

Selected Demographic Data of the Bird Cherry-Oat Aphid, *Rhopalosiphum padi* L. on Corn, *Zea mays* L. at Different Temperatures

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ABSTRACT

The bird cherry-oat aphid, *Rhopalosiphum padi* (L.) (Hemiptera: Aphididae), is a serious pest of Poaceae plants, especially wheat and corn, in the world and in Iran. In this study, the demographic parameters of *R. padi* were determined at seven constant temperatures (8.5, 15, 20, 25, 27.5, 29 and 31±0.5 °C), 65±5% RH, and 14:10 (L: D) photoperiods on *Zea mays* L., KSC704 cultivar. The total lifespan, from birth to death, decreased with increasing the temperature from 8.5 to 29 °C, but the nymphal stage duration increased a little at 29 °C. The highest value of life expectancy (e_x) was observed at 8.5 °C and at 31 °C, the nymphs died before reaching the adult phase. The percentage of survival for nymphal stages was highest at 15 and 25 °C, and the net reproductive rate ($R_0=23.671$ female/generation) had the highest value at 15 °C. The intrinsic rate of increase (r_m) and the finite rates of increase (λ) increased at the temperature interval of 8.5 to 25 °C. At this range, the doubling time (DT) and the mean generation time (T) decreased as the temperature increased. According to the highest value of r_m (0.22 day⁻¹) and λ (1.134day⁻¹) and also the lower value of T (9.095 d) and DT (2.16 d), the temperature of 25 °C was determined as the optimal temperature and the data showed that the proper temperature range for growth and reproduction of this aphid was between 15-25 °C. The effect of temperature on reproduction, especially the intrinsic rate of increase (r_m), of *R. padi* would be useful for predicting its long-term population fluctuation over several generations and establishing integrated pest management (IPM) strategies against this pest.

Keywords: Intrinsic rate of increase, Life table, Reproductive rate, Poaceae family, Insect pests.

INTRODUCTION

Corn (*Zea mays* L., Poaceae family) is one of the three main world cereals, after wheat and rice. According to the latest estimations by FAO (2016), more than one hundred million hectares are under corn cultivation in the world. Aphids are among the most destructive insect pests on the cultivated plants such as corn. The known number of Aphididae family reached 5,000 species, with

450 species feeding on agricultural crops in the world (Blackman and Eastop, 2000). The bird cherry-oat aphid, *Rhopalosiphum padi* (L.) (Hem: Aphididae) is a heteroecious species with alternate parthenogenesis and sexual reproduction. This aphid has primary winter hosts (*Prunus padus* in Europe, *Prunus virginiana* and *Prunus pennsylvanica* in North America) and secondary summer Poaceae hosts (Blackman and Eastop, 2000; Voegtlin and Halbert, 1998). The sexual form is rarely seen in Iran (Rezvani, 2004 and

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2001). This aphid can affect different cereals and grasses as the secondary host, by direct feeding and with the transmission of some viruses. The most important viruses are “BYDV” (barley yellow dwarf virus) (Aleosfoor *et al.*, 2007) and “MLFV” (maize leaf fleck virus) (Blackman and Eastop, 2000; Powell and Hardie, 2000; Riedell *et al.*, 2003; Borer *et al.*, 2009). Colonies of *R. padi* collected from Shahrekord have the highest percentage of infection to BYDV-PAV in Iran (Aleosfoor *et al.*, 2007). In this region, farmers usually cultivate corn from early June to late September, and wheat in winter. Previous studies have shown that *R. padi* can migrate from corn field to the wheat field and infest that, so, the factors that can affect the population of this aphid on corn are important on others hosts (Bragg, 2011; Abotalebian, 2011). Aphids as a vector, virus, host plant, and the environment are parts of a feedback system that influence each other. The environment can affect another part especially the development, survival, and abundance of aphids (Finlay and Luck, 2011).

Aphids have various ways of adapting to different climates and geographical places (Tang *et al.*, 1999). Temperature is an abiotic factor that can influence the growth and development rate of insects (Bale, 2002). Although many studies have been done on the effect of temperature on life table of *R. padi*, most of them are limited to winter host (Dean, 1974; Lykouressis, 1985; Kieckhefer *et al.*, 1989; Elliot and Kieckhefer, 1989; Sengonca *et al.*, 1994; La Rossa *et al.*, 2005; Adams, 2007; Auad *et al.*, 2009; Karami *et al.*, 2010, 2016). There are only a few articles about the effect of temperature on *R. padi* development on summer host such as corn (Kuroli, 1984; Asin and Pons, 2001; Kuo *et al.*, 2006). It is necessary to know the effect of temperature as a key factor on life table parameters of this aphid, which is adaptable to the climate of the location. Because of a large number of generations (in the season), this aphid easily adapts to the climatic conditions of the habitat. It is known that the populations of *R. padi* inhabiting Iran and neighboring countries are

different from those features that are present in e.g. Central Europe. Therefore, direct literature comparisons of the parameters are not completely compatible.

In this study, we aimed to evaluate the development rates and population growth parameters of the bird cherry-oat aphid at seven levels. The main value of this kind of work is the ability to use these data in order to construct the model for studying population dynamics and for establishing management tactics for pest control.

MATERIALS AND METHODS

Insect Culture

The aphids used in this experiment were collected from corn fields (hybrid KSC704, dominant variety) in Agriculture and Natural Resources Research Center of Chahar Mahal Va Bakhtiari, Shahrekord, Iran (50.84E,32.30N), in late August when the population of *R. padi* was high. To rear aphids in laboratory conditions, at first, ears (cob) of corn were picked from the farm and they were infested with aphids and placed in dishes (25cm in diameter and 35cm height) covered with a net. Every week, a new cob was placed and the dried one was removed. These dishes were placed in growth chambers with a temperature of $25\pm 1^{\circ}\text{C}$, $50\pm 10\%$ RH, and 14:10 (L: D) hr photoperiods. Three weeks after breeding aphid population, apterous parthenogenesis aphids in the colony were used for the experiment and were placed in a Petri. After parthenogenesis, a nymph was kept, and the others were removed. The Nymphs of *R. padi* were reared at seven constant temperatures of 8.5, 15, 20, 25, 27.5, 29 and $31\pm 0.5^{\circ}\text{C}$, $65\pm 5\%$ RH, and 14L:10D photoperiod on corn (*Z. mays* L.), hybrid KSC.704. To rear *R. padi*, seedlings in the two-leaf stage were used. The temperature treatments were used to obtain the factors involved in this research and other studies, this temperature range was selected according to the characteristics of the insect, conditions, features and incubator fluctuations.

Experimental Conditions

A number of apterous parthenogenetic aphids were selected from the colony and one adult aphid was placed in each dish. After four hours, one nymph was kept and other nymphs were removed. To monitor the aphid biological parameters, a seedling of corn with 2 leaves was used in a petri dish (9 cm in diameter) and covered with wet cotton (to maintain moisture). The experiment was started with 66, 52, 42, 87, 82, and 84 replications at a temperature of, respectively, 8.5, 15, 20, 25, 27.5, 29 °C. When the aphids reached the adult stage, mortality and fecundity of aphids were counted at 24-hour intervals.

Demographic Analysis

Data were analyzed using age-stage, two-sex life table theory (Chi and Liu, 1985) and the method described by Chi (1988). The intrinsic rate of increase was estimated by using the iterative bisection method from the Euler-Lotka equation with age indexed from zero (Goodman, 1982):

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

The Net reproductive rate was calculated as:

$$R_0 = \sum_{x=0}^{\infty} l_x m_x \tag{2}$$

The mean generation time was calculated as:

$$T = \frac{\ln R_0}{r} \tag{3}$$

Doubling Time

$$DT = \frac{\ln 2}{r}$$

Finite rate of increase

$$\lambda = e^r$$

Life expectancy

$$e_x = \frac{T_x}{l_x}$$

Where, l_x is age-specific survivorship, m_x is age-specific fertility, and $l_x m_x$ age-specific maternity, e_x life expectancy, and q_x age-specific mortality. Their charts with real data were drawn at Excel (2010).

Statistical Analysis

Analysis of demographic parameters and other equations was calculated based on the above-mentioned methods. Biological characteristics such as development time, the longevity of adult, and life span at different temperatures were tested for normality using skewness and kurtosis test. If significant differences were detected, multiple comparisons were made using Tukey's test ($P < 0.05$, SPSS 16.0). Population growth parameters were obtained by using the Bootstrap method and using computer program Two Sex-MS Chart (Chi, 2019). The mean and standard errors of parameters of λ , r_m , DT and R_0 were calculated using the bootstrap technique (Tibshirani and Efron, 1993), 10,000 replications were used in this study (Huang and Chi, 2012).

A paired bootstrap test procedure was used to detect the difference among treatments based on the confidence interval of differences (Chi, 2019). Other calculations were done by Excel 2010 software. The figures were drawn with Sigma plot V.12.

RESULTS

Development Duration or Life Table Parameters and Biology

Analysis of the main Biological parameters of *R. padi* was obtained at different temperatures and shown in Table 1. Also, some of Life table parameters are presented in Figure 1. Life table parameters were not established at the temperature of 31 °C,



Table 1. The values of different life stages (Mean ± SE) of the bird cherry-oat aphid, *Rhopalosiphum padi* at six constant temperatures.

Temperature (°C)	Development time (Days)	Adult time (Days) ^a	Total (Days)
8.5	17.89±0.41 ^a (27)	12.16±1.48 ^a (25)	29.15±1.44 ^a (27)
15	12.32±0.16 ^b (38)	10.92±1.43 ^a (38)	21.87±0.16 ^b (38)
20	7.81±0.22 ^c (32)	8.61±0.81 ^a (31)	16.42±0.87 ^c (32)
25	5.48±1.18 ^d (42)	3.62±0.38 ^b (26)	7.71±0.39 ^d (42)
27.5	4.64±0.098 ^{de} (25)	4.25 ±0.68 ^b (12)	6.69±0.5 ^d (25)
29	4.91±0.09 ^{de} (48)	2.78±0.20 ^b (42)	7.40±0.22 ^d (48)
Pvalue	0.00	0.00	0.00
df	5. 204	5. 164	5. 209

^a Pre-oviposition + Oviposition + Post-oviposition, ^b Aphids died after exposure to 31 °C.

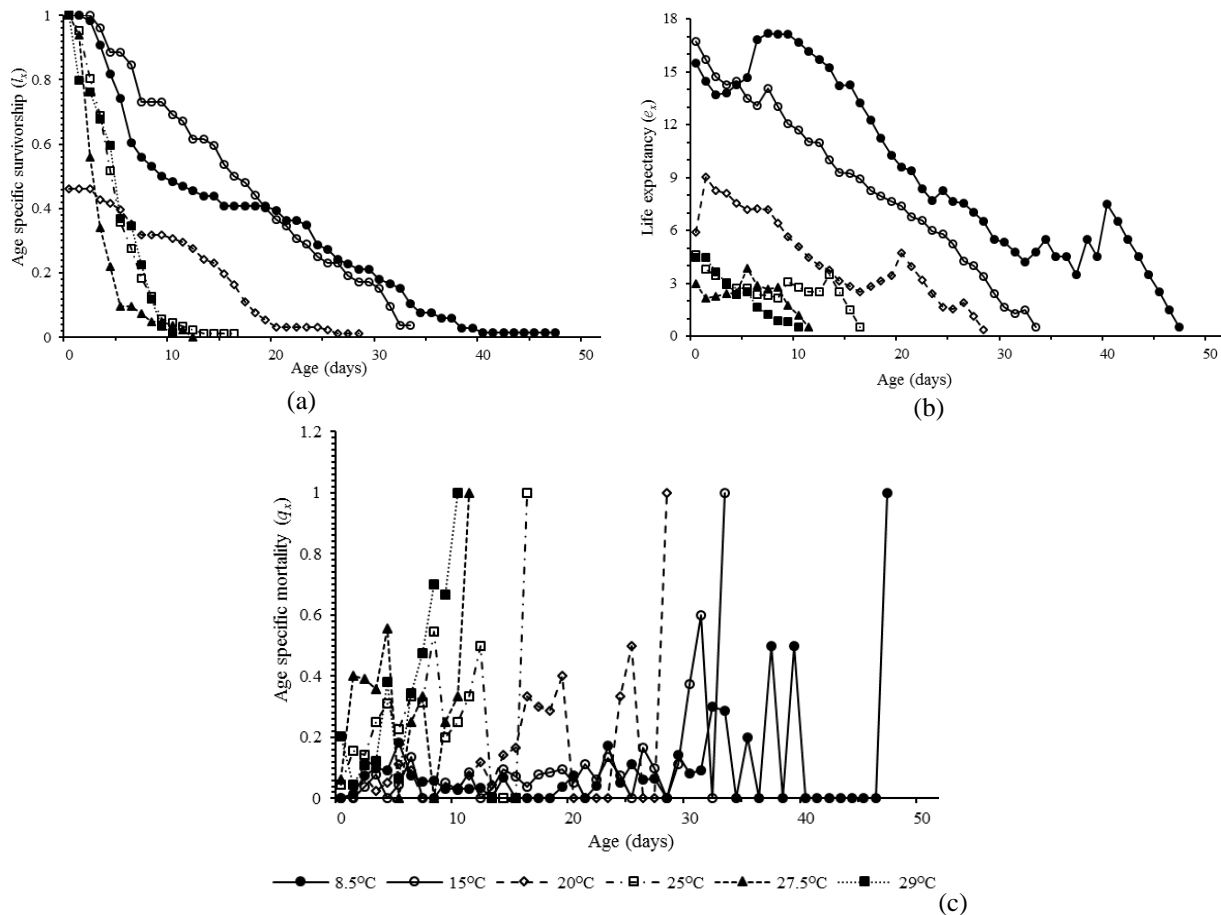


Figure 1. Changes in age-specific survivorship (l_x) [a] and Life expectancy (e_x) [b] and age-specific mortality (q_x) [c] of *Rhopalosiphum padi* from birth to death at six temperatures.

because at this temperature, nymphs could not complete their developmental stages and died before reaching the adult. When the last molting occurred, survival rates of nymph at

temperatures of 8.5, 15, 20, 25, 27.5 and 29 °C were 0.41, 0.69, 0.41, 0.52, 0.22, and 0.37, respectively. Development time decreased with increasing temperature, but for

immature stages, there was a slight increase at 29 °C. Age-specific mortality (q_x), increased with some fluctuations and, at the end of life, reached the highest value (Figure 1c).

Life Expectancy

Life expectancy at different temperatures was descending and increasing in some short time intervals, with the highest values of 17.18, 16.71, 9.02, 4.61, 3.87 and 4.44 day at the temperatures of 8.5, 15, 20, 25, 27.5, and 29 °C, respectively.

Fertility and Survival

Trends in age-specific survival rate (l_x) and age-specific fertility rate (m_x) of *R. padi* as a function of temperature are shown in Figure 2. Fertility of *R. padi* was started at days of 18.5, 10.5, 7.5, 4.5, 4.5 and 5.5. The highest values of age-specific fertility (m_x) were seen on days 22.5, 19.5, 11.5, 15.5, 8.5, and 9.5, with values of 3.11, 4.5, 5.53, 8, 5.75, and 6 nymphs/female/day at temperatures of 8.5, 15, 20, 25, 27.5 and 29 °C, respectively. After m_x reached the highest value, a gradual decline began with some fluctuations.

Population Growth Parameters

Parameters of the population were analyzed using the Bootstrap method (Table 2). Net reproductive rates of *R. padi* were 7.293 ± 1.003 , 23.671 ± 3.059 , 22.012 ± 1.271 , 6.430 ± 1.086 , 2.311 ± 0.775 , and 2.141 ± 0.391 females per generation, at temperatures of 8.5, 15, 20, 25, 27.5 and 29 °C, respectively. Intrinsic rate of increase (r_m) increased with temperature from 0.080, 0.170, 0.22, 0.23, and 0.14 to 0.130 per day at particular temperatures (Table 2). The r_m increased from 8.5 to 25 °C, and was highest at 25 °C, then decreased at 27.5 and 29 °C. Changes in the finite rate of increase (λ) were the same as in r_m . The temperature of 8.5 °C had the

highest values of T and DT , values of mean generation time, indicating an indirect relationship with increasing temperature. Doubling time, it showed a direct relationship interval temperature of 8.5 to 25 °C and a slight decrease was observed at the temperature of 27.5 °C.

DISCUSSION

In this research, relationship between temperatures and some parameters such as development time and population growth parameters were studied. The results showed a reduction in development time from 8.5-27.5 °C (from 17.89 to 4.64 d) with a slight increase in the temperature of 29 °C (4.91d). In fact, the values of development time declined with the increase in temperature (from 8.5 to 27.5 °C). However, the time required increased between 27.5 and 29 °C, indicating that upper developmental thresholds must be near 29 °C. In other research such as Asin and Pons (2001), a reduction was observed at 18 to 27.5 °C, and a slight increase at 30 °C and the upper developmental threshold was 30 °C. The same decline was seen at 12-24 °C by Auad *et al.* (2009) who calculated the high-temperature threshold between 27.5-29 °C. In fact, the results of Auad *et al.* (2009) are closer than the study of Asin and Pons (2001) to our results. Therefore, the difference could be attributed to the host plant, but it was not enough; also, they had different breeding methods for their study. A notable point is that they used colonies adapted to high-temperature condition; however, they used corn as the host plant.

Elliot and Kieckhefer (1989) found that, in the northern plains of the United States, the highest rate of development of *R. padi* on barley, as host-plant, was at the temperature of 25.09 °C (5.78 d). Dean (1974) found that developmental time decreased with temperature to a minimum at 25 °C on

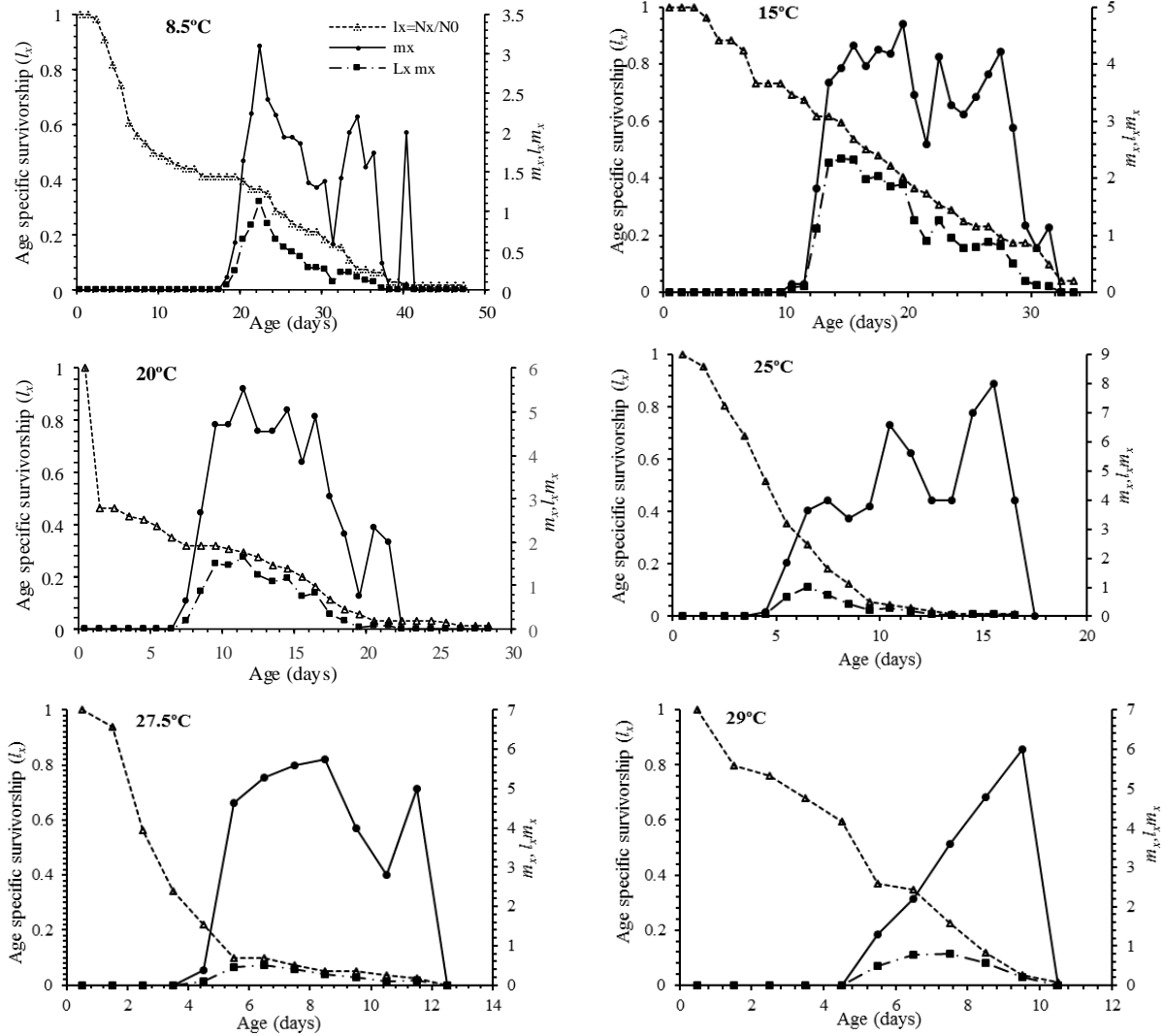


Figure 2. Changes in age-specific survivorship (l_x), age-specific fertility (m_x) and Age-specific maternity ($l_x m_x$) of *Rhopalosiphum padi* from birth to death at six temperature.

Table 2. Parameters of population growth (Mean±SE) of the bird cherry-oat aphid, *Rhopalosiphum padi* at six temperatures.^a

Temperature (°C)	Net Reproductive Rate (R_0)	Intrinsic Rate of Increase (r_m) (Day ⁻¹)	Mean generation time (T)(Day)	Doubling Time (DT) (Day)	Finite rate of increase (λ) (Day ⁻¹)
8.5	7.293±0.003 ^b	0.080±0.004 ^d	20/603±0.565 ^a	6.011±0.354 ^a	0.926±0.005 ^e
15	23.671±3.059 ^a	0.170±0.005 ^b	14.810±0.400 ^b	2.701±0.079 ^b	1.003±0.006 ^c
20	22.012±1.271 ^a	0.223±0.001 ^a	9.095±0.265 ^c	2.359±0.098 ^b	1.134±0.02 ^b
25	6.430±1.086 ^b	0.226±0.024 ^a	5.814±0.778 ^d	2.169±0.225 ^b	1.168±0.031 ^a
27.5	2.311±0.775 ^c	0.144±0.042 ^c	5.016±0.341 ^d	3.232±1.058 ^b	0.983±0.049 ^d
29	2.141±0.391 ^c	0.130±0.024 ^c	4.827±0.169 ^d	3.347±0.686 ^b	0.948±0.028 ^e

^a Means with the same letters in the columns are not significantly different (Paired Bootstrap Test $P \leq 0.05$).

clones from English barley. Kuroli (1984) found that the lowest developmental time of ontogenesis population of *R. padi* on corn was at 21 °C (among three temperatures of 17, 21, and 25 °C), but longer (8.2-9.6 d) than the minimum recorded by Dean (1974). Results of Descamps and Chopra (2011) on developmental time showed 5.10-6.50 days on different cereal crops at 24 °C, while in our study this value was 5.58 days.

Life cycle duration of *R. padi* was calculated by El Fatih *et al.* (2015) on wheat seedling at 15, 20, and 25 °C (12.77, 8.36, and 6.74 d, respectively). These values are quite different from the present study at the same temperatures (21.87, 16.18, and 7.71 d, respectively) but have the same decline in this range. This difference may be because of the errors, the conditions of experiment and colony with the special growth conditions, and the host plant. It seems that the values of the life cycle duration calculated by Kuo *et al.* (2006) on different species of *R. maidis* (51.7, 5.2 and 8 d at 6, 30, and 35 °C) do not match with *R. padi* in our research. However, according to the results of various studies that have been reviewed by Finlay and Luck (2011), aphids usually show a positive linear relationship between temperatures (7-25 °C) and development time, and a decline at temperatures higher than 25 °C. Nymphs of *R. padi* showed this pattern in this study and some other studies (Dean, 1974; Elliot and Kieckhefer, 1989; Sengonca *et al.*, 1994; Villanuevab and Strong, 1964; Zaidi, 1981).

Asin and Pons (2001) found that at 30 °C, 55% of individuals survived, while in our study at 30 and 31°C, immature aphids did not reach adult stages. Some previous studies showed that the constant temperature of 30 °C caused mortality rates of 100% (Dean, 1974; Villanuevab and Strong, 1964; Zaidi, 1981). In experiments of Auad *et al.* (2009) and Karami *et al.* (2010), the nymphal stage of *R. padi* died at 32 °C, before they reach the adult stage. The impact of temperature on the survival rate of *R. padi* in perennial grass pastures of South Australia, the mortality threshold for *R. padi* was found to be 32 °C, corresponding to an air temperature of 36 °C

(De Barro and Maelzer, 1993). According to the result of Campbell *et al.* (1974), increase in temperature extends mortality to the highest value; in fact, when the temperature is kept constant, higher temperatures will cause increased mortality because of changes in the structure of proteins or metabolic disturbances by toxic accumulation.

Intrinsic rate of increase (r_m), is a measure of the potential maximum rate of increase in the population per individual for comparing potential rates of increase for a nymph in an age reared under different conditions (Dixon, 1987). The maximum and minimum amount of r_m in this study were 0.08 and 0.23 (females female⁻¹ d⁻¹) for the temperature of 8.5-25°C. These values for Asin and Pons (2001) research on corn at temperatures of 18 and 30°C were 0.26 and 0.5 values of r_m increased from 18-27.5 °C and at a temperature of 30 showed a decrease (0.52 to 0.5 females female⁻¹ d⁻¹). The highest value was at 25 and 27.5 °C, somewhat similar to our results. Auad *et al.* (2009) understood that the highest value of the finite rate of increase ($\lambda=1.9$ nymphs/female/day) and the intrinsic rate of increase ($r_m=0.64$) was at 24 and 28 °C, respectively. The minimum value of r_m was 0.086 at 12 °C. Karami *et al.* (2016) showed that the r_m value was from 0.32 to 0.37 female/female/day on different barley (*Hordeum vulgare* L.) cultivars at 26±1 °C. In addition, on several different cereal crops at 24±1 °C, Descamps and Chopra (2011) found the value of the intrinsic rate of increase in the best host (beer barley) was $r_m=0.31$ females female⁻¹. Taheri *et al.* (2010) found that the highest and the lowest r_m values on different cultivars for this aphid were 0.38 day⁻¹ on Niknezhad, and 0.33 day⁻¹ on Darab cultivars. At 24 °C, compared to the present study, this difference can be due to different hosts. r_m for *R. padi* apterous nymphs reared at constant temperatures in most studies, increased from 10 to approximately 25°C (Finlay and Luck, 2011). Just one study provided data for r_m at a high temperature of 28 °C (Zaidi, 1981). The highest value of r_m was obtained at 25, 25, 26, 28 and 27°C in the researches of Karami *et al.*



(2010), Auad *et al.* (2009) and Asin and Pons (2001), respectively.

The highest net reproduction rates (R_0) (Table 2) occurred at 15 and 20 °C. This value in the results of Auad *et al.* (2009) was at 24 and 28 °C (13.42-13.88). At 16 and 20 °C, the R_0 values were 9.92 and 9.85, respectively. Karami *et al.* (2016) achieved the range of 43.83 to 60.65 female/female/generation for net reproductive rate (R_0) at 26 °C on different barley cultivars. Mean generation time (T) decreased with increasing temperature (Table 2). A significant decline in this interval was also observed by Sengonca *et al.* (1994) studying *R. padi* at the condition of 8 to 20 °C. The result of Auad *et al.* (2009) and Asin and Pons (2001) achieved the same results. In our study, life expectancy had an indirect relationship with temperature increase and had some fluctuations. A slight increase in life expectancy can be due to passing through a critical phase. In addition, age-specific mortality indicated a direct relationship with temperature. This result was consistent with Auad *et al.* (2009) and Asin and Pons (2001) studies.

Overall review of the information showed that aphids have the best growth conditions in the temperature range of 15-20 °C. The temperature of 25 °C, with the shortest growth period and the highest infinite rate of increase (r_m), has the best conditions. However, the most suitable temperature for population development was 26.5 °C in Asin and Pons (2001) study and 28 °C in Auad *et al.* (2009) research. The results of this research are used to obtain the upper and lower threshold of temperature to estimate the time of aphid migrations to other hosts and to manage the pest effectively. The highest net reproductive rate was at a temperature of 15°C, and highest values of r_m was at temperatures of 20 and 25°C. It could be concluded that a temperature of 20°C is the optimum temperature could be used to grow aphids. Research has shown that these values are consistent with what happens on the field and the population of *R. padi* increase at the optimum temperature range (Abotalebian, 2011).

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داده های انتخابی دموگرافی شته ی یولاف *Rhopalosiphum padi* L. روی ذرت
Zea mays L. در چند دمای ثابت آزمایشگاهی

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چکیده

شته یولاف، (*Rhopalosiphum padi* (L.)) یکی از آفات مهم غلات زمستانه و ذرت است. در این مطالعه فرآیندهای جدول زندگی شته *R. padi* در هفت دمای ثابت (5/8، 15، 20، 25، 27/5، 29 و 31±0/5 درجه سلسیوس)، رطوبت نسبی ۵±۶۵ درصد و دوره ی نوری ۱۴ ساعت روشنایی و ۱۰ ساعت تاریکی روی ذرت رقم KSC704 تعیین شد. کل طول دوره ی زندگی شته از زمان تولد تا مرگ با افزایش دما از ۸/۵ تا ۲۹ درجه سلسیوس کاهش یافت، اما طول مراحل پورگی در دمای ۲۹ درجه کمی افزایش نشان داد. بالاترین مقدار امید به زندگی (ex) برای مراحل پورگی در دمای ۸/۵ درجه مشاهده شد و در دمای ۳۱ درجه، تمام پوره ها پیش از رسیدن به بلوغ مردند. بالاترین درصد بقا برای مراحل پورگی در دمای ۱۵ و ۲۵ درجه سلسیوس بدست آمد و بالاترین نرخ خالص تولیدمثل (R0=۲۶/۶۳=ماده/نسل) در دمای ۱۵ درجه سلسیوس مشاهده شد. نرخ ذاتی افزایش جمعیت (rm) و نرخ نامتناهی افزایش جمعیت (λ) در فاصله ی دمایی ۸/۵ تا ۲۵ درجه سلسیوس افزایش یافت. در همین دامنه میانگین طول یک نسل (T) و مدت زمان دو برابر شدن جمعیت (DT) با افزایش دما کاهش یافت. با توجه به بالاترین مقدار λ (30/1) روز-۱ و rm (27/0) روز-۱ و همچنین مقادیر پایین T(89/6) روز و DT (56/2) روز، دمای ۲۵ درجه سلسیوس به عنوان بهترین دما برای این شته می باشد. اثر دما روی تولید مثل به خصوص اثر روی نرخ ذاتی افزایش جمعیت (rm) برای پیش بینی نوسانات جمعیت شته یولاف در دراز مدت و طی چندین نسل و هم چنین ایجاد مدیریت تلفیقی آفت و استراتژی مقابله با آن استفاده می شود.