). It can develop on different tetranychid species of the genera *Eutetranychus*, *Oligonychus*, and *Tetranychus* (Nusartlert *et al.* 2011). Several studies demonstrated the potential of the predatory mite

to control spider mites outbreaks, including *Oligonychus coffeae* (Nietner) on tea (Rahman *et al.* 2013), *Stigmaeopsis nanjingensis* (Ma & Yuan) on bamboo in China (Zhang *et al.* 1999) or *Eotetranychus cendanai* (Rimando) in greenhouse crops (Thongtab *et al.* 2001). In addition, *N. longispinosus* was also found to have a great potential for practical application due to its resistance or tolerance to agricultural chemicals (Zhang *et al.* 1996). However, there are only a few articles on the biology and predatory efficiency of this species when feeding on mite pests in citrus, more in particular on the citrus red spider mite *P. citri*. The present study was conducted to investigate the life table parameters of *N. longispinosus* when fed on *P. citri*, with the goal to provide useful data for setting up an IPM programme against *P. citri* in South-East Asia.

## Materials and Methods

### *Stock colony of P. citri*

Citrus red spider mites were collected from a pomelo (*Citrus maxima*) garden at Chuong My, Hanoi, Vietnam and a laboratory colony was established using pomelo seedlings. The infested plants were kept in plastic pots (25cm high, 30cm in diameter) in a climatized room at  $25 \pm 1^\circ\text{C}$ ,  $70 \pm 5\%$  RH and a 16:8 (L: D) h photoperiod.

### *Stock colony of N. longispinosus*

A culture of *N. longispinosus* was initiated with mites collected from a pomelo garden at Chuong My, Hanoi, Vietnam and was reared on leaves of the kamala tree (*Mallotus* sp.) which were heavily infested with the carmine spider mite, *Tetranychus cinnabarinus* (Boisduval). The leaves were placed upside down on a wet sponge in a rectangular plastic tray (20 x 13 x 5 cm), with a cotton layer on the leaf edges to provide free water and prevent the mites from escaping.

### *Rearing microcosms*

To examine the development and reproduction of individual *N. longispinosus*, modified Munger cells as described by Nguyen *et al.* (2013) were used as rearing microcosms. Each cell consisted of a transparent acrylic board (top board; 40 x 40 mm, 1.5 mm thick) with a 22 mm diameter hole in the center, a black acrylic board (middle board; 40 x 40 mm, 3 mm thick) with a 20 mm diameter hole in the center, and another black acrylic board (bottom board; 40 x 40 mm, 2 mm thick) without hole. Transparent film was placed between the top and middle boards and was pierced 15 times with an insect pin (size 01) allowing ventilation but precluding escape of the mites. A square pomelo (*C. maxima*) leaf disc (40 x 40 mm) upside down on a wet tissue paper (40 x 60 mm) was placed between the middle and bottom boards. A paper clip was used to hold the boards together. The microcosms were placed on a plastic support containing tap water.

### *Experimental setup*

Experiments were conducted in climatic chambers set at  $75 \pm 5\%$  RH, a 16:8 (L:D) h photoperiod and at five constant temperature regimes (20°C, 25°C, 27.5°C, 30°C, 32.5°C and 35°C).

Eight hours before the start of the experiments, new pieces of sewing thread were placed in the stock colony of *N. longispinosus*. At each temperature regime, 60 eggs (less than 8 hours old) were transferred individually to the rearing microcosms. Citrus red spider mites (mixed stages) were offered ad libitum from the larval stage of the predator on and were refreshed every 2 days. To obtain data on the duration of each developmental stage of the predatory mite and on mortality and escape rates, observations were made every 24 hours until all individuals had reached adulthood. The developmental stage of each individual was determined based on the presence of exuviae in the

rearing microcosms. After completing immature development, each female was paired with a male from the same cohort. Males that died during the experiment were replaced with males from the same cohort. Adults were observed daily to determine the preoviposition and oviposition period, longevity and fecundity. All eggs laid were removed from the rearing microcosm every day to avoid influence of the egg density to fecundity of the female. Eggs from females of the same age were transferred to new rearing microcosms and the resulting larvae and nymphs were fed on *P. citri* up to adulthood in order to determine the sex ratio of the offspring; all eggs laid were collected throughout the lifetime of all tested females. Mites that escaped or died due to unnatural causes were excluded from data analysis. Females that died before laying eggs were excluded from calculation of reproductive parameters.

#### Life table parameters

The intrinsic rate of increase ( $r$ ) was calculated according to the formula of Birch (1948) and Fathipour & Maleknia (2016):

$$\sum_{x=0}^{\omega} e^{-r(x+1)} l_x m_x = 1$$

where  $x$  equals the female age from the time of hatching (days),  $l_x$  is the age specific survival of the females at age  $x$  and  $m_x$  is the number of daughters produced per female at age  $x$ . The latter parameter is obtained by multiplying the mean number of eggs laid per female by the proportion of female offspring produced at age  $x$ . The Jackknife procedure was used according to Meyer *et al.* (1986) and Hulting *et al.* (1990) to calculate the standard error of  $r$ . Other parameters calculated according to Maia *et al.* (2000) and Fathipour & Maleknia (2016) were the mean generation time  $T$ , i.e. the length of time that is required for a population to increase  $R_0$ -fold of its size (days),

$$T = \frac{\ln R_0}{r}$$

with the net reproductive rate,  $R_0$ , i.e. the mean number of female offspring produced per female (females/female),

$$R_0 = \sum_{x=\alpha}^{\beta} l_x m_x$$

Finite rate of natural increase ( $\lambda$ ) is the multiplication per female in unit time of a population with a stable age distribution. This was calculated as,

$$\lambda = \text{antilog } e^r$$

Doubling time (DT) is defined as the time in days that is required by a population to double in number and was calculated using the formula,

$$DT = \ln(2)/r$$

#### Statistical analysis

Data were subjected to statistical analysis (IBM SPSS Statistics, Ver. 20) to analyze the effect of temperature regimes on the duration of the immature stages, preoviposition and oviposition period, daily and total oviposition, and adult longevity of *N. longispinosus*. When a Kolmogorov–Smirnov test indicated that means were normally distributed, the parameter was analyzed using a one-way analysis of variance (ANOVA). If a Levene test indicated heteroscedasticity, a Tamhane test was used instead of Tukey's test. When means were not normally distributed, a nonparametric Kruskal–Wallis ANOVA was used and means were separated using a Mann–Whitney U test. Immature survival and sex ratios of the progeny were compared by means of a logistic regression. This regression is a generalized linear model using a probit (log odds) link and a binomial error function.

Each test consists of a regression coefficient that is calculated and tested for being significantly different from zero, for which P-values are presented (McCullagh & Nelder 1989). P-values smaller than or equal to 0.05 are considered significant.

### Modeling

For further analysis, we only used female developmental rates ( $D_r$ , in  $\text{day}^{-1}$ ) which were derived by calculating the reciprocal of the developmental times (D) obtained from the experiments. Developmental rates were subjected to both linear and nonlinear regression.

*Linear regression:* Data that deviated from the straight line were omitted for calculation of the linear regression model (Vangansbeke *et al.* 2015).

$$D_r = a + b * T$$

with

- $D_r$  = developmental rate ( $\text{day}^{-1}$ )
- T = temperature ( $^{\circ}\text{C}$ )
- a = intercept of the regression line
- b = slope of the regression line

The lower developmental threshold ( $T_0$ ) was estimated from the linear model as the intercept of the developmental rate-temperature curve with the temperature axis. The thermal constant (K) indicates the amount of thermal units (in degree-days) that are needed to complete development and can be derived from the linear model as the reciprocal of the slope b ( $K = 1/b$ ).

*Nonlinear regression:* The four-parameter, nonlinear developmental equation of Briere *et al.* (1999), was used to model the relationship between temperature and female developmental rates (in  $\text{day}^{-1}$ ). The Briere nonlinear equation has a low level of complexity, predicts biologically relevant parameters and has the ability to intersect with the x-axis, thereby allowing an estimation of the development rate, thermal minima and maxima, and the optimum development temperature (Briere *et al.* 1999; Roy *et al.* 2002). Thus

$$R(T) = a T (T - T_L)(T_U - T)^{(1/m)}$$

where  $R(T)$  is development rate (1/days) at a given temperature,  $T$  is the rearing temperature ( $^{\circ}\text{C}$ ),  $a$  is a scale parameter,  $T_L$  is the lower development threshold ( $^{\circ}\text{C}$ ),  $T_U$  is the upper development threshold ( $^{\circ}\text{C}$ ), and  $m$  is an empirical constant and a shape parameter (Briere *et al.* 1999). The optimum temperature was calculated following Briere *et al.* (1999) approach.

$$T_{\text{OPT}} = ((2mT_U + (m+1)T_L) + (4m^2T_U^2 + (m+1)^2T_L^2 - 4m^2T_UT_L)^{0.5}) / (4m+2)$$

The data were fitted to these models using Sigma Plot version 12 (SYSTAT Software Inc.).

## Results

The developmental times of immature stages of *N. longispinosus* reared on *P. citri* at different temperatures are shown in Table 1.

The developmental times of the predatory mite were significantly affected by temperature (Table 1). All female and male immature stages developed faster as the temperature increased from 20 to 30  $^{\circ}\text{C}$ , but development slowed down as the temperature reached 32.5  $^{\circ}\text{C}$ . The mean total developmental times of females were longest at 20 $^{\circ}\text{C}$  (9.73 days), followed by those at 25 $^{\circ}\text{C}$  (5.67 days), 27.5 $^{\circ}\text{C}$  (4.46 days), and 32.5  $^{\circ}\text{C}$  (4.55 days) and were shortest at 30 $^{\circ}\text{C}$  (3.69 days). A similar trend as for the females was observed for males, with mean total developmental times averaging 10.31, 5.73, 5.38, 4.67 and 3.29 days at 20, 25, 32.5, 27.5 and 30 $^{\circ}\text{C}$ , respectively.

**TABLE 1.** Developmental time (days) of the immature stages of *Neoseiulus longispinosus* fed on *Panonychus citri* at five constant temperature regimes.

Temperatures (°C)	N	Developmental time (days)				
		Egg	Larva	Protonymph	Deutonymph	Total immature
<b>Females</b>						
20.0	33	2.73±0.10a	1.15±0.06a	2.76±0.08a	3.09±0.08a	9.73±0.16a
25.0	33	2.06±0.06b	0.82±0.07bc	1.33±0.11b	1.45±0.09b	5.67±0.16b
27.5	37	1.68±0.13c	0.68±0.05c	1.05±0.14bc	1.05±0.17c	4.46±0.20c
30.0	36	1.33±0.09c	0.55±0.03d	0.77±0.11c	1.05±0.10c	3.69±0.19d
32.5	33	1.42±0.09c	0.91±0.06b	1.03±0.11b	1.18±0.08c	4.55±0.10c
$\chi^2$		73.093	64.641	81.351	85.924	111.187
df		4	4	4	4	4
P		<0.001	<0.001	<0.001	<0.001	<0.001
<b>Males</b>						
20.0	13	2.62±0.18a	1.23±0.12a	2.77±0.17a	3.69±0.21a	10.31±0.29a
25.0	15	2.20±0.14ab	0.83±0.11b	1.17±0.13bc	1.53±0.19b	5.73±0.15b
27.5	15	1.73±0.18bc	0.70±0.07b	0.90±0.10c	1.33±0.21bc	4.67±0.29c
30.0	14	1.29±0.13c	0.54±0.06c	0.61±0.09d	0.86±0.14c	3.29±0.22d
32.5	16	1.56±0.13c	1.16±0.11a	1.34±0.12b	1.31±0.15bc	5.38±0.15bc
$\chi^2$		28.476	33.036	44.864	38.271	53.824
df		4	4	4	4	4
P		<0.001	<0.001	<0.001	<0.001	<0.001

n: number of individuals reaching the adult stage; Means ± SE within a column and sex followed by the same letter are not significantly different (Mann-Whitney U test;  $P > 0.05$ ).  $\chi^2$ , df- and P-values refer to Kruskal-Wallis ANOVAs.

Nearly all individuals reached adulthood at 20, 25, 27.5, 30 and 32.5 °C, with immature survival rates of 96.67, 100, 100, 100 and 98.33%, respectively. However, all mites exposed to 35 °C died in the immature stages with mortality rates of egg, larva, protonymph and deutonymph stages amounting up to 20, 25, 52.78 and 100%, respectively.

When developmental rates at the highest temperatures (32.5 and 35 °C) were omitted from the regression analysis, the linear model showed a good fit to the data as demonstrated by high values of  $R^2$  (0.9878) and  $R^2$  adj (0.9816) and low values of RSS (0.0003) (Figure 1). Fitted parameters ( $\pm$  SE) of the linear regression of developmental rates were  $a = -0.2919 \pm 0.0397$  and  $b = 0.0195 \pm 0.0015$ , developmental threshold ( $T_0$ ) = 14.97 °C and thermal constant ( $K$ ) = 51.28 degree-days.

The four-parameter model of Briere *et al.* (1999) provided a good fit of the observed development rate values (1/days) over the temperatures (T) at which they were observed (Figure 2,  $D(T) = 0.0003 * T * (T - 10.00) * (35.00 - T)^{1/3.0561}$ ,  $R^2 = 0.9617$ ). The lower development threshold was estimated at 10°C, the upper development threshold at 35.00°C, and the optimum temperature was calculated to be 30.92°C.

Pre-oviposition periods of *N. longispinosus* females at the lower temperatures of 20, 25 and 25 °C were significantly longer than those of females at 27.5, 30 and 32.5 °C (Table 2). Oviposition period and female longevity of the predatory mites were significantly affected by temperature. The females had a shorter oviposition period and lived shorter as temperature increased. Oviposition rate and total fecundity of *N. longispinosus* were highest at 27.5 °C (2.80 eggs/female/day and 43.76

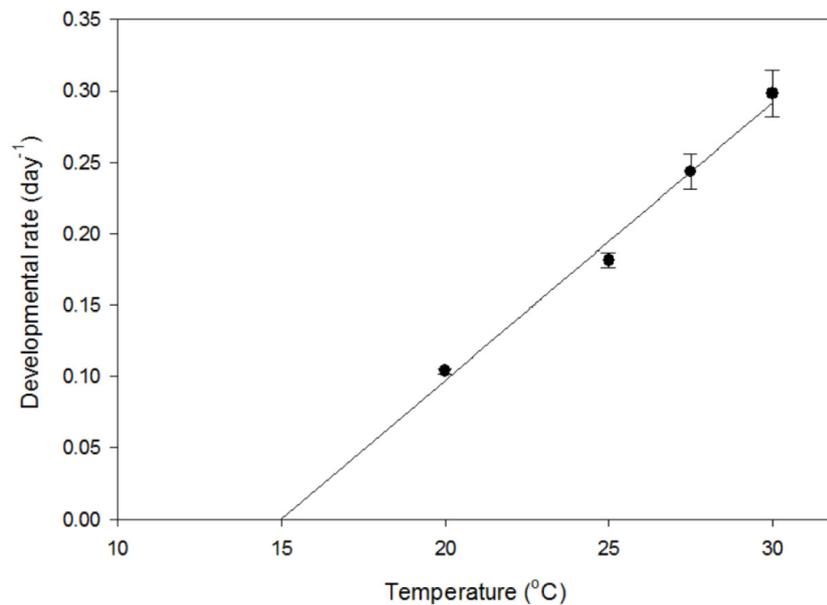
eggs/female, respectively) and lowest at 20 °C (0.78 eggs/female/day and 21.64 eggs/female, respectively). Peak oviposition was reached after 5 days at 32.5 °C, after 7 days at 20 °C and 30 °C, after 9 days at 25 °C and after 8 days at 27.5 °C (Figure 3). Temperature had no influence on the sex ratio of offspring with the proportion of females ranging from 0.62 to 0.65 (Table 2).

All life table parameters of *N. longispinosus* were significantly affected by temperature (Figure 4 and Table 3). The survival rate ( $l_x$ ) of *N. longispinosus* remained constant (100%) up to the 47<sup>th</sup> day at 20 °C, 26<sup>th</sup> day at 25 °C, 17<sup>th</sup> day at 27.5 and 30 °C, and only to the 14<sup>th</sup> day at 32.5 °C (Figure 4). Net reproductive rate ( $R_0$ ) of *N. longispinosus* was the highest at 27.5°C and lowest at 20 and 32.5 °C. Generation time (T) of the mite was significantly shortened as the temperature increased. The shortest generation times of *N. longispinosus* were observed at 30 and 32.5°C (9.42 and 9.64 days, respectively). Finally, the finite rate of increase ( $\lambda$ ) and intrinsic rate of increase ( $r$ ) differed significantly among temperatures. The highest intrinsic rate of increase of *N. longispinosus* was 0.32 (females female<sup>-1</sup> day<sup>-1</sup>) at 30 °C (Table 3).

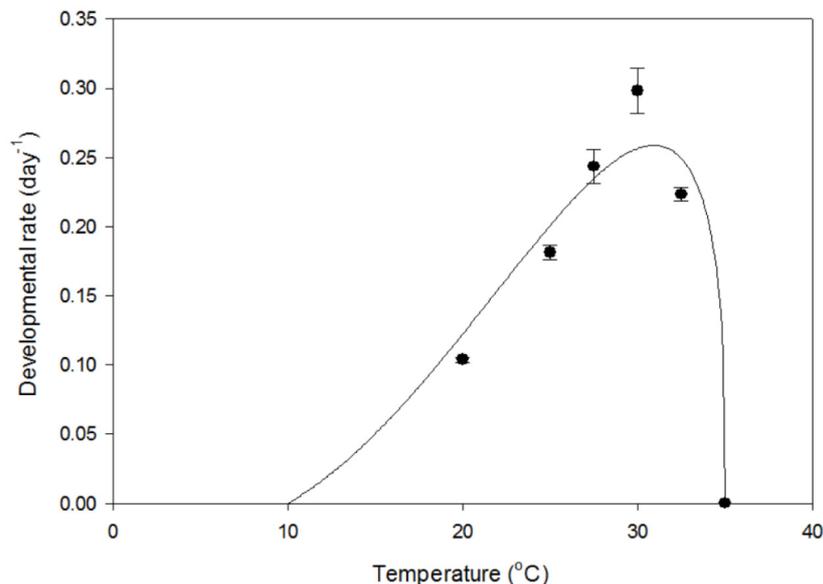
**TABLE 2.** Reproduction and longevity of *Neoseiulus longispinosus* fed on *Panonychus citri* at five constant temperature regimes.

Parameter	Temperatures (°C)					$\chi^2/F$	df	P
	20 (n = 33)	25 (n = 33)	27.5 (n = 37)	30 (n = 36)	32.5 (n=33)			
Preoviposition period (days) <sup>a</sup>	3.76±0.12a	2.97±0.05b	1.32±0.10c	1.11±0.05c	1.48±0.09c	137.331	4	<0.001
Oviposition period (days) <sup>b</sup>	27.76±0.43a	20.67±0.46b	15.76±0.48c	13.56±0.33d	10.09±0.41e	252.422	4,167	<0.001
Female longevity (days) <sup>a</sup>	52.18±0.57a	36.36±0.67b	24.51±0.42c	21.22±0.49d	19.03±0.50e	144.622	4	<0.001
Oviposition rate (eggs/female/day) <sup>b</sup>	0.78±0.01e	1.61±0.03d	2.80±0.06a	2.44±0.05b	2.20±0.07c	257.662	4,167	<0.001
Total fecundity (eggs/female) <sup>b</sup>	21.64±0.43c	33.30±0.92b	43.76±1.49a	33.22±1.13b	21.76±0.78c	79.813	4,167	<0.001
Female proportion of the progeny <sup>c</sup>	0.63±0.02a	0.62±0.02a	0.65±0.01a	0.63±0.01a	0.60±0.02a	4.404	4	0.354

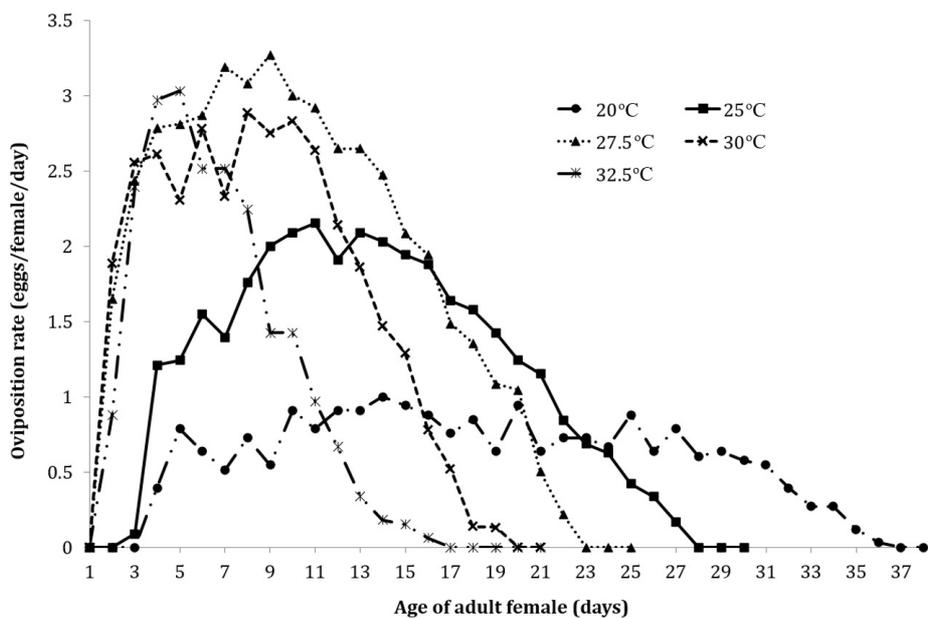
n = number of reproducing females observed; Means ± SE within a row followed by the same letter are not significantly different (P>0.05); <sup>a</sup> Kruskal-Wallis ANOVA followed by Mann-Whitney U tests; <sup>b</sup> one-way ANOVA followed by Tukey tests (Oviposition period) or Tamhane tests (Oviposition rate and Total fecundity); <sup>c</sup> Probit (Wald Chi-square test).



**FIGURE 1.** Linear regression of female immature developmental rate versus temperature for *Neoseiulus longispinosus*.



**FIGURE 2.** The relationship between temperature and female immature developmental rate of *Neoseiulus longispinosus* using the four-parameter model of Briere *et al.* (1999).

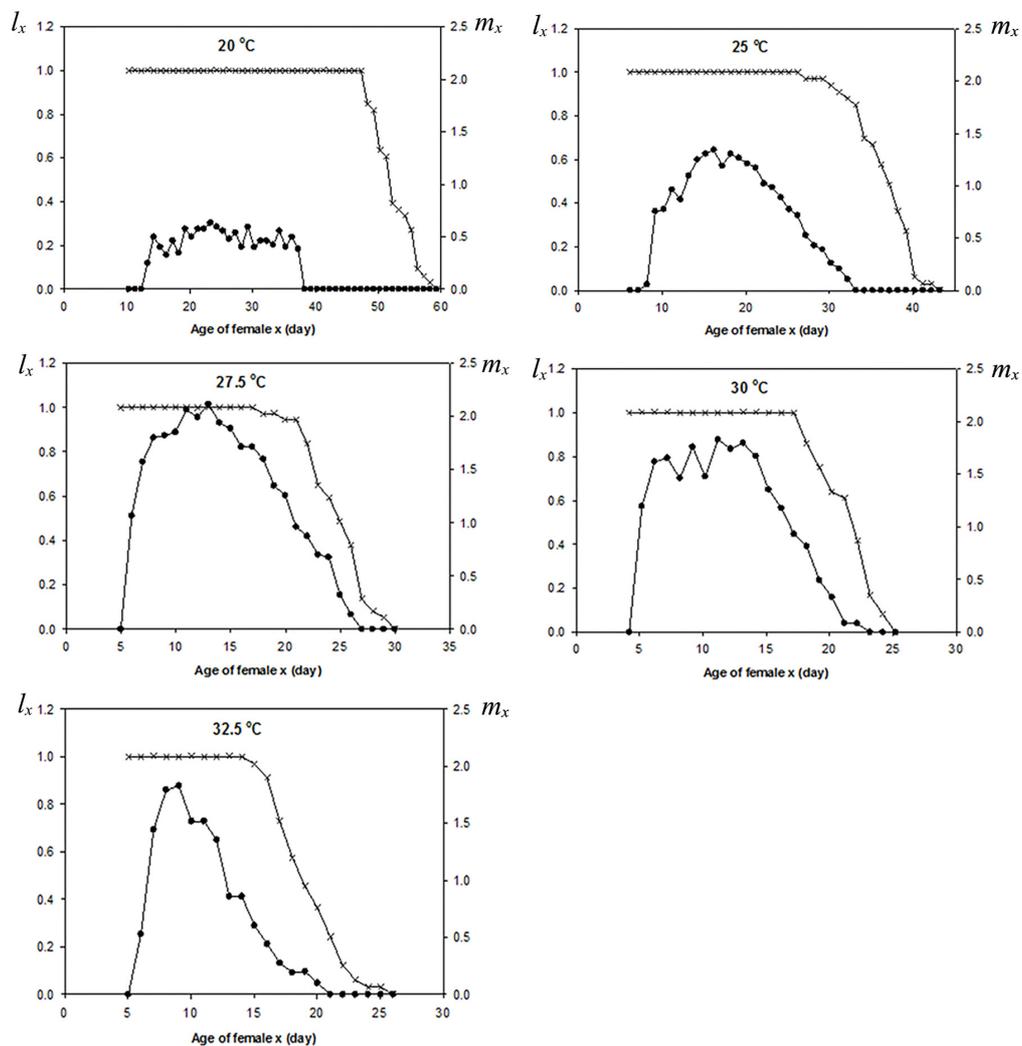


**FIGURE 3.** Daily oviposition rate of *Neoseiulus longispinosus* fed on *Panonychus citri* at five constant temperature regimes.

## Discussion

Our results demonstrate that *N. longispinosus* can develop and complete its life cycle at a constant 20, 25, 27.5, 30 and 32.5°C (Table 1). Developmental time of predatory mite decreased with increasing temperature but at temperatures above 30°C development slowed down and at 35°C no

survival up to the adult stage was noted. Life table parameters of *N. longispinosus* differed over the range of temperatures (Table 2 and Table 3), with the highest intrinsic rate of increase at 30°C. This has implications for the performance of *N. longispinosus* as a biological control agent of the citrus red mite *P. citri* in North Vietnam where the spider mites often occur in citrus orchards at high density from April to June and October to November with temperatures ranging from 25.4 to 30.6 °C (Dinh 2002). Additionally, the development rate of *P. citri* in relation to the temperature shows a similar trend as that of the predatory mite. At 35 °C, *P. citri* suffered high mortality (75.8%) and no oviposition was noted (Kasap 2009). Development, fecundity and  $r$  of *P. citri* were substantially reduced below 20°C, and the most favourable temperature for population growth of *P. citri* was deemed to be around 25°C (Kasap 2009; Yasuda 1982). Thus, the temperature responses of *N. longispinosus* and its prey *P. citri* appear quite similar.



**FIGURE 4.** Specific fertility ( $m_x$ ) and survival rate ( $l_x$ ) of *Neoseiulus longispinosus* fed on *Panonychus citri* at five constant temperature regimes.

On the other hand, our results also show that the population of *N. longispinosus* grows faster than that of its prey *P. citri*. In this study the intrinsic rates of increase of the predatory mite at 20, 25, 27.5, 30 and 32.5 °C were 0.107, 0.189, 0.303, 0.323 and 0.267 (females female<sup>-1</sup> day<sup>-1</sup>), respectively. These values mostly exceed those reported for its prey (0.11, 0.16, and 0.15 at 20, 25 and 30°C respectively)(Kasap 2009). A greater intrinsic rate of increase of a predator mite as compared to its prey has been suggested to be an important criterion for evaluating the efficacy of a predatory mite as a control agent against spider mites (Janssen & Sabelis 1992; Tanigoshi 1982).

**TABLE 3.** Life table parameters of *Neoseiulus longispinosus* fed on *Panonychus citri* at five constant temperature regimes.

Parameter	Temperatures (°C)					F	df	P
	20 (n = 33)	25 (n = 33)	27.5 (n = 37)	30 (n = 36)	32.5 (n = 33)			
Net reproductive rate $R_0$ (females female <sup>-1</sup> )	11.87±0.24c	20.76±0.58b	28.30±0.96a	21.02±0.72b	13.12±0.01c	113.649	4,167	<0.001
Generation time T (days)	23.04±0.13a	16.02±0.13b	11.04±0.13c	9.42±0.11d	9.64±0.00d	2472.572	4,167	<0.001
Doubling time DT (days)	6.45±0.06a	3.66±0.03b	2.29±0.03d	2.14±0.03e	2.60±0.00c	2696.149	4,167	<0.001
Finite rate of increase $\lambda$	1.11±0.001e	1.21±0.002d	1.35±0.005b	1.38±0.005a	1.31±0.00c	1048.911	4,167	<0.001
Intrinsic rate of increase r (females female <sup>-1</sup> day <sup>-1</sup> )	0.107±0.001e	0.189±0.001d	0.303±0.003b	0.323±0.004a	0.267±0.0001c	1240.026	4,167	<0.001

n = number of reproducing females observed; Means ± SE within a row followed by the same letter are not significantly different (P>0.05; one-way ANOVA followed by Tukey tests)

The biological parameters of the phytoseiid *N. longispinosus* reared on *P. citri* in this study are in line with those of the predatory mite reared on other food sources as reported by previous authors. At 20°C the development times of females and males (9.73 and 10.31 days, respectively) were similar to those of *N. longispinosus* fed on *O. coffeae* as reported by Rahman *et al.* (2013) at the same temperature (9.3 and 9.4 days, for males and females, respectively). At temperatures around 25°C, immature developmental periods in our study (on average 5.7 days) were shorter than those observed when the predatory mite was fed on *Tetranychus tumidus* Banks (7 days at 24.34 °C) (Madruga *et al.* (2012) or *T. urticae* (6.0 days at 25°C) (Lee *et al.* 1987) but longer than that on *O. coffeae* (4.9 days at 25°C) (Rahman *et al.* 2013). Total fecundity in the present study was highest (43.76 eggs/female) at 27.5°C; this value is higher than that of females presented with *E. cendanai* (19.5 eggs/female) at 28°C (Thongtab *et al.* 2001) but somewhat lower than that of females fed on *T. cinnabarinus* at 25°C (48.8 eggs/female) (Lababidi 1989), *T. urticae* at 25–28°C (50.7 eggs/female) (Ibrahim & Palacio 1994) or *O. coffeae* at 25°C (62.1 eggs/female)(Rahman *et al.* 2013). The highest intrinsic rate of increase of *N. longispinosus* in the present study was found at 30°C (0.32). This r value was higher than that of *N. longispinosus* fed on other prey including *O. coffeae* (0.268 at 30°C) (Rahman *et al.* 2013), *P. citri* (0.225 at 28°C) (Puspitarini 2010), *T. urticae* (0.272 at 30°C) (Nguyen 2009) or *Polyphagotarsonemus latus* (Banks) and *Tetranychus truncatus* Ehara (0.123 and 0.129 respectively, at 27°C) (Kongjarean 2006). It deserves emphasis that comparison of life history parameters among studies is complicated by different experimental and analytical methods.

In conclusion, our results demonstrate that the predatory mite *N. longispinosus* is a potential biological control agent against the citrus red spider mite *P. citri*. The predatory mite has a similar favourable temperature range and a higher population growth rate than its target prey. However, it should be noted that our studies were conducted at constant temperatures and on artificial arenas, so further research will need to focus on the predatory potential of *N. longispinosus* against *P. citri* in citrus orchards. Furthermore, it is warranted to investigate the predator's control potential against

other spider mite pests in key fruit and vegetable crops in North Vietnam and other parts of South-East Asia.

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