

Life history of *Neoseiulus agrestis* (Karg) (Acari: Phytoseiidae) fed on the storage mite, *Thyreophagus* sp. (Acari: Acaridae) at different temperatures

Maryam Moradi^a, Yana V. Misharova^{id}^b, Vladislav V. Snigirev^{id}^b, Ismail Döker^{id}^{a,c}, Omid Joharchi^{id}^a, Vladimir A. Khaustov^{id}^a

^a Institute of Environmental and Agricultural Biology (X-BIO), Tyumen State University, Tyumen, Russia.

^b Institute of Biology, Tyumen State University, Tyumen, Russia.

^c Agricultural Faculty, Department of Plant Protection, Acarology Laboratory, Cukurova University, Adana, Turkey.

Original research

ABSTRACT

The development and life history parameters of *Neoseiulus agrestis* feeding on the storage mite, *Thyreophagus* sp., were studied at three different temperatures of 20, 25, and 30 °C. The results show that juvenile development and oviposition period as well as reproductive potential of this predatory mite are significantly affected by the temperature. The development times of immature and the life expectancy of adults ranged from 11.36 to 6.06 days and 58.71 to 38.65 days, respectively, depending on the temperature. The average total number of eggs laid per female at 20 °C (27.21), 25 °C (46.38), and 30 °C (61.12) differed significantly from each other. The highest net reproductive rate (R_0) was 51.95 (offspring/individual) at 30 °C, although there was no significant difference from that obtained at 25 °C (37.10). Furthermore, the highest intrinsic rate of increase (r_m) is 0.286 day⁻¹ at 30 °C. Moreover, the highest finite rate of increase ($\lambda = 1.331$ day⁻¹) and the shortest mean generation time ($T = 13.786$ days) and doubling time ($DT = 2.418$ days) were also determined at 30 °C. Our results indicate that *N. agrestis* successfully completed immature development and can survive and reproduce at all temperatures tested. However, a number of biological traits of this predator are affected by the temperature on this food source. Finally, a temperature of 30 °C seems to be more suitable for mass rearing of this predator on *Thyreophagus* sp. Further studies should be carried out to determine the biological characteristics and life cycle parameters of *N. agrestis* on various important pests such as spider mites, whiteflies and thrips.

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Corresponding authors

Maryam Moradi: m.moradi@utmn.ru

Ismail Döker^{id}: idoker@cu.edu.tr

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Moradi M. *et al.*

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Introduction

Predatory mites belonging to the family Phytoseiidae (Acari: Mesostigmata) are one of the most widely utilized groups for the biological control of certain phytophagous mites and insect species (McMurtry *et al.* 2013). Although more than 2500 phytoseiid species are currently known, only a few have been studied with regard to their potential as biological control agents (Tsolakis *et al.* 2013; Knapp *et al.* 2018). On the other hand, knowledge of the life history and demographic parameters of phytoseiid mites is one of the most important steps for the evaluation of their potential on their prey (Tsolakis *et al.* 2016; Ben Chaaban *et al.* 2018). Previous studies have shown that the life history and demographic parameters of phytoseiid mites are differentially affected by several important factors such as temperature, relative

humidity, host plant, prey species, age, and pesticide application (Sugawara *et al.* 2017; Tsolakis *et al.* 2019). *Neoseiulus agrestis* (Karg) was first described based on the material collected from soil in Germany (Karg 1960). It has been reported from a series of western Palearctic countries, but also in central Asia (Kazakhstan) and the USA (Demite *et al.* 2023). This species is a generalist predator that belongs to the Type III-e feeding habits from soil/litter habitats but may periodically move up onto low-growing plants (McMurtry *et al.* 2013). Although there has been limited knowledge on the biological control potential of *N. agrestis*, two *Neoseiulus* species, *N. barkeri* (Hughes) and *N. cucumeris* (Oudemans) both showing the same lifestyle, have been extensively utilized for the biological control of mites and especially thrips (Zhang 2003; Knapp *et al.* 2018). In addition, both *N. barkeri* and *N. cucumeris* are produced using several species of acarid mites as prey, and they are available commercially worldwide (Vangansbeke *et al.* 2022). Since *N. agrestis* is a parthenogenetic species and its male is not known so far, its mass rearing may be easier and require less effort compared to sexual species (Khaustov *et al.* 2022; Moradi *et al.* 2023). Storage mites [*Carpoglyphus lactis* (L.) and *Thyreophagus entomophagus* (Laboulbène & Robin)] have been used as factitious prey for commercial production of different species of phytoseiid mites particularly *Amblyseius swirskii* Athias-Henriot since 2005 (Bolckmans and van Houten 2006; Fidgett and Stinson 2008; Massaro *et al.* 2016; McGregor *et al.* 2020; Pirayeshfar *et al.* 2021). The genus *Thyreophagus* is distributed worldwide, containing species occurring in stored food, house dust, bark, subcortical habitats, scale insect associations, and nests of wasps and bees (Klimov *et al.* 2022). According to Fidgett and Stinson (2008), suitability of different storage mites was evaluated for *A. swirskii*. Successful development and reproduction of this predatory mite were reported on *Thyreophagus entomophagus* (Laboulbène & Robin) which can easily serve as a food source for the mass rearing of predatory mites. In this study, as a first step in determining the optimal temperature for mass rearing, the life history and demographic parameters of *N. agrestis*, fed on the storage mite *Thyreophagus* sp., were studied at three temperatures under laboratory conditions.

Material and methods

Mite colonies

Initial colonies of *Thyreophagus* sp. were obtained from the Institute of Environmental and Agricultural Biology (X-BIO), Tyumen State University, Tyumen, Russia. The mites were mass-reared in transparent plastic containers (12 X 8 X 4 cm) with a mesh ventilated cover (100 micrometers pore size). The containers were kept in desiccators with a saturated NaCl solution providing 90% relative humidity and incubated at 25 ± 1 °C. The temperature and humidity conditions were monitored by using a data logger during the experiments. The rearing diet contained a yeast powder biomass (Pripravich, RU) (Fidgett and Stinson 2008). The predatory mite, *N. agrestis* was collected from steppe soil (top surface $\approx$ 2 cm) in Altai Republic, Russia (Khaustov *et al.* 2022). The stock culture of the predator was maintained in the plastic containers described above using *Thyreophagus* sp. as food source. The prey and the predator rearing units were kept separately in incubators (SANYO Electric Biomedical co., Japan) at 25 °C and $90 \pm 5\%$ RH and 12:12 L:D. The predatory mites were reared for one to three generations, before being used in experiments.

Pre-adult duration and survival

The pre-adult duration (developmental time from egg to adult) and survival of the predators were individually observed by using transparent plastic containers (3 cm in diameter and 1.8 cm deep). The lid of the experimental test units was drilled (2 cm in diameter) and covered with a fine mesh (30 micrometers in size) to allow ventilation. More than 50 females of the predator obtained from the stock culture were transferred to experimental arenas using a brush (number

000) under a stereo microscope (Zeiss, Stemi-305, Germany). Subsequently, egg laying was observed in the arenas at two-hour intervals. Then one egg was transferred to each experimental unit using a brush. Sufficient amounts of *Thyreophagus* sp. (> 20 individuals) mixed with yeast powder were provided as a food source for the predators at daily intervals. In total, 20 replicates were used for each temperature. The duration of the immature stages including egg, larva, protonymph, and deutonymph were separately determined at three temperatures (20, 25 and 30 °C, and a constant humidity $90 \pm 5\%$ RH and photoperiod 16:8 L:D), based on the observations conducted at 12-hour intervals.

Adult longevity and fecundity

The individuals which successfully reached adulthood were individually monitored at daily intervals to obtain the preoviposition, oviposition, and postoviposition periods as well as the number of eggs produced in the same experimental units and conditions described earlier. The observations were finalized when the last individual of the original female had died. Therefore, longevity of females was also recorded.

Life history and population parameters

Even though *N. agrestis* is a parthenogenetic species and no males were observed in the population, its life history and population parameters were estimated by using age-stage, two-sex life table analysis program (Chi and Liu 1985). Because, the immatures were also considered for the life table analysis. The age-stage-specific survival rate (s_{xj}) (where x and j are age and stage, respectively); the age-stage specific fecundity (f_{xj}); the age-specific survival rate (l_x); the age-specific fecundity (m_x), adult preoviposition period (APOP), total preoviposition period (TPOP), and the life table parameters including the net reproductive rate (R_0), intrinsic rate of increase (rm), finite rate of increase (λ), gross reproductive rate (GRR), DT doubling time and mean generation time (T) were calculated in the TWOSEX-MSChart computer program (Chi, 2020). The standard errors were estimated by using the bootstrap method, and the differences were determined with the paired bootstrap test (Efron and Tibshirani 1993).

Results

Pre-adult duration and survival

Table 1 Pre-adult duration (mean $\pm$ SE in days) and survival rate (mean $\pm$ SE) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions.

	20 °C	25 °C	30 °C
Egg	3.07 $\pm$ 0.20a*	2.25 $\pm$ 0.11b	1.53 $\pm$ 0.12c
Larva	1.36 $\pm$ 0.13	1.31 $\pm$ 0.12	1.24 $\pm$ 0.11
Protonymph	3.29 $\pm$ 0.19a	2.12 $\pm$ 0.09b	1.71 $\pm$ 0.11c
Deutonymph	3.64 $\pm$ 0.17a	1.75 $\pm$ 0.11b	1.59 $\pm$ 0.12b
Egg to adult	11.36 $\pm$ 0.31a	7.44 $\pm$ 0.27b	6.06 $\pm$ 0.18c
Survival rate	0.70 $\pm$ 0.10	0.80 $\pm$ 0.09	0.85 $\pm$ 0.08

*Means within a row followed by different letters are significantly different according to the paired bootstrap test with 100,000 replicates ($P < 0.05$).

Although the temperature had a significant effect on its immature development, *N. agrestis* successfully reached adulthood at the three temperatures (Table 1). The duration of each developmental stage was significantly different from each other based on the temperature, except for larva at all temperatures and for deutonymph at 25 °C and 30 °C. No significant differences, however, were detected among the immature survival rates obtained at different temperatures tested (Table 1).

Adult longevity and fecundity

Table 2 Total pre-oviposition, adult pre-oviposition and oviposition periods (TPOP, APOP, OP), longevity, (mean $\pm$ SE in days) and fecundity (mean $\pm$ SE) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions.

	20 °C	25 °C	30 °C
TPOP	14.36 $\pm$ 0.32a*	9.56 $\pm$ 0.30b	7.59 $\pm$ 0.21c
APOP	3.00 $\pm$ 0.23a	2.12 $\pm$ 0.12b	1.53 $\pm$ 0.12c
OP	22.21 $\pm$ 1.54	21.69 $\pm$ 1.60	20.82 $\pm$ 1.36
Female total longevity	58.71 $\pm$ 2.58a	45.31 $\pm$ 2.09b	38.65 $\pm$ 1.76c
Total fecundity	27.21 $\pm$ 1.84c	46.38 $\pm$ 3.76b	61.12 $\pm$ 3.72a

*Means within a row followed by different letters are significantly different according to the paired bootstrap test with 100,000 replicates ($P < 0.05$).

Similar to the immature development, total pre-oviposition (TPOP), adult pre-oviposition (APOP), and longevity of *N. agrestis* were significantly affected by the temperature (Table 2). In contrast, no significant difference was detected among oviposition periods (OP) obtained at different temperatures. The shortest TPOP (7.59 days), APOP (1.53 days), OP (20.82 days) and total female longevity (38.65 days) were obtained at 30 °C and these values were significantly different than those obtained at 20 °C and 25 °C, except OP. However, the OP obtained at 30 °C (20.82 days) is still numerically lower than those obtained at the other two temperatures (21.69 days at 25 °C and 22.21 days at 20 °C). The highest total mean number of offspring produced per female was obtained at 30 °C (61.12) followed by 25 °C (46.38) and 20 °C (27.21). In addition, these values are significantly different from each other.

Life history and population parameters

Table 3 Population parameters: r_m , intrinsic rate of increase; λ , finite rate of increase; R_0 , net reproductive rate; T , mean generation time; GRR, gross reproductive rate; and DT, doubling time of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions (mean $\pm$ SE in days).

	20 °C	25 °C	30 °C
r_m (day ⁻¹)	0.122 $\pm$ 0.007c*	0.213 $\pm$ 0.009b	0.286 $\pm$ 0.010a
λ (day ⁻¹)	1.130 $\pm$ 0.008c	1.237 $\pm$ 0.012b	1.331 $\pm$ 0.014a
R_0 (offspring/individual)	19.050 $\pm$ 3.038b	37.100 $\pm$ 5.062a	51.950 $\pm$ 5.766a
T (day)	23.961 $\pm$ 0.647a	16.944 $\pm$ 0.573b	13.786 $\pm$ 0.425c
GRR (offspring/individual)	27.600 $\pm$ 1.818c	48.140 $\pm$ 3.663b	65.620 $\pm$ 6.266a
DT (day)	5.635 $\pm$ 0.364a	3.250 $\pm$ 0.154b	2.418 $\pm$ 0.009c

*Means within a row followed by different letters are significantly different according to the paired bootstrap test with 100,000 replicates ($P < 0.05$).

The highest intrinsic rate of increase ($r = 0.286$ day⁻¹), finite rate of increase ($\lambda = 1.331$ day⁻¹), reproductive rate ($R_0 = 51.950$ offspring/individual), and gross reproductive rate (GRR = 65.620 offspring/individual) were detected at 30 °C and these values were significantly different from those obtained at the other two temperatures, except R_0 which was statistically similar to that obtained at 25 °C (37.100 offspring/individual) (Table 3). In addition, the shortest mean generation time ($T = 13.786$ days), and doubling time (DT = 2.418 days) were also detected at 30 °C, and these values were significantly higher than those obtained at the other two temperatures.

The age-stage survival rate curves (S_{xj}) show the probabilities of survival rate of newly emerged *N. agrestis* individuals to age x and stage j (Figure 1A). The variations in pre-adult

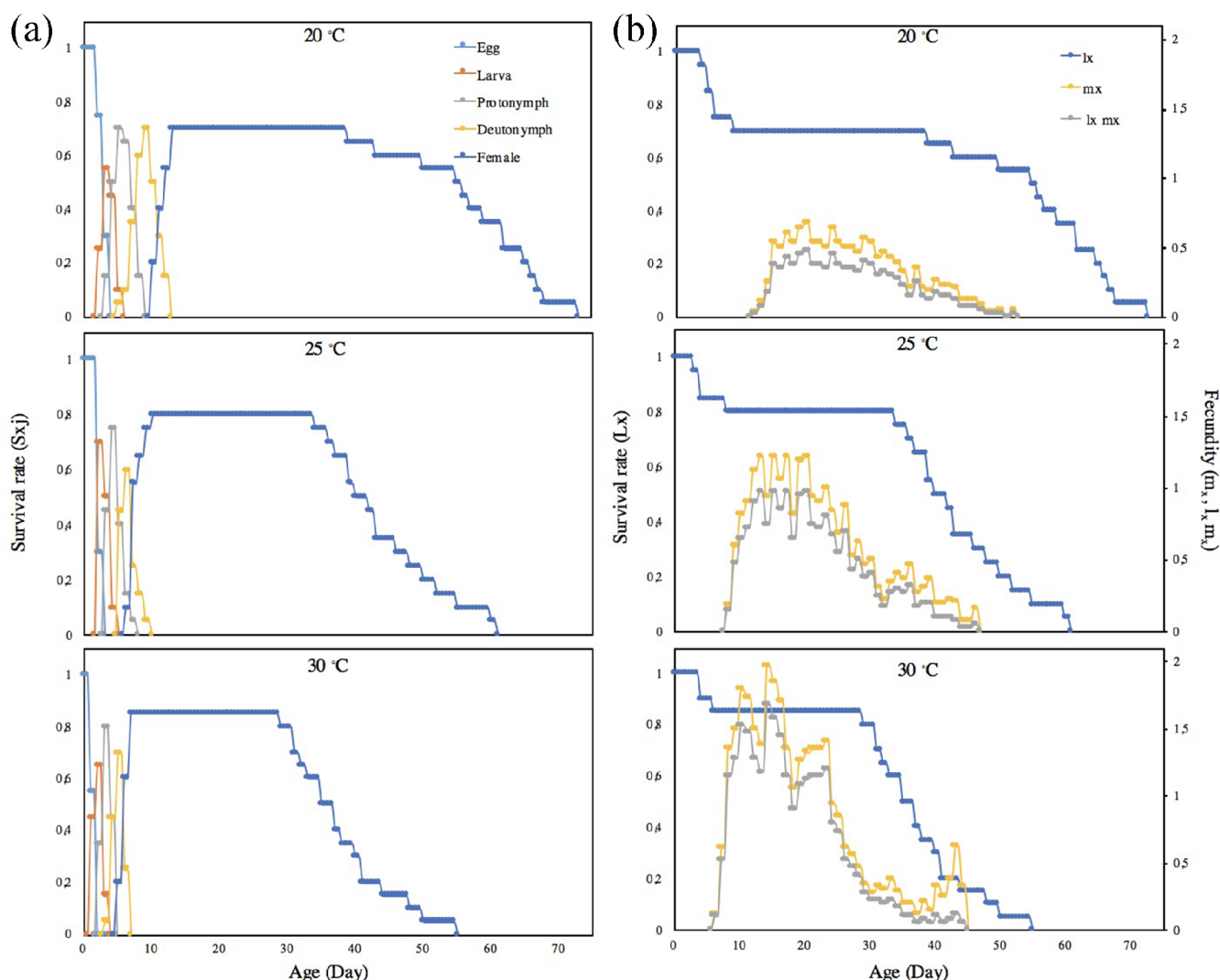


Figure 1 A – Age-stage specific survival rate (S_{xj}) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions; B – Age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions.

development rates resulted in overlaps of different developmental stages at three temperatures. The highest survival rates of females were 0.70, 0.80 and 0.85 at 20 °C, 25 °C, and 30 °C, respectively. The age-specific survival rate (l_x) showed a similar pattern of gradual decline during the development at three different temperatures, but l_x declined faster at 30 °C compared to the other two temperatures (Figure 1B). The first oviposition occurred at 20, 25 and 30 °C, on the days 13th, 8th, and 6th, respectively. The oviposition stopped at 20, 25 and 30 °C, on the days 52nd, 46th, and 44th, respectively. The highest fecundity (m_x) at 20, 25 and 30 °C were recorded on the days 20th (0.68 eggs/female), 13th (1.22 eggs/female) and 14th (1.97 eggs/female), respectively. The age-stage-specific life expectancy (e_{xj}) of a newly emerged individual were 42.85, 37.20 and 33.55 days at 20, 25 and 30 °C, respectively (Figure 2A). In general, the (e_{xj}) value obtained at 30 °C was lower compared to the those obtained at other two temperatures, which demonstrated that life expectancies might be shorter at high temperatures. The highest age-stage-specific reproductive values (v_{xj}) of *N. agrestis* at 20 °C, 25 °C, and 30 °C were detected on 15th (8.70), 12nd (10.51) and 10th (12.21) days, respectively (Figure 2B).

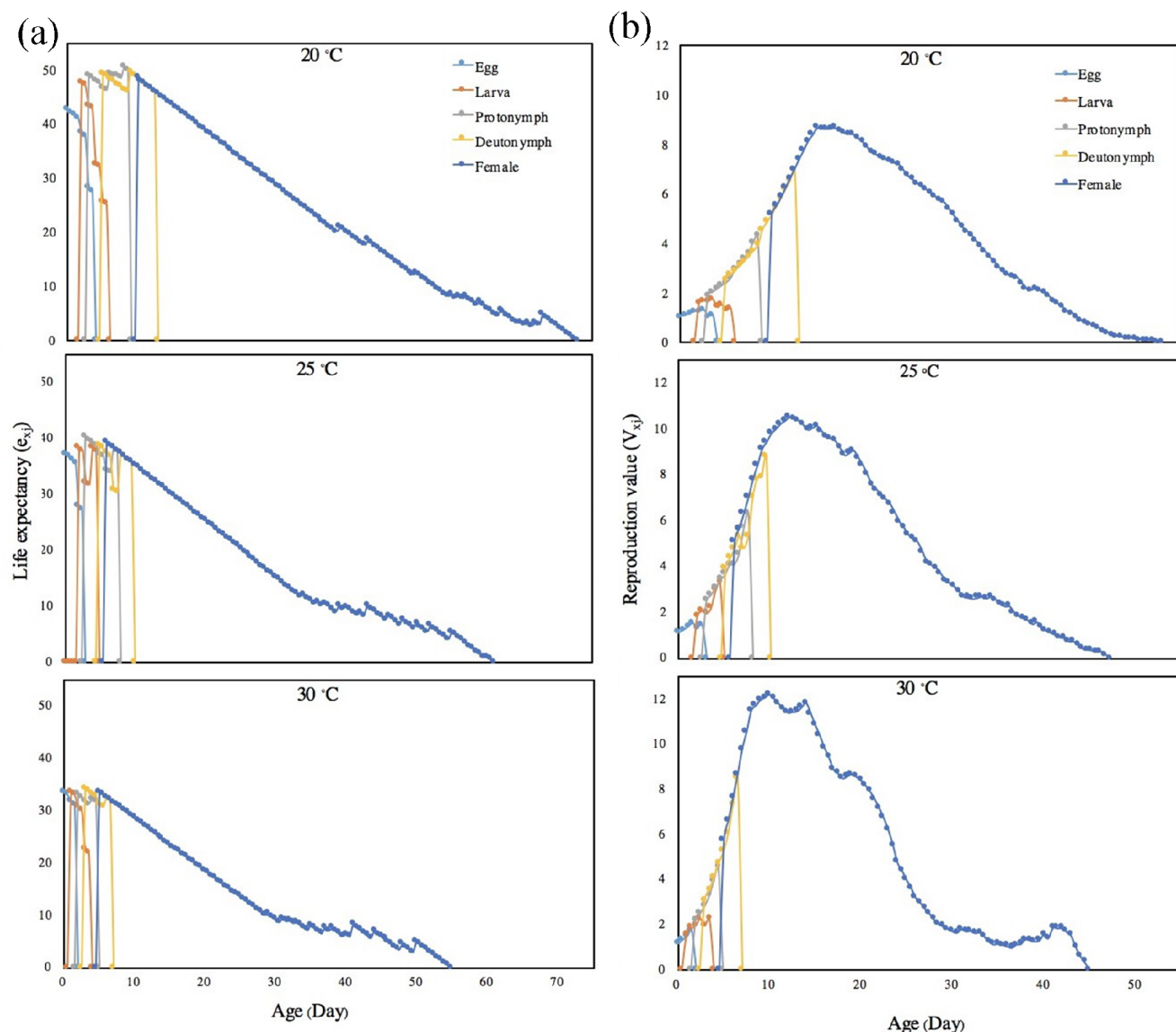


Figure 2 A – Age-stage-specific life expectancy (e_{xj}) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions; B – Age-stage-specific reproductive value (v_{xj}) of *Neoseiulus agrestis* fed on *Thyreophagus* sp. at three different temperatures under laboratory conditions.

Discussion

Similar to many other insects and mites, the longevity and fecundity of adult females of *N. agrestis* are significantly affected by temperature. Previous studies reported that temperature is one of the most important abiotic factors that affect the life history and demographic parameters of phytoseiids (Tsoukanas *et al.* 2006; Vangansbeke *et al.* 2013; Yazdanpanah *et al.* 2022). In this regard, knowledge about a suitable temperature is important and considered the first step for their mass rearing and usage in biological control. This study presents the first and preliminary data regarding the life history and demographic parameters of *N. agrestis* fed on *Thyreophagus* sp.

Our results confirm that *N. agrestis* has thelytokous parthenogenesis since no males were produced by the females during the life history study (Kolodochka 1975). Parthenogenesis is

common among not only phytoseiids but also other groups of mites (Oliver 1983). However, most phytoseiid species are believed to be arrhenotokous (males arise from unfertilized eggs) and pseudo-arrhenotokous where males arise from fertilized eggs but become haploids after inactivation or elimination of the paternal chromosome (Sabelis 1985; Hoy 1985). In contrast, thelytokous parthenogenesis is reported for a series of species including *Amblyseius guatemalensis* (Chant), *A. herbicolus* (Chant), *A. parasundi* (Blommers), *N. agrestis*, *N. salish* (Chant and Hansell), *Typhlodromus transvaalensis* (Nesbitt), *Transeius herbarius* (Wainstein) (Amitai *et al.* 1969; Kolodochka 1974, 1975; Hoy 1985; Akimov and Kolodochka 1991; Zhang and Zhang 2021).

According to the results, offspring of *N. agrestis* could develop into adults when *Thyreophagus* sp. was provided as prey at all temperatures tested. Nevertheless, certain life history and demographic parameters were affected by the temperature. The immature developmental periods of *N. agrestis* obtained at 25°C are more or less in line with those reported for another thelytokous phytoseiid mite, *A. herbicolus* fed on *Carpoglyphus lactis* (L.) at the same temperature (Zhang and Zhang 2021), except for the duration of larva and protonymph which are shorter in the current study. In addition, our results are also similar to those reported by Huang *et al.* (2013) for *N. barkeri* fed on *Tyrophagus putrescentiae* (Schrank) at 25 °C. In contrast, Moradi (2023) reported generally lower immature developmental times, for *N. neoagrestis* fed on *T. putrescentiae*, a similar species to *N. agrestis* in terms of feeding habits and morphology. In addition, the immature developmental periods of *N. agrestis* found in this study were also longer than those reported for *N. cucumeris* females fed on *C. lactis* (Ji *et al.* 2015). Furthermore, much shorter immature developmental times were also reported for *Neoseiulus longispinosus* (Evans) (Rahman *et al.* 2013). These results clearly show that immature developmental periods of phytoseiid mites vary depending on predator species and their prey. Similar to the immature developmental times pre-oviposition, oviposition and total fecundity of *N. agrestis* adult females are also influenced by the temperature. Our results are also generally in line with those reported for *Neoseiulus neoagrestis* Khaustov & Döker by Moradi *et al.* (2023) and also for *Neoseiulus californicus* (McGregor) fed on *Tetranychus urticae* Koch by Gotoh *et al.* (2004). In contrast, the values for oviposition (21.69 days), longevity (45.31 days) and total fecundity (46.38 eggs/female) of *N. agrestis* found in this study at 25 °C are much higher than those reported by Zhang *et al.* (2003) and Zhang (2021) for *A. herbicolus* fed on *C. lactis* at the same temperature. The authors reported oviposition (13.40 days), longevity (19.08 days) and total fecundity (21.6 eggs/female) for *A. herbicolus*. In addition, values found in the present study are also higher than those reported by Rahman *et al.* (2013) for *N. longispinosus* fed on *Oligonychus coffeae* (Nietner), except OP which is lower in *N. agrestis*. On the contrary, much higher values of oviposition are reported for *N. cucumeris* fed on *C. lactis* at the same temperature (Ji *et al.* 2015).

The intrinsic rate of increase (r_m), finite rate of increase (λ), reproductive rate (R_0) and gross reproductive rate (GRR) in the present study were higher than those in *N. neoagrestis* reported by Moradi *et al.* (2023) at all temperatures tested. In contrast, generation time (T), except at 30 °C and doubling time (DT) observed in the current study are lower than those reported by Moradi *et al.* (2023). Although slightly higher intrinsic rate of increase (r_m) and finite rate of increase (λ) values are reported for *N. californicus* fed on *T. urticae* (red form), the net reproductive rate found in this study are higher than those reported for *N. californicus* (Gotoh *et al.* 2004).

In conclusion, this study reports for the first time the life history of *N. agrestis*, a promising biological control agent. Our results show that temperature is one of the key factor that affect the life history parameters of *N. agrestis*. In addition, as better life table parameters and shorter immature developmental times are obtained at 30 °C, we suggest this temperature for the mass rearing of this predator on the prey *Thyreophagus* sp. Further studies should be conducted to determine life table parameters and biological control potential of *N. agrestis* against several pest species such as spider mites, thrips and whiteflies under laboratory and greenhouse conditions.

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ORCID

Yana V. Misharova  <https://orcid.org/0009-0003-1655-2619>
 Vladislav V. Snigirev  <https://orcid.org/0009-0008-7596-5938>
 Ismail Döker  <https://orcid.org/0000-0002-1412-1554>
 Omid Joharchi  <https://orcid.org/0000-0002-2741-4946>
 Vladimir A. Khaustov  <https://orcid.org/0000-0003-2831-7213>

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