

# Modeling Demographic Response to Constant Temperature in *Bryobia rubrioculus* (Acari: Tetranychidae)

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Received 8 March 2014 | Accepted 5 April 2014 | Published online 7 April 2014.

## Abstract

The demographic parameters of brown mite, *Bryobia rubrioculus* Scheuten were carried out in order to characterize the population growth potential at five constant temperatures: 20, 22.5, 25, 27.5 and 30°C, 60 ± 5 % RH and 16: 8 (L: D) h. The highest intrinsic rate of natural increase ( $r_m = 0.0243/\text{day}$ ), net reproductive rate ( $R_0 = 2.4 \text{ ♀/♀/T}$ ) and finite rate of increase ( $\lambda = 1.0245 \text{ day}^{-1}$ ) values were determined at 22.5°C. The mean generation time (T) of the population ranged from 22.7 days at 30°C to 45.8 days at 20°C. The maximum and minimum survival rates ( $l_x$ ) were recorded at 22.5°C and 30°C. Survivorship data ( $l_x$ ) of adult females were summarized and compared using the shape and scale parameters of the Weibull frequency distribution model across. The age specific fecundity data ( $m_x$ ) was modeled as a function of time by using Polynomial model. The lower temperature threshold ( $t$ ) and thermal constant ( $k$ ) of the immature stages were estimated using Ikemoto and Takai linear model to be 12.85°C and 279.7 degree days (DD), respectively. Of the non-linear models, the Analitis-1, Analitis-2, Analitis-3 and Analitis/Allahyari models were found to be the best for the modeling development rate of immature stages of *B. rubrioculus*. The optimal temperature for population growth of brown mite on apple was found at 22.5°C.

**Key words:** brown mite, immature survival, development time, modeling, population dynamics.

## Introduction

*Bryobia rubrioculus* Scheuten (Acari: Tetranychidae) infests many horticultural crops such as apple, sour cherry, sweet cherry and plum in the western Iran (Khanjani and Irani-Nejad 2009). This mite is thelytokious and eggs overwinter in the bark of fruit trees (Osakabe et al. 2000; İncekulak and Ecevit 2002). It prefers to feed on young leaves of host plants and can cause severe browning and sometimes whitish-grey spots on the upper surface of young or spur leaves by sucking. Severely damaged young leaves do not grow and usually fall (Osakabe et al. 2000; Kasap 2008).

Population development of *B. rubrioculus* depends on the ecological and biological conditions such as temperature and host plants (Kasap 2006). Understanding the influence of climatic factors on survival and reproduction of *B. rubrioculus* may provide insight to predicting population dynamics and efficacy of the subsequent management programs (Carey 1993). Demographic analysis have been widely applied to *B. rubrioculus* to quantify intrinsic potential for population growth using life tables (Herbert 1962; Kasap 2008; Honarparvar et al. 2012; Keshavarze-Jamshidian 2004). Life tables are an important tool in the study of population ecology, invasiveness of introduced species and estimating the potential damages (Sakai et al. 2001).

Temperature has a direct influence on the key life processes of survival, development, reproduction, and movement of poikilotherms and hence their population dynamics (Price 1997). The variability of thermal characteristics may be studied among species (Honek 1999), populations (Lee and Elliott, 1998), developmental stages (Honek and Kocourek, 1990), and with other ecological factors such as food source, especially when the developmental conditions are adverse (Golizadeh et al. 2007). Temperature driven rate models have been frequently used to predict the occurrence and seasonal population dynamics of pests (Tobin et al. 2001) and to model trophic interactions in various ecosystems associated with possible consequences of global warming (Logan et al. 2006). Models enable us to describe the reproductive capacity and survival curve and to compare data with similar average values, which differ in their temporal distribution (Kontodimas et al. 2007). The predictions degree-days is based on a linear relationship between temperature and development rate, which have been based on the thermal characteristic.

In recent years, economical importance of *B. rubrioculus* was remarkably increased and the population density of this mite was poorly investigated observed the difference among localities, plant genotypes and different temperature (Herbert 1962; Kasap et al. 2004; Kasap 2008; Honarparvar et al. 2012). The present study was primarily designed to provide data on the population dynamics of *B. rubrioculus* based on the age-stage, two-sex life table theory and then test the rate isomorphy for this species and compare several linear and nonlinear temperature-driven rate models that have been already proposed and are most commonly used for arthropods to determine the key bioclimatic parameters.

## Material and methods

Mite samples were collected from apple trees in Hamedan, western part of Iran (34°48'N, 48°28'E, 1830 m asl), on May 2010. The stock culture was maintained on apple trees (*Malus domestica* L. cv Golab) in a rearing chamber (25 ± 2°C, 65 ± 10 % RH, and 16:8-h (L: D)). This culture was the source of all mites used in this study. Mites were reared for at least three consecutive generations prior to the experiments. Studies were conducted on apple leaf discs (*Malus domestica* L. cv Golab) at 20, 22.5, 25, 27.5 and 30 ± 1°C, 65 ± 10 % RH, and a 16:8-h (L:D) photoperiod. Mature, but non-senescent apple leaf discs were used as experimental areas. Each area consisted of a leaf placed on a layer of filter paper over a polystyrene pad saturated with distilled water in a 100' 15-mm petri dish. Each leaf was covered with filter paper that had a 40-mm diameter opening in the center as a barrier to prevent the mites from escaping. Water was added daily to keep the filter paper and polystyrene pad moist, and to cover the base of the petri dish to prevent the mites from escaping. All leaves were placed ventral-side up. Leaf discs were renewed weekly, if necessary. Approximately 25 adult females from the stock culture were introduced onto each leaf disc and allowed to lay eggs for a 6-h period. Eggs were transferred one at a time and reared on a fresh leaf disc, as described above. Survival of the eggs and the subsequent stages (larva, protochrysalis, protonymph, deutochrysalis, deutonymph and teliochrysalis) carefully checked at least once a day. After emergence of the adults, duration of pre-oviposition, oviposition and post-oviposition periods as well as longevity, daily fecundity (eggs per day during reproduction period) and the total fecundity (eggs during reproduction period) were recorded for each temperature treatment. Assays were replicated 120 times.

## Statistical analysis

Data on pre-oviposition period, ovi-position period, female longevity, and total progeny per female were analyzed per temperature with one-way analysis of variance (ANOVA), and Tukey's multiple range test ( $P \leq 0.05$ ). The individual development rate values were modeled as linear and nonlinear functions of temperature. Ikemoto and Takai model (equation 1) (Ikemoto and Takai 2000) were fitted and used as a linear model to estimate the respective parameters, where  $D$  indicates the duration of development;  $t$ , the lower temperature threshold and  $k$ , the effective cumulative temperature.

$$DT = k + tD \quad [\text{equation 1}]$$

The individual development rate values were also modeled as nonlinear functions of temperature using nonlinear models (equation 2-5) to estimate the respective parameters, where  $T_{\min}$ ,  $T_{\text{opt}}$ , and  $T_{\max}$  indicates the bioclimatic parameters;  $a$ ,  $m$ ,  $n$  and  $p$ , are models' parameters.

Estimates of the models parameters were accomplished using nonlinear platform of JMP version 8.0.2 (SAS Institute 2009). Sum of squares error (*SSE*) is the objective that is to be minimized during the iteration process. The best fit of the model was assessed and decided on by comparing the *SSE* of each iteration result. The bioclimatic parameters (i.e.,  $T_{\text{Min}}$ ,  $T_{\text{Opt}}$ , and  $T_{\text{Max}}$ ) were either directly estimated by the fitted model or Model performance evaluation was made based on both goodness-of-fit and biological significance. We used the Akaike information criterion (AIC) to appraise goodness-of-fit of nonlinear models (Akaike 1974). AIC is decided as  $\text{AIC} = n \ln (SSE/n) + 2p$ , where  $n$  is the number of observations,  $p$  is the number of model parameters and *SSE* is the sum of squares for the model error term. The model that has the smallest value of AIC is considered the best. Bioclimatic criteria were compared with observed data to assess their biological significance.

According to the above mentioned reasons we used four nonlinear models:

$$\begin{array}{ll} \text{Analytis-1} & r(T) = P\delta^n(1-\delta)^m, \delta = \frac{T-T_{\min}}{T_{\max}-T_{\min}} \end{array} \quad \text{[equation 2]}$$

Analytis (1977)

$$\begin{array}{ll} \text{Analytis-2} & r(T) = [P\delta^n(1-\delta)]^m, \delta = \frac{T-T_{\min}}{T_{\max}-T_{\min}} \end{array} \quad \text{[equation 3]}$$

Analytis (1980)

$$\begin{array}{ll} \text{Analytis-1/Allahyari} & r(T) = P\delta^n(1-\delta^m), \delta = \frac{T-T_{\min}}{T_{\max}-T_{\min}} \end{array} \quad \text{[equation 4]}$$

Allahyari (2005)

$$\begin{array}{ll} \text{Analytis-3} & r(T) = a(T-T_{\min})^n(T_{\max}-T)^m \end{array} \quad \text{[equation 5]}$$

Analytis (1977)

All graphs were plotted by SigmaPlot version 11.0 (Systat Software, Inc. 2008). The life history raw data of all individuals were analyzed based on the age-stage, two sex life table theories (Chi and Liu 1985, Chi 1988) by using the TWOSEX-MSChart program. The means and standard errors of the population parameters were estimated using the Bootstrap method. The age-stage specific survival rate ( $s_{xj}$ ) (where  $x$  is the age and  $j$  is the stage), age-stage specific fecundity ( $f_{xj}$ ), age-specific survival rate ( $l_x$ ), age-specific fecundity ( $m_x$ ), and population parameters ( $r$ , intrinsic rate of increase;  $R_0$ , net reproductive rate; and  $T$ , the mean generation time) calculated accordingly. The intrinsic rate of increase is estimated by using iterative bisection method;

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1 \quad \text{[equation 6]}$$

with age indexed from 0 (Goodman 1982). To take stage differential into consideration, the  $l_x$  and  $m_x$  by the use of the following formulae:

$$l_x = \sum_{j=1}^k s_{xj} \quad \text{[equation 7]}$$

and

$$m_x = \frac{\sum_{j=1}^k s_{xj} f_{xj}}{\sum_{j=1}^k s_{xj}} \quad \text{[equation 8]}$$

where  $k$  is the number of stages (Chi and Liu 1985). As calculating life table is extremely time consuming and replication is impractical, we used the Bootstrap method to calculate the means and standard errors of the life table parameters. The mean generation time is defined as the time length that a population needs to increase to  $R_0$ -fold of its size (i.e.,  $e^{rT} = R_0$  or  $\lambda^T = R_0$ ) at the stable age-stage distribution. The mean generation time is calculated as  $T = \ln R_0 / r$ . The TWOSEX-MS Chart program is available at <http://140.120.197.172/ecology> (Chi 2008).

The Weibull frequency distribution was applied to describe the age-specific survival rate ( $l_x$ ) of the adult female [equation 9]. In Weibull model,  $b$  is the scale parameter that is inversely related to the mortality rate, and  $c$  is the shape parameter that allows the model to produce survival distributions of different forms, from exponential to an extreme inverted S shape (Kontodimas et al. 2007).

$$lx = a \exp\left(-\left[\frac{x}{b}\right]^c\right) \quad [\text{equation 9}]$$

Age-specific fecundity model ( $m_x$ ) was fitted to Polynomial [Equation 10], Tanigoshi and Browne (1978), Harcourt and Yee (1982).

$$mx = a_0 + a_1x^2 + a_3x^3 + a_4x^4 + a_5x^5 + a_6x^6 \quad [\text{equation 10}]$$

Both SSE and AIC were used to appraise goodness of fit of the nonlinear models, Weibul and Polynomial.

## Results

Brown mite mortality increased and longevity decreased significantly with increasing Temperatures (Fig. 2). Maximum longevity for adult females was attained at 20°C (62 d) followed by that at 22.5°C (58 d) (Fig. 2). The highest rate of mortality occurred at 30°C in which, survivorship rate ( $lx$ ) of *B. rubrioculus* decreased more sharply than at 27.5°C (Fig. 2).

When individuals of different stages are pooled together, we obtained the age-specific survival rate ( $l_x$ ). The curve  $l_x$  is the simplified version of  $s_{xj}$ . The important information of stage differentiation should not be observed in  $l_x$ . Distribution of the age specific survival rate of the adult female using the Weibull frequency distribution (Fig. 2). The weibull model is accordance with age specific survival rate ( $l_x$ ) data on 20°C as indicated low AIC value. The values of respective parameters obtained are presented in Table 3. The survival curve of brown mite on different temperatures was type I because in this study parameters  $c$  was  $> 1$  (Tingle and Copland 1989). Survival rate gradually decreased by an increase of temperature from 20°C -30 °C. The graphs of which could be seen in Fig 2. The survival rates in 27.5 and 30°C were steeper, than in 20°C, so, we could express, that the survival rate ( $l_x$ ) should be mostly affected in temperatures with steepest slopes and vice-versa (Fig. 2). The age-stage survival rates ( $s_{xj}$ ) of Brown mite at constant temperature are shown in Fig. 3. It shows the probability that an egg will survival to age  $x$  while in stage  $j$ . as the age-stage, life table takes the variable developmental rate among individuals into consideration, thus significant stage overlapping, could be observed. Acquisition of this result from our experiment, was an important achievement for our research, as it showed by us, that, the adults could emerge at different ages, and disproves as erroneous the possibility that the survival rate should be based on "female adult age".

Mites reared at lower temperatures produced offspring for a significantly longer period than mites at higher temperatures, ranging from 16 d (30°C) to 29 d (22.5°C) (Fig. 2). Oviposition was sharply reduced at 30°C. The highest progeny production was recorded on day 25 (0.5 eggs per female per d) at 30°C (Fig. 2). The gross maternity schedule ( $m_x$ ) fluctuated throughout the oviposition period, showing an asymmetrical pattern, skewed toward older individuals (Fig. 2). Data of age specific fecundity ( $m_x$ ) are compatible with polynomial model and give a good fit to data of age specific fecundity ( $m_x$ ) on 22.5°C (Fig. 2). The highest daily age specific fecundity ( $m_x$ ) of Brown mite was recorded on 30°C (0.50, ♀/d) and the lowest, at 20°C (0.20, ♀/d) (Fig. 2). The oviposition started at 27.5°C and arrived to its pick at 30°C. The mites were most fecund at 30°C (4.79 eggs per female); however; net maternity schedules ( $l_x m_x$ ) of the mite achieved its highest value at 22.5°C (Table 2).

The female age-specific fecundity ( $f_{x8}$ ) is plotted in Fig. 4. It is the mean fecundity of female adults at age  $x$ . The age-specific fecundity ( $m_x$ ) and the age-specific maternity ( $l_x m_x$ ) are also displayed in Fig. 4. The summation of the age-specific maternity over all age produces the net reproductive rate ( $R_0$ ). The  $f_{x8}$  is plotted with age indexed from egg stage. Thus, it is the correct fecundity curve. Chi & Su (2006) pointed out the problem of construction fecundity curve based on "adult" age.

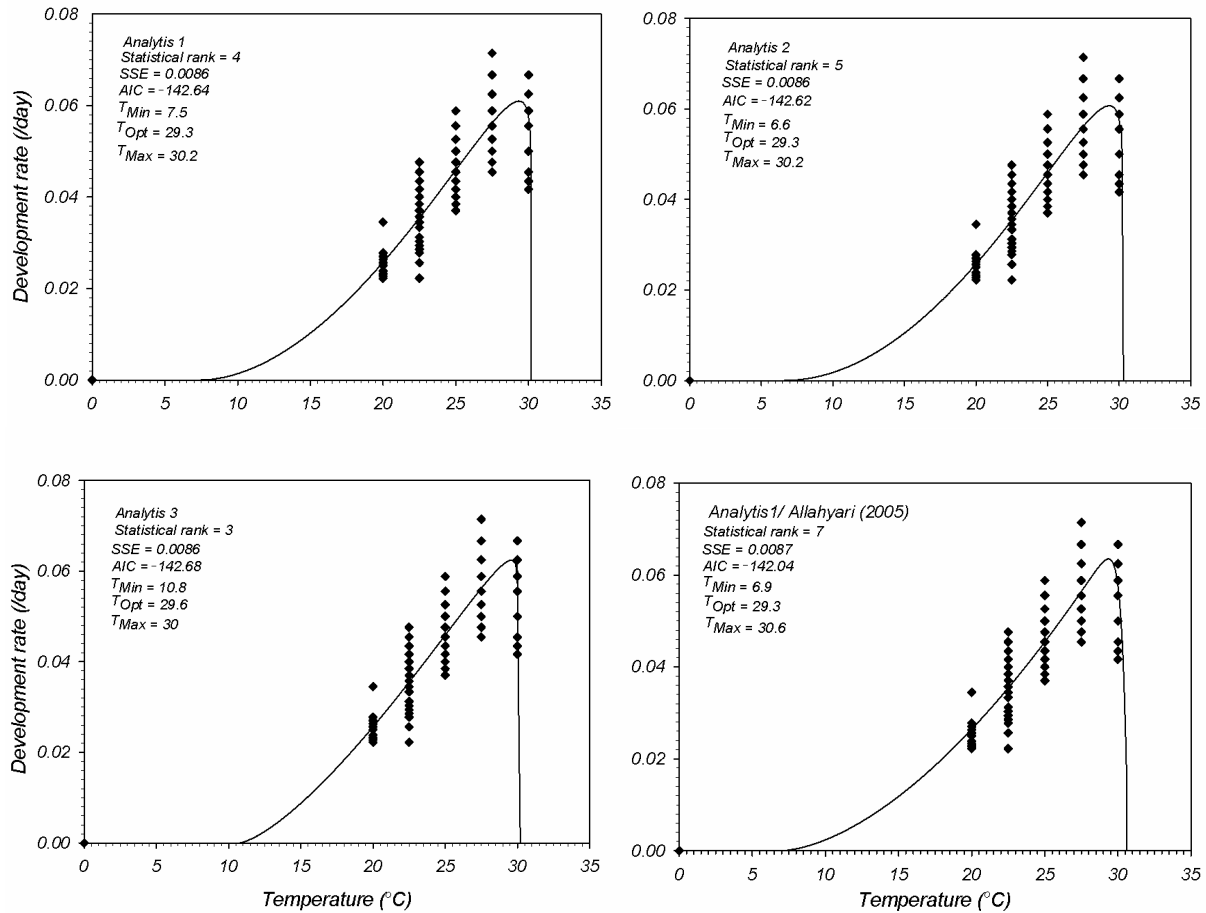
Net reproductive rates ( $R_0$ ), the average number of female offspring that would be born to a birth cohort of females during their life- time if they experienced a fixed pattern of age-specific birth and death rates (Carey, 1993), ranged from 0.11 females per female (20°C) to 2.4 females per female (22.5°C) ( $F_{4, 480} = 7.96$ ,  $P < 0.0001$ ) (Table 2). Analysis of the fertility life table columns indicated that the intrinsic rate of increase ( $r_m$ ) rose from -0.0483 to 0.0245 day<sup>-1</sup> ( $F_{4, 480} = 4.91$ ,  $P = 0.0007$ ). Mean generation time ( $T$ ), the time required for the mite population to increase by a factor equal to the net reproductive rate, were significantly reduced with increasing temperature over the range of temperature tested. The longest mean

generation time was observed on 20°C ( $F_{4, 480} = 268.69$ ,  $P < 0.0001$ ) (Table 2). The highest net reproductive rates ( $R_0 = 2.4 \text{ ♀/♀/T}$ ) were observed at 22.5°C, which is significantly higher than those in other experiment temperature. The lowest Finite Rate of Increase ( $\lambda = 0.9527 \text{ day}^{-1}$ ) was observed at 20°C ( $F_{4, 480} = 5.03$ ,  $P = 0.0006$ ) (Table 2).

**Table 1.** Lower temperature threshold ( $t$ ) and thermal constant ( $k$ ) of immature stages of *Bryobia rubrioculus* estimated by linear temperature-driven rate model at selected temperature ranges.

Stage	Temperature rang	Linear Regression		(°C)	$t$ (K) (DD)
		Equation	R <sup>2</sup>		
Egg	20–30	DT = 132.6 + 12.37D	0.983	12.4	132.6
Larva	20–30	DT = 20.64 + 13.88D	0.930	13.9	20.6
Protochrysalis	20–30	DT = 23.65 + 13.48D	0.994	13.5	23.65
Protonymph	20–30	DT = 22.26 + 13.60D	0.926	13.6	22.3
Deutochrysalis	20–30	DT = 21.83 + 14.27D	0.963	14.3	21.8
Deutonymph	20–30	DT = 21.27 + 14.39D	0.923	14.4	21.3
Teliochrysalis	20–30	DT = 30.67 + 12.98D	0.992	13.0	30.7
Immature	20–30	DT = 279.7 + 12.85D	0.981	12.9	279.7

Using Ikemoto & Takai linear model

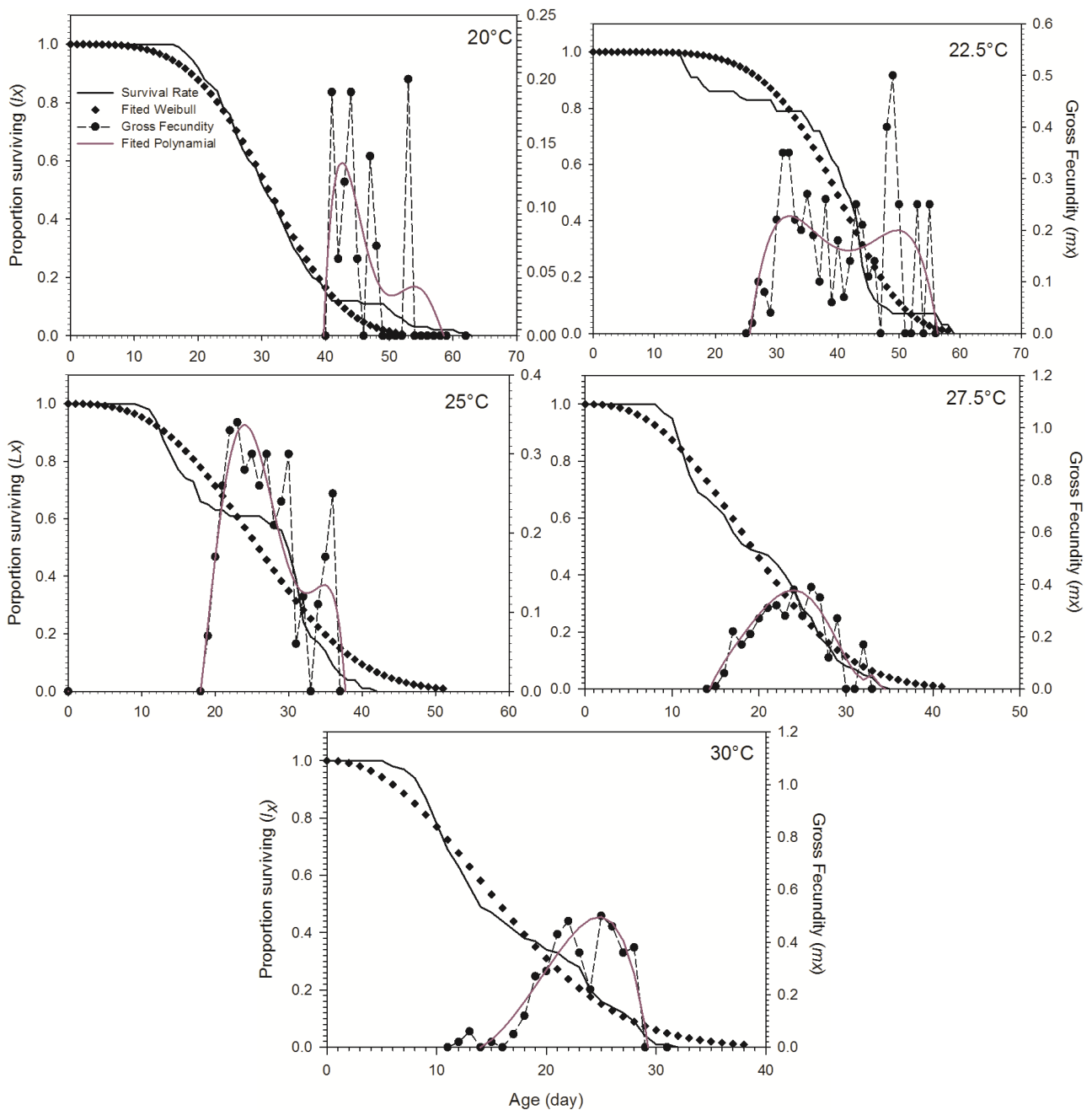


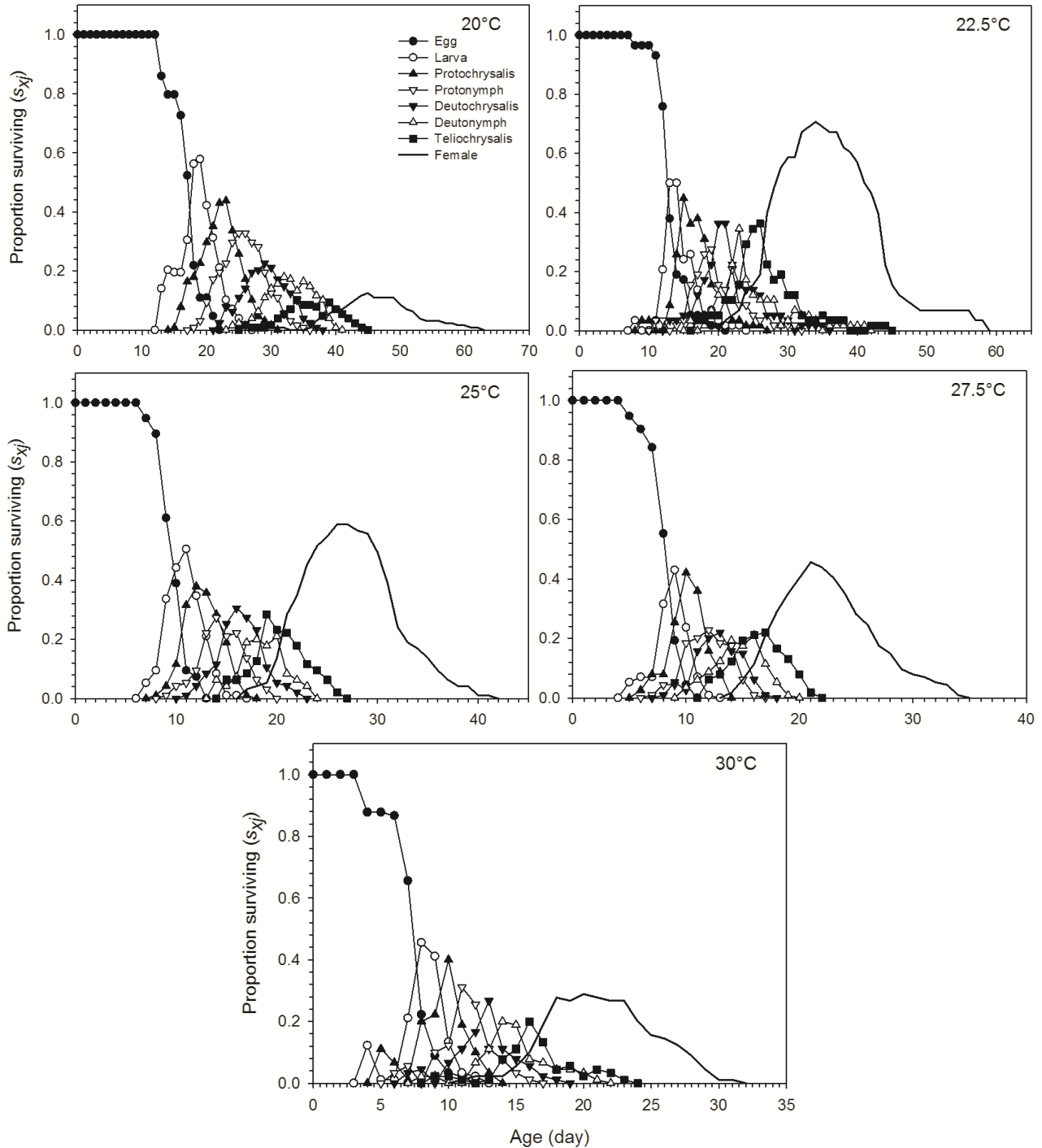
**Figure 1.** Observed (dots) and predicted (lines) development rate of entire immature stages of *Bryobia rubrioculus*. Predicted values are nonlinear models estimates. Critical temperatures ( $T_{Min}$ ,  $T_{Opt}$ ,  $T_{Max}$ ) computed using nonlinear platform of JMP software.

**Table 2.** Parameters related to potential rates of population increase of *Bryobia rubrioculus* at five constant temperatures.

Temperature (°C)	Net Reproductive Rate ( $R_0$ )	Intrinsic Rate of Increase ( $r_m$ )	Mean Generation Time ( $T$ )	Finite Rate of Increase ( $\lambda$ )
20	$0.11 \pm 0.06d$	$-0.0483 \pm 0.0170c$	$45.8 \pm 2.34a$	$0.9527 \pm 0.0957e$
22.5	$2.4 \pm 0.44a$	$0.0243 \pm 0.0051a$	$36 \pm 0.89b$	$1.0245 \pm 0.0053a$
25	$1.72 \pm 0.37b$	$0.0195 \pm 0.0082a$	$27.6 \pm 0.67d$	$1.0197 \pm 0.0081b$
27.5	$1.32 \pm 0.29c$	$0.0120 \pm 0.0095a$	$22.7 \pm 0.87c$	$1.0121 \pm 0.0096c$
30	$0.98 \pm 0.34d$	$-0.0009 \pm 0.016b$	$22.7 \pm 1.33c$	$0.9990 \pm 0.0165d$

Means in a column followed by the same letter do not differ significantly at  $P < 0.05$  level (Tukey's test).

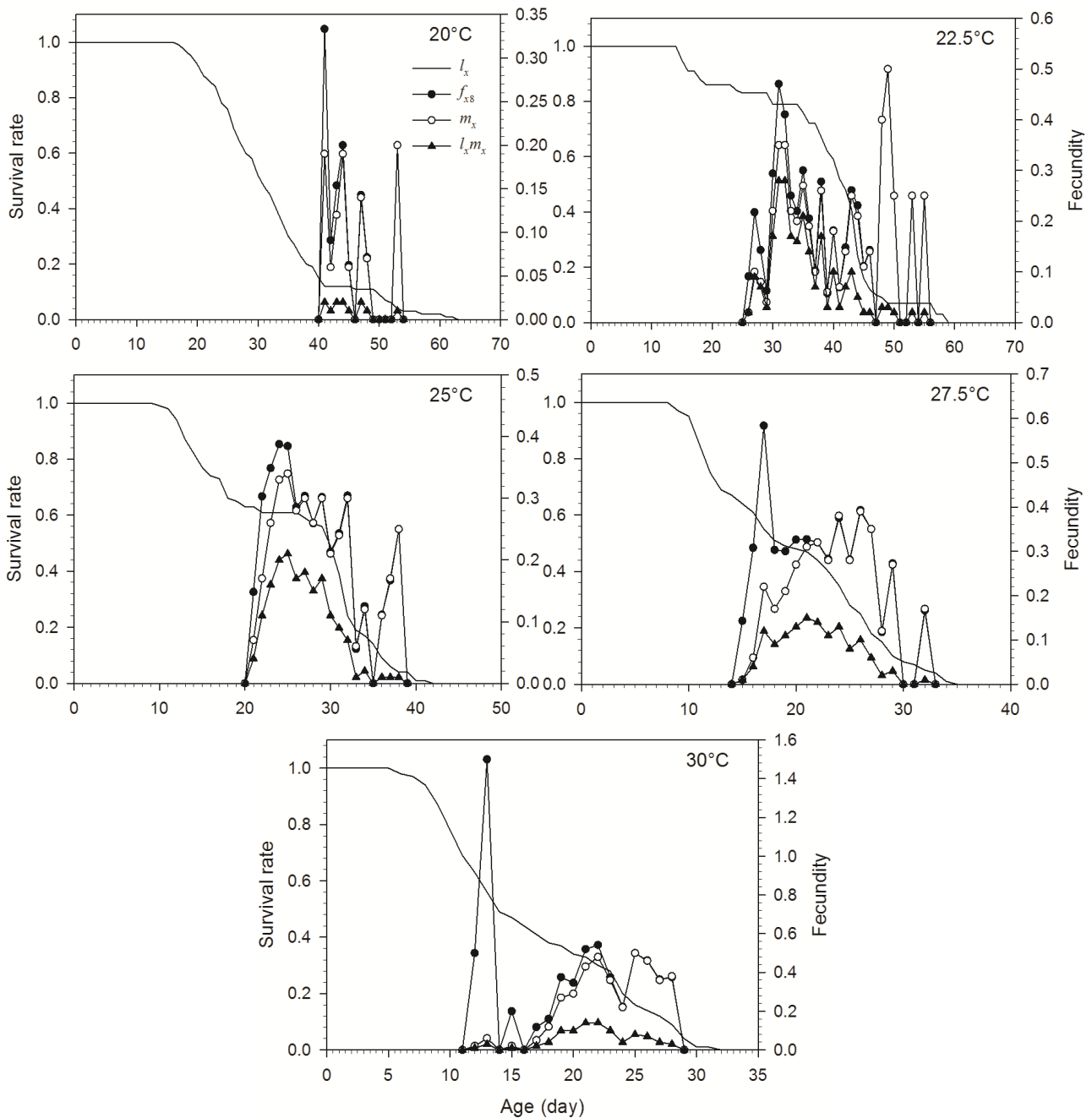
**Figure 2.** Observed Age-specific survival rate ( $l_x$ ) and Observed age-specific fecundity ( $m_x$ ) of *Bryobia rubrioculus* at five constant temperatures fitted to the Weibull's and Polynomial's estimates respectively.



**Figure 3.** Age-stage specific survival rate ( $s_{xj}$ ) of *Bryobia rubrioculus* at five constant temperatures.

The rates of development were positively correlated with the temperature until the upper limit of 30, followed by an inverse correlation. The estimated lower development threshold ( $t$ ) and the thermal constants ( $k$ ) of immature stages of apple brown mite, within particular temperature ranges, were estimated using all observed development rate data (Table 1).

Linear regression analysis (Ikemoto and Takai model 2000) estimated lower development threshold ( $t$ ) and the thermal constants ( $k$ ) of immature stages of *Bryobia rubrioculus*, at the temperature ranges (Table 1), the lower development threshold for total immature stage was estimated to be 12.85°C and based on the threshold of development mites required 279.7°C degrees-days for completeness of its life cycle (egg to adult) (thermal constant) ( $k$ ) (Table 1).



**Figure 4.** Age-specific survival rate ( $l_x$ ), female age-specific fecundity ( $f_{x8}$ ), age-specific fecundity ( $m_x$ ), and age-specific maternity ( $l_x m_x$ ) of *B. rubrioculus* at five constant temperatures.

The nonlinear models (equation 2, 3, 4, 5) fitted the development rate of entire immature time of brown mite. The Anallytis1, Anallytis 2, Anallytis 3 and Anallytis/Allahyari models give a good Estimation for entire immature stage data, Indicated by low AIC values. We selected four models, the data calculated and the values of respective parameters obtained are presented in fig. 1 Regarding these models, critical temperature ( $T_{Min}$ ,  $T_{Optm}$  and  $T_{Max}$ ) for the brown mite, *Bryobia*'s development are 7.5, 29.3 and 30.2, 6.6, 29.3 and 30.2, 10.8, 29.6 and 30.0, 6.9, 29.3 and 30.6°C respectively (Fig. 1).

## Discussion

Temperature is important factor in biology and life table parameters of the specific pest when measured in terms of survival, development and reproductive rates (Kasap 2004). *B. rubrioculus* individuals were capable of producing offspring across the studied temperatures. As expected, survival and fecundity of the mites



were greatly affected by temperature, showing temperature dependent patterns. Temperature-dependent survival and development time of *B. rubriulus* were precisely determined in this study under constant temperatures, which more closely resembled the actual temperature range of the local field during a typical apple growing season (Kasap 2006). Temperature expectedly influenced the survival and the time necessary for development through all immature stages. However, temperature effects were difficult to determine at 17.5 and 32.5°C because very few eggs hatched after a very long time, without any surviving to the next stage. It seems the temperatures (17.5 and 32.5°C) had a harmful effect on fecundity of *B. rubrioculus* compared to other temperatures therefore the true minimum and maximum effective temperature lies between 17.5°C and 32.5. Few researchers have studied the effect of temperature on survival and development of *B. rubrioculus* that they used insufficient points to accurately draw the development rate curve, especially around the optimum (Honarparvar 2010).

The phenomenon has been demonstrated by Honarparvar et al. (2012) whom observed with laboratory experiments that daily oviposition rate is directly dependent on the temperature. Their experiments showed that a temperature of 32.5°C was much less favorable for oviposition than 27.5°C, because mites discontinued laying gradually after mite become adult at the higher temperature, which conforms to our data.

In this survey adult longevity was significantly affected by various temperatures. The short adult longevity at 30°C suggests that brown mite are sensitive to warmer temperatures on apple and that temperatures > 30°C would be detrimental. Curve-fitting enable us to describe the reproductive capacity and survival of the mite and to compare data with similar average values, which differ in their temporal distribution (Kontodimas et al. 2007; Carey 1993). Weibull, and Polynomial models gave a satisfactory fit to our data over the temperature range tested, indicated by low values of SSE. However, at 20 and 22.5°C, Polynomial model slightly underestimated the peak of  $m_x$  rate (Fig. 1). It seems that Weibull model tends to overestimate  $lx$  close to the end of survival period, especially at 25, 27.5, and 30°C (Fig. 1). Therefore, they bracket the data and together correct tendencies to over and underestimate parameters of interest. The data obtained by us, could not be fitted with analytis model, but closer to the Weibull-fitted  $lx$ , although, there are problems, which need to be discussed. Firstly because, the Weibull  $lx$  has extended too much older age than the experimental data, and secondly, the Weibull function is a descending function, it gives always  $lx+1 < lx$ . But we should consider that, the real survival curves are seldom a smooth descending curve and sometimes there are no mortalities during a specific period or stage. All of these show that the use of Weibull function model should be reconsidered. Although, in our study of Apple brown mite, we used Weibull- $lx$  indexed from age 0 (the egg stage), and not “adult” age, so, we could express, that, our results of fittings are more real than those based on adult age (Chi and Su 2006)

**Table 3.** Goodness of fit and parameters of Weibull model fitted to the age specific survivorship ( $lx$ ) and Polynomial model fitted to the age specific gross maternity ( $Mx$ ) of brown mite at five constant temperatures.

Model	GF & P*	20°C	22.5°C	25°C	27.5°C	30°C
Weibull	SSE	0.07	0.26	0.24	0.06	0.07
	AIC	-410.21	-309.85	-207.18	-208.51	-184.15
	b	34.26	42.78	29.45	22.10	18.59
	c	3.79	5.10	2.81	2.53	2.15
Polynomial	SSE	0.11	0.41	0.07	0.08	0.11
	AIC	-84.37	-127.25	-99.11	-96.75	-84.37
	a0	6.01	-1.51	2.33	3.72	-0.00135
	a1	- 1.06	5.72	- 0.0021	- 3.23	0.000679
	a2	6.93	0.0002	0.0007	0.00009	- 0.009
	a3	- 0.0002	- 0.004	- 0.009	- 0.001	0.03
	a4	0.002		0.03	0.004	- 0.02
	a5	- 0.01			- 0.003	

The values are given as mean.\*Goodness of Fit (GF) and model Parameters (P); SSE is the residual Sum of Squares Error and AIC is Akaike Information Criterion.

Based on the Weibull parameters, the survival curve was type I on all studied temperatures, which indicated that the mortality mostly occurred in old individuals. In this type of survival curve, pest survivorship is initially high and decreases rapidly in late ages (Slobodkin 1962). Honarparvar (2010) indicated the highest

and the lowest age specific survival rate ( $l_x$ ) as: 38.77 and 12.02 days at 15 and 32.5°C for *Bryobia rubrioculus* on the Sweet cherry while we have found: 51.88 and 25.11 days at 20 and 30°C respectively.

The age specific fecundity ( $m_x$ ) curves of *Bryobia rubrioculus* is indicated varies value on different temperature which these curves revealed that the age specific fecundity schedule fluctuated throughout the oviposition period, showing an asymmetrical pattern, skewed toward older individual. The number of eggs laid per day increased according to the temperature from 20 to 27.5°C, where the maximum was attained ( $1.30 \pm 0.10$  eggs/female/day). Previous study were shown the number of daily fecundity was greatest between 22.5 and 27.5 °C. (Honarparvar et al. 2012). Kasap (2008) reported a daily fecundity of 1.3 and 1.2 eggs on Golden and Starking apple, respectively. The present findings showed that the daily fecundity at 25°C (1.3) was close to that observed by Kasap (2008) on apple and was lower than that reported by Honarparvar et al. (2012) at the same temperature of 25°C.

The life table parameters are a good tools for evaluate and understanding effects of temperature and host on the growth, survival, reproduction and increase rate of an insect (Bellows et al. 1992) and understanding of these values are important in Integrate pest management (Kanjani and Khalghani 2008).

The intrinsic rate of increase ( $r_m$ ) and fecundity have been used as indicators of the pest population performance and they are very important in relation to different pest population growth studies in particular in Tetranychid mites (Sabelis, 1985). The parameter  $r_m$  integrates the effects of mortality and fecundity into a single value, therefore, it is crucially influenced by a wide range of variables including preimaginal survival, developmental rate, longevity of females, fecundity schedule and sex ratio, which are all affected by temperature. The present study offers strong reason, from the viewpoint of mite population growth parameters, which there are significant differences among constant temperature. Apple brown mite maintained an  $r_m$  over -0.0483 per female per day above 20°C, with a maximum at 22.5°C (Table 2). A major point here is that the value of a life history trait in *B. rubrioculus* that would tend to lower the intrinsic rate of increase was frequently offset by the value of another that would tend to increase it. For example, at 30°C the low preimaginal survival was offset by a short preimaginal developmental time, and low progeny production was offset by a short generation time. The differentially influence of the available set of temperature-dependent life history variables on the  $r_m$ -temperature relationship (table 2). Previous studies using brown mites, has reported ,that the intrinsic rate of increase ( $r_m$ ), should increase gradually, by increasing temperature, and could attain a peak of 0.067at 20°C and then will decrease to 0.025 ♀/♀/d at 32.5°C (Honarparvar 2010) and 0.10 ♀/♀/d on Golden delicious and 0.11 ♀/♀/d on Starking at 25°C for the same mite (Kasap 2008). In the present study the  $r_m$  value of the brown mite was lower than those of this species on two apple cultivars and sweet cherry. The  $r_m$  value is an important parameter, describing the growth potential of a population under climatic and food conditions, because it reflects the overall effects of temperature and food on development, reproduction and survival characteristic of the populations (Southwood 1978). These variations determined on different plant cultivars might be due to the chemical contents, the food quality and the leaf texture of the host plants. These leaf characteristics are significantly related to oviposition and development rates of *B. rubrioculus* and they can play an important role in the direct defence to *B. rubrioculus*.

The lower developmental threshold for total immature stages was 12.58°C, which was higher than that of 4.9°C for the same mite on Sweet cherry (Honarparvar et al. 2012). A total of 279.7 DD (degree-days) above the threshold temperature was required to complete development from egg to adult while the thermal constant ( $k$ ) for the Immature stages were reported 400 DD for brown mite on Sweet cherry (Honarparvar et al., 2012),

The goal of nonlinear models is to find the curve that comes closest to the points. In this study, only four models (Analytis-1, Analytis-2, Analytis-3 and Analytis/Allahyari) were retained in each case based on goodness-of-fit and biological significance Although, Kontodimas et al. (2004) applied both the coefficient of determination ( $R_2$ ) and the residual sum of squares (RSS or SSE) to provide complementary information on goodness-of-fit and usefulness for predicting observations, there is no well-defined  $R_2$  statistic for nonlinear fits, and the  $R_2$  and RSS values do not provide fine discrimination between models with different number of parameters. Because the more parameters they have, the better the fit, we used the AIC, which is parameter independent (Akaike 1974). Furthermore, the ability to estimate key points (i.e.,  $T_{Min}$ ,  $T_{Opt}$ , and  $T_{Max}$ ) is extremely critical feature of such models. The Analytis-1, Analytis-2, Analytis-3 and Analytis/Allahyari (2005) models provided satisfactory estimates of  $T_{Min}$ ,  $T_{Opt}$  and  $T_{Max}$  for immature stages and were best models based on biological parameters with lower AIC than other models and gave a close fit to data obtained by us for the 20–30°C range of temperatures. Ullah et al. (2011) used non-linear thermodynamic

model (Ikemoto 2005; 2008), and they were observed the intrinsic optimum temperature and upper threshold temperature as: 24.0-37.2°C and 24.0-36.7°C for females and males of *Tetranychus merganser* Boudreaux and 25.0-38.7°C and 25.0-38.8°C for females and males of *T. kanzawai* Kishida respectively. Also Gotoh et al. (2010) used the non-linear Lactin-2 model, fitted to rates of egg to adult of *T. evansi* Baker & Pritchard and they were obtained the lower thermal thresholds, optimum developmental temperatures range and the upper developmental threshold range as: 11.9, 36.7 and 44.9°C. Obviously here the the lower thermal threshold, which was found by Gotoh and co-workers, on *T. evansi*, was similar to our findings on *B. rubrioculus*.

Finally, the current study was the first to evaluate the effect of temperature on demographic parameters of *B. rubrioculus* and provides direction for future research on evaluating the performance of *B. rubrioculus* and the efficiency of its natural enemies in orchards under variable environmental conditions. Our finding revealed that the population characteristics of *B. rubrioculus* are lower than those of the same mite on the other hosts (Honarparvar 2010) and 22.5°C is the most suitable temperature for population growth of *B. rubrioculus*.

### Acknowledgements

The authors are highly appreciated to Prof. Dr. Hsin Chi (Laboratory of Theoretical and Applied Ecology, Department of Entomology, National Chung Hsing University, Taichung 402, Taiwan, Republic of China) and Dr. Alinaghi Mirmoayedi (Department of Plant Protection, Faculty of Agriculture, Razi University, Kermanshah, Iran) for their valuable help in analysis and revision of the draft version.

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