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Estimating some demographic parameters of *Aphidius matricariae* Haliday (Hymenoptera: Braconidae), the parasitoid of the greenbug aphid, *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), at different temperatures

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Abstract

Some demographic parameters of the indigenous parasitoid, *Aphidius matricariae* Haliday (Hymenoptera: Braconidae) parasitizing the greenbug, *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), were estimated at 3 different temperatures (20, 25, and 30 ± 1 °C; 70 ± 5% RH; 16 L:8D). According to age-specific theory, the demographic parameters of the parasitoid were computed by related formulas. The results showed that duration of mummy's formation to adult emergence and oviposition to adult emergence were significantly prolonged at 30 °C. The high temperature (30 °C) markedly shortened the longevity and lifespan of the wasp. The lowest value of fecundity (6.35 ± 0.85) significantly occurred when the female wasps were exposed to 30 °C. The estimated values of r_m were remarkably high when the female wasps were exposed to 20 (0.320 ± 0.011) and 25 °C (0.310 ± 0.009). The lowest and highest values of the R_0 significantly occurred at 30 (6.167 ± 0.754) and 20 °C (55.306 ± 6.316). The λ , T , DT , and r_w values were noticeably decreased at high temperature, and there was non-significant difference between the two other temperatures. High temperature decreased the number of females produced per female per day (mx) and survival rate (lx) of the parasitoid wasp. The highest mx and lx happened at 20 and 25 °C, respectively. Therefore, the results showed that the parasitoid wasp was sensitive to the high temperature, as its low reproduction, survival, and short adult longevity were recorded. Considering the characteristics, the wasp appeared to be well-adapt with the temperatures below 30 °C. Understanding the optimal temperatures for the life history traits of *A. matricariae* could promote the performance of the parasitoid wasp in different climatic regions, and this might advance the mass production of the parasitoid applied in IPM program for successful biological control of *S. graminum*.

Keywords: *Aphidius matricariae*, Fecundity, Life table, Longevity, *Schizaphis graminum*, Temperature

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Background

The braconid wasps are important parasitoids in controlling aphids (Jones et al., 2003). Accordingly, one of the most efficient member of the family is a proovigenic and koinobiont parasitoid, *Aphidius matricariae* Haliday (Hymenoptera: Braconidae), which is used as a successful biological control agent to suppress several aphid pest populations (Boivin et al., 2012). Most studies have investigated the role of *A. matricariae* to control aphid pests in orchards and vegetables (Zamani et al., 2007 and Wick 2009). However, there are several evidences showing the performance of the parasitoid wasp as a biocontrol agent of cereal aphid species such as *Diuraphis noxia* (Mordvilko) (De Farias and Hopper, 1999) and *Schizaphis graminum* (Rondani) (Mustață and Mustață, 2009).

The greenbug, *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), is an important aphid pest of cereal crops that causes enormous losses via direct (e.g., sap suction, germination decrease, and other phytotoxic impacts) and indirect damage (virus transmission like barley yellow dwarf *luteovirus*) (Costa et al., 2010). Use of the indigenous parasitoid, *A. matricariae*, can be considered as an alternative and safe way to suppress the greenbug invasion instead of insecticide application. However, some abiotic variables affect the wasp ability in parasitizing the aphid hosts and its fitness (El-Heneidy et al., 2003). As insects are poikilotherms, temperature is a critical abiotic factor during their life cycle, and any thermal fluctuation can affect their biological properties such as their growth and reproduction (Wang et al., 2009).

Parasitism of *A. colemani* Viereck (Hymenoptera: Braconidae) to the bird cherry-oat aphid, *Rhopalosiphum padi* (L.), was tested at different temperatures, and it was found that 20 and 25 °C were the preferred thermal condition (Goh et al., 2001). Liu and Tsai (2002) exhibited that the maximum population growth of *Lysiphlebia mirzai* Shuja-Uddin, the braconid parasitoid of the brown citrus aphid, *Toxoptera citricida* (Kirkaldy), occurred at a temperature range of 15–25 °C. Likewise, parasitism rate and biological characteristics of the aphelinid parasitoid wasp, *Aphelinus asychis* Walker, were negatively influenced by the unfavorable high temperatures (Wang et al., 2016).

Some biological and life table parameters of the parasitoid, *Aphelinus varipes* (Forster), were investigated under a range of temperature (Yashima and Murai, 2013). The results manifested that the increased temperature had detrimental effects on the wasp developmental period, emergence rate, and sex ratio. Moreover, the intrinsic rate of increase (r_m) and net reproductive rate (R_0) values were higher at 25 than 20 °C (Yashima and Murai, 2013). In addition to the crucial effects of thermal changes on insects, it would be

worthwhile having knowledge on demographic parameters of insects like life table parameters (Maia et al., 2000).

Therefore, the aim of the present research was to determine the impacts of different temperatures on some life table parameters of the Iranian native population of *A. matricariae* when parasitizing the greenbug, *S. graminum* under laboratory conditions.

Materials and methods

Plant and insect sources

For rearing the greenbug, *S. graminum*, and conducting the experiments, a native wheat cultivar, named Alvand, was planted in pots (12-cm high and 15-cm diameters) under greenhouse conditions. The colony of the greenbug was initiated by adults collected from gramineous plants in Kerman (Kerman province, Iran) in a control environment chamber at 25 ± 1 °C, $70 \pm 5\%$ RH, and a photoperiod of 16 L:8D. The 3rd instar nymphs were used in all tests.

The indigenous parasitoid wasps, *A. matricariae*, were gained from the mummies of greenbug collected from gramineous plants in Kerman (Kerman province, Iran). After the wasp identification, the parasitoids were reared in a Plexiglas cage (50 × 50 × 60 cm), using *S. graminum* on potted wheat plants in the control environment chamber. The parasitoid wasps were provided by 60% honey solution. In the present study, 1-day-old mated female wasps from one generation were applied.

Effect of different temperatures on biological characteristics of *A. matricariae*

To test the effects of 3 different constant temperatures including 20, 25, and 30 °C on some demographic parameters of *A. matricariae*, an experimental unit was designed ($70 \pm 5\%$ RH, 16 L:8D). Hence, the cut wheat leaves were laid onto 2% water-agar in a Petri dish (9-cm diameter) with perforated lid. Then, the hole was covered with a piece of thin mesh (2-cm diameter), and after that, 30 3rd instar nymphs of the greenbug were placed in the experimental unit as well as a 1-day-old mated female of the parasitoid. Each treatment was repeated 20 times (20 replicates for each temperature). The developmental times including mummification to adult emergence and oviposition to adult emergence were recorded.

After adult emergences, each 1-day-old mated female wasp was daily provided by 30 new 3rd instar nymphs of the greenbug until death, and the nymphs were then kept for mummy formations. Subsequently, longevity, lifespan, fecundity, and life table parameters were calculated.

Table 1 Development time (mean \pm SE) of *Aphidius matricariae* parasitizing *Schizaphis graminum* at various temperatures

Temperature (°C)	Mummy formation to adult emergence (day)			Oviposition to adult emergence (day)		
	♀	♂	♂ + ♀	♀	♂	♂ + ♀
20	4.90 \pm 0.17 ^b	4.80 \pm 0.18 ^b	4.90 \pm 0.12 ^b	8.80 \pm 0.17 ^b	8.90 \pm 0.16 ^b	8.90 \pm 0.11 ^b
25	4.90 \pm 0.15 ^b	4.90 \pm 0.12 ^b	4.90 \pm 0.16 ^b	8.70 \pm 0.17 ^b	8.90 \pm 0.14 ^b	8.80 \pm 0.11 ^b
30	5.40 \pm 0.17 ^a	6.20 \pm 0.23 ^a	5.80 \pm 0.17 ^a	10.25 \pm 0.17 ^a	10.75 \pm 0.25 ^a	10.50 \pm 0.18 ^a

Means followed by different letter in the same column are significantly different (Tukey's test, $P < 0.05$)

Statistical analysis

In terms of the Carey (1993) (age-specific theory), the demographic parameters were computed by the following formulas:

$$R_0 = \sum l_x m_x \quad (1)$$

$$\sum l_x m_x e^{-rx} = 1 \quad (2)$$

$$DT = \ln(2)/r \quad (3)$$

$$\lambda = e^r \quad (4)$$

$$T = \frac{\ln(R_0)}{r} \quad (5)$$

$$r_w = (e^r)^7 \quad (6)$$

where the m_x and l_x are the numbers of females produced per female per day and survival rate of the parasitoid wasp, respectively; r_m and R_0 are the intrinsic rate of increase and net reproductive rate, respectively; r_w and λ are the increase rate in one week and finite rate of increase, respectively; and T and DT are mean generation and doubling times. The data were subjected to analysis of variance (ANOVA), and the averages were compared by Tukey's test at the 0.05 level. The Statistical Analysis System (SAS Institute, 1989) was applied for the calculations.

Results and discussion

The developmental time of the parasitoid wasp, *A. matricariae*, parasitizing the greenbug, *S. graminum*, including mummy formation to adult emergence and oviposition to adult emergence was calculated at different

temperatures. The results showed that there was non-significant difference between 20 and 25 °C (Table 1). However, duration of mummy formation until adult emergence ($F_{2, 119} = 18.57$, $P < 0.05$) and oviposition until adult emergence ($F_{2, 119} = 16.94$, $P < 0.05$) were significantly prolonged at 30 °C. There was non-significant difference between males and females in the above-mentioned biological properties.

The thermal alteration, as an abiotic factor, could affect the biological characteristics of the biocontrol agents as well as their insect hosts (Wang et al., 2014). Similarly, the present study revealed that the developmental time of *A. matricariae*, parasitizing the greenbug, *S. graminum*, was influenced by changing the temperature. Therefore, the high temperature (30 °C) prolonged the mummy formation to adult emergence and oviposition to adult emergence.

In contrast, the developmental time of the aphelinid endoparasitoid, *Aphelinus asychis* Walker, parasitizing the cotton aphid, *Aphis gossypii* Glover, decreased when the constant temperature was elevated from 15 to 32.5 °C (Schirmer et al., 2008 and Byeon et al., 2011) as well as the parasitoid *A. varipes* (Yashima and Murai 2013) and *A. matricariae* parasitizing *Nasonovia ribisnigri* (Mosely) (Farsi et al., 2019) and *R. padi* (El-Heneidy et al., 2003). The difference might be resulted from the difference between the parasitoid species and/or host aphids. In consistent with the obtained results, there were non-significant differences in total developmental time of *A. varipes* at 20 and 25 °C when parasitized 3rd nymphal instar of *A. gossypii* (Rohne 2002). Zamani et al. (2007) reported that *A. matricariae* had its maximum development at 25 °C, and the total developmental

Table 2 Influence of various temperatures on adult longevity, lifespan, and fecundity of *Aphidius matricariae* parasitizing *Schizaphis graminum*

Temperatures (°C)	Longevity (day)			Lifespan (day)			Fecundity
	♀	♂	♂ + ♀	♀	♂	♂ + ♀	
20	7.15 \pm 0.63 ^a	6.20 \pm 0.47 ^a	6.67 \pm 0.42 ^a	16.05 \pm 0.58 ^a	15.10 \pm 0.48 ^a	15.07 \pm 0.40 ^a	51.10 \pm 7.07 ^a
25	7.80 \pm 0.87 ^a	6.40 \pm 0.60 ^a	7.10 \pm 0.57 ^a	16.90 \pm 0.88 ^a	15.75 \pm 0.58 ^a	16.32 \pm 0.58 ^a	46.90 \pm 0.93 ^a
30	3.30 \pm 0.35 ^b	2.35 \pm 0.22 ^b	2.82 \pm 0.25 ^b	13.30 \pm 0.30 ^b	12.60 \pm 0.32 ^b	12.95 \pm 0.22 ^b	6.35 \pm 0.85 ^b

Means followed by different letter in the same column are significantly different (Tukey's test, $P < 0.05$)

Table 3 Life table parameters (mean \pm SE) of *Aphidius matricariae* parasitizing *Schizaphis graminum* at various temperatures

Parameters	Temperature ($^{\circ}$ C)		
	20	25	30
r_m ($\text{Q}/\text{Q}/\text{day}$)	0.320 \pm 0.011 ^a	0.310 \pm 0.009 ^a	0.160 \pm 0.014 ^b
R_0 ($\text{Q}/\text{Q}/\text{generation}$)	55.306 \pm 6.316 ^a	48.890 \pm 5.148 ^b	6.167 \pm 0.754 ^c
λ (day^{-1})	1.382 \pm 0.014 ^a	1.362 \pm 0.013 ^a	1.171 \pm 0.017 ^b
T (day)	14.530 \pm 0.306 ^a	15.655 \pm 0.172 ^a	10.780 \pm 0.160 ^b
DT (day)	2.155 \pm 0.067 ^a	2.235 \pm 0.069 ^a	4.281 \pm 0.342 ^b
r_w ($\text{Q}/\text{Q}/\text{week}$)	9.660 \pm 0.096 ^a	9.536 \pm 0.091 ^a	8.216 \pm 0.117 ^b

Means followed by different letter in the same row are significantly different (Tukey's test, $P < 0.05$)

r_m intrinsic rate of increase, R_0 net reproductive rate, λ finite rate of increase, T mean generation time, DT doubling time, r_w increase rate in 1 week

times of the parasitoid wasp parasitizing the aphid hosts including *A. gossypii* and *Myzus persicae* (Sulzer) were higher than that obtained in the present study.

In the present study, the high temperature (30 $^{\circ}$ C) decreased the lifespan of *A. matricariae*, due to higher metabolic rate (Brown et al., 2004). Moreover, there was non-significant difference between males and females of the parasitoid wasp in different developmental durations, which was in consistent with the outcome of Liu and Tsai (2002).

As shown in Table 2, the high temperature (30 $^{\circ}$ C) significantly affected the lifetime of *A. matricariae* adults parasitizing *S. graminum* by decreasing their longevity ($F_{2, 119} = 23.19$, $P < 0.05$) and lifespan ($F_{2, 119} = 22.85$, $P < 0.05$). In contrast, Bernal and Gonzalez (1997) reported non-significant differences between males and females at each temperature. Similar to the lifetime of the parasitoid, the fecundity did not differ at 20 and 25 $^{\circ}$ C. However, the lowest value of fecundity differently

occurred when the female wasps were exposed to 30 $^{\circ}$ C ($F_{2, 59} = 21.18$, $P < 0.05$).

In the present study, the longevity and lifespan of the wasps decreased at the high temperature. Similarly, Wang et al. (2016) demonstrated that the increased temperature decreased the longevity of *A. asychis* parasitizing *M. persicae*. As well, Schirmer et al. (2008) and Farsi et al. (2019) confirmed the same for *A. matricariae* parasitizing *N. ribisnigri*. Also, the adult longevity of the aphidiid, *Lysiphlebia mirzai* Shuja-Uddin, a parasitoid of *Toxoptera citricida* (Kirkaldy), was reduced by increasing the temperature (Liu and Tsai, 2002) similar to the longevity of *Diaeretiella rapae* (M'Intosh) attacking *D. noxia* (Bernal and Gonzalez, 1997).

Similarly, Wang et al. (2016) and Farsi et al. (2019) confirmed the obtained results that the high temperature had adverse effect on the fecundity of *A. matricariae*. Accordingly, the females had short longevities at high temperatures. However, there were non-significant differences between 20 and 25 $^{\circ}$ C in longevity and fecundity of *A. matricariae* which is in accordance with the results of Yashima and Murai (2013). Besides, Liu and Tsai (2002) reported that the female wasps of *L. mirzai* were able to lay high and low eggs at 25 and 32 $^{\circ}$ C, respectively. However, Rohne (2002) explained that different constant temperatures had no considerable effect on the mummies produced by the female parasitoid, *A. varipes* as well as the fecundity of *D. rapae* parasitizing *D. noxia* (Bernal and Gonzalez, 1997).

All life table parameters of *A. matricariae* parasitizing the greenbug, *S. graminum*, were affected by the tested temperatures (Table 3). The intrinsic rate of increase (r_m) values had significant difference at 30 $^{\circ}$ C among the 3 tested temperatures, and the high temperature resulted in decreasing the parameter ($F_{2, 62} = 62.80$, $P < 0.05$).

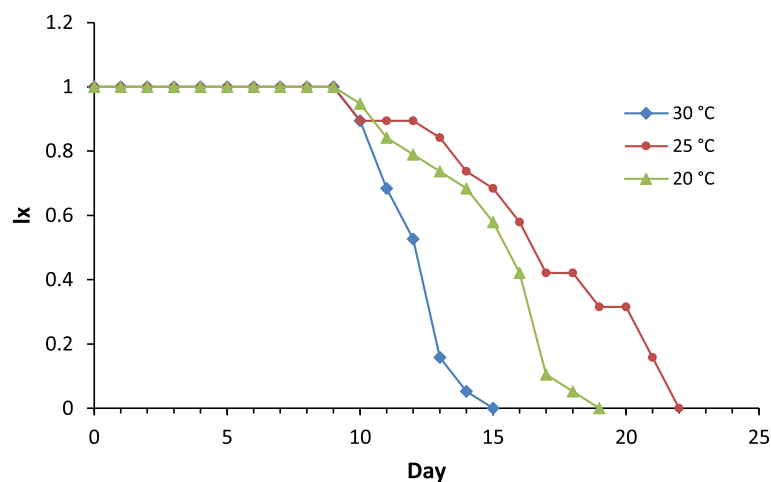


Fig. 1 Survival rate (l_x) of *Aphidius matricariae* parasitizing *Schizaphis graminum* at various temperatures

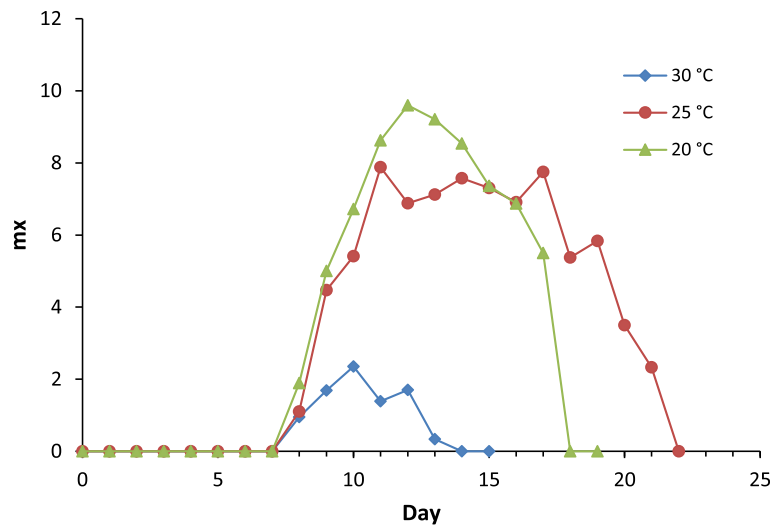


Fig. 2 Number of females produced/female/day (mx) by *Aphidius matricariae* parasitizing *Schizaphis graminum* at various temperatures

The estimated values of r_m were remarkably higher, when the female wasps of *A. matricariae* were exposed to 20 and 25 °C. Also, a significant difference was observed in the net reproductive rate (R_0) value ($F_{2, 54} = 33.72$, $P < 0.05$) among the treatments (Table 3). The lowest and highest values of the R_0 were significantly occurred at 30 and 20 °C.

In addition, other life table parameters of *A. matricariae* including finite rate of increase (λ) ($F_{2, 62} = 64.24$, $P < 0.05$), mean generation time (T) ($F_{2, 62} = 15.43$, $P < 0.05$), doubling time (DT) ($F_{2, 62} = 34.45$, $P < 0.05$), and increase rate in 1 week (r_w) ($F_{2, 62} = 61.43$, $P < 0.05$) were affected by different temperatures. The results elucidated that the λ , T , DT , and r_w values noticeably decreased at the high temperature (30 °C), and there was non-significant difference between the 2 other temperatures (20 and 25 °C).

Results of the present study demonstrated that all the life table parameters (e.g., r_m , and T) of *A. matricariae*, except R_0 , had non-significant differences at 20 than 25 °C, which agree with the results of Farsi et al. (2019). However, in the present research, the r_m value was higher than the values reported by Farsi et al. (2019) for *A. matricariae* parasitizing *N. ribisnigri*, and by Shahrokhii et al. (2004) for *A. matricariae* parasitizing *S. graminum*. It was indicated that the greenbug was the more suitable host for the parasitoid rather than the lettuce aphid, and also, the indigenous parasitoid population used in the present study was more efficient to control *S. graminum*. Moreover, the r_m values for *A. matricariae* parasitizing the peach aphid (Shijko 1989) and the Russian wheat aphid (Reed et al. 1992) were lower than that of data obtained at 20 °C. Nevertheless, Tahriri Adabi

et al. (2010) reported that the r_m value of *A. matricariae* parasitizing *Aphis fabae* Scopoli was 0.41 at 25 °C.

Accordingly, in contrast with the r_m and T values of the parasitoid, *A. varipes* was noticeably altered at 25 °C than at 20 °C, and the increased temperature resulted in decreasing the mean generation time and the elevated intrinsic rate of natural increase (Yashima and Murai 2013).

Denis et al. (2011) found that increasing the temperature negatively affected the foraging efficiency of parasitoids and consequently declining their reproduction. This was supported by the present research that the high temperature (30 °C) had detrimental effects on the life table parameters of *A. matricariae*. Accordingly, the findings were similar to those reported by Giri et al. (1982) who stated that *A. matricariae* efficiently parasitized *M. persicae* at 21 °C. However, the parasitism rate could be increased along with temperature (ambient + 2.0 °C) (Bezemer et al. 1998).

Figures 1 and 2 clarified that survival rate of the parasitoid wasp (lx) and the number of females' produced/female/day (mx) were differentially altered at different temperatures. Hence, the high temperature (30 °C) led to decrease the lx and mx . In regard with that, the highest mx and lx happened at 20 and 25 °C, respectively.

Likewise, the survival rate of *A. matricariae* was markedly affected by the high temperature (30 °C) and then decreased; as it was reported by Zamani et al. (2007). Several factors might be involved in this decrease. For instance, the synchronization between development of parasitoid and its host could be altered by temperature and could result in their mortality (Mustață and Mustață, 2009). In addition, high temperature might induce the immune system of the parasitoid host to be effective

(Zufelato et al., 2004). Denis et al. (2011) proposed that thermal increasing resulted in declining the fitness of pro-ovigenic parasitoids. Similarly, the developmental rate of *A. matricariae* parasitizing *D. noxia* decreased at the temperature above 26 °C, and all parasitoid wasps died at 31 °C (Miller and Gerth 1994).

Conclusion

Considering the characteristics, the parasitoid wasp *A. matricariae* parasitizing the greenbug, *S. graminum*, appeared to be well-adapted with the temperatures below 30 °C. Understanding the optimal temperatures for the life history traits of the parasitoid could promote its performance in different climatic zones for the greenbug population suppression which this may advance the mass production of the parasitoid required to be applied in IPM program for successful biological control of *S. graminum*.

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Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

MR created the research plan and wrote the paper. AS analyzed the data and FH performed the experiments. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors read and approved the final manuscript and gave consent for this publication.

Competing interests

The authors declare that there are no conflicts of interest in the publication of this manuscript.

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