

Temperature-dependent life table parameters of *Aphidius matricariae* (Hym.: Braconidae), an important parasitoid of the currant lettuce aphid, *Nasonovia ribisnigri* (Hem.: Aphididae)

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Abstract

The effects of temperature on demographic parameters of the aphid parasitoid, *Aphidius matricariae* (Haliday), on lettuce aphid, *Nasonovia ribisnigri* Mosely, were studied at five constant temperatures, 15, 20, 22, 25 and 27 ± 1°C, 65 ± 5% RH and a photoperiod of 16L: 8D h. The life table parameters were estimated using age-stage, two-sex life table procedure. Moreover, the bootstrap method was used for estimating variance, mean and standard error of the population growth parameters, at studied temperatures. All estimated parameters were considerably affected by temperature. Accordingly, nymphs of *N. ribisnigri* could not settle and survive on the leaves at 27°C. Thus, mummies were not formed. Developmental time of the parasitoid wasp decreased with increasing temperature from 21.21 days at 15°C to 11.19 days at 25°C. The oviposition periods were 15.21±0.12, 9.47±0.10, 5.91±0.05 and 5.6±0.09 days at the temperatures of 15, 20, 22 and 25°C. Similarly, average number of mummies was 249.74±12.6, 192.72±12.8, 105.15±6.2 and 102.3±7.0, at the mentioned temperatures, respectively. The highest intrinsic rate of increase (r) and finite rate of increase (λ) were estimated to be 0.251 and 1.285 (d⁻¹) at 20°C, respectively. However, there was no significant difference among the estimated values regarding intrinsic rate of increase and finite rate of increase at the temperatures of 20, 22 and 25°C. The highest value of net reproductive rate (R_0) was 123.06 (offspring/individual) at 15°C and the shortest mean generation time (T) was 13.98 (day) at 25°C. According to the obtained results, the temperatures 20-25°C, can be considered as optimal temperature range for the biological control of the currant lettuce aphid by using *A. matricariae*.

Keywords: *Aphidius matricariae*, *Nasonovia ribisnigri*, demography, temperature

تأثیر دما روی پراسنجه‌های جدول زندگی *Aphidius matricariae* (Hym.: Braconidae) پارازیتوئید مهم شته کاهو، *Nasonovia ribisnigri* (Hem.: Aphididae)

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چکیده

تأثیر دما روی پراسنجه‌های جدول زیستی پارازیتوئید *Aphidius matricariae* Haliday روی شته کاهو *Nasonovia ribisnigri* Mosely در ۵ دمای ۱۵، ۲۰، ۲۲، ۲۵ و ۲۷±۱ درجه سلسیوس، رطوبت نسبی ۶۵±۵ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی بررسی شد. پراسنجه‌های جدول زیستی بر اساس روش جدول زندگی سن-مرحله رشدی، دو جنسی برآورد شدند. علاوه بر این، به‌منظور برآورد واریانس، میانگین و خطای معیار پراسنجه‌های جمعیت از روش بوت استرپ استفاده شد. تمام پراسنجه‌های برآورد شده به مقدار قابل ملاحظه‌ای تحت تأثیر دما قرار گرفتند. در دمای ۲۷ درجه سلسیوس، پوره‌های *N. ribisnigri* نتوانستند بر روی برگ‌ها مستقر شوند و بقا داشته باشند. بنابراین هیچ‌گونه مومیایی تشکیل نشد. افزایش دما سبب کاهش طول دوره رشدی پیش از بلوغ پارازیتوئید از ۲۱/۲۱ روز (۱۵ درجه سلسیوس) به ۱۱/۱۹ روز (۲۵ درجه سلسیوس) شد. طول دوره تخم‌ریزی به ترتیب در دماهای ۱۵، ۲۰، ۲۲ و ۲۵ درجه سلسیوس

۱۵/۲۱±۰/۱۲، ۹/۴۷±۰/۱۰، ۵/۹۱±۰/۰۵ و ۵/۶±۰/۰۹ روز بود. به طور مشابه، در دماهای ذکر شده، تعداد مومیایی‌ها به طور میانگین ۲۴۹/۷۴±۱۲/۶، ۱۹۲/۷۲±۱۲/۸، ۱۰۵/۱۵±۶/۲ و ۱۰۲/۳±۷/۰ شمارش شدند. بیشترین نرخ ذاتی افزایش جمعیت (r) و بیشترین نرخ متناهی افزایش جمعیت (λ) به ترتیب ۰/۲۵۱ و ۱/۲۸۵ (روز^{-۱}) در دمای ۲۰ درجه سلسیوس به دست آمد. اگرچه در میزان پراسنجه‌های نرخ ذاتی افزایش جمعیت و نرخ متناهی افزایش جمعیت دماهای ۲۰، ۲۲ و ۲۵ درجه سلسیوس، اختلاف معنی‌داری مشاهده نشد. همچنین بیشترین نرخ خالص تولیدمثل (R₀) ۱۲۳/۰۶ (نتاج/فرد) و کوتاه‌ترین طول دوره یک نسل جمعیت (T) (۱۳/۹۸ روز) به ترتیب در دماهای ۱۵ و ۲۵ درجه سلسیوس مشاهده شد. بر اساس نتایج بدست آمده، به نظر می‌رسد، دامنه دمایی ۲۰-۲۵ درجه سلسیوس به عنوان دمای مناسبی به منظور کنترل زیستی شته کاهو با استفاده از زنبور *A. matricariae* باشد.

واژگان کلیدی: *Nasonovia ribisnigri* *Aphidius matricariae* جمعیت‌نگاری، دما

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Introduction

Nasonovia ribisnigri (Mosely) (Aphididae) is a primary pest of the lettuce that has spread throughout Europe, Canada, Asia, the Middle East, North and South America (Blackman & Eastop, 2000) and recently invaded the New Zealand (Stufkens & Teulon, 2003; Fagan *et al.*, 2009) and Australia (Diaz & Fereres, 2005). This pest was reported on *Crepis* sp. (Asteraceae) in the Alborz Mountains of Iran in 1994 (Rezvani, 2001) and for the first time on romaine lettuce fields in Ahwaz, south of Khuzestan province, in 2008 (Bagheri *et al.*, 2008).

Nasonovia ribisnigri colonizes the innermost leaves of the lettuce plants that cannot be treated easily with insecticides resulted in the serious contamination problem, for the simple reason that lettuces with high population of aphids are unsaleable (MacKenzie & Vernon, 1988; Liu, 2004).

The main problem with lettuce aphid is its capacity to act as a vector for viruses including Gooseberry vein banding virus, Cauliflower mosaic virus, Cucumber virus, and Lettuce mosaic virus (Davis *et al.*, 1997). Mackenzie (1986) and afterwards Morales *et al.* (2013) have reported that the economic threshold of the lettuce aphid in the fields was 0.5 and 0.07 aphids per plant, respectively. These results show that to avoid critical and heavy damage, insecticide sprays are needed when a very low aphid density is seen in lettuce seedlings soon after transplant. Although, the widespread use of insecticides to control this pest resulted in a serious resistance problem (Palumbo, 2000; Kift *et al.*, 2004). For this reason, biological control has been increasingly considered in the field and greenhouse crops. In California, this invasive aphid has been recognized as a suitable host for a number of indigenous natural enemies (Bugg *et al.*, 2008). Parasitoids and predators along with fungal entomopathogens are potential biocontrol agents against lettuce aphids (Nebreda *et al.*, 2005; Diaz *et al.*, 2007; Smith & Chaney, 2007; Fagan *et al.*, 2010; Shrestha & Enkegaard, 2013; Shrestha *et al.*, 2013; Shrestha *et al.*, 2014).

Especially aphid parasitoids are presently considered as the most effective and reliable biocontrol agents, because of their high population growth rates and ability to react as density-dependent factors (Nebreda *et al.*, 2005). Regarding the parasitoids of the lettuce aphid, *Aphidius hieraciorum* (Stray) (Hymenoptera: Braconidae) has recently been described as a promising candidate against *N. ribisnigri* in the United Kingdom and Spain. However, this species is still not commercially available (Nebreda *et al.*, 2005).

Little documentation exists on the efficacy of aphid parasitoids to control of *N. ribisnigri* in Iran. Based on the survey conducted on the lettuce aphid parasitoids in Khuzestan, Iran, *N. ribisnigri* individuals were found to be parasitized by two braconid wasp species: *Aphidius matricariae* (Haliday) and *Praon volucre* (Haliday). Among them, *A. matricariae* was the important parasitoid of aphid occurred in the greatest numbers (94%) in association with *N. ribisnigri* (Farsi *et al.*, 2014). *A. matricariae* is a broadly oligophagous parasitoid found on the various species of aphids all over the world (Stary, 1988). It is produced commercially in the United Kingdom and elsewhere in Europe for the biological

control of aphids in protected cropping systems. This led to the further attention to consider their potential role in the current lettuce aphid biological control programs in Iran.

Having knowledge on both the population ecology of the target species and its natural enemies are necessary to achieve successful control strategies. Information on the life table is important in aiming to control a given pest species, as it gives the most comprehensive description on the growth, survival and fecundity concisely.

Several factors may influence on the rate of parasitism and subsequently on the development of parasitoids on their host aphids (Jervis & Copland, 1996). Temperature is a key abiotic factor regulating insect population dynamics, developmental rates, and seasonal occurrence (Goodman, 1982). Present study was designed to evaluate the population growth rate and life table parameters of *A. matricariae* based on an age-stage, two-sex life table at five constant temperatures that may be useful for developing biological control of the lettuce aphid in the fields and greenhouses.

Materials and methods

Insect cultures

The currant lettuce aphid *N. ribisnigri* and its parasitoid *A. matricariae* were collected from lettuce fields in Khuzestan province (Southwestern Iran) in March 2016. The insects were reared on lettuce seedlings (*Lactuca sativa* L. var *longifoli*) growing in netted hyaline cages (176×70×70 cm) at 25±2°C, 40-60% RH and a photoperiod of 16L: 8D h.

Biology and life table parameters

This study was conducted at five constant temperatures: 15, 20, 22, 25 and 27 ± 1°C, 65 ± 5% RH and a photoperiod of 16L: 8D h. Before initiating the experiment, the colony of aphid as host and its parasitoid were kept under the conditions as described above, for one generation.

An opaque cylindrical container (diameter: 7.5 cm; length: 18 cm) containing 4-5 leaf-stage lettuce seedlings kept in vial of water and infested with approximately 100 third instar nymphs of *N. ribisnigri* was used as rearing containers. Each container was covered with fine mesh net for ventilation. To have a cohort of the same age of parasitoid wasps (< 8 h), five male and five female adults (24-48 h old) of *A. matricariae* were released into each container and then removed after 24-h period. The aphids on lettuce were checked daily for the formation of mummies. Mummies were transferred into the plastic petri dishes (diameter: 6 cm; height: 1 cm) and observed daily for adult emergence. Adults were paired after emergence. Twenty-two pairs of *A. matricariae* were used in the life table study. Each pair was transferred to a lettuce seedlings container with 50 third instar nymphs of *N. ribisnigri*. The parasitoids were moved to a new container with the same number of aphids daily. It continued until the death of all parasitoids. Dead males were also steadily replaced with the treated males of the same age. Mummies from different days were recorded and kept separately until the emergence of the adult parasitoids. The date of all emerged offspring was recorded.

Statistical analysis

The data were analyzed based on the age stage, two-sex life table procedure (Chi & Liu, 1985; Chi, 1988). The adult pre-oviposition period (APOP) (the duration from adult emergence to first oviposition) and total pre-oviposition period (TPOP) (the duration from egg to first oviposition) were calculated. The age-stage specific survival rates (s_{xj}), the age specific survival rate (l_x), the age-stage specific fecundity (f_{xj}), the age-specific fecundity (m_x) and the population parameters (the intrinsic rate of increase (r), the net reproductive rate (R_0), the finite rate of increase (λ) and the mean generation time (T) were estimated, accordingly.

The intrinsic rate of increase (r) was estimated using the iterative bisection method and Euler-Lotka equation with age indexed from 0 (Goodman, 1982):

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

The finite rate of increase (λ), net reproductive rate (R_0) and mean generation time (T) were calculated as follows:

$$\lambda = e^r \quad (2)$$

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \quad (3)$$

$$T = \frac{\ln R_0}{r} \quad (4)$$

All the life table parameters were estimated by using TWSEX-MSChart software (Chi, 2013). The bootstrap (Efron and Tibshirani, 1993; Yu *et al.*, 2013) technique was used to estimate the mean, variance, and standard error of the population parameters. To generate less variable results, 10000 replications were used in this study. The paired bootstrap test, based on confidence interval (Akca *et al.*, 2015; Reddy and Chi, 2015) was used to compare the differences among developmental time, adult longevity, adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), oviposition period, and fecundity among treatments. The population parameters (r , λ , R_0 , and T) among treatments were also compared by using the paired bootstrap test (Reddy and Chi, 2015).

Results

Demographic parameters of the aphid parasitoid considerably affected by temperature. Nymphs of *N. ribisnigri* could not settle and survive on the leaves and their growth was incomplete. Accordingly, mummies were not formed at 27°C. Therefore biological characteristics of this parasitoid were recorded only at 15, 20, 22 and 25°C. From 100 eggs at the beginning of each experiment, 69, 66, 73 and 75 eggs hatched at 15, 20, 22 and 25°C, respectively. The total developmental time, from egg hatch to adult emergence decreased significantly with increasing the temperature, with the longest period recorded at 15°C and the shortest at 25°C (Table 1). Adult longevity was significantly longer at 15°C than that of adults reared at other temperatures (Table 2).

Table 1. Mean (\pm SE) developmental time of *Aphidius matricariae* at four constant temperatures

| Developmental stage | Temperature (°C) | | | |
|---------------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|
| | 15 | 20 | 22 | 25 |
| Pre-pupa (day) | 13.74 \pm 0.33 ^a | 9.17 \pm 0.10 ^b | 7.62 \pm 0.09 ^c | 6.81 \pm 0.09 ^d |
| Pupa (day) | 7.32 \pm 0.24 ^a | 5.15 \pm 0.09 ^b | 4.84 \pm 0.10 ^{bc} | 4.39 \pm 0.07 ^c |
| Pre-adult (day) | 21.21 \pm 0.44 ^a | 14.4 \pm 0.11 ^b | 12.45 \pm 0.13 ^c | 11.19 \pm 0.13 ^d |

Means followed by different letters within each row are significantly different according to the paired bootstrap test at 95% confidence interval. The SEs were estimated by 10000 bootstraps.

Table 2. Mean (\pm SE) adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), oviposition period, adult longevity and fecundity of *Aphidius matricariae* at four constant temperatures.

| Biological index | Temperature (°C) | | | |
|------------------------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|
| | 15 | 20 | 22 | 25 |
| Female adult longevity (day) | 37.32 \pm 0.96 ^a | 25.14 \pm 0.66 ^b | 19.64 \pm 0.38 ^c | 17.75 \pm 0.43 ^c |
| Male adult longevity (day) | 39.42 \pm 1.95 ^a | 26.37 \pm 0.98 ^b | 19.1 \pm 0.33 ^c | 17.59 \pm 0.26 ^c |
| APOP (day) ^a | 1.26 \pm 0.07 ^a | 1.11 \pm 0.05 ^a | 1.09 \pm 0.05 ^a | 1.10 \pm 0.06 ^a |
| TPOP (day) ^b | 20.91 \pm 0.54 ^a | 14.44 \pm 0.15 ^b | 12.67 \pm 0.17 ^c | 11.15 \pm 0.16 ^d |
| Oviposition days (day) | 15.21 \pm 0.12 ^a | 9.47 \pm 0.1 ^b | 5.91 \pm 0.05 ^c | 5.6 \pm 0.09 ^c |
| Fecundity (eggs/female) | 249.74 \pm 12.62 ^a | 192.72 \pm 12.81 ^b | 105.15 \pm 6.2 ^c | 102.3 \pm 7.02 ^c |
| Maximum daily fecundity | 47 | 45 | 50 | 44 |

Means followed by different letters within each row are significantly different according to the paired bootstrap test at 95% confidence interval. The SEs were estimated by 10000 bootstraps.

^a APOP: Adult pre-oviposition period.

^b TPOP: Total pre-oviposition period.

Except for the adult pre-oviposition period (APOP), total pre-oviposition period (TPOP), oviposition period and fecundity decreased significantly with increasing the temperature. Parasitoids began oviposition at the age of 20.91 d (TPOP) at 15°C. However, oviposition started at age of 11.15 d at 25°C which was the shortest in comparison with the other examined temperatures (Table 2). The oviposition period of *A. matricariae* was not significantly different between the temperatures of 22 and 25°C. The longest oviposition

period (15.21 day) was recorded at 15°C (Table 2). The highest mean fecundity was 249.74 eggs/female at 15°C and the lowest was 102.3 eggs/female at 25°C. There was no significant difference between fecundity values at temperatures of 22 and 25°C (Table 2).

The age-stage specific survival rate (s_{xj}) curve of *A. matricariae* indicates the probability of a newborn larva surviving to age x and stage j (Fig. 1). Due to the variation in the developmental rates among individuals, there are overlaps in the stage survival rate. The probability that a newly laid egg will develop to the adult stage increases with increasing temperature between 15 and 20°C and then decreases at 22 and 25°C. Both females and males at 15°C survived longer than those at other temperatures (Fig. 1).

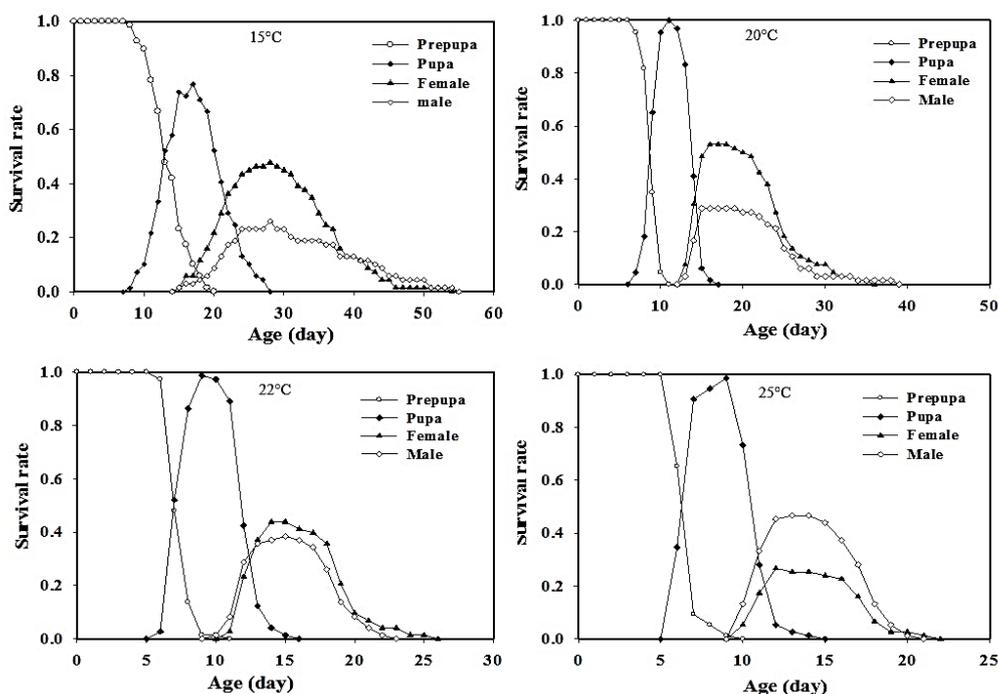


Fig. 1. Age-stage survival rate (s_{xj}) of *Aphidius matricariae* at four constant temperatures

The number of offspring produced by an individual of *A. matricariae* in age x and stage j is shown in figure 2. Moreover, age-specific survival rate (l_x), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) show periodic peaks in reproduction (Fig. 2). Based on the estimated data for these curves, the age-specific survival rate (l_x) decreased with increase in temperature between 15 and 25°C. The highest peak for age-stage specific fecundity ($f_{x,3}$) and age specific maternity ($l_x m_x$) were recorded at 20°C and the age-specific fecundity (m_x) was highest at 22 °C (Fig. 2).

The negative effect of a decrease in temperature on reproduction in *A. matricariae* can be observed in the age-specific reproductive curve (v_{xj}). The maximum reproductive peak of the females reared at 15°C ($v_{20} = 107/22$) occurred much later than that of females reared at other temperatures (Fig. 3). In contrast, at 25°C, reproductive value reached a peak of 74.58 at age the age of 10 d, earlier than other temperatures. The highest reproductive value at the temperatures of 20 and 22°C was occurred at age of 13 and 11 d, respectively (Fig. 3).

The age-stage life expectancy (e_{xj}) of *A. matricariae* at all examined temperatures are presented in figure 4. Based on the results, the age-stage specific life expectancy (e_{xj}) of a newborn (e_{01}) is exactly the same, as the mean longevity. Life expectancy decreased gradually with age. Accordingly, the maximum life expectancy of all stages of *A. matricariae* was recorded at 15°C (Fig. 4).

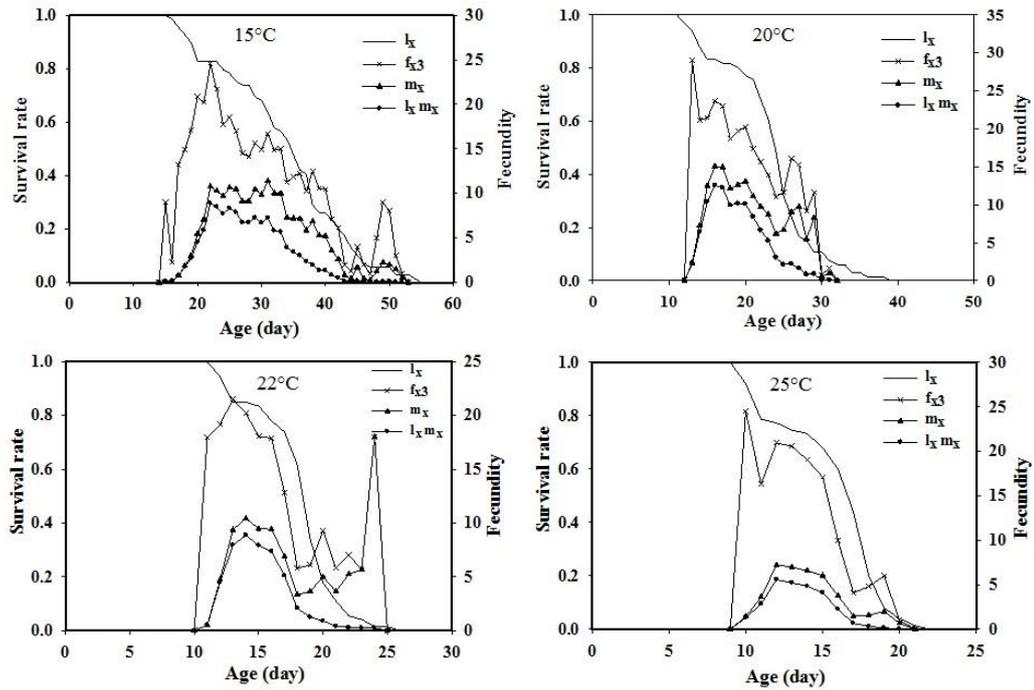


Fig. 2. Age-specific survival rates (l_x), female age-specific fecundity (f_{x3}), adult age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) of *Aphidius matricariae* at four constant temperatures

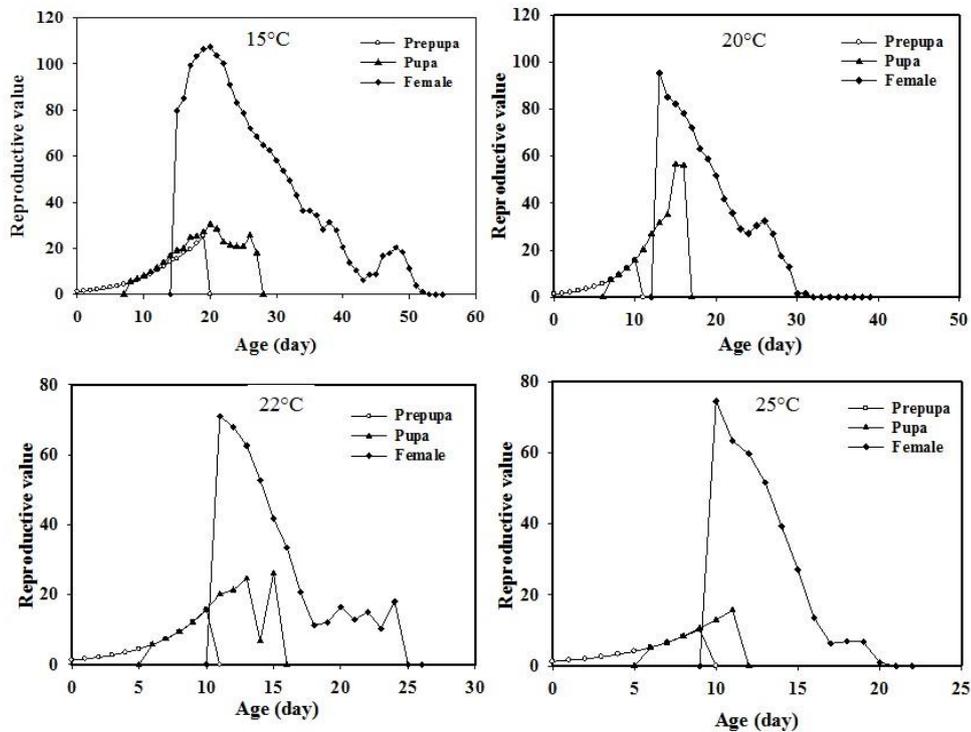


Fig. 3. Age-stage-specific reproductive value (v_{ij}) of *Aphidius matricariae* at four constant temperatures

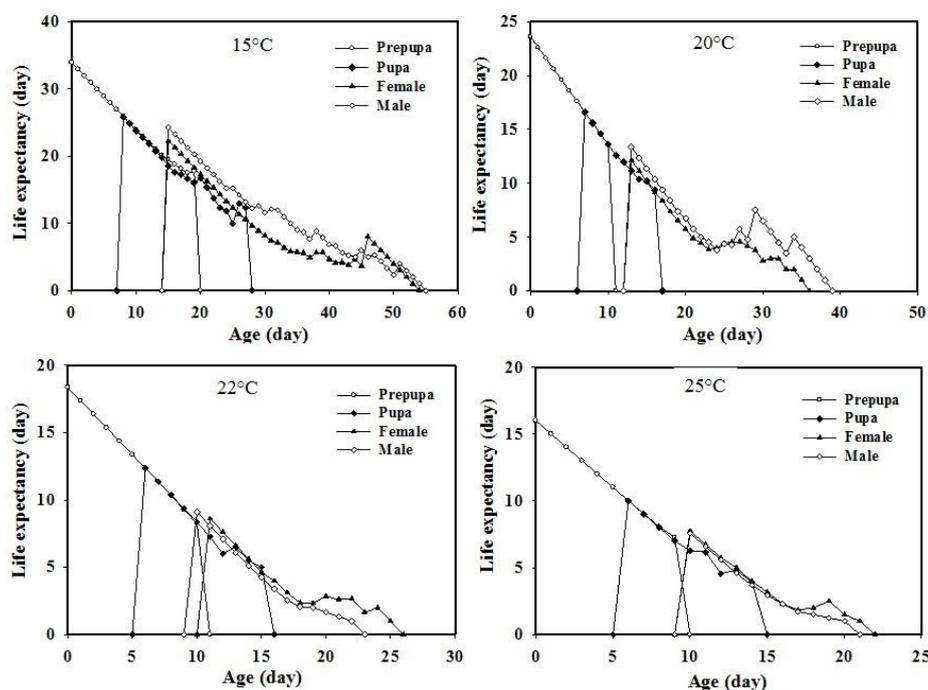


Fig. 4. Age-stage-specific life expectancy (e_{xj}) of *Aphidius matricariae* at four constant temperatures

The intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0) and mean generation time (T) are presented in table 3. Temperature had a significant effect on intrinsic rate of increase (r). The lowest and highest r value was estimated to be 0.1831 and 0.2507 d^{-1} at 15 and 20 °C, respectively. However, there was a reduction in the value of this parameter at 22 (0.2491 d^{-1}) and 25 °C (0.2363 d^{-1}) (Table 3).

The estimated values of finite rate of increase (λ) of *A. matricariae* indicated the same trend as intrinsic rate of increase, among the examined temperatures. The finite rate of increase was greatest at 20°C. Although, there was no significant difference in the intrinsic rate of increase (r) and finite rate of increase (λ) between 20, 22 and 25°C. The mean generation time (T) decreased with increasing temperatures, reached the lowest value at 25°C. The net reproductive rate (R_0) of *A. matricariae* decreased with increasing temperature from 15 to 25°C. The highest net reproductive rate (R_0) was 123.05 offspring/individual at 15°C and the lowest was 27.28 offspring/individual at 25°C (Table 3).

Table 3. Comparison of estimated life table parameters of *Aphidius matricariae* at four constant temperatures

| Temperature (°C) | Life table parameters (Mean \pm SE) | | | |
|---------------------|---------------------------------------|----------------------------------|---------------------------------|-------------------------------|
| | r (day^{-1}) | λ (day^{-1}) | R_0 (offspring/individual) | T (day) |
| 15 | 0.1831 \pm 0.0062 ^b | 1.2010 \pm 0.0075 ^b | 123.05 \pm 16.33 ^a | 26.27 \pm 0.59 ^a |
| 20 | 0.2507 \pm 0.0073 ^a | 1.2849 \pm 0.0094 ^a | 105.12 \pm 13.66 ^a | 18.56 \pm 0.25 ^b |
| 22 | 0.2491 \pm 0.0095 ^a | 1.2829 \pm 0.0122 ^a | 47.53 \pm 6.78 ^b | 15.49 \pm 0.21 ^c |
| 25 | 0.2363 \pm 0.0154 ^a | 1.2666 \pm 0.0195 ^a | 27.28 \pm 5.57 ^b | 13.98 \pm 0.20 ^d |

Means followed by different letters within each column are significantly different according to the paired bootstrap test at 95% confidence interval. The SEs were estimated by 10000 bootstraps.

Abbreviations: r : Intrinsic rate of increase, λ : Finite rate of increase, R_0 : Net reproductive rate, T : Generation time.

Discussion

Although insects are not subjected to constant or alternating temperatures in nature, controlled laboratory studies can provide a valuable insight into the population dynamics of pests and their natural enemies. One of the main factors influencing the biology, ecology and dynamics of pests and their natural enemies, is temperature (Jervis & Copland, 1996). The

present study demonstrated significant difference in the performance of *A. matricariae*, the parasitoid of lettuce aphid at five constant temperatures. There is no reliable information on the full range of temperatures being suitable for the development and survival of *A. matricariae* on lettuce aphid, *N. ribisnigri*, in Iran.

Our results showed that *A. matricariae* could not develop from egg to adult stage at 27°C, because nymphs of *N. ribisnigri* could not settle and survive on the lettuce. In the current study, we found that an increase in temperature led to a reduction in the developmental time of *A. matricariae*. Zamani *et al.* (2007) reported that *A. matricariae* could not grow successfully on *Aphis gossypii* Glover and *Myzus persicae* Sulzer at 5 and 35°C from egg to adult. The survival rate of pupa stage was greatest at 25°C and least at 30°C. Moreover, according to the results, TPOP, oviposition periods, fecundity and total longevity of *A. matricariae* dramatically declined as temperature increased from 15 to 25°C. The females were most fecund at 15°C (249.7 eggs).

Fisher (1930) defines the reproductive value as the contribution of an individual to the future population. Earlier occurrence of the maximum reproduction value at 25°C compared to the lower studied temperatures, confirmed that increasing temperature lead to more population increase in high temperatures. Because life expectancy value is calculated using the age-stage survival rate (s_{xj}), which does not assume the population reaches a stable age-stage distribution, it can be used to predict the survival of a population (Chi & Su, 2006). By using life expectancy, we can predict that both males and females of *A. matricariae* can be expected to live for more than 1 months and 3 weeks at 15 and 25°C, respectively. However, this value could be different under field conditions where both biotic and abiotic factors vary. Tahriri Adabi *et al.* (2010) have reported that the life expectancy of *A. matricariae* decrease with increasing temperature which it can survive 12 days at 25°C.

The Life table is a useful tool for evaluating the effectiveness of natural enemies for controlling pests under various climatic conditions in different habitats (Jervis & Copland, 1996). Among life table parameters (R_0 , r , λ , T), the r parameter is especially valuable because it integrates mortality and fertility into a single value.

The maximum intrinsic rate of increase for *A. matricariae* was recorded at 20°C which is considerably higher than that estimated by Reed *et al.* (1992) (0.092) and Shijko (1989) (0.1550) at the same temperature. Shahrokhi *et al.* (2004) and Tahriri Adabi *et al.* (2010) reported the intrinsic rate of increase of *A. matricariae* on *Schizaphis graminum* and *A. fabae* to be 0.24 and 0.41 at 25°C, respectively. One of the major features of latter studies is that the parameters were estimated according to the traditional female age specific theory, which does not consider the role of males in population projection and therefore, may lead to a biased estimation of life-history parameters. However, the mentioned results also were affected by different host species.

According to our results, there was no significant difference between intrinsic rate of increase and finite rate of increase at 20, 22 and 25°C. Based on our results, the moderate temperatures (i.e., 20, 22 and 25°C) were favorable as external factor for *A. matricariae* to has greater survival, longevity and higher reproductive capacity compared with the lower and higher temperatures (i.e., 15 and 27°C). Our results are similar to Pourtaghi *et al.* (2016) who concluded that at 30°C, the intrinsic rate of increase, net reproductive rate, finite rate of increase, mean generation time of *A. matricariae* with *A. fabae*, as host, were all significantly lower compared to the lower temperatures. They reported that the best temperature was at 20-25°C. van Schelt *et al.* (2011) also suggested that the number of mummies produced per female of *A. matricariae* on *M. persicae* ssp. *Nicotianae*, was the highest at 20 and then 25°C and it produced only a few mummies with a delayed development and high mortality, at 30°C. According to Zamani *et al.* (2007), the optimal temperature for population growth of *A. matricariae* on *A. gossypii* and *M. persicae* was 25°C. These results showed that this parasitoid cannot undergo very high temperatures during the hot summer months in the greenhouses. Giri *et al.* (1982) tested an introduced American strain of *A. matricariae* on *M. persicae*. They found an optimum for most parameters at 21°C and a rapid decline above 24°C.

One of the most outstanding features of our study in compression to other similar ones is that in the current study, the variance and standard error of life table parameters have been

undertaken both by the bootstrap method (with 10000 repeats). Huang & Chi (2012) have reported that the bootstrap technique is more reliable than the jackknife technique for estimating variances. The variances obtained with the jackknife technique are usually much larger than those were obtained with the bootstrap technique. As a results of frequency data that were estimated by jackknife method, failed in normality test (Ebrahimi *et al.*, 2013).

According to the obtained results here, *A. matricariae* can be considered as a favorable and proper natural enemy for the biocontrol of *N. ribisnigri* at a temperature range of 20-25°C. On the other hand, considering that the current study was the first attempt for evaluation of *A. matricariae* as biological agents of *N. ribisnigri*, more information is necessary to fully understand the other ecological aspects of this species. Thus, more researches should be designed for studying the effect of host plants and other environmental factors on development and efficacy of *A. matricariae*. By understanding these factors, we would able to develop suitable strategies for the biological control of lettuce aphid.

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References

- Akca, I., Ayvaz, T., Yazici, E., Smith, C. L. & Chi, H.** (2015) Demography and population projection of *Aphis fabae* (Hemiptera: Aphididae): with additional comments on life table research criteria. *Journal of Economic Entomology* 108, 1466-1478.
- Bagheri, S., Tavosi, M. & Dehghani, A.** (2008) Introduction of *Nasonovia ribisnigri* (Mosely) (Hom.: Aphididae) as the most important lettuce aphid in south of Khuzestan province and study on the effect of cultivation date and lettuce cultivars on its population. *Proceedings of 18th Iranian Plant Protection Congress*, Hamedan, Iran, 79-80.
- Blackman, R. L. & Eastop, V. F.** (2000) *Aphids on the World crops: An Identification and Information Guide*. 2nd ed. 476 pp. Wiley, Ltd., Chichester, United Kingdom.
- Bugg, R. L., Colfer, R. G., Chaney, W. E., Smith, H. A. & Cannon, J.** (2008) Flower flies (Syrphidae) and other biological control agents for aphids in vegetable crops. *University of California Division of Agriculture and Natural Resources* 8285, 1-25.
- Chi, H.** (1988) Life-table analysis incorporation both sexes and variable development rate among individual. *Environmental Entomology* 17(1), 26-34.
- Chi H.** (2013) TWSEX-MSChart: A computer program for the age-stage, two-sex life table analysis. Available from: <http://140.120.197.173/Ecology/Download/TwosexMSChart.rar>.
- Chi, H. & Liu, H.** (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology, Academia Sinica* 24, 224-240.
- Chi, H. & Su, H. Y.** (2006) Age-stage, two-sex life tables of *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae) and its host *Myzus persicae* (Sulzer) (Homoptera: Aphididae) with mathematical proof of the relationship between female fecundity and the net reproductive rate. *Environmental Entomology* 35, 10-21.
- Diaz, B. M. & Fereres, A.** (2005) Life table and population parameters of *Nasonovia ribisnigri* (Homoptera: Aphididae) at different constant temperatures. *Environmental Entomology* 34(3), 527-534.
- Diaz, B. M., Muniz, M., Barrios, L. & Fereres, A.** (2007) Temperature thresholds and thermal requirements for development of *Nasonovia ribisnigri* (Homoptera: Aphididae). *Environmental Entomology* 36(4), 681-688.
- Davis, R. M., Subbarao, K. V., Raid, R. N. & Kurtz, E. A.** (1997) *Compendium of lettuce diseases*. 240 pp. APS Press, St. Paul, MN.
- Ebrahimi M, Sahragard A, Talaei-Hassanloui R, Kavousi A. & Chi, H.** (2013) The Life Table and parasitism rate of *Diadegma insulare* (Hymenoptera: Ichneumonidae) reared on larvae of *Plutella xylostella* (Lepidoptera: Plutellidae), with special reference to the variable sex ratio of the offspring and comparison of Jackknife and Bootstrap Techniques. *Annals of the Entomological Society of America* 106, 280-287.

- Erfon, B. & Tibshirani, R. J.** (1993) *An introduction to the bootstrap*. 444 pp. Chapman and Hall, New York.
- Fagan, L. L., McLachlan, A. C., Till, M. & Walker, M. K.** (2010) Synergy between chemical and biological control in the IPM of currant-lettuce aphid (*Nasonovia ribisnigri*) in Canterbury, New Zealand. *Bulletin of Entomological Research* 100, 217-223.
- Farsi, A., Kocheili, F., Mossadegh, M. S., Rasekh, A. & Tavoosi, M.** (2014) Natural enemies of the currant lettuce aphid, *Nasonovia ribisnigri* (Mosely) (Hemiptera: Aphididae) and their population fluctuations in Ahwaz, Iran. *Journal of Crop Protection* 3(4), 487-497.
- Fisher, R. A.** (1930) *The genetical theory of natural selection*. 2nd ed. 287 pp. Dover, New York.
- Giri, M. K., Pass, B. C., Yeargan, K. V. & Parr, J. C.** (1982) Behavior, net reproduction, longevity, and mummy-stage survival of *Aphidius matricariae* (Hym.: Aphidiidae). *Entomophaga* 27, 147-153.
- Goodman, D.** (1982) Optimal life histories, optimal notation and the value of reproductive value. *The American Naturalist* 119, 803-823.
- Huang, Y. B. & Chi, H.** (2012) Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. *Journal of Applied Entomology* 64 (1), 1-9.
- Jervis, M. A. & Copland, M. J. W.** (1996) The life cycle. pp. 63-161 in Jervis, M. A. & Kidd, N. A. C. (Eds) *Insect natural enemies: Practical approaches to their study and evaluation*. Chapman & Hall, London.
- Kift, N. B., Mead, A., Reynolds, K., Sime, S., Barber, M. D., Denholm, I. & Tatchell, G. M.** (2004) The impact of insecticide resistance in the currant-lettuce aphid, *Nasonovia ribisnigri*, on pest management in lettuce. *Agricultural and Forest Entomology* 6, 295-309.
- Liu, Y. B.** (2004) Distribution and population development of *Nasonovia ribisnigri* (Homoptera: Aphididae) in iceberg lettuce. *Journal of Economic Entomology* 97(3), 883-890.
- MacKenzie, J. R.** (1986) Improved insect pest management of crisp head lettuce grown in S. W. British Columbia. MSc Thesis, Simon Fraser University, 150 pp.
- MacKenzie, J. R. & Vernon, R. S.** (1988) Sampling for distribution of the lettuce aphid, *Nasonovia ribisnigri* (Homoptera: Aphididae), in fields and within heads. *Journal of the Entomological Society of British Columbia* 85, 10-14.
- Morales, I., Diaz, B. M., Mendoza, A. H. D., Nebreda, M. & Fereres, A.** (2013) The development of an economic threshold for *Nasonovia ribisnigri* (Hemiptera: Aphididae) on lettuce in central Spain. *Journal of Economic Entomology* 106(2), 891-898.
- Nebreda, M., Michelena, J. M. & Fereres, A.** (2005) Seasonal abundance of aphid species on lettuce crops in central Spain and identification of their main parasitoids. *Journal of Plant Diseases and Protection* 112(4), 405-415.
- Palumbo, J. C.** (2000) Seasonal abundance and control of the lettuce aphid, *Nasonovia ribisnigri* on head lettuce in Arizona. Available from: <http://arizona.openrepository.com/arizona/handle/10150/220018>.
- Portaghi, E., Shirvani, A. & Rashki, M.** (2016) Effect of temperature on biological parameters of *Aphidius matricariae*, the *Aphis fabae* parasitoid. *Animal Biology* 66(3-4), 120-131.
- Reddy, G. V. P. & Chi, H.** (2015) Demographic comparison of sweet potato weevil reared on a major host, *Ipomoea batatas*, and an alternative host, *I. triloba*. *Scientific Reports* 5, 11871.
- Reed, H. C., Reed, D. K. & Elliot, N. C.** (1992) Comparative life table statistics of *Diaeretiella rapae* and *Aphidius matricariae* on the Russian wheat aphid. *Southwestern Entomologist* 17(5), 307-312.
- Rezvani, A.** (2001) *Identify key aphids in Iran*. 304 pp. Agriculture Research, Education and Extension Organization, Tehran, Iran.
- Shahrokhi, S., Shojai, M., Rezvani, A., Ostovan, H. & Abdollahi, G. A.** (2004) Investigation on biology and comparison of fertility life table parameters of *Aphidius*

- matricariae* Haliday on host aphid *Schizaphis graminum* (Rondani). *Proceeding of the 16th Iranian Plant Protection Congress*, University of Tabriz, Iran, 37-38.
- Shrestha, G. & Enkegaard, A.** (2013) The green lacewing, *Chrysoperla carnea*: Preference between lettuce aphids, *Nasonovia ribisnigri*, and western flower thrips, *Frankliniella occidentalis*. *Journal of Insect Science* 13, 85-94.
- Shrestha, G., Enkegaard, A. & Steenberg, T.** (2013) Susceptibility of *Nasonovia ribisnigri* developmental stages to *Beauveria bassiana* and the effect of infection on adult fecundity. *International Symposium Ecology of Aphidophaga*, Belgrade, Serbia, 79-80.
- Shrestha, G., Skovgard, H. & Enkegaard, A.** (2014) Parasitization of commercially available parasitoid species against the lettuce aphid, *Nasonovia ribisnigri* (Hemiptera: Aphididae). *Environmental Entomology* 43(6), 1535-1541.
- Shijko, E. S.** (1989) Rearing and applications of the peach aphid parasites, *Aphidius matricariae* Haliday (Hymenoptera, Aphidiidae). *Acta Entomologica Fennica* 53, 53-56.
- Smith, H. A. & Chaney, W. E.** (2007) A survey of syrphid predators of *Nasonovia ribisnigri* in organic lettuce on the central coast of California. *Journal of Economic Entomology* 100(1), 39-48.
- Stary, P., Sampaio, M. V. & Bueno, V. H. P.** (2007) Aphid parasitoids (Hymenoptera, Braconidae, Aphidiinae) and their associations related to biological control in Brazil. *Revista Brasileira de Entomologia* 51(1), 107-118.
- Stufkens, M. A. W. & Teulon, D. A. J.** (2003) Distribution, host range and flight pattern of the lettuce aphid in New Zealand. *New Zealand Plant Protection* 56, 27-32.
- Tahriri Adabi, S., Talebi, A. A., Fathipour, Y. & Zamani, A. A.** (2010) Life history and demographic parameters of *Aphis fabae* (Hemiptera: Aphididae) and its parasitoid, *Aphidius matricariae* (Hymenoptera: Aphidiidae) on four sugar beet cultivars. *Acta Entomologica Serbica* 15(1), 61-73.
- Zamani, A. A., Talebi, A. A., Fathipour, Y. & Baniameri, V.** (2007) Effect of temperature on life history of *Aphidius colemani* and *Aphidius matricariae* (Hymenoptera: Braconidae), two parasitoids of *Aphis gossypii* and *Myzus persicae* (Homoptera: Aphididae). *Environmental Entomology* 36(2), 263-271.
- Yu, J. Z., Chi, H. & Chen, B. H.** (2013) Comparison of the life tables and predation rate of *Harmonia dimidiata* (F.) (Coleoptera: Coccinellidae) fed on *Aphis gossypii* Glover (Hemiptera: Aphididae) at different temperatures. *Biological Control* 64, 1-9.
- van Schelt, J., Hoogerbrugge, H., Becker, N., Messelink, G. & Bolckmans, K.** (2011) Comparing *Aphidius colemani* and *Aphidius matricariae* on *Myzus persicae* ssp. *nicotianae* in sweet pepper. *Integrated control in protected crops, temperate climate* 68, 169-172.
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