

Comparison of life table parameters of Russian wheat aphid, *Diuraphis noxia*, and its parasitoid, *Diaeretiella rapae* under constant temperatures

Z. TAZEROUNI¹, A. A. TALEBI¹✉, E. RAKHSHANI² and A. A. ZAMANI³

1-Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, P. O. Box: 14115-336, Tehran, Iran

2-Department of Plant Protection, Faculty of Agriculture, Zabol University, Zabol, Iran

3- Department of Plant Protection, Faculty of Agriculture, Razi University, Kermanshah, Iran

(Received: September 2012; Accepted: March 2013)

Abstract

This study was conducted to determine the effects of four constant temperatures (10, 15, 20 and 25±1 °C) on life table parameters of *Diuraphis noxia* (Mordvilko) (Hemiptera: Aphididae) and its parasitoid *Diaeretiella rapae* (McIntosh) (Hymenoptera: Braconidae) as a step toward efficient biological control of Russian wheat aphid. The survival rates (l_x) of *D. noxia* and *D. rapae* decreased with increasing temperature. The Kolmogorov-Smirnov test revealed significant difference between survivorship of *D. noxia* and *D. rapae* at different constant temperatures. The highest life expectancy of *D. noxia* and *D. rapae* was observed at 10°C and were 45.69 and 19.61 days, respectively. The highest R_0 -value for *D. rapae* was obtained at 10 °C. The r_m -value of *D. rapae* was higher than *D. noxia* at 10 °C and it was exactly equal for both Russian wheat aphid and its parasitoid at 15 °C. The mean generation time of *D. rapae* was significantly shorter than *D. noxia* at all examined temperatures. The obtained results of this research showed that *D. rapae* is potentially able to control *D. noxia*, especially at 10 and 15 °C.

Key words: *Diaeretiella rapae*, Russian wheat aphid, life table, Iran.

مقایسه پارامترهای جدول زندگی شته روسی گندم، *Diuraphis noxia* و زنبور پارازیتوئید آن، *Diaeretiella rapae* در دماهای ثابت

زهرا تازرونی^۱، علی اصغر طالبی^۱✉، احسان رخشانی^۲ و عباسعلی زمانی^۳

۱- دانشگاه تربیت مدرس، دانشکده کشاورزی، گروه حشره‌شناسی، صندوق پستی ۳۳۶-۱۴۱۱۵، تهران

۲- گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه زابل، زابل؛ ۳- گروه گیاهپزشکی، دانشکده کشاورزی، دانشگاه رازی، کرمانشاه

چکیده

در این تحقیق اثر ۴ دمای ثابت آزمایشگاهی (۱۰، ۱۵، ۲۰ و ۲۵±۱) درجه سلسیوس بر پارامترهای جدول زندگی شته روسی گندم، *Diuraphis noxia* (Mordvilko) (Hemiptera: Aphididae) و زنبور پارازیتوئید آن، *Diaeretiella rapae* (McIntosh) (Hymenoptera: Braconidae) به منظور بررسی کارایی زنبور پارازیتوئید در کنترل بیولوژیک این شته مورد بررسی قرار گرفت. نرخ بقاء (l_x) شته و زنبور با افزایش دما روند کاهشی داشت. آزمون Kolmogorov-Smirnov نشان داد، میزان بقای شته *D. noxia* و زنبور *D. rapae* در دماهای مورد آزمون با یکدیگر اختلاف معنی‌دار دارند. بیشترین امید به زندگی در شته و زنبور در دمای ۱۰ درجه سلسیوس و به ترتیب ۴۵/۶۹ و ۱۹/۶۱ روز مشاهده شد. بیشترین میزان نرخ خالص تولیدمثل (R_0) زنبور *D. rapae* در دمای ۱۰ درجه سلسیوس به دست آمد. نرخ ذاتی افزایش جمعیت زنبور *D. rapae* در دمای ۱۰ درجه سلسیوس نسبت به شته میزان بیشتر و در دمای ۱۵ درجه سلسیوس مقدار پارامتر نام‌برده در زنبور پارازیتوئید و شته میزان برابر بود. میانگین طول نسل زنبور *D. rapae* در تمام دماها نسبت به شته *D. noxia* کوتاه‌تر بود. نتایج حاصل از این تحقیق نشان داد زنبور *D. rapae* در دماهای پایین (۱۰ و ۱۵ درجه سلسیوس) قادر به کنترل شته *D. noxia* می‌باشد.

واژه‌های کلیدی: *Diaeretiella rapae*، شته روسی گندم، جدول زندگی، ایران.

Introduction

Parasitoids are as part of important biological control agents to control pests. They can help reduce pest infestation levels and the number of their hosts, preventing the outbreak of the pests (van Driesche and Bellows, 1996). The Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Hemiptera: Aphididae) is one of the most important pests of wheat in Iran (Zare *et al.*, 1995; Rakhshani *et al.*, 2008). This aphid causes severe damage to plants at seedling, vegetative and generative stages (Rezvani, 2001). Parasitoid wasp, *Diaeretiella rapae* (McIntosh) (Hymenoptera: Braconidae, Aphidiinae), is a polyphagous parasitoid of aphids. It has been reported attacking *D. noxia* (Hem., Aphididae), in many areas of the world including central Asia, eastern and western Europe, the Mediterranean region, the Middle East, northern Africa, South America, North America including the USA and Iran (Kovalev *et al.*, 1991; Mc Kinnon *et al.*, 1992; Feng *et al.*, 1991, 1992; Bernal & Gonzalez, 1993; Zare *et al.*, 1995; Rakhshani *et al.*, 2008).

Insect demography has always been very important research fields in entomology and pest management (Carey, 2001). Demographic parameters are important in measurement of population growth capacity of a species under specified conditions (Southwood and Henderson, 2000). The information about the demographic parameters of pest and its parasitoids are essential to understand their role in preventing the pest outbreak. Many factors, including temperature, photoperiod, and size of the adult female may influence the performance and efficiency of parasitoids (Force & Messenger, 1964; Botto *et al.*, 1988; Powell & Bellows, 1992; van Steenis, 1993).

Several studies have been carried out on the demographic parameters of *D. rapae* on *D. noxia* and *Brevicoryne brassicae* (L.) (Reed *et al.*, 1992; Bernal & Gonzalez, 1997, Hosseini-Gharalari *et al.*, 2003), but there are no studies on demographic parameters of Iranian population of *D. rapae* in association with *D. noxia* in Iran as native area of distribution for the both species (Durr, 1983; Dolatti *et al.*, 2005).

The objective of this study was to determine the effect of temperature on demographic parameters of *D. noxia* and its parasitoid, *D. rapae* and evaluation of efficiency *D. rapae* to

control of *D. noxia* at different constant temperatures. The results of this research provided useful information for the establishment of a Russian wheat aphid management program in Iran.

Materials and Methods

Insect culture: Russian wheat aphid was collected from wheat fields in the suburbs of Karaj, Iran (35° 45'47.69" N, 50° 55'53.50" E, 1235 m) during October 2009 to initiate the culture. laboratory colonies of Russian wheat aphid were continuously reared on young foliage of wheat (Pishtaz variety) at 25±1 °C, relative humidity of 60±5% and a photoperiod of 16L: 8D h. The *D. rapae* colony was originally established from mummified cabbage aphids, *B. brassicae* collected from the canola field in the college of agriculture, Tarbiat Modares University in Tehran, Iran, (35°44'28.99" N, 51°09'50.07" E, 1205 m) in April 2010. Emerged adult parasitoids were transferred on *D. noxia* and reared for at least one generation. Laboratory colonies of *D. rapae* were continuously reared on infested young foliage of wheat by *D. noxia* at 20±1 °C, relative humidity of 60±5 % and a photoperiod of 16L: 8D h.

Demographic parameters: In order to obtain demographic parameters of Russian wheat aphid at each temperature, an apterous female of *D. noxia* was randomly selected from the stock culture transferred individually on wheat leaves into 1.5 ml micro tube and placed in BD Falcon™ 50 ml conical centrifuge tubes (<http://www.bdbiosciences.com/cellculture/tubes>) as a leaf cage. According to previous studies (Kazemi *et al.*, 2001; Clua *et al.*, 2004), apterous females were used for the experiments because they were more dominant than winged females. After 24 hours, adult females of *D. noxia* were removed and only one newly born nymph was maintained per each leaf cage. The nymph on each leaf cage was checked daily and their survival recorded. The presence of the discarded exuviae was used to determine time of molting. The experiments carried out with 250 newly born aphids at each temperature. When the immature nymphs become adults, they were observed daily for reproduction and survival and all new-born nymphs were counted and removed from each leaf cage. The observations continued until the death of all examined aphids in all

temperatures. To reduce the effects of plant age on reproduction and survivorship, aphids were transferred on new wheat leaves every 4-5 days.

For studying demographic parameters of *D. rapae*, young leaves of wheat were initially infested with 50 third instar nymphs of *D. noxia*, put into the 1.5 ml micro tube and placed in BD Falcon™ 50 ml conical centrifuge tubes. Subsequently, a pair of male-female parasitoid was released into the each container tube for a period of 12h. The 25% diluted honey was streaked on the inside of each container to feeding of adult parasitoids during the experiment. After 12h, parasitoid wasps were removed and the exposed aphids were maintained under experimental conditions until formation of the mummies. Each mummified aphid was separately placed into a 7 ml glassy tube. The lids of glassy tubes were closed with micromesh screen. They were checked daily until adult emergence then the gender were determined. These parasitoids were used in the experiments <12 h after emergence, without regard for prior mating or oviposition experience (Weathersbee *et al.*, 2004). Adults of *D. rapae* were daily fed on a 25% diluted honey was streaked on the inside of each container. When the male died before the female, an alternative male were replaced from the stock culture. Fresh wheat leaves infested with 50 third instar nymphs of *D. noxia* were daily offered to each examined female parasitoid for oviposition. The exposed nymphs were removed after 24h and maintained under experimental conditions until formation of aphid mummies. The numbers of mummified aphids were counted and considered as the number of laid eggs by each female parasitoid.

These experiments were similarly carried out at four constant temperatures of 10, 15, 20 and 25 °C, relative humidity of 60±5% and a photoperiod of 16L: 8D h. Temperatures of 10, 15, 20 and 25 were tested because both aphid and parasitoid rise in early spring season and increase their populations in range temperatures. Both aphid and parasitoid were reared at each temperature for 20 days prior to the start of the experiments to adapt to the experiment conditions.

Data analyses: All data of longevity and stable population growth parameters were analyzed for each temperature using SAS statistical package (SAS Institute,

2003). Using the fertility and survivorship schedules, the life table parameters were calculated according to the formulae suggested by Carey (1993, 2001). The pseudo-values of life table parameters were calculated using jackknife procedure (Meyer *et al.* 1986; Maia *et al.* 2000). The estimated pseudo-values of life table parameters at different temperatures were subjected to a one-way ANOVA. If significance differences were detected, multiple comparisons were made using the SNK procedure ($P < 0.05$).

Age specific survival rates (l_x) of Russian wheat aphid and *D. rapae* were compared using Kolmogorov-Smirnov test ($P < 0.05$) (Pyke & Thomson 1986).

Statistical analysis was carried out using SAS (SAS Institute, 2003) and MINITAB softwares (MINITAB, 2000). The differences in reproduction and population growth parameters between *D. noxia* and *D. rapae* at each constant temperature were compared using *t*-test ($P_{\text{value}} < 0.05$) with SPSS 16 (SPSS, 2004).

Results and Discussion

Survivorship, mortality and fecundity: The comparison of age-specific survival between *D. noxia* and *D. rapae* at different temperatures is shown in Figure 1. There were significant differences between survivorship of *D. noxia* and *D. rapae* at all constant temperatures according Kolmogorov-Smirnov test ($P < 0.05$). The lowest (21%) and highest (70%) immature mortality rates of *D. noxia* were observed at 25 and 10°C, respectively. Contrarily, the maximum mortality during pupal stage of *D. rapae* was occurred at 25°C as 34%. The highest survivorship period of both *D. noxia* and *D. rapae* were observed at 10°C as 83 and 58 days, respectively (Fig. 1). In general, life expectancy (e_x) at the time of adult emergence for both *D. noxia* and *D. rapae* decreased with increasing age (Fig. 2). The greatest life expectancy of one-day-old individuals of *D. noxia* and *D. rapae* were estimated to be 27.75 and 44.52 days at 15 and 10°C, respectively. The maximum life expectancy of *D. noxia* and *D. rapae* at the time of the emergence of adults were 45.69 and 19.61 days at 10°C, respectively (Fig. 2). Age-specific fecundities (m_x) of *D. noxia* and *D. rapae* at various constant temperatures are shown in Fig. 3. Longer reproductive periods for both *D. noxia* and *D. rapae* were

observed at lower temperatures. No clear peaks were observed during reproductive period of Russian wheat aphid at all studied temperature, while maximum daily fecundities of *D. rapae* were occurred at the beginning of its oviposition period at different constant temperatures (Figure 3). The greatest age-specific fecundities of *D. rapae* were 7.68, 12.79, 10.48 and 3.64 at 10, 15, 20 and 25°C, respectively.

Reproduction and population growth parameters:

The calculated reproductive parameters of *D. noxia* and *D. rapae* are presented in Table 1. The effect of temperature was highly significant for the different reproductive parameters of both *D. noxia* and *D. rapae* including gross fecundity rate ($F = 7.109$; $d_f = 3, 580$; $P_{value} < 0.05$ and $F = 48.132$; $d_f = 3, 161$; $P_{value} < 0.05$), net fecundity rate ($F = 103.262$; $d_f = 3, 580$; $P_{value} < 0.05$ and $F = 48.416$; $d_f = 3, 161$; $P_{value} < 0.05$), mean offspring per female per day ($F = 57.049.66$; $d_f = 3, 580$; $P_{value} < 0.05$ and $F = 37.571$; $d_f = 3, 161$; $P_{value} < 0.05$), respectively (Table 1). The highest values of gross fecundity rates of *D. noxia* and *D. rapae* were found at 20 and 10°C, respectively. The maximum values of mean offspring per day were estimated at 20 and 25°C for *D. noxia* (2.08 ± 0.05 and 2.07 ± 0.05 , respectively) and at 15°C for *D. rapae* (7.69 ± 0.48) (Table 1).

The comparison of population growth parameters of *D. noxia* and *D. rapae* at four constant temperatures are summarized in table 1. There were significant differences among the net reproductive rates (R_0) of both *D. noxia* ($F = 111.734$; $d_f = 3, 580$; $P_{value} < 0.05$) and *D. rapae* ($F = 55.165$; $d_f = 3, 160$; $P_{value} < 0.05$) at four constant temperatures. The highest R_0 -value of *D. rapae* was observed at 10°C (22.99 ± 0.647). The intrinsic rates of natural increase (r_m) of *D. noxia* ($F = 1.439$; $d_f = 3, 580$; $P_{value} < 0.05$) and *D. rapae* ($F = 106.382$; $d_f = 3, 161$; $P_{value} < 0.05$) were also found to be significantly different depending on the temperatures on which they were reared. The highest ($0.279 \pm 0.002 \text{ days}^{-1}$) and lowest ($0.068 \pm 0.0007 \text{ ys}^{-1}$) r_m -values of *D. noxia* were obtained at 25 and 10°C, respectively, while as temperature increased, the r_m -values of *D. rapae* followed a typical asymmetrical dome-shape pattern, with maximum value of $0.189 \pm 0.003 \text{ day}^{-1}$ at 20°C. The r_m -value of *D. rapae* was significantly greater than *D. noxia* at 10°C. The λ -values of Russian wheat aphid ($F = 1.31$; $d_f = 3, 580$; $P_{value} < 0.05$) and *D. rapae* ($F = 37.222$;

$d_f = 3, 161$; $P_{value} < 0.05$) showed significant differences among the various temperatures. The aphids reared at 25 °C had the largest λ -value, and the highest λ -value for *D. rapae* was obtained at 20°C. Significant differences were observed between λ -values of *D. noxia* and *D. rapae* at 10, 20 and 25°C (t -test; $P_{value} < 0.05$), but there was no significant difference at 15°C. The doubling times (DT) of both Russian wheat aphid ($F = 3.358$; $d_f = 3, 580$; $P_{value} < 0.05$) and *D. rapae* ($F = 50.641$; $d_f = 3, 161$; $P_{value} < 0.05$) were also found to be significantly different among various constant temperatures (Table 1). The lowest DT -values of *D. noxia* and *D. rapae* were obtained at 25 and 20°C, respectively. The doubling time of *D. rapae* was significantly shorter than *D. noxia* when reared at 10°C. The mean generation time (T) of either species decreased with increasing temperature. The T -values of *D. rapae* were significantly shorter than *D. noxia* at all studied temperatures (Table 1).

The present study demonstrated significant differences in the performance of the Russian wheat aphid and its parasitoid, *D. rapae*, among various constant temperatures, because temperature is one of the most important environmental factors in insect mass-rearing, affecting development time, maturation, survival, demographic parameters and population dynamics of insect pests (Force and Messenger, 1964; Botto *et al.*, 1988; Powell and Bellows, 1992; Van Steenis, 1993; Huffaker *et al.*, 1999; Kemp and Bosch., 2005; Kalaitzaki *et al.*, 2007). Also, study on the effect of temperature on the performance of the parasitoid and its host can be useful to obtain optimal biological control. No other study has accomplished the full range of temperatures that are suitable to development and reproduction of *D. noxia* and *D. rapae* in Iran.

The net fecundity rates of host and parasitoid are among the most important factors in selecting natural enemies (Bigler, 1994). The data were reported by Hosseini-Gharalari *et al.* (2003) on the number of produced eggs per female of *D. rapae* was 40.82 eggs on *Brevicoryne brassicae* (L.), while Fukui and Takada (1988) found 238.7 eggs of *D. rapae* on green peach aphid, *Myzus persicae* (Sulzer) at 20°C.

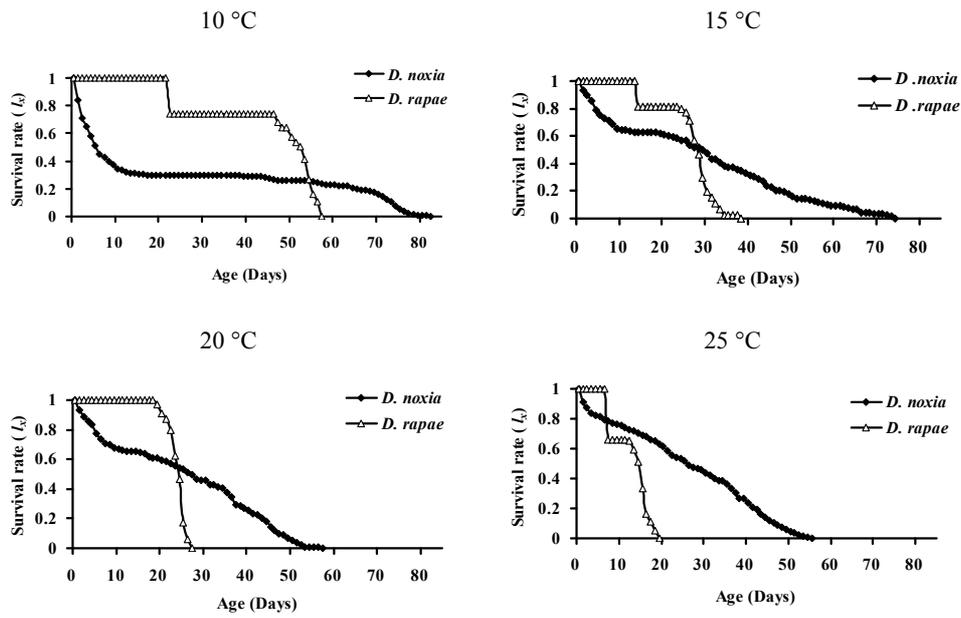


Fig. 1- Age-specific survival curves (L_x) of *Diuraphis noxia* and *Diaeretiella rapae* on wheat at four constant temperatures

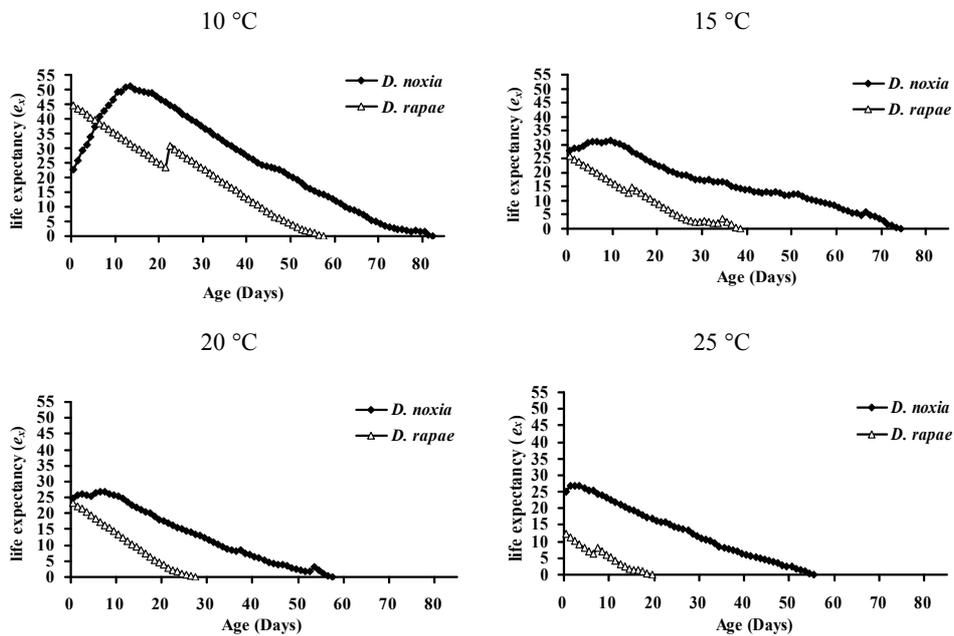


Fig. 2- Life expectancy (e_x) of *Diuraphis noxia* and *Diaeretiella rapae* on wheat at four constant temperatures.

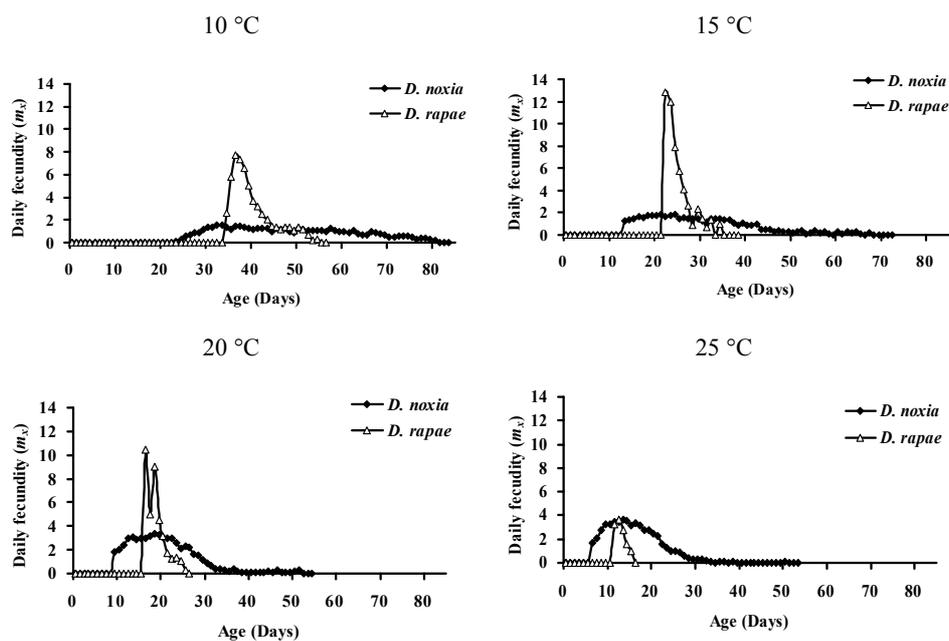


Fig. 3- Age-specific fecundity curves (m_x) of *Diuraphis noxia* and *Diaeretiella rapae* on wheat at four constant temperatures

Table 1- The reproduction and population growth parameters of *Diuraphis noxia* and its parasitoids *Diaeretiella rapae* (mean \pm SE) at four constant temperatures

Parameters	Species	Temperatures (°C)			
		10	15	20	25
Gross fecundity rate	<i>D. noxia</i>	53.54 \pm 0.96 ab,x	48.46 \pm 2.28 b,x	59.21 \pm 1.94 a,x	55.58 \pm 0.89 a,x
	<i>D. rapae</i>	57.96 \pm 1.52 a,x	54.62 \pm 4.51 a,x	37.59 \pm 1.46 b,y	13.17 \pm 1.09 c,y
Net fecundity rate	<i>D. noxia</i>	13.69 \pm 0.41 d,x	21.53 \pm 0.082 c,x	32.82 \pm 0.97 b,x	37.01 \pm 0.97 a,x
	<i>D. rapae</i>	41.21 \pm 1.17 a,y	30.03 \pm 3.17 b,x	33.80 \pm 1.51 b,x	4.91 \pm 0.60 c,y
Mean offspring per day	<i>D. noxia</i>	1.22 \pm 0.02 c,x	1.59 \pm 0.03 b,x	2.08 \pm 0.05 a,x	2.07 \pm 0.05 a,x
	<i>D. rapae</i>	3.71 \pm 0.14 c,y	7.69 \pm 0.48 a,y	2.25 \pm 0.27 b,y	3.04 \pm 0.19 c,y
R_0	<i>D. noxia</i>	13.79 \pm 0.41 d,y	21.66 \pm 0.81 c,x	33.19 \pm 0.96 b,x	37.58 \pm 0.94 a,x
	<i>D. rapae</i>	22.99 \pm 0.65 a,x	18.07 \pm 0.76 b,x	17.53 \pm 1.71 b,x	2.53 \pm 0.27 c,x
r_m	<i>D. noxia</i>	0.068 \pm 0.001 d,y	0.142 \pm 0.001 c,x	0.219 \pm 0.002 b,x	0.279 \pm 0.002 a,x
	<i>D. rapae</i>	0.094 \pm 0.001 c,x	0.143 \pm 0.004 b,x	0.189 \pm 0.003 a,y	0.089 \pm 0.001 c,y
λ	<i>D. noxia</i>	1.07 \pm 0.001 d,y	1.15 \pm 0.002 c,x	1.25 \pm 0.003 b,x	1.32 \pm 0.003 a,x
	<i>D. rapae</i>	1.10 \pm 0.001 c,x	1.15 \pm 0.006 b,x	1.21 \pm 0.003 a,y	1.09 \pm 0.011 c,y
DT	<i>D. noxia</i>	10.12 \pm 0.10 a,x	4.86 \pm 0.06 b,x	3.15 \pm 0.03 c,y	2.48 \pm 0.02 d,y
	<i>D. rapae</i>	7.36 \pm 0.08 a,y	4.84 \pm 0.16 b,x	3.67 \pm 0.05 c,x	7.62 \pm 0.86 a,x
T	<i>D. noxia</i>	38.33 \pm 0.46 a,x	21.59 \pm 0.37 b,x	15.93 \pm 0.20 c,x	12.96 \pm 0.12 d,x
	<i>D. rapae</i>	33.29 \pm 0.16 a,y	20.05 \pm 0.07 b,y	15.33 \pm 0.07 c,y	10.40 \pm 0.06 d,y

Different letters (a, b, c, d) in the rows indicate significant ($P < 0.05$) differences within species on various constant temperatures and different letters (x, y) in the columns indicate significant ($P < 0.05$) differences between aphid and parasitoid on the same temperature; Formula and calculations conform to Carey (1993).

The estimated net fecundity rates of *D. rapae* in the current study ranged from 4.91 to 41.21 eggs per female at various constant temperatures (Table 1). The differences among various studies could be attributed to factors other than temperatures e.g. difference in host species, host plants, photoperiod etc. Hosseini-Gharalari *et al.* (2003) calculated the R_0 -value of *D. rapae* on *B. brassicae* to be 10.5 at 25°C, while reported value by Reed *et al.* (1992) on the net reproduction rate of *D. rapae* on *D. noxia* was 58.6 at 20°C. Bernal and Gonzalez (1997) found R_0 -values of *D. rapae* on *D. noxia* at 10, 21.1 and 26.7°C to be 24.77, 21.27 and 14.96 (females/female/generation), respectively. The net reproduction rates of *D. rapae* in the current study were 22.99, 18.07, 17.53 and 2.53 at 10, 15, 20 and 25°C, respectively. Different reports on the fecundity of *D. rapae* are presented by various authors (Hafez, 1961; Hughes, 1963; Sedlag, 1964; Sethumadhavan and Dharmadhikari, 1969; Wilson and Lambdin, 1987; Abidi *et al.*, 1990; Hayakawa *et al.*, 1990). A number of factors, including temperature, photoperiod and size of the adult female are known to influence the fecundity of aphidiid wasps (Force and Messenger, 1964; Stáry, 1970, 1988; Mackauer and Kambhampati, 1988; Hagvar and Hofsvang, 1991; van Steenis, 1993). The impact of a parasitoid population on its host population depends upon several interrelated factors. The ability of the parasitoid population to increase in numbers and consequently exert a greater suppressive effect on the growth rate of its host's population is of special importance (Bernal and Gonzales, 1997). The intrinsic rate of increase is a parameter that can be used as a measure of a parasitoid population's potential rate of increase (Birch, 1948). This parameter also has been used as a relative index of a parasitoid population's potential impact on a host population (Force and Messenger, 1968; Kambhampati and Mackauer, 1989). Tripathi and Singh (1990) declared that different factors to affect the r_m -value and related demographic parameters, such as host and parasitoid species (Jervis and Copland, 1996), host and parasitoid size (Sinha and Singh, 1982; Jervis and Copland, 1996), host plant and temperature (Force and Messenger, 1964), the number of male, Kairomone and adult feeding (Jervis and Copland, 1996) and photoperiod (Bernal and Gonzalez, 1997). The intrinsic rate of natural increase is one of the most important criteria in evaluation of suitability of parasitoids in biological control of insect pest.

As temperature increased, the intrinsic rate of increase (r_m) of *D. rapae* followed a typical asymmetrical dome-shape pattern, with maximum value of 0.189 day⁻¹ at 20°C. On the other hand, the r_m -values of *D. noxia* increased with increasing temperature from 10 to 25°C. The comparison between r_m -values of *D. noxia* and *D. rapae* at different examined temperatures reveal that *D. rapae* has a greater potential in biocontrol of *D. noxia* at lower temperatures, especially at 10°C. Bernal and Gonzalez (1997) have reported the r_m -values of *D. rapae* on *D. noxia*, at all temperatures according to the pattern of 26.7 > 21.1 > 10°C. Reed *et al.* (1992) estimated the r_m -value of *D. rapae* on Russian wheat aphid equal to 0.26 (day⁻¹), which is greater than those estimated for *D. rapae* in the current study. Since the doubling time of *D. rapae* was significantly shorter than *D. noxia* at 10°C, this parasitoid is able to produce more generations than its host aphid at the mentioned above temperature. The DT -values of *D. rapae* and *D. noxia* was exactly equal at 15°C and then at 20 and 25°C, DT of *D. noxia* became shorter than *D. rapae*. The doubling time of *D. rapae* on *B. brassicae* was observed 3.269 days at 25°C (Hosseini-Gharalari *et al.*, 2003), which is so smaller than our data at the same temperature (7.62±0.86 days). This obvious variation in our findings and other study at 25°C reveal different thermal adaptations of various populations of *D. rapae* and different host aphids. The demographic parameters of aphids and their parasitoids may affect on different host plants (Kazemi *et al.*, 2001; Clua *et al.*, 2004; Fukui and Takada, 1988; Hosseini-Gharalari *et al.*, 2003)

The studied population parameters of *D. rapae* in the current research had a better performance at lower temperatures. Since the greatest density of *D. noxia* in Iran conditions occurs at the beginning of spring and autumn and during these periods, the mean daily temperature is usually lower than 20°C, *D. rapae* could be considered as a good candidate for biocontrol of *D. noxia* in wheat fields of Iran.

Acknowledgments

We are grateful to the Department of Entomology, Tarbiat Modares University for financial supporting this research. The author also thank to three anonymous reviewers for their valuable comments and recommendations on the earlier version of this paper.

References

- ABIDI, A. Z., A. KUMAR and C. P. M. TRIPATHI, 1990. Impact of male on the longevity, fecundity and oviposition frequency, developmental period and sex ratio on the offspring of *Diaeretiella rapae* (M'Intosh) (Hymenoptera: Aphidiidae), a parasitoid of *Lipaphis erysimi* Kalt. (Homoptera: Aphididae). *Zeitschrift für Angewandte Zoologie*, 76: 333–348.
- BERNAL, J. and D. GONZALEZ, 1993. Temperature requirements of four parasites of the Russian wheat aphid *Diuraphis noxia*. *Entomologia Experimentalis et Applicata*, 69: 173–182.
- BERNAL, J. and D. GONZALEZ, 1997. Reproduction of *Diaeretiella rapae* on Russian wheat aphid hosts at different temperatures. *Entomologia Experimentalis et Applicata*, 82: 159–166.
- BIGLER, F. 1994. Quality control in *Trichogramma* production species for use in biological control. In: Wajnberg E, Hassan SA, editors. *Biological Control with Egg Parasitoids*, 93-111. CAB International, Wallingford, UK.
- BIRCH, L. C. 1948. The intrinsic rate of increase of an insect population. *Journal of Animal Ecology*, 17: 15–26.
- BOTTO, N. E., D. GONZALEZ and T. S. BELLOWS JR, 1988. Effect of temperature on some biological parameters of two populations of *Aphidius ervi* Haliday (Hymenoptera: Aphidiidae). Pp. 367-377. In: *Advances in Parasitic Hymenoptera Research*. (Gupta V. K., ed.). E. J. Brill, New York.
- CAREY, J. R. 1993. *Applied Demography for Biologists, with Special Emphasis on Insects*. Oxford University Press, UK.
- CAREY, J. R. 2001. Insect biodemography. *Annual Review of Entomology*, 46:79-110.
- CLUA, A., A. M. CASTRO, S. RAMOS, D. O. GIMENEZ, A. VASICEK, H. O. CHIDICHIMO and A. F. G. DIXON. 2004. The biological characteristics and distribution of the greenbug, *Schizaphis graminum*, and Russian wheat aphid, *Diuraphis noxia* (Homoptera: Aphididae), in Argentina and Chile. *European Journal of Entomology*, 101: 193–198.
- VAN DRIESCHE, R. G. and T. S. BELLOWS, 1996. *Biological Control*. Chapman and Hall, New York.
- DOLATTI, L., B. GHAREYAZIE, S. MOHARRAMIPOUR and M. R. NOORI-DALOII, 2005. Evidence for regional diversity and host adaptation in Iranian populations of the Russian wheat aphid. *Entomologia Experimentalis et Applicata*, 114: 171-180.
- DURR, H. J. R. 1983. *Diuraphis noxia* (Mordvilko) (Homoptera: Aphididae), a recent addition to the aphid fauna of South Africa. *Phytophylactica*, 15: 81-83.
- FENG, M. G., J. B. JOHNSON and S. E. HALBERT, 1991. Natural control of cereal aphids (Homoptera: Aphididae) by entomopathogenic fungi (Zygomycetes: Entomophthorales) and parasitoids (Hymenoptera: Braconidae and Encyrtidae) on irrigated spring wheat in southwestern Idaho. *Environmental Entomology*, 20: 1699–1710.
- FENG, M. G., J. B. JOHNSON and S. E. HALBERT, 1992. Parasitoids and their effect on aphid populations in southwestern Idaho. *Environmental Entomology*, 21:1433-1440.
- FORCE, D. C. and P. S. MESSENGER, 1964. Duration of development, generation time, and longevity of three hymenopterous parasites of *Therioaphis maculata* reared at various constant temperatures. *Annals of the Entomological Society of America*, 57: 405–413.
- FORCE, D. C. and P. S. MESSENGER, 1968. The use of laboratory studies of three hymenopterous parasites to evaluate their field potential. *Journal of Economic Entomology*, 61: 1371–1378.
- FUKUI, M. and H. TAKADA, 1988. Fecundity, oviposition period and longevity of the parasitoids *Diaeretiella rapae* and *Aphidius gifuensis*, two parasitoids of *Myzus persicae*. *Japanese Journal of Applied Entomology and Zoology*, 32: 331-333.
- HAFEZ, M. 1961. Seasonal fluctuations of population density of the cabbage aphid, *Brevicoryne brassicae* (L.), in The Netherlands, and the role of its parasite, *Aphidius (Diueretieia) rapae* (Curtis). *Tijdschrift over plantenziekten*, 67: 445-548.
- HAGVAR, E. B. and T. HOFVANG, 1991. Aphid parasitoids (Hymenoptera: Aphidiidae): biology, host

- selection and use in biological control. *Biocontrol News and Information*, 12:13–41.
- HAYAKAWA, D. L., E. GRAFIUS and F. W. STEHR, 1990. Effects of temperature on longevity, reproduction and development of the asparagus aphid and the parasitoid *Diaeretiella rapae*. *Environmental Entomology*, 19: 890–897.
- HOSSEINI-GHARALARI, A., Y. FATHIPOUR and A. A. TALEBI, 2003. A Comparison of stable population parameters of Cabbage Aphid *Brevicoryne brassicae* and its Parasitoid *Diaeretiella rapae*. *Iranian Journal of Agricultural Sciences*, 34 (4): 785–791.
- HUFFAKER, C., A. BERRYMAN and P. TURCHIN, 1999. Dynamics and regulation of insect populations. Pp. 269–305. In: *Ecological entomology*. (Huffaker, C. B. and Gutierrez A. B., eds). Wiley, New York.
- HUGHES, R. D. 1963. Population dynamics of the cabbage aphid. *Journal of Animal Ecology*, 32: 393–424.
- JERVIS, M. A. and M. J. W. COPLAND, 1996. The life cycle. Pp. 63–131. In: *Insect Natural Enemies*. (Jervis M. and Kidd N., eds). Chapman and Hall, London.
- KALAITZAKI, A. P., D. P. LYKOURESSIS, D. CH. PERDIKIS and V. Z. ALEXANDRAKIS, 2007. Effect of temperature on development and survival of the parasitoid *Pnigalio pectinicornis* (Hymenoptera: Eulophidae) reared on *Phyllocnistis citrella* (Lepidoptera: Gracillariidae). *Environmental Entomology*, 36:497–505.
- KAMBHAMPATI, S. and M. MACKAUER, 1989. Multivariate assessment of inter- and intraspecific variation in performance criteria of several pea aphid parasites (Hymenoptera: Aphidiidae). *Annals of the Entomological Society of America*, 82: 314–324.
- KAZEMI, M. H., P. TALEBI-CHAICHI, M. R. SHAKIBA and M. MASHHADI JAFARLOO. 2001. Biological responses of Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Homoptera: Aphididae) to different wheat varieties. *Journal of Agricultural Science and Technology*, 3: 249–255
- KEMP, W. P. and J. BOSCH, 2005. Effect of temperature on *Osmia lignaria* (Hymenoptera: Megachilidae) prepupa-adult development, survival, and emergence. *Journal of Economic Entomology*, 98: 1917–1923.
- KOVALEV, O. V., T. J. PAPROWSKI, A. V. STEKOLSHCHIKOV, A. B. VERESHCHAGINA and S. A. GANDRABUR, 1991. *Diuraphis* Aizenberg (Hom., Aphididae): key to apterous viviparous females, and a review of Russian language literature on the natural history of *Diuraphis noxia* (Kurdjumov, 1913). *Journal of Applied Entomology*, 112: 425–436.
- MACKAUER, M. and S. KAMPBHAMPATI, 1988. Parasitism of aphid embryos by *Aphidius smithi*: some effects of extremely small host size. *Entomologia Experimentalis et Applicata*, 49: 167–173.
- MAIA, A. H. N., A. J. B. BLUIZ and C. CAMPANHOLA, 2000. Statistical influence on associated fertility life table parameters using jackknife technique: computational aspects. *Journal of Economic Entomology*, 93: 511–518.
- MC KINNON, L. K., F. E. GILSTRAP, D. GONZALEZ, J. B. WOOLEY, P. STÁRY and P. A. WHARTON, 1992. Importations of natural enemies for biological control of Russian wheat aphid. Pp: 136–145. In: *Proceedings of the fifth Russian Wheat Aphid Conference*. (Morrison W. P., comp.). Great Plains Agricultural Council Publication No. 142, Forth Worth, USA.
- MINITAB, 2000. MINITAB User's Guide, version 13.20. MINITAB Ltd, UK.
- POWELL, D. A. and T. S. BELLOWS JR, 1992. Development and reproduction of two populations of *Eretmocerus* species (Hymenoptera: Aphelinidae) on *Bemisia tabaci* (Homoptera: Aleyrodidae). *Environmental Entomology*, 21: 651–658.
- PYKE, D. A. and J. N. THAMPSON, 1986. Statistical analysis of survival and removal rate experiments. *Ecology*, 67(1): 240–245.
- RAKSHSHANI, E., Z. TOMANOVIC, P. STARY, A. A. TALEBI, N. G. KAVALLIERATOS, A. ZAMANI and S. STAMENKOVIC, 2008. Distribution and diversity of wheat aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) in Iran. *European Journal of Entomology*, 105: 863–870.
- REED, H. C., D. K. REED and N. C. ELLIOT, 1992. Comparative life table statistics of *Diaeretiella rapae*

- and *Aphidius matricariae* on the Russian wheat aphid. Southwestern Entomologist, 17: 307–312.
- REZVANI, A. 2001. Key to the aphids (Homoptera: Aphidinea) in Iran. Ministry of Jihad Agriculture, Tehran, Iran.
- SAS Institute, 2003. GLM: A Guide to Statistical and Data Analysis, version 9.1. SAS Institute, Cary, NC.
- SEDLAG, U. 1964. Zur Biologie und Bedeutung von *Diaeretiella rapae* (McIntosh) als Parasit der Kohlblattlaus (*Brevicoryne brassicae* L.). Nachrichtenblatt des Deutschen Pflanzenschutzdienstes, 18: 81–86.
- SETHUMADHAVAN, T. V. and P. R. DHARMADHIKARI, 1969. Notes on *Diaeretiella rapae* (McIntosh) (Hym.: Aphidiidae) parasitic on aphids on crucifers in India. Technical bulletin of the Commonwealth Institute of Biological Control, 11: 173–177.
- SOUTHWOOD, T. R. E. and P. A. HENDERSON, 2000. *Ecological Methods*. 3rd edition. Blackwell Sciences, Oxford.
- SPSS, 2004. SPSS base 13.0 users guide. SPSS, Chicago, IL.
- STÁRY, P. 1970. Biology of Aphid Parasites with Respect to Integrated Control. Dr W Junk, The Hague, the Netherlands.
- STÁRY, P. 1988. Aphidiidae. Pp: 171-184. In: Aphids, their Biology, Natural Enemies and Control. (Minks A. K. and Harrewijn P., eds.). Elsevier Science Publishers, Amsterdam.
- TRIPATHI, R. N. and R. SINGH, 1990. Fecundity, reproduction rate longevity and intrinsic rate of natural increase of aphidiid parasite *Lusiphlebia mirzai*. Entomophaga, 35: 601-610.
- VAN STEENIS, M. J. 1993. Intrinsic rate of increase of *Aphidius colemani* Vier. (Hym., Braconidae), a parasitoid of *Aphis gossypii* Glov. (Hom., Aphididae), at different temperatures. Journal of Applied Entomology, 116: 192–198.
- WEATHERSBEE, A. A., C. L. MCKENZIE and Y. Q. TANG, 2004. Host plant and temperature effects on *Lysiphlebus testaceipes* (Hymenoptera: Aphidiidae), a native parasitoid of the exotic brown citrus aphid (Homoptera: Aphididae). Annals of the Entomological Society of America, 97: 476-480.
- WILSON, G. B. and P. L. LAMB DIN, 1987. Suitability of *Brevicoryne brassicae* and *Myzus persicae* as hosts of *Diaeretiella rapae*. Entomological News, 98: 140-146.
- ZARE, N., D. GONZALEZ, A. AHMADI, M. ESMAILI, H. MALEKI-MILANI, J. VAFABAKHSH, Y. SALIMI, F. GILSTRAP, P. STÁRY, J. B. WOOLLEY and F. C. THAMPSON. 1995. A search for the Russian wheat aphid, *Diuraphis noxia* (Mordvilko) (Homoptera: Aphididae), and its natural enemies in Iran. In: Proceedings of the 12th Iranian Plant Protection Congress, Karaj, Iran, p. 12.