Journal of Plant Diseases and Protection (2022) 129:1189–1199
https://doi.org/10.1007/s41348-022-00621-8

ORIGINAL ARTICLE

Demographic parameters of *Nephus includens* Kirsch (Coleoptera: Coccinellidae) fed on vine mealybug, *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) at different temperatures

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Received: 5 January 2022 / Accepted: 6 May 2022 / Published online: 26 May 2022
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Abstract
Development and reproduction of *Nephus includens* Kirsch (Coleoptera: Coccinellidae) on *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) were evaluated in climate cabins at four different temperatures (20, 25, 30, and 35 ± 1 °C), 60% ± 10 relative humidity, and 16:8 h (light:dark) photoperiod. The shortest development durations of the predator were observed at 30 and 35 °C (23.3 and 22.43 days, respectively). The fecundity of the predator was highest (87.47 eggs) at 30 °C and lowest at 35 °C (0.40 eggs). The longest female and male longevity was at 20 °C (124.80 and 125.08 days, respectively) and their shortest values at 35 °C (40.40 and 53.00 days, respectively). The highest intrinsic rate of increase ($r = 0.0703$ day^{-1}), finite rate of increase ($\lambda = 1.0727$ day^{-1}), and net reproductive rate ($R_0 = 33.24$ eggs) of the predator were obtained at 30 °C. Based on present findings, it was concluded that *N. includens* could be used in biological control of the vine mealybug, especially in regions with average temperatures (25–30 °C).

Keywords Biological control · Intrinsic rate of increase · Net reproductive rate · Predator · Two-sex life table

Introduction

Vine mealybug, *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), is a common species encountered worldwide. It generates significant economic losses in vineyards, especially of Mediterranean countries, the USA, Pakistan, Argentina, and South Africa (Ben-Dov 1994; Walton and Pringle 2004a; Daane et al. 2012). The *P. ficus* was reported on 36 host plant species of 30 genera of 24 families (Garcia Morales et al. 2016). The pest spends winter months in bottom sections of the plant, under the bark or soil, in colonies extending 30 cm underground, and then, it moves toward upper sections of the plant in spring and summer months, and feed through suction (Ben-Dov 1994). Furthermore, the secreted honeydew-like substances from *P. ficus* result in development saprophyte fungi on the plants (Godfrey et al. 2002; Walton and Pringle 2004a). The pest also exhibits a symbiotic life with Clastero-viruses and transmits leafroll virus to vines (Rosciglione and Gugerli 1989; Engelbrecht and Kasdorf 1990).

Biological control is one of the most significant methods for controlling of *Planococcus ficus* (Cocco et al. 2021). Although the efficacy of some entomopathogenic fungi and entomopathogenic nematodes on the vine mealybug has been reported, encyrtid parasitoids and predator species of Coccinellidae, especially *Nephus* spp., are considered as the most efficient and common natural enemies (Walton and Pringle 2004b; Shahina et al. 2010; Daane et al. 2012; Le Vieux and Malan 2013; Muştu and Kılınçer 2013; Muştu et al. 2015; Mohamed 2016; Sharma et al. 2018). *Nephus includens* Kirsch (Coleoptera: Coccinellidae) was recorded as an important predator of the mealybug in Italy, Spain, Egypt, Portugal, Syria, Saudi Arabia, Turkey, and Greece (Bodenheimer 1951; Viggiani 1974; Argyriou et al. 1976; Uygun 1981; Longo and Benfatto 1987; Katsoyannos 1996; Magro et al. 1999; Magro and Hemptinne 1999).

Life tables offer important clues about the effects of different ecological conditions, such as temperature, on the development of insect populations (Chi and Su 2006). There are a few studies about the development and reproduction

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of *N. includens* at different temperatures (Canhilal et al. 2001; Kontodimas et al. 2004, 2007). In these studies, data on some biological characteristics of *N. includens* on citrus mealybug, *Planococcus citri* Risso have been achieved. It has been reported that *N. includens* may usually feed on different mealybug species, especially *P. ficus* and rarely on the pests of different genus and families (Soylu 1978; Bayoumy and Michaud 2012). So, the objectives of the present study were to investigate the development and reproduction of *N. includens* on the vine mealybug at different temperatures. The obtained results can be used in integrated pest management (IPM) programs of vine mealybug and for assessing the proper conditions for mass production of the predator.

Materials and methods

Planococcus ficus stock culture

Planococcus ficus individuals were collected from mulberry trees in the Adana province (N: 37°01′42.36″ E: 35°18′45.46″, 59 m) in Turkey and brought to the laboratory. Mealybugs were reared on germinated potatoes and pumpkins in 3-L plastic jars and also in 4 × 11 × 10 cm and 28.5 × 36 × 58 cm plastic boxes with ventilation holes on the sides in incubators under 25 ± 1 °C temperature, 60 ± 10% relative humidity, and 16:8 h (light:dark) photoperiod conditions. The eggs of *P. ficus* females were again placed on potatoes and pumpkins with a soft brush to provide the sustainability of the stock culture.

Nephus includens stock culture

N. includens individuals were initially collected from mulberry plants infested with *P. ficus* in Adana province in Turkey. They were reared in laboratory, but then re-supplied from Adana Biological Control Research Institute, because of some problems encountered in the stock culture. *N. includens* was reared on *P. ficus* population, feeding on germinated potatoes in 3-L plastic jars with two ventilation holes (10 × 10 cm) and tulle covering in incubators under 25 ± 1 °C temperature, 60 ± 10% relative humidity, and 16:8 h (light:dark) photoperiod conditions. To provide the sustainability of the predator's stock culture, the newly emerged adults were periodically released in other rearing jars, containing potatoes infested with *P. ficus* population.

Life table studies

N. includens was separately reared on each temperature regimes for one generation before experiments. Since there were not sufficient predators that had reached adult stage at 35 °C, many numbers of predators were reared to reach sufficient number of eggs.

To obtain predator eggs, 10–20-day-old adult predators were placed in groups of 10 adults (5 ♀ and 5 ♂) into 9 cm diameter four Petri dishes containing *P. ficus* individuals of all stages. Petri dishes were monitored daily under stereo binocular microscope, and 50 newly laid eggs were transferred with a soft brush to previously prepared Petri dishes. Hatching was monitored daily, and the newly emerged 1st instar larvae were transferred into new Petri dishes containing *P. ficus*. These Petri dishes (5.5 cm diameter and tulle-covered holes for ventilation) were filled with water agar to about one third of the dish, and then, a disk-shaped vine leaf (Narince cultivar) was placed upside down on the agar. A single larva of the predator was introduced in each prepared Petri dish. Petri dishes contained mealybugs of mixed stages in numbers greater than the number of *N. includens* larvae to be fed. Larvae were transferred into new Petri dishes every three days, and the development stages of egg and larvae were monitored in 24-h intervals until they reached adult stage. In this way, duration of egg, larva, prepupa, and pupa stages of the predator (from egg stage to adult stage) were determined in climate cabins at 20 ± 1, 25 ± 1, 30 ± 1, and 35 ± 1 °C temperatures, 60% ± 10 relative humidity, and 16:8 h (light:dark) photoperiod.

Since gender of *N. includens* adults could not be identified, adult individuals hatched from the pupae, on the same day, were placed into 9 cm Petri dishes containing additional numbers of *P. ficus* for 10-day feeding, until they reach the sexual maturity. Then, adults were separately transferred into 5.5 cm Petri dishes, prepared as mentioned above. Following the identification of females, a male individual was paired with a female individual. During the experiment, new males to mate with females were placed instead of died male individuals. Female and male individuals were monitored every 24 h under a stereo binocular microscope, until the death of last individuals. In this way, number of eggs oviposited by *N. includens* female individuals (fecundity), preoviposition duration, number of oviposition days, lifespan of female and male individuals (longevity) was determined.

Statistical analysis

Life table parameters were calculated based on age–stage, two-sex life table analyses (Chi 1988; Chi 2021; Chi and Liu 1985). The TWOSEX MSChart (Chi 2021) software was used to analyze life table raw data. With these analyses, age–stage specific survival rates (s_{xj}) (x age and j stage), age–stage specific fecundity (f_{xj}), age-specific survival rate (l_x), female age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) values were calculated. Intrinsic rate of increase (r) was calculated with the use of the following equation (Goodman 1982).

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

Net reproductive rate (R_o) (individual) is expressed as reproductive rate of each generation or average number of reproducing females obtained from new oviposited eggs and expected to survive. It is calculated through multiplying the age-specific survival rate of individuals of a population (l_x) by age-specific fecundity (m_x) rates.

$$R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The l_x and m_x values in the age–stage specific two-sex life table were calculated with the use of the following equations.

$$l_x = \sum_{j=1}^{k} s_{xj}$$

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

Finite rate of increase was determined with the following equation:

$$(\lambda)(\text{day}^{-1}), \quad (\lambda = e^r)$$

Mean generation time, (T) (day), which is the time span required to increase population size up to net reproductive rate was calculated with the use of $T = \ln(R_0)/r$.

Age–stage specific life expectancy, (e_{xj}), was calculated with the use of the following equation (Chi and Su 2006).

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s'_{iy}$$

Age–stage specific reproductive value (v_{xj}) (Fisher 1930) was calculated with the use of the following equation (Tuan et al. 2014).

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{k} s'_{iy} f_{iy}$$

The Bootstrap (Efron and Tibshirani 1993) method was used to test the significance of the effects of temperatures on life table parameters 100,000 artificial bootstraps were produced with the use of TWOSEX MSChart (Chi 2021) software, and thus, the means and standard errors of the life table parameters were obtained. With the use of the resultant values, differences between different temperatures were tested by applying a Paired Bootstrap test.

Results

There were significant differences in duration of development stages of *N. includens* (Table 1). Total preadult development stage of the predator shortened with increasing temperatures. The longest total preadult stage at 20 °C and its shortest value at 35 °C. Preadult mortality rates of *N. includens* at 25 and 30 °C were significantly lower than its values at other temperatures (20 and 35 °C) (Table 1).

The shortest adult preoviposition (APOP) and total preoviposition (TPOP) periods of the predator were observed at 30 °C, and the highest values of these parameters were observed at 20 °C (Table 2). The highest values of oviposition days and fecundity were observed at 30 °C, and the lowest values of them were seen at 35 °C (Table 2). The longest

Table 1 Developmental times (d) and preadult mortality rates (%) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures (Mean ± SE)

Stage	Temperature							
	n	20 °C	*n*	25 °C	*n*	30 °C	*n*	35 °C
Egg	50	11.85 ± 0.25a*	50	5.63 ± 0.15b	50	4.66 ± 0.07c	50	4.32 ± 0.25c
L_1	46	6.95 ± 0.20a	49	3.21 ± 0.11b	50	2.51 ± 0.09c	28	3.36 ± 0.25b
L_2	37	5.11 ± 0.27a	47	3.11 ± 0.13b	49	2.27 ± 0.09c	25	2.06 ± 0.22c
L_3	35	5.45 ± 0.24a	44	2.79 ± 0.11b	48	2.32 ± 0.10c	16	2.08 ± 0.23c
L_4	33	5.00 ± 0.24a	42	2.69 ± 0.14b	47	2.5 ± 0.12b	13	2.45 ± 0.25b
Prepupa	29	4.10 ± 0.22a	39	2.13 ± 0.10b	46	2.09 ± 0.13b	11	2.00 ± 0.30b
Pupa	29	23.82 ± 0.44a	39	11.05 ± 0.21b	46	6.93 ± 0.17c	9	6.00 ± 0.48c
Total preadult duration	50	62.12 ± 0.39a	50	30.59 ± 0.29b	50	23.30 ± 0.16c	50	22.43 ± 1.04c
Preadult mortality rate	50	0.66 ± 0.07b	50	0.22 ± 0.06c	50	0.14 ± 0.049c	50	0.86 ± 0.05a

*The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level. The standard errors were calculated using the bootstrap procedure with 100,000 resampling

Table 2 The adult preoviposition period (APOP), total preoviposition period (TPOP), oviposition days, fecundity, and female and male longevity of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures (Mean ± SE)

Stage	Temperature							
	n	20 °C	*n*	25 °C	*n*	30 °C	*n*	35 °C
APOP	5	28.00 ± 0.55a*	19	13.94 ± 0.50b	19	9.59 ± 0.47c	5	13.00 ± 0.00b
TPOP	5	88.80 ± 0.59a	19	43.78 ± 0.69b	19	33.18 ± 0.42d	5	38.00 ± 0.00c
Oviposition days	5	16.40 ± 3.91b	19	20.78 ± 3.63b	19	29.35 ± 2.16a	5	2.00 ± 0.00c
Fecundity	5	24.80 ± 6.54b	19	42.58 ± 8.53b	19	87.47 ± 11.38a	5	0.40 ± 0.34c
Female longevity	5	124.80 ± 8.43a	19	105.68 ± 8.44a	19	74.42 ± 4.19b	5	40.40 ± 5.07c
Male longevity	12	125.08 ± 6.87a	20	134.75 ± 9.59a	24	64.17 ± 3.73b	2	53.00 ± 16.00b

*The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level. The standard errors were calculated using the bootstrap procedure with 100,000 resampling

female longevity was measured at 20 and 25 °C (Table 2). The same trend was observed for male's longevity (Table 2).

Age–stage specific survival rate (s_{xj}) indicates survival possibility of a newly oviposited egg up to age x and stage j. Survival possibility of a newly oviposited *N. includens* egg until adult stage at 20, 25, 30, and 35°C for female and male individuals was identified as 0.10 and 0.24, 0.38 and 0.40, 0.38 and 0.48, and 0.10 and 0.04, respectively (Fig. 1). The highest entire population age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) values were observed at 30 °C (Fig. 2).

Temperature greatly affected the intrinsic rate of increase of *N. includes* (Table 3). The highest value of this parameter was observed at 30 °C (Table 3). However, its lowest value was observed at 35 °C, at which the population of the predator was decreasing (Table 3). The highest finite rate of increase (λ) was observed at 30 °C, and its lowest value was at 35 °C (Table 3). The highest and lowest values of net reproductive rate (R_0) were observed at 30 and 35 °C, respectively (Table 3). The mean generation time (T) was longer at 20 °C than at other temperatures (Table 3).

Life expectancy (e_{xj}) indicates the expected life of an individual at the age x and stage j. Life expectancy of *N. includens* was longer at 25 °C as compared to other temperatures (Fig. 3). The shortest life expectancy of the predator was observed at 35 °C (Fig. 3). The peak value on reproductive curve presents the greatest contribution to the population. Reproductive rate of *N. includens* females reached the highest levels on the 87th day (v87 = 21.26), 51st day (v51 = 16.21), 41st day (v41 = 37.84) and 19th day (v19 = 2.19) at 20, 25, 30, and 35 °C, respectively (Fig. 4).

Discussion

The previous studies about the development of *N. includens* are mostly related to development of the predator on the citrus mealybug, *P. citri*. In the present study, the total preadult durations of the predator were 62.12, 30.59, 23.30, and 22.43 days at 20, 25, 30 and 35 °C, respectively. Tranfaglia and Viggiani (1973) reported preadult stage of *N. includens* fed on *P. citri* 25.9 days at 25–27 °C. Soylu et al. (1983) reported total development period of the predator on *P. citri* 32.6 days at 25 °C and 23.3 days at 28 °C. Canhilal et al. (2001) show that the development duration of *N. includens* fed on *P. citri* was 48.8, 31.4, 24.6, and 22.0 days at 20, 25, 30, and 35 °C, respectively. Kontodimas et al. (2004) reported the development duration of *N. includens* fed on *P. citri* at 20, 25, 30, and 35 °C as 46.3, 29.1, 20.9, and 21.4 days, respectively. The findings of the present study on development durations at 25, 30, and 35 °C were generally similar to the previously reported values. However, the present development duration obtained at 20 °C was longer than the previous reports (Canhilal et al. 2001; Kontodimas et al. 2004), which can be related to prolonged development of different stages of the predator at this temperature.

In the present study, preadult mortality rate of the predator was 0.66, 0.22, 0.14, and 0.86% at 20, 25, 30 and 35 °C, respectively. Canhilal et al. (2001) reported total preadult mortality rates of *N. includens* at 20, 25, 30, and 35 °C temperatures as 55.6, 36.7, 34.4, and 71.6%, respectively. The present study's preadult mortality rates at 25 and 30 °C were lower and at the temperatures of 20 and 35 °C were higher than the values of Canhilal et al. (2001). It shows that low and high temperatures negatively influenced the predator as compared to average temperatures.

In the present study, the shortest preoviposition (APOP) duration of *N. includens* (9.8 days) was at 30 °C. Canhilal et al. (2001) reported preoviposition duration of *N. includens* at 30 °C as 4.6 days. Findings of Kontodimas et al. (2004) also showed that the preoviposition period of *N. includens* was 4.56 days at 30 °C. In the present study, the preoviposition periods were almost twice as much as the values reported in previous studies. It is thought that this difference may be due to the use of different mealybug species or the different experimental designs.

In the present study, the fecundity of *N. includens* was 24.80, 42.58, 87.47, and 0.40 eggs at 20, 25, 30 and 35 °C,

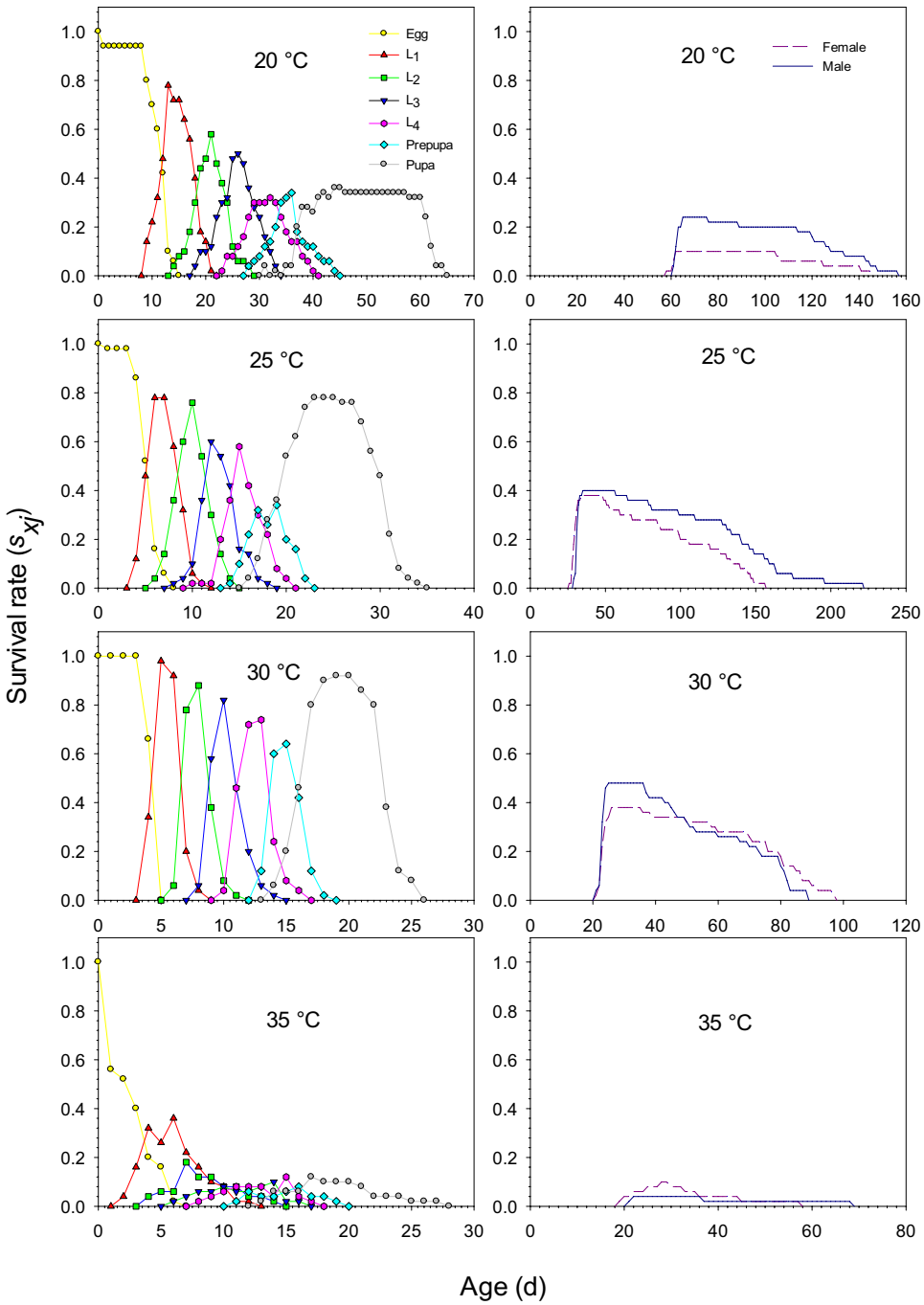


Fig. 1 Age–stage specific survival rate (s_{xj}) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures

respectively. The values were quite lower than the values reported in previous studies, in which the predator's prey was *P. citri*. For example, Tranfaglia and Viggiani (1973) reported that *N. includens* oviposited totally 150.9 eggs at 25–27 °C. Canhilal et al. (2001) indicated a decreasing total and daily number of eggs with increasing temperatures and reported the number of eggs oviposited at 25, 30, and 35 °C as 133.5, 123, and 50.8, respectively. Furthermore, Kontodimas et al. (2007) reported the fecundity of *N. includens* at 20, 25, 30, and 35 °C as 97.8, 162.8, 108.5, and 31.1 eggs, respectively. Differences in fecundity values from this study and previous studies were mostly attributed to differences in prey species.

In the present study, females and males longevity of *N. includens* was quite longer at 20 and 25 °C than at 30 and 35 °C. Under 25–27 °C and 50–70% relative humidity conditions, Tranfaglia and Viggiani (1973) reported that the longevity of *N. includens* females was 74 days and males was 62 days. Canhilal et al. (2001) reported that the females and males longevity of *N. includens* at 25 °C was 70 and 78 days,

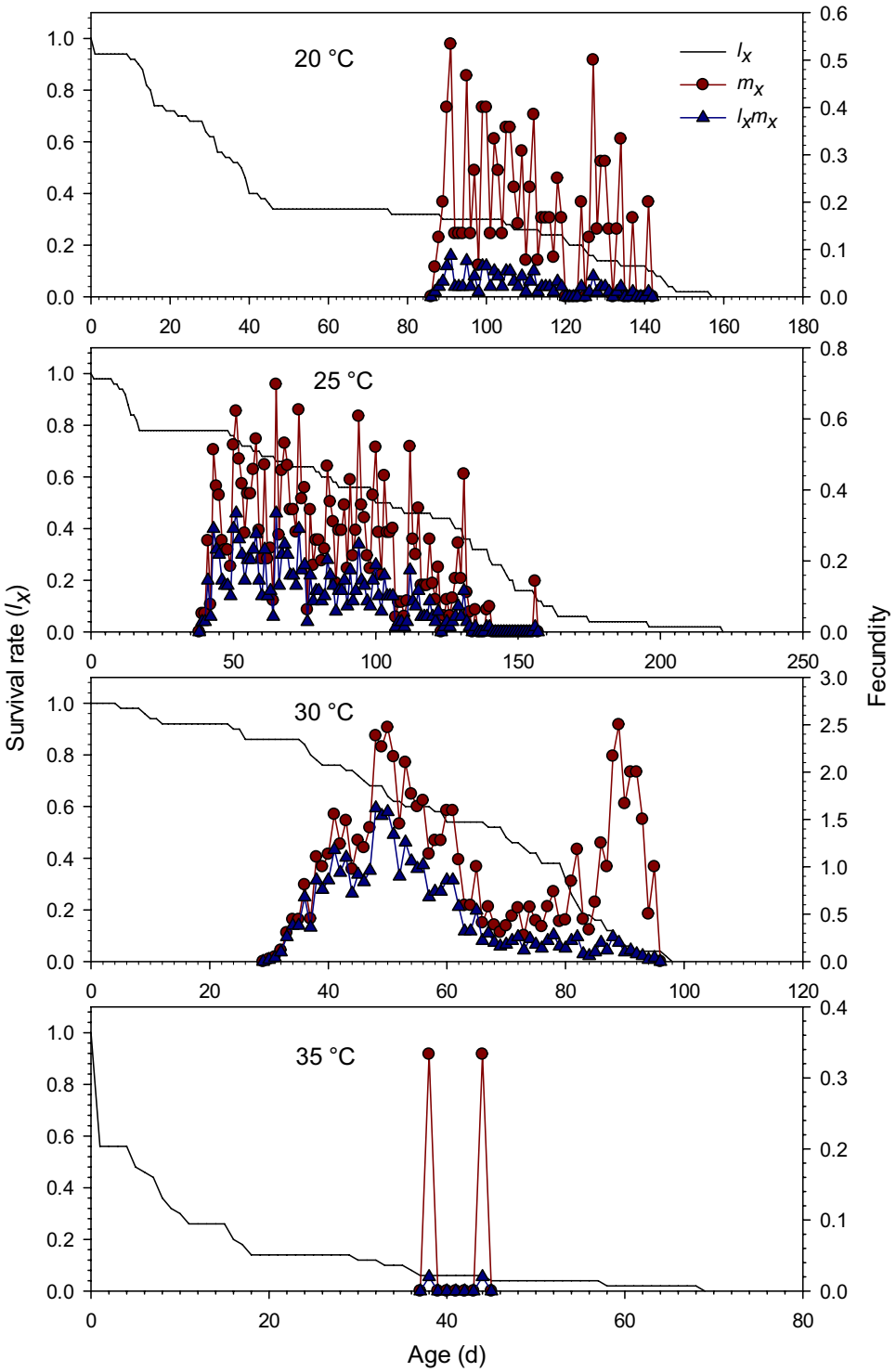


Fig. 2 Age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity (l_xm_x) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures

respectively. According to Kontodimas et al. (2007) findings, the longevity of females of *N. includens* was 69.5 days at 25 °C. In the present study, the obtained values for the longevity of the predator's females and males were quite longer than those reported in above-mentioned studies. It is thought that this result may be related to the different mealybug species used in this study and previous studies.

In the present study, the intrinsic rate of increase (r) and net reproductive rate (R_0) of *N. includens* were 0.0086 d^{-1} and 2.48 eggs, 0.0415 d^{-1} and 16.18 eggs, 0.0703 d^{-1} and 33.24 eggs, and −0.0760 d^{-1} and 0.04 eggs at 20, 25, 30, and 35 °C, respectively. Kontodimas et al. (2007) reported the intrinsic rate of increase (r) and net reproductive rate (R_0) of *N. includens* at 20, 25, 30, and 35 °C as 0.041 d^{-1}

Table 3 Population parameters of intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures (Mean ± SE)

Parameter	Temperature			
	20 °C	25 °C	30 °C	35 °C
r	0.0086 ± 0.0058c*	0.0415 ± 0.0041b	0.0703 ± 0.0047a	−0.0760 ± 0.0103d
λ	1.0086 ± 0.0058c	1.0423 ± 0.0043b	1.0728 ± 0.0050a	0.9268 ± 0.0097d
R_0	2.48 ± 1.19c	16.18 ± 4.33b	33.24 ± 7.37a	0.04 ± 0.03d
T	106.00 ± 3.51a	67.16 ± 2.80b	49.86 ± 1.07c	42.34 ± 0.05d

*The means followed by different letters in the same row are significantly different using the paired bootstrap test at 5% significance level. The standard errors were calculated using the bootstrap procedure with 100,000 resampling

and 32.2 eggs, 0.083 d^{-1} and 60.7 eggs, 0.086 d^{-1} and 32.6 eggs, and 0.024 d^{-1} and 2.6 eggs, respectively. Canhilal et al. (2001) reported the intrinsic rate of increase (r) and net reproductive rate (R_0) of *N. includens* fed on *P. citri* at 25, 30, and 35 °C as 0.067 d^{-1} and 54.4 eggs, 0.081 d^{-1} and 38.0 eggs, and 0.053 d^{-1} and 7.7 eggs, respectively. In the present study, the values of (r) and (R_0) were generally lower than the values of Canhilal et al. (2001) and Kontodimas et al. (2007). In this study, unlike previous studies, the (r) value of the predator was determined as negative at 35 °C. This result shows that if the predator is fed on vine mealybug at this temperature, its population will gradually decrease and it may disappear over time. In the present study, the finite rate of increase values and the mean generation times of *N. includens* were 1.0086 d^{-1} and 106.00 days, 1.0423 d^{-1} and 67.16 days, 1.0728 d^{-1} and 49.86 days, and 0.9268 d^{-1}, 42.34 days at 20, 25, 30, and 35 °C, respectively. Kontodimas et al. (2007) reported the finite rate of increase (λ) of *N. includens* at 20, 25, 30, and 35 °C as 1.04, 1.09, 1.09, and 1.02 d^{-1} and its mean generation times as 84.6, 49.4, 40.4, and 39.7 days, respectively. Canhilal et al. (2001) reported the mean generation times of *N. includens* at 25, 30, and 35 °C as 59.6, 44.9, and 38.4 d, respectively. In the present study, the finite rate of increase values at the same temperatures was lower than the values of Kontodimas et al. (2007). A similar trend was observed in the mean generation times. In the present study, the values of mean generation times at the same temperatures were longer than those reported in Kontodimas et al. (2007) and Canhilal et al. (2001). It is thought that the type of prey affects these parameters of the predator as well as other parameters. Comparing to the other studies, the values of the population parameters *N. includens* feeding on *P. ficus* as prey were generally lower than on *P. citri* (Canhilal et al. 2001; Kontodimas et al. 2007). Boggs (2009) stated that food is one of the most important factors affecting life-history parameters of an insect. To date, the biological properties of *N. includens* have not been studied on any mealybug species other than *P. citri*. On the other hand, it has been reported that there are differences in the biological characteristics of *C. montrouzieri* feeding on different mealybug species (Baskaran et al. 1999, 2002; Naser et al. 2011; Qin et al. 2014). A similar result was reported in another study in which two different mealybug species were presented as prey to another mealybug predator, *Hyperaspis polita* Weise (Coleoptera: Coccinellidae) (Madih et al. 2017).

Age–stage specific life expectancy (e_{xj}) and age–stage specific reproductive value (v_{xj}) are important parameters used in mass production and release time of natural predators in biological control. Tsai and Chi (2007) indicated that being at the same age of individuals, but in different stages and genders could cause differences in life expectancy. Thus, age–stage, two-sex life tables may reveal such differences and they may yield more precise outcomes than conventional female age-specific life tables. Chi and Su (2006) indicated a reproductive value of newly oviposited eggs as same as the finite rate of increase (λ). In the current study, at the optimum temperature (30 °C), the age–stage specific life expectancy of the females (e_{xj}) was 98 days and the highest age–stage specific reproductive value was obtained at 41st day (v41 = 37.84). Female individuals kept ovipositing until the last two days of their life. At 25 °C, the highest age–stage specific reproductive value was obtained at the 51st day (v51 = 16.21) and the predator kept living and ovipositing 105 days after that day. Kontodimas et al. (2007) indicated that *N. includens* females achieved the highest reproductive value at 25 °C in the 7th day and the expected remaining lifetime (e_x) was lasted 55 days. It was determined that when *N. includens* fed on *P. ficus*, reaching to the highest reproductive value was delayed and it oviposited less eggs, but its adult longevity was prolonged nearly twice as much (Kontodimas et al. 2007).

The present study findings revealed that *N. includens* could survive on *P. ficus* at all temperatures tested. However, it was determined that the reproduction of the predator was affected by the high temperature and the predator population decreased drastically at 35 °C. Population parameters obtained at these temperatures revealed that the optimum temperature for the predator was 30 °C. It was concluded that *N. includens* mass production could be done at 30 °C and used in biological control of the vine mealybug. If *Nephus* species are used for biological

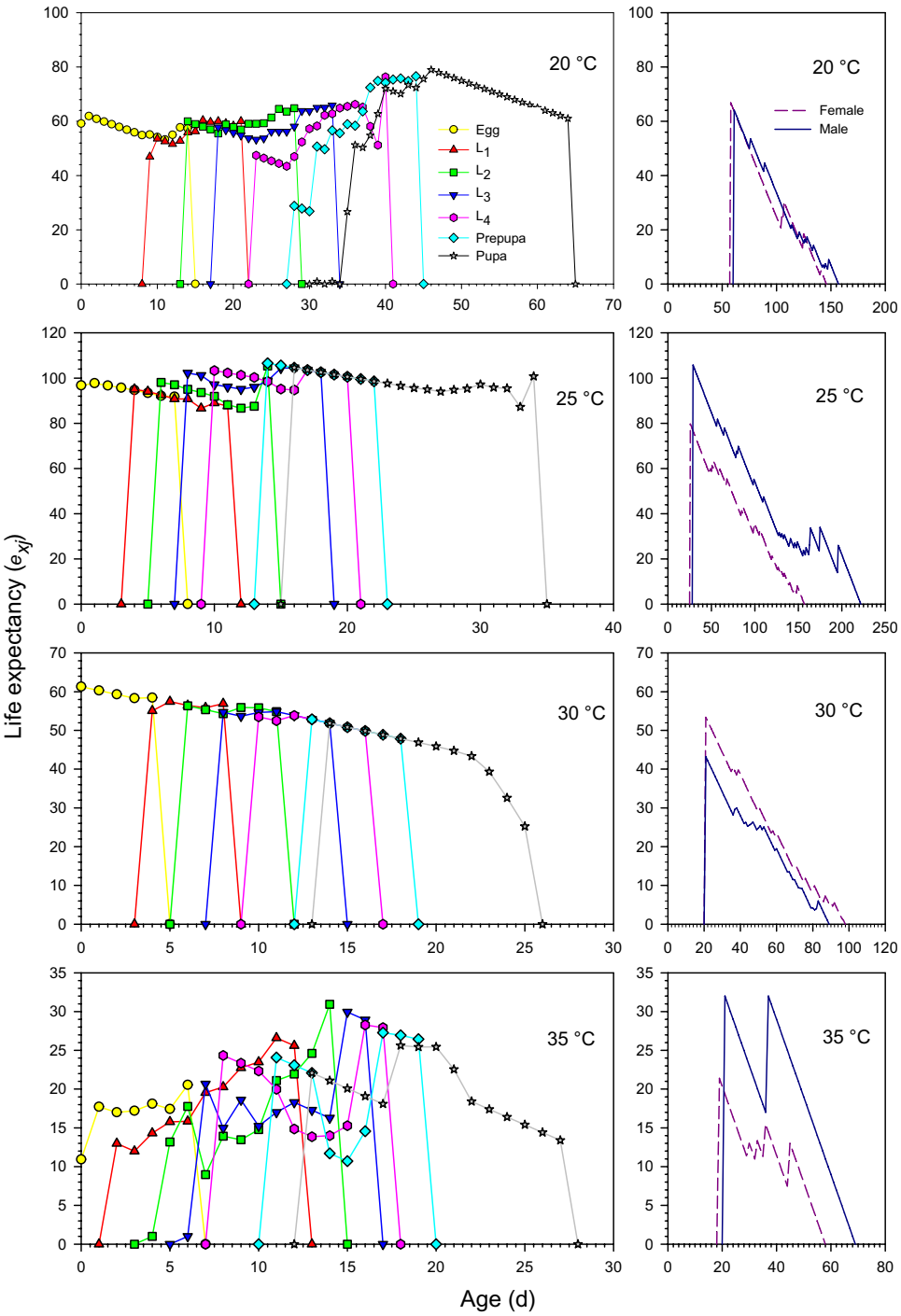


Fig. 3 Age–stage specific life expectancy (e_{xj}) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures

control of vine mealybug in vineyards especially, they may more comfortably move under vine barks as compared to larger-sized Coccinellids such as *Cryptolaemus montrouzieri* Mulsant. Considering the fact that *C. montrouzieri* could not spend winter in Turkey and the other countries within the same climate zone, it is thought that *N. includens* could be used in biological control of pests in vineyards and orchards in which mulberry and fig-like *P. ficus* host trees are grown. However, to reach an absolute judgment on this issue, efficacy of the predator on vine mealybug should also be tested under field conditions.

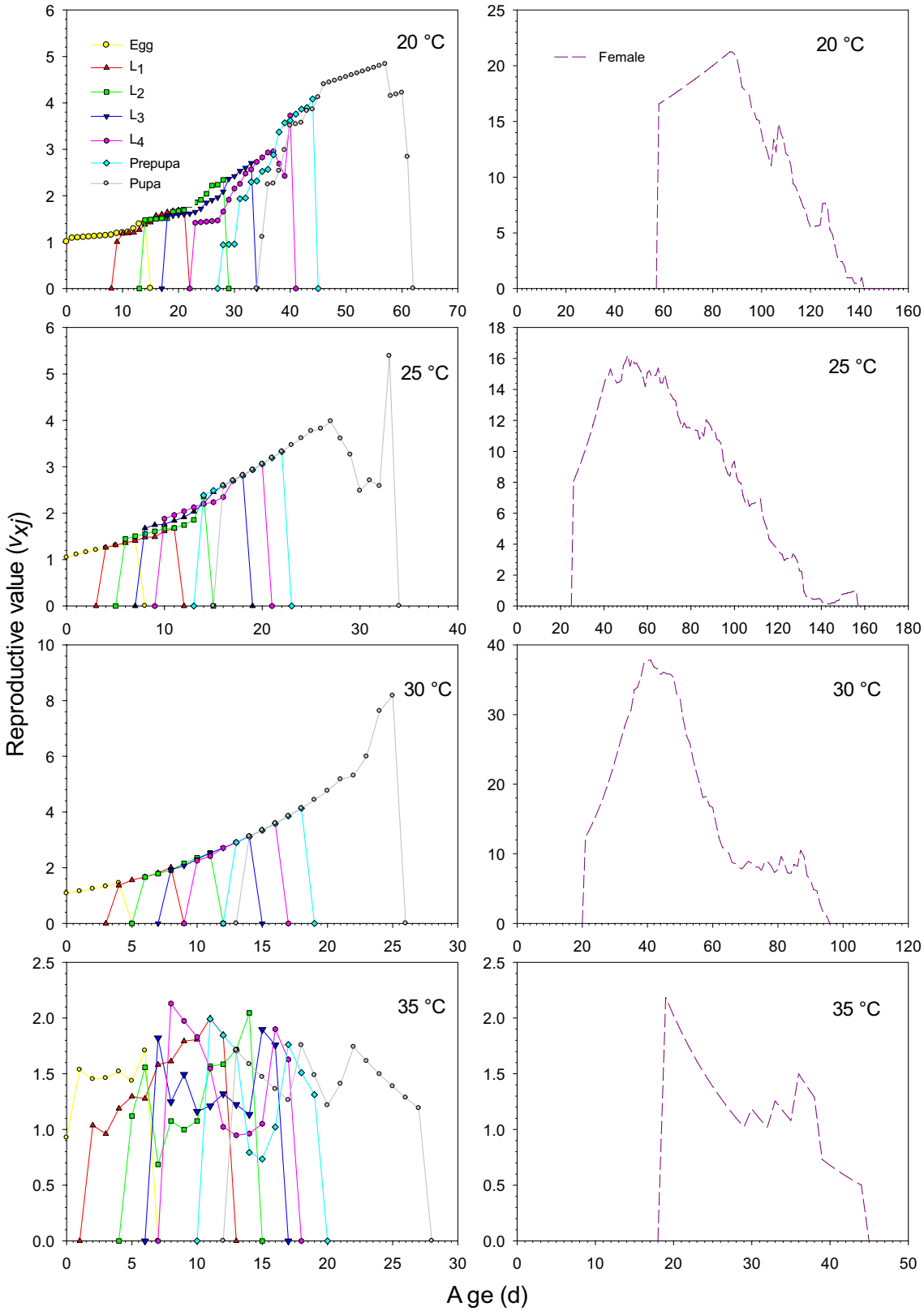


Fig. 4 Age–stage specific reproductive value (v_{xj}) of *Nephus includens* fed on *Planococcus ficus* at various constant temperatures

Acknowledgements This publication has formed from a part of the master's thesis of second author. We are grateful to Prof. Dr. M. Bora Kaydan and Prof. Dr. Nedim UYGUN (Retired) (Çukururova University, Adana, Turkey) for identifications of insects. We thank Biological Control Research Institute, Adana, Turkey for culture of *Nephus includens*. This work has been supported by Erciyes University Scientific Research Projects Coordination Unit under Grant Number FBA-2016-6614.

Funding Not applicable.

Availability of data and material The data that support the findings of this study are available from the corresponding author.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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