

## Temperature Effects on Development and Life Table Parameters of *Tetranychus urticae* (Acari: Tetranychidae)

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### ABSTRACT

Development, reproduction and life table parameters of *Tetranychus urticae* Koch were determined on leaves of peach (G. H. Hale cultivar) at different temperatures, ranging from 13 to 33°C under laboratory conditions. No development was observed at 13°C. Egg-to-adult developmental time decreased gradually from 17 to 27°C and increased at higher temperatures (27 to 33°C). An average of 136.43 degree-days was required to complete development above the lower threshold temperature (13.79°C). Mean total egg productions per female were 40.09, 18.74, 8.03 and 21.33 at 25, 27, 30 and 33 °C, respectively. Mean longevities of the females were 12.91±1.65, 5.92±0.55, 3.56±0.54 and 6.53±0.56 days, respectively at the above mentioned temperatures. The intrinsic rate of increase ( $r_m$ ) at different temperatures ranged from 0.108 to 0.213 day<sup>-1</sup>, with the highest value recorded at 27 °C. The highest and the lowest values of the net reproductive rate ( $R_0$ ) were obtained at 25°C (16.87) and 30°C (4.18), respectively. Doubling time (DT) varied significantly at different temperatures and the shortest and longest values of this period were obtained at 27 and 30°C, respectively. The results suggested that *T. urticae* was able to develop and reproduce within a wide range of temperatures, and that temperatures from 27- 30°C are the most suitable conditions for the development, survivorship and reproduction of the mite.

**Keywords:** Development, Life table parameters, Peach, Temperature, *Tetranychus urticae*.

### INTRODUCTION

Peach (*Prunus persicae* Batsch) production is an emerging industry in Chaharmahal va Bakhtiari province, western Iran (Anonymous, 2008). A recent survey identified the key pests of peach in this province, which included two mite species: the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch, and *Schizotetranychus smirnovi* Wainstein (Acari: Tetranychidae) (Saeidi *et al.*, 2010).

*T. urticae* is an important pest of a variety of agricultural crops (Jeppson, 1975). Adults and immatures feed primarily on leaves producing tiny gray or silvery spots known as stippling damage. Damage to the leaves inhibits photosynthesis, and severe infestations can result in premature leaf fall, shoot dieback, and decreased plant vigor (Zhang, 2003). High infestation can also result in fruit feeding and damage.

Temperature is usually the environmental factor with the greatest effect on developmental rate of immature mites and other poikilotherms. To quantify the effect

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of temperature on mite development, life stages of a species may be held at constant temperatures and the resultant development times can be used to estimate developmental rate curves (Southwood, 1978). From these developmental rate curves, models can be formulated to predict development time as a function of temperature. These models are useful in making pest management decisions, or to be used as components of more comprehensive models for the investigation of population dynamics.

Several studies have investigated the effects of temperature on development and reproduction of tetranychid mites on different host plants, such as *T. urticae* on cotton (Carey and Bradley, 1982), *Tetranychus piercei* McGregor on banana (Yueguan et al., 2002), *Tetranychus truncatus* Ehara on mulberry (Sakunwarin et al., 2003), *Eutetranychus banksi* (McGregor) on sweet orange (Badii et al., 2003), *T. urticae* on beans (Parslika and Huszar, 2004), *T. urticae* on apple (Kasap, 2004), *T. turkestanii* Ugarov and Nikolski on eggplant (Nemati et al., 2005), *Amphitetranychus viennensis* (Zacher) (Ji et al., 2005), *T. turkestanii* on bean (Sohrabi and Shishehbor, 2008), *T. urticae* Koch on eggplant (Ju et al., 2008), *E. orientalis* (Klein) on Siris (Imani and Shishehbor, 2009), *Panonychus citri* on sweet orange (Kasap, 2009), *T. turkestanii* on cucumber (Karami Jamour, 2011) and *T. horridus* (Canestrini and Fanzago) on hazelnut (Pahlavan et al., 2012).

To our knowledge, however, few attempts have been made to determine the basic history such as developmental rate, survivorship, longevity, fecundity, sex ratio and life table parameters of *T. urticae* on fruit trees. Although it is one of the key pests of peach in Iran, the majority of biological studies on *T. urticae* have been conducted on host plants other than peach. Thus, the main objective of the present study is to determine the effects of various constant temperatures on the above-mentioned demographic parameters of *T. urticae* inhabiting detached peach leaves.

## MATERIALS AND METHODS

### Stock Culture of *T. urticae*

*T. urticae* specimens were collected from cucumber (*Cucumis sativa* L.) leaves at fields located around Shahrekord, Iran, and were used to start the culture. The collected mites were maintained on the detached sprouts and leaves of peach (G. H. Hale cultivar). Infested plants were kept in wood-framed rearing cages (120×60×60 cm) where the top and two sides were punched and covered with fine mesh gauze (120 µm aperture) for ventilation. There was an opening at one side the cage for inserting and removing plant foliage. They were maintained in the laboratory at 26±1°C, 50±10 RH. The photoperiod was 12: 12 (L: D) hours with illumination (4,000 lux) provided by fluorescent lamps. The plants were kept until they were severely damaged by the spider mites and then replaced by the new ones. After several generations, the mites from the stock colony were used for the tests.

### Preimaginal Development and Mortality Assessment

The study was done using leaf disk bioassays. Plastic Petri dishes (10 cm diameters) were used as test arenas. A layer of cotton was soaked in water and placed in the Petri dish. A detached peach leaf (G. H. Hale cultivar) was placed upside-down on the cotton wool in each arena. For individual studies, the leaf surface was divided into four equal areas using narrow strips of tissue paper. One mated adult female from the stock colony was transferred to each area of disk using a fine camel hair brush (size 000), and allowed to lay eggs. After 12 hours, the adult and all her eggs, except one, were removed. The study was conducted at 7 different temperatures: 13±1, 17±1, 20±1, 25±1, 27±1, 30±1 and 33±1°C. The humidity was 50±10 RH, and photoperiod

was 12: 12 (L: D) hours which correspond to the conditions prevailing in the area during the period where *T. urticae* is active on peach trees. Observations were made every 12 hours under a dissecting microscope (x100), to determine developmental time and mortality of individual mites. The presence of an exuvium indicated a successful molting. For calculation purposes, we assumed that molting or death occurred at the midpoint between two successive observations. Mites that were trapped in the wet cotton wad or tissue paper were excluded from the data analysis. The detached peach leaves were replaced every three or five days throughout the study period.

### Adult Longevity and Reproduction

Eggs laid by the females at different temperatures were allowed to develop and after emergence of adults, one female and one male were transferred onto a new test arena. Adult longevity and fecundity were recorded twice a day until the death of the last adult.

Eggs laid by each female were collected separately and maintained under the same conditions. After emergence of the adults, the sex ratio of the progeny was estimated daily at each temperature during the oviposition period.

### Data Analysis

Developmental time, mortality, longevity, fecundity and sex ratio under different constant temperatures were compared using ANOVA (SAS 9.0). Means were compared by Fisher's LSD method.

Developmental rates (1/developmental time) at different temperatures were fitted by a straight line, and the line's intercept with the abscissa was used as an estimate of the lower developmental threshold temperature (Arnold, 1959). The thermal unit required for development of each life stage was

calculated using the equation  $DD = D(T - t)$ , where  $D$  is the developmental duration (days),  $T$  is the temperature ( $^{\circ}\text{C}$ ), and  $t$  is the lower developmental threshold ( $^{\circ}\text{C}$ ) (Price, 1984).

Fertility life table parameters were estimated by combining data from the preimaginal development, and adult survival and reproduction experiments at different temperatures. The intrinsic rates of population increase were estimated by the following equation (Birch, 1948):  $\sum e^{-r_m x} l_x m_x = 1$ :

Where,  $x$  denotes age class,  $l_x$  is the proportion of female surviving to age  $x$  and  $m_x$  is the mean number of female progeny produced per female at age  $x$ .

Sex ratio of the offspring, reared at different temperatures, was estimated as described previously, and the results were incorporated in the data analysis to obtain  $m_x$ .

Furthermore, data were also used for calculating at each temperature: net reproduction rate ( $R_0 = \sum l_x m_x$ , number of female offspring produced per female), the finite rate of increase ( $\lambda = e^{r_m}$ , the factor at which the population increases per unit of time, a discrete form of intrinsic rate of increase), mean generation time ( $T = (\ln R_0) / r_m$ ), and doubling time ( $DT = (\ln 2) / r_m$ , number of days required for the population to double its size) (Birch, 1948). Differences in  $R_0$ ,  $T$ ,  $DT$ ,  $\lambda$ , and  $r_m$  values were tested for significance by estimating variances through the jackknife procedure (Maia *et al.*, 2000). This procedure is used mostly to estimate variances and bias of estimators and is based on repeated recalculation of the required estimator, missing out each sample in turn (Maia *et al.*, 2000).

## RESULTS

No eggs hatched at  $13^{\circ}\text{C}$ . At higher temperatures, developmental times of *T. urticae* were significantly different (Tables 1 and 2). Mean developmental times



**Table 1.** Female immature developmental time (Mean±SE, days) of *T. urticae* at different temperatures.

| Stage          | C°17             | C°20             | C°25             | C°27           | C°30            | C°33           |
|----------------|------------------|------------------|------------------|----------------|-----------------|----------------|
| Egg            | 9.66±1.11a       | 12.46±0.69b      | 3.70±0.15c       | 3.90±0.10c     | 3.92±0.18c      | 3.50±0.13c     |
| Range          | 8.00-14.00       | 11.00-12.00      | 3.00-5.04        | 2.04-5.10      | 3.00-6.00       | 4.00-5.80      |
| Larva          | 3.86±1.06a       | 3.64±0.93a       | 2.08±0.12b       | 0.88±0.07c     | 1.62±0.11b      | 1.64±0.07b     |
| Range          | 1.00-1.17        | 1.00-6.00        | 1.00-3.05        | 0.47-1.73      | 0.88-2.35       | 0.58-2.30      |
| Protochrysalis | 2.82±0.73a       | 2.50±0.63b       | 1.47±0.13c       | 0.67±0.05d     | 1.04±0.05e      | 0.88±0.07ed    |
| Range          | 1.08-6.17        | 1.00-4.00        | 0.93-3.00        | 0.43-1.60      | 0.85-1.890      | 0.50-2.10      |
| Protonymph     | 3.30±0.916a      | 2.34±0.49b       | 1.49±0.126c      | 0.76±0.05d     | 1.09±0.05e      | 1.26±0.07ce    |
| Range          | 2.00-6.13        | 1.00-3.00        | 0.93-2.96        | 0.42-1.51      | 0.88-2.08       | 0.93-2.01      |
| Deutochrysalis | 2.56±0.98a       | 2.11±0.57b       | 1.30±0.09c       | 0.89±0.08d     | 1.04±0.05cd     | 0.96±0.09cd    |
| Range          | 1.08-6.21        | 1.00-4.00        | 0.93-1.05        | 0.47-2.39      | 0.58-1.97       | 0.43-2.56      |
| Deutonymph     | 4.29±1.50a       | 2.54±0.74b       | 1.56±0.11c       | 1.12±0.05c     | 1.35±0.09c      | 1.44±0.09c     |
| Range          | 1.00-11.21       | 1.00-5.00        | 0.97-2.04        | 0.64-2.09      | 0.89-2.35       | 0.92-2.70      |
| Teliochrysalis | 3.84±1.02a       | 3.03±0.59b       | 1.69±0.14c       | 1.22±0.09c     | 1.19±0.07c      | 1.31±0.09c     |
| Range          | 2.00-7.00        | 1.00-4.00        | 0.97-2.98        | 0.27-3.02      | 0.89-2.04       | 0.72-2.73      |
| Total          | 30.33±3.25a      | 28.63±2.20b      | 13.23±0.25 C     | 9.43±0.18d     | 11.25±0.24e     | 11.03±0.30e    |
| Range (n)      | 24.00-40.00 (42) | 24.30-32.00 (35) | 11.00-16.10 (22) | 6.60-12.2 (35) | 9.10-14.55 (30) | 9.30-15.30(27) |

Means in a row followed by the same letter are not significantly different ( $\alpha=0.05$ , LSD).

**Table 2.** Male immature developmental time (Mean±SE, days) of *T. urticae* at different temperatures.

| Stage          | C°17             | C°20             | C°25            | C°27            | C°30           | C°33           |
|----------------|------------------|------------------|-----------------|-----------------|----------------|----------------|
| Egg            | 10.10±0.61a      | 10.90±0.53a      | 2.85±0.32c      | 3.84±0.17bc     | 4.29±0.07bc    | 2.58±0.32b     |
| Range          | 8.00-14.00       | 9.00-13.00       | 2.00-5.01       | 3.09-4.21       | 4.22-4.50      | 2.00-5.013     |
| Larva          | 3.02±0.14a       | 2.57±0.28ab      | 2.09±0.20b      | 0.98±0.153d     | 1.85±0.26bc    | 2.09±0.20c     |
| Range          | 2.00-4.00        | 1.00-4.00        | 1.05-3.00       | 0.47-1.93       | 1.08-2.29      | 1.05-3.00      |
| Protochrysalis | 2.37±0.31a       | 2.70±0.15a       | 1.49±0.15b      | 0.75±0.08c      | 1.01±0.04bc    | 1.49±0.15c     |
| Range          | 1.08-4.13        | 2.00-3.00        | 0.98-2.10       | 0.47-1.19       | 0.97-1.13      | 0.98-2.10      |
| Protonymph     | 2.08±0.20a       | 2.10±0.18a       | 1.52±0.14b      | 1.09±0.20b      | 1.02±0.02b     | 11.52±0.14b    |
| Range          | 0.94-3.10        | 1.00-3.00        | 0.94-2.02       | 0.47-2.47       | 1.00-1.10      | 0.94-2.02      |
| Deutochrysalis | 2.31±0.20a       | 1.7±0.153b       | 1.31±0.13bc     | 0.93±0.12cd     | 1.04±0.02cd    | 1.31±0.13d     |
| Range          | 1.08-3.21        | 1.00-2.00        | 0.93-2.05       | 0.46-1.43       | 1.00-1.08      | 1.00-2.05      |
| Deutonymph     | 2.80±0.27a       | 2.30±0.21a       | 10.41±0.14b     | 0.96±0.16b      | 1.130±0.16b    | 1.41±0.14b     |
| Range          | 1.83-4.01        | 1.00-3.00        | 1.01-2.05       | 0.54-2.26       | 0.64-1.60      | 1.01-2.05      |
| Teliochrysalis | 2.91±0.37a       | 1.30±0.15b       | 1.54±0.15b      | 1.21±0.12b      | 0.90±0.09b     | 1.54±0.15b     |
| Range          | 1.50-4.92        | 1.00-2.00        | 0.98-2.04       | 0.68-1.69       | 0.67-1.13      | 0.98-2.04      |
| Total          | 25.57±0.65 a     | 23.57±0.53b      | 12.23±0.41c     | 9.75±0.34d      | 11.25±0.47dc   | 11.19±0.41c    |
| Range (n)      | 22.54-29.40 (11) | 21.00-26.00 (10) | 10.60-16.10(13) | 8.30-11.36 (10) | 9.95-12.10 (4) | 8.80-13.97(13) |

Means in a row followed by the same letter are not significantly different ( $\alpha=0.05$ , LSD).

decreased with increasing temperature up to 27°C, then increased when temperature reached 30°C or above. Analysis of variance indicated significant differences in developmental times of females ( $F= 589.05$ ;  $df= 5, 185$ ;  $P< 0.0001$ ) and males ( $F= 204.37$ ;  $df= 5,55$ ;  $P< 0.0001$ ).

The lower temperature thresholds for completing the development of female and male *T. urticae* were 13.8 and 12.1°C, respectively (Table 3). The mean numbers of degree-days required by *T. urticae* for egg-to-adult were 136.43 and 152.58 DD, for female and male, respectively (Table 3).

Exposure of immature stages to 17 and 20°C resulted in emergence of winter-type females (diapausing females). At the remaining temperatures, ANOVA indicated no significant temperature effects on adult male longevity ( $F= 2.1$ ;  $df= 3,36$ ;  $P= 11.74$ ); in contrast, adult female longevities of *T. urticae* were significantly different among the different temperatures examined ( $F= 20.37$ ;  $df= 3,110$ ;  $P< 0.0001$ ), with the longest at 25°C (12.91 days) and the shortest at 30°C (3.56 days) (Table 4).

At 17 and 20°C, diapausing females laid no eggs. At the remaining temperatures, mean daily and total fecundity showed no consistent trends with temperature. An ANOVA indicated no significant

**Table 3.** The low temperature threshold (T) and thermal constant (DD) for complete development of *T. urticae*.

| Sex    | Parameters |                |              |
|--------|------------|----------------|--------------|
|        | T (°C)     | R <sup>2</sup> | DD±SE        |
| Female | 13.79      | 0.91           | 136.43±19.31 |
| Male   | 12.11      | 0.94           | 152.58±16.28 |

temperature effects on mean daily fecundity ( $F= 1.17$ ;  $df= 3, 110$ ;  $P= 0.3277$ ); however, mean total fecundities of *T. urticae* were significantly different among temperatures tested ( $F= 15.24$ ;  $df= 3, 110$ ;  $P< 0.0001$ ). The highest mean number of eggs was recorded at 25 °C (40.1±5.6 egg female<sup>-1</sup>) (Table 4).

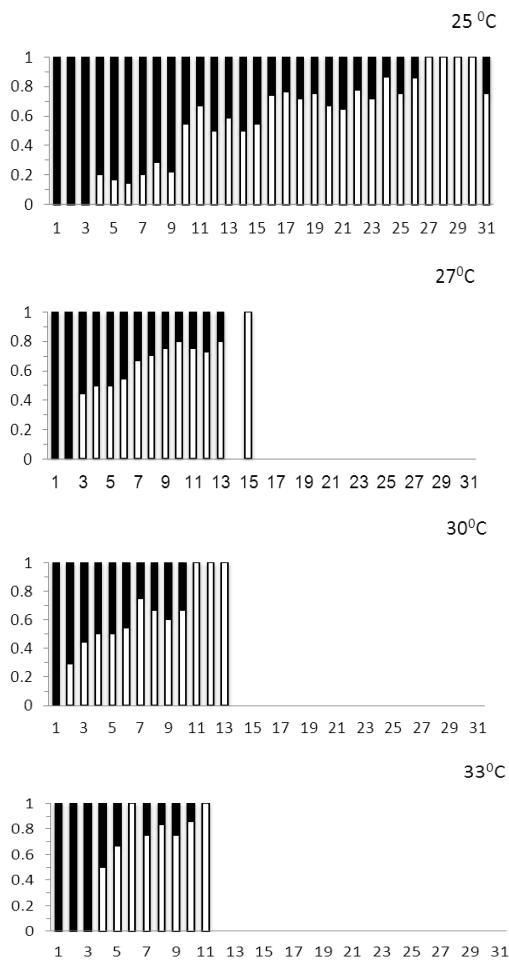
The sex ratios of *T. urticae* were 63, 78, 88 and 68% female at 25, 27, 30 and 33°C, respectively. At all tested temperatures, the sex ratio of progeny was male biased during the first 3-4 days of the oviposition period. However, in the following days and throughout the oviposition period, the sex ratio was female biased (Table 4 and Figure 1).

The demographic parameters of *T. urticae* at the four constant temperatures are given in Table 5. Estimated intrinsic rates of natural increase ( $r_m$ ) ranged from 0.108 day<sup>-1</sup>

**Table 4.** Female and male longevity (in days) and fecundity of *T. urticae* at different temperatures.

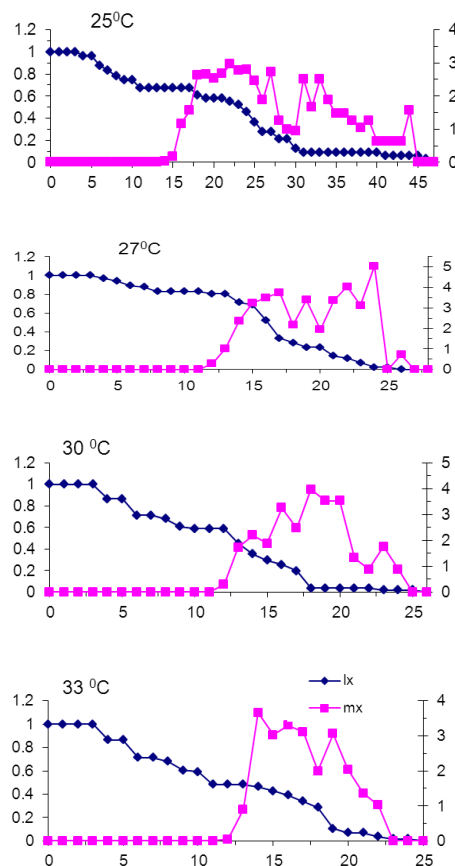
| Stage                  | 25°C           | 27°C           | 30°C           | 33°C           |
|------------------------|----------------|----------------|----------------|----------------|
| Preoviposition period  | 1.26± 0.13a    | 1.42± 0.13a    | 1.44± 0.12a    | 1.59± 0.13a    |
| Range (n)              | 0.0- 2.0 (22)  | 0.0- 3.6 (35)  | 0.5- 3.1 (30)  | 0.0- 3.0 (27)  |
| Oviposition period     | 11.30±1.60a    | 4.36± 0.55b    | 2.1± 0.5b      | 4.19± 0.5b     |
| Range (n)              | 0.0- 29.0 (22) | 0.0- 11.4 (35) | 0.0- 11.0 (30) | 0.0-9.0 (27)   |
| Postoviposition period | 0.47± 0.11a    | 0.37± 0.06a    | 0.22± 0.06a    | 1.04± 0.34b    |
| Range (n)              | 0.0-2.0 (22)   | 0- 1.1 (35)    | 0.0- 1.1 (30)  | 0.0- 1.0 (27)  |
| Female longevity       | 12.91± 1.65a   | 5.92± 0.55b    | 3.56± 0.54c    | 6.53± 0.56b    |
| Range (n)              | 2.0- 31.0 (22) | 0.4- 13.1 (35) | 0.5- 14.0 (30) | 1.2-13.0 (27)  |
| Male longevity         | 6.80± 1.13a    | 3.75± 0.62a    | 3.20± 1.66a    | 5.23± 0.93a    |
| Range (n)              | 1.0- 13.0 (13) | 0.5- 6.6(10)   | 0.9-8.0 (4)    | 0.7- 12.0 (13) |
| Daily fecundity        | 2.34± 0.26a    | 3.10± 0.55a    | 1.96± 0.38a    | 2.47± 0.54a    |
| Range (n)              | 0.0- 4.7 (22)  | 0.0- 7.0 (35)  | 0.0- 4.5 (30)  | 0.0- 5.4(27)   |
| Total fecundity        | 40.09± 5.57a   | 18.74± 2.61b   | 8.03± 1.78c    | 21.33± 3.07b   |
| Range (n)              | 0.0- 87.0 (22) | 0.0- 60.0 (35) | 0.0- 29.0 (30) | 0.0- 52.0 (27) |
| Sex Ratio (female %)   | 63             | 78             | 88             | 68             |

Means in a row followed by the same letter are not significantly different ( $\alpha= 0.05$ , LSD).



**Figure 1.** Offspring sex ratio of females of *T. urticae* reared at different constant temperatures. Egg samples were collected on all days throughout the oviposition period. At each sampling date, black and white bars indicate the percentages of males and female offspring, respectively.

for mites held at 30°C to a maximum rate of 0.213 day<sup>-1</sup> at 27°C (Table 5). The finite rate of increase ( $\lambda$ ) ranged from 1.114 at 30°C to 1.241 at 27°C (Table 5). The time required to double population size reached a minimum of only 3.24 days at 27°C. The net reproduction rate was highest at 25°C. Age-specific survivorship ( $l_x$ ) and fecundity ( $m_x$ ) curves derived from data at each



**Figure 2.** Survival rate ( $l_x$ ) and daily proportion of female progeny per female ( $m_x$ ) of *Tetranychus urticae*.

experimental temperature are illustrated in Figure 2.

### DISCUSSION

Immature developmental times of *T. urticae* at 17°C were 30.3 and 25.6 days for female and male, respectively, which are higher than those reported by Ju *et al.* (2008) on eggplant (25.8 days at 17°C) and Carey and Bradley (1982) on cotton (16.5 and 15 days for female and male, respectively at 18.3°C). Our findings at 20°C is higher than those of Kasap (2004) who reported 15.5 and 14.5 days for female and male, respectively, as duration of development on apple. At 25°C, our findings are close to

**Table 5.** Life table parameters of *T. urticae* reared at different temperatures.

| Stage     | 25°C              | 27°C             | 30°C             | 33°C              |
|-----------|-------------------|------------------|------------------|-------------------|
| $r_m$     | 0.144± 0.01 ab    | 0.213± 0.01 a    | 0.108± 0.02 c    | 0.146± 0.01 bc    |
| Range (n) | 0.10- 0.21 (22)   | 0.13- 0.33 (35)  | 0.03- 0.28 (30)  | 0.07- 0.25 (27)   |
| $R_0$     | 16.87± 2.33 a     | 12.10± 1.69 b    | 4.18± 0.93 c     | 6.99± 1.01 c      |
| Range (n) | 0.0- 36.7 (22)    | 0.0- 38.7 (35)   | 0.0- 15.1 (30)   | 0.0- 17.0 (27)    |
| $\lambda$ | 1.157± 0.01 ab    | 1.241± 0.01a     | 1.114± 0.02 c    | 1.163± 0.02 bc    |
| Range (n) | 1.10- 1.23 (22)   | 1.13- 1.38 (35)  | 1.03- 1.31 (30)  | 1.07- 1.47 (27)   |
| $T$       | 19.32± 0.65 a     | 11.68± 0.41 b    | 13.28± 0.48 c    | 13.47± 0.23 c     |
| Range (n) | 15.60- 28.06 (22) | 8.86- 20.64 (35) | 6.93- 23.43 (30) | 10.56- 16.47 (27) |
| $DT$      | 4.74± 0.21 a      | 3.24± 0.15 b     | 6.42± 0.10 c     | 3.80± 0.34 ab     |
| Range (n) | 2.76- 6.35 (22)   | 1.48- 4.52 (35)  | 0.71- 10.74 (30) | 1.33- 7.17 (27)   |

$r_m$ : Intrinsic rate of natural increase (/day);  $R_0$ : Net reproductive rate;  $\lambda$ : Finite rate of increase;  $T$ : generation time (days),  $DT$ : Doubling time of the population size (days).

Means in a row followed by the same letter are not significantly different ( $\alpha=0.05$ , LSD).

those found by Ahmadi *et al.* (2007) (13.75 days) on lima bean, but higher than those found on different host plants at the same temperature: 11.7 days (Skirvin and Williams, 1999), 9.38 days (Razmjou *et al.*, 2009), 12.36 and 10.7 days for female and male, respectively (Rajakumar *et al.*, 2005) and 10.0 and 9.3 days (Kasap, 2004). Shih *et al.* (1976) reported that immature *T. urticae* required about 7.5 days to reach adulthood at 27°C, which was markedly lower than our results. The developmental time reported by Sedaratian *et al.* (2009) on different soybean genotypes varied from 7.6 to 8.8 days for female and from 7.1 to 8.4 days for male, which were shorter than the values obtained in the present study. At 30°C, our findings are considerably higher than those found in other studies (Inglinski and Rainwater, 1954; Kasap, 2004; Parslika and Huszar, 2004; Forghani *et al.*, 2006). Host plants, experimental conditions, as well as, mite strain may provide an explanation for longer or lower developmental times.

The lower temperature threshold of 12.1°C for males, computed by linear regression, is similar to the 12.8°C reported by Ju *et al.* (2008), but the value for that of females (13.8°C) is quite different from the 8.4°C reported by Kasap (2004) on apple and 12.5°C by Ju *et al.* (2008) on eggplant, suggesting different temperature adaptations among various populations. The mean number of degree-days required by *T.*

*urticae* to complete its development was 160.2 DD for females and 174.8 DD for males, which were higher than those estimated by Ju *et al.* (2008) on eggplant (80.5 and 74.7 DD for females and males, respectively); but lower than that reported by Kasap (2004) for female *T. urticae* (172.4 DD) on apple. These differences may be explained by the existence of three genetically distinct host races of *T. urticae* on peach, eggplant, and apple.

Longevity of the adult *T. urticae* determined in the present study is lower than those reported in other studies conducted at similar constant temperatures. Carey and Bradley (1982) found the mean longevity of females to be 14.71 and 9.71 days at 23.8 and 29.4°C respectively. Kasap (2004) reported the longevity of females to be 29.9, 25.9, 16.8 and 4.7 days at 20, 25, 30 and 35°C, respectively. Rajakumar *et al.* (2005) estimated that at 25°C female and male *T. urticae* lived for 18.7 and 12.1 days, respectively. Forghani *et al.* (2006) found that females and males lived for 20.8 and 19.2 days, respectively at 28°C. The scatter in development values among studies can be attributed to the effects of multiple factors, including: disparities in host plant suitability, the source of *T. urticae* stock colony, discrepancy in humidity and photoperiod conditions, in addition to the frequently of checking.



At 25°C, the mean total number of eggs laid by *T. urticae* in the present study was substantially lower than egg numbers recorded on different crops in several previous studies (Shih *et al.*, 1976; Parslika and Huszar, 2004; Rajakumar *et al.*, 2005; Karimi *et al.*, 2006; Ju *et al.*, 2008; Razmjou *et al.*, 2009; Sedaratian *et al.*, 2009; Saeidi, 2011).

Overall, the differences between our results and the findings in other studies can probably be attributed to the following three reasons: (i) the nutritional suitability of peach, (ii) the geographic origin and adaptation of the *T. urticae* population, and finally (iii) different laboratory conditions such as photoperiod and humidity.

According to our results, and independent of the tested temperatures, most of the eggs gave rise to male progeny in the first 3-4 days of oviposition period and thereafter to female progeny. The same trend has been observed in other tetranychid species such as *T. turkestanii* (Karami, 2011). According to Sabelis (1985), the male-biased progeny production at the beginning of the oviposition period could contribute to the early insemination of females that would afterwards start to disperse in search of a suitable host plant.

Over the four temperature regimes tested, female-biased sex ratios were consistently observed varying from 63 to 88% female progeny produced throughout their lifetime. A similar trend has also been reported for other tetranychid species such as *T. turkestanii* (Karami, 2011) and *T. evansi* Baker and Pritchard (Morales and McMurtry, 1987). However, Margolies and Wrensch (1996) reported that the sex ratio of *T. urticae* females exposed to a high temperature (32°C) was more male biased (53.6%) than for females exposed to a low temperature (22°C, 72.7%).

Effects of temperature and photoperiod on induction of diapauses in *T. urticae* had been studied by several researchers. Similar to our results, Bondarenko (1950) produced winter forms by exposing deutonymphs and adult females to a short day regime; Boudreaux

(1956) also obtained winter-type females by exposure of larvae and protonymphs to a short-day period. Furthermore, Veerman (1977) reported that exposure to 12: 12 (L: D) at 20 and 15°C induced diapause in adult female *T. urticae*.

All demographic parameters showed significant differences among the tested temperatures. In the present study, the intrinsic rate of natural increase ( $r_m$ ) was 0.144 day<sup>-1</sup> at 25°C, which is in agreement with the results of Ahmadi *et al.* (2007) and Karimi *et al.* (2006) who reported 0.142 and 0.130 as  $r_m$  on lima bean and sweet pepper, respectively, but in disagreement with other studies reporting values of 0.243 on apple (Kasap, 2004), 0.182 on bean (Pietrosiuk *et al.*, 2003), 0.214 on legume (Razmjou, 2009), 0.193 on peach (Yong Hao *et al.*, 2008) and varied from 0.233 to 0.392 on soybean (Sedaratian *et al.*, 20011). These latter values are higher than our findings. Shih *et al.* (1976) found that  $r_m$  of *T. urticae* was 0.336 at 27°C, which is considerably higher than our value (0.213). The intrinsic rate of natural increase reported by Rezaie (2010) on squash (0.22) and on cucumber (0.26) at 27°C is almost identical to what we found. Some possible reasons for these disagreements are physiological differences depending on the host plants, genetic differences as a result of laboratory rearing, as well as, different experimental conditions.

Our value of the net reproduction rate was considerably lower than those reported by Kasap (2004) on apple (92.19), Pietrosiuk *et al.* (2003) on bean (39.85) and Khanamani *et al.* (2012) on eggplant (25.8), at 25°C, while it was close to those reported by Rezaie (2010) on cucumber (12.6) and on squash (11.83) at 27°C. Karimi *et al.* (2006) estimated the finite rate of increase ( $\lambda$ ) to be 1.139 and 1.229 on sweet pepper and green bean, respectively at 25°C, which are close to ours (1.157). The finite rate of increase of *T. urticae* was 1.157 and 1.241 at 25 and 27°C, respectively. The former is similar to the finding by Pietrosiuk *et al.* (2003) on bean at 25°C (1.2) and the latter is in agreement with Rezaie (2010) on tomato



and bean (1.21), on squash (1.24) and on cucumber (1.29) at 27°C. Kasap (2004) estimated that the mean generation times of *T. urticae* were 22.09 and 16.58 days at 25 and 30°C, respectively while Rezaie (2010) reported 15.27 and 14.18 days at 27°C, respectively, which are considerably higher than our values at the same temperatures. However, at 27°C the generation time in Rezaie (2010) study on squash (11.39 days) is close to our finding. These differences indicate a possible role of host plants on demographic parameters of *T. urticae*.

The present study indicates that temperature is a substantial factor that can affect the reproduction and survival of *T. urticae*. Our results have several advantages: First, they can be used in mass-rearing projects. Thus, the optimum rearing temperature for development, survival, and fecundity can be chosen from our data. Furthermore, for pest management purposes, our data can be used in the construction of computer simulation models to predict *T. urticae* development and population dynamics. Finally, they can be utilized in order to develop biological control programs against *T. urticae* utilizing its predators, because to achieve this goal, creditable information on the developmental time and population growth parameters of *T. urticae* is necessary. To obtain practical information for controlling this mite in peach orchards, however, field studies should be undertaken to complement laboratory studies.

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### اثرات دما روی نمو و پارامترهای جدول زندگی کنه *Tetranychus urticae* Koch (Acari: Tetranychidae)

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#### چکیده

نمو، تولیدمثل و پارامترهای جدول زندگی کنه *T. urticae* Koch روی برگ هلو (رقم جی-اچ-هیل) در دماهای مختلف (۱۳-۳۳ درجه سلسیوس) در شرایط آزمایشگاهی مورد مطالعه قرار گرفت. در دمای ۱۳ درجه سلسیوس هیچگونه رشدی مشاهده نشد. مدت زمان رشد و نمو از تخم تا بالغ به تدریج از ۱۷ تا ۲۷ درجه سلسیوس کاهش یافت و سپس در دماهای بالاتر (۲۷ تا ۳۳) افزایش یافت. به طور متوسط ۱۳۶.۴۳ درجه-روز برای رشد و نمو در دماهای بیشتر از آستانه پائین رشد و نمو (۱۳/۷۹ درجه سلسیوس) مورد نیاز بود. بالغین ماده *T. urticae* به طور متوسط در دماهای ۲۵، ۲۷، ۳۰ و ۳۳ درجه سلسیوس به ترتیب ۴۰/۰۹، ۱۸/۷۴، ۸/۰۳ و ۲۱/۳۳ تخم گذاشتند و متوسط طول عمر آنها در دماهای مذکور به ترتیب  $12/91 \pm 1/65$ ،  $5/92 \pm 0/55$ ،  $3/56 \pm 0/54$  و  $6/53 \pm 0/56$  روز بود. نرخ ذاتی افزایش جمعیت ( $r_m$ ) از ۰/۱۰۸ تا ۰/۲۱۳ متغیر بود که بیشترین مقدار آن در دمای ۲۷ درجه سلسیوس به دست



آمد. بیشترین و کمترین مقدار نرخ خالص تولیدمثل ( $R_0$ ) به ترتیب در ۲۵ درجه سلسیوس (۱۶/۸۷) و ۳۰ درجه سلسیوس (۴/۱۸) به دست آمد. مدت زمان دو برابر شدن جمعیت ( $DT$ ) در دماهای مختلف به طور معنی داری متفاوت بود و کوتاهترین و بلندترین مقدار به ترتیب در ۲۷ و ۳۰ درجه سلسیوس محاسبه شدند. این نتایج نشان دادند که *T. urticae* توانست در دامنه وسیعی از دماها رشد یافته و تولید مثل نماید و از دماهای مورد مطالعه ۲۷-۳۰ درجه سلسیوس مناسبترین دماها برای رشد و بقا و تولیدمثل این کنه برآورد شدند.