J. Agric. Sci. Technol. (2023) Vol. 25(5): 1101-1114

Biological and Two-Sex Life Table Parameters of the Carob Moth, *Apomyelois* (=*Ectomyelois*) *ceratoniae* (Zeller, 1839) (Lep.: Pyralidae) at Various Constant Temperatures

K. Eyidozehi[1], S. Ravan[1*], M. Soufbaf[2], M. R. Razvan[3], and A. Khani[1]

ABSTRACT

Biological parameters and life tables are the most appropriate criteria for measuring a population's adaptation to environmental and dietary circumstances. The effects of temperatures 10, 14, 20, 25, 27, 30, 33, and 35°C on biological and life table parameters of the carob moth *Ectomyelois ceratoniae* (Zeller) [a 10:14 hour (D: L cycle) and 65±5% RH] were experimentally studied. Based on the age-stage, two-sex life table theory, data were analyzed at different temperatures. The findings indicated that by increasing temperature, the mean incubation period of eggs, larvae, pupae, total immature development time, and adult longevity change significantly. The Adult Pre-Oviposition Periods (APOP) were 1.75, 1.93, 1.14, 1.06, 1.06, 1.09, 0.68, and 0.68 days, with Total Pre-Oviposition Period of (TPOP), 110.56, 93.82, 81.59, 42.8, 39.3, 33.96, 30, and 27.96 days at the experimental temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C, respectively. At the study temperature, the total life span was 121.22, 101.15, 88.82, 48.02, 44.55, 39.53, 34.83, and 32.73 days, respectively. The intrinsic rates of increase (r) were -0.0016 d^{-1} at 10°C and 0.0085 d^{-1} at 30°C. The highest finite rate of population increase (λ) was 1.0086 at 30°C, and the minimum finite rate was 0.9915, at 35°C. At 35°C, the minimum mean generation Time (T) was 28.87 days. The net Reproductive rates (R0) were 0.83, 1.08, 1.1, 1.03, 1.03, 1.35, 1.02, and 0.78, at the experimental temperatures.

Keywords: Cohort-based life tables, Pomegranate, Rate of population increase.

INTRODUCTION

The pomegranate, *Punica granatum* L. (Lythraceae), is one of the tropical and semi-tropical fruit trees cultivated in Iran since ancient times (Shakeri and Dehghani, 2008). The carob moth, *Ectomyelois ceratoniae* Zeller (Lep.: Pyralidae), is a critical pest in pomegranate orchards in Iran (Al-lzzi, 1987) and date gardens in, for example, the United States and Tunisia causing substantial damage annually (Warner *et al*., 1990; Ranjbar *et al*., 2011; Kishani-Farahani *et al*., 2012; Soufbaf *et al*., 2018). In Iran, more than 80% of pomegranates are infested by this pest throughout the orchard and storage phases (Mozaffarian *et al*., 2007). The insects also damage pistachio and fig in Iran (Mehrnejad, 2002). Acacia, grapes, almonds, peanuts, oak, dates, carob, apricots, olives, apples, walnuts, peaches, oranges, another citrus, and dried fruits are some of the insect's other hosts (Gothilf, 1984; Mehrnejad, 2002). The economic damage caused by this insect varies depending on cultivars, climatic conditions, cultivation regions, and years. According to estimations, almost 30% of the overall crop per year is lost in Iran (Shakeri and Daneshvar, 2004). This insect leads to a premature drop of pomegranate blooms and fruits at the start of the season, followed by decay and penetration

[1] Department of Plant Protection, Faculty of Agriculture, University of Zabol, Zabol, Islamic Republic of Iran.
[2] Nuclear Agriculture Research School, Nuclear Science and Technology Research Institute, Karaj, Islamic Republic of Iran.
[3] Department of Mathematical Sciences, Sharif University of Technology, Tehran, Islamic Republic of Iran.
*Corresponding author; e-mail: SultanRavan@uoz.ac.ir

[DOI: 10.22034/jast.25.5.1101]

of saprophytic fungi and other organisms of the fruit in the garden and during storage (Shakeri, 2004). Since the pest spends its life inside the pomegranate fruit, the chance of success in chemical control remains low (Mamay *et al*., 2014). For this reason, in pest control, scientific studies have been focused on alternative methods, including mating disruption (Mamay *et al*., 2016), mass trapping (Mamay and Dağ, 2016), fruit bagging (Mamay, 2021), and mechanical management (Mamay, 2018).

Temperature affects the growth and development of poikilothermous organisms, including insects (Lamb, 1992; Golizadeh, 2009). Temperature is the most important factor that changes the rate of any biological process (Golizadeh, 2009). Temperature is also an essential abiotic element influencing insect population dynamics and ranges of biological activity. For example, low, high, and optimal temperature thresholds may be calculated for all phases of life. Different species have different thermal characteristics, including their populations, developmental phases, and other environmental factors, such as food sources (Gilbert and Raworth, 2002).

A life table is a significant tool in entomological studies as it is the foundation for categorizing age-specific mortality and insect survival, as well as providing precise information about a given cohort of insects (Carey, 2001), leading to a better understanding of the biology and improved integrated pest management programs. Accordingly, due to the widespread presence of this insect in different regions of Iran, the thermal life history of the pest was studied under laboratory conditions via cohort-based life tables.

MATERIALS AND METHODS

Rearing Insects

Infested fruits containing larvae or pupae of the carob moth were collected and taken to the laboratory, where some fruit were kept in wooden grated cages measuring 50×50×50 cm in a growth chamber. The infected pomegranates were carefully splitted, and larvae of various ages and their pupae were isolated and then raised at 10:14 hours (D: L) and 65±5% RH. After emergence, adult moths were collected using an oral aspirator and placed in oviposition cylinders. For hatching, eggs were moved to translucent nylon pouches of rectangular plastic. In the next phase, the bag's apertures were sealed shut to prevent freshly hatched larvae from escaping. Daily inspections of the eggs were carried out, and freshly-hatched larvae were removed.

Effect of Different Temperatures on Biological Parameters of Carob Moth

The influence of temperature on different biological parameters of carob moth was studied at eight temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C. In the laboratory, the number of even-aged eggs was recorded (up to 24 hours) on pomegranate, including the growth period of immature stages development period, time and mortality ratio (and adult) through pre-oviposition periods, oviposition and post-oviposition periods, and the number of eggs produced daily until the death of the last adult reared from eggs were recorded daily.

Effect of Different Temperatures on the Population Growth Parameters of Carob Moth

The growth chambers population growth parameters, such as the intrinsic population growth rate (r), finite rate of increase (λ), net Reproductive rate (R_0), mean generation Times (T), and Gross Reproductive Rate (GRR) of the carob moth were recorded at temperatures of 10, 14, 14, 20, 25, 27, 30, 33, and 35°C with a day-night cycle of 14:10 hour (L: D) at 65±5% RH. Other parameters included were age-stage specific survival rate (s_{xj}), where x is the insect's age in days and j developmental stage or period. This value shows the probability of the egg surviving up to age x while in the growth stage j. Likewise, the shift from one

[DOI: 10.22034/jast.25.5.1101]

developmental stage to the next is described by this characteristic. Age-stage fertility (f_{xj}) shows the number of males and females produced monthly. The life expectancy of the age steps (e_{xj}) indicates total length of time in which an organism is expected to survive up to age x and stage j.

Statistical Analyses

Data from experiments carried out at various temperatures, based on age-stage and step two sex life table theory, were analyzed using two sex-MSchart software (Chi, 2022). The mean and standard error of biological and life table correlates were calculated using the Bootstrap procedure (Huang and Chi, 2022), which involves randomly selecting a sample of n people from the same group of the same size and estimating the indicators with a certain number of repetitions (m) (in these experiments m= 100,000). All diagrams were produced using Sigma Plot software (2022).

RESULTS

Biological Parameters under Different Thermal Regimes

The results of the growth and development of immature stages of the carob moth are presented in Table 1. Regarding data analysis, the length of the incubation period (from egg to first instar larvae) indicated considerable variance among the studied temperatures ($P< 0.01$). The length of the egg incubation period at eight constant temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C was averaged as 11.00, 9.00, 7.68, 6.2, 6.2, 2.95, 2.41, and 2.42 days, respectively (Table 1). The egg incubation period decreased from 10 to 35°C. The larval period differed considerably among the studied temperatures ($P< 0.01$). Larval periods at 10, 14, 20, 25, 27, 30, 33 and 35°C were 74.63, 65.00, 58.12, 27.07, 25.00, 24.23, 21.1 and 19.00 days, respectively (Table 1).

As given in Table 1, the pupal stage lasted 23.00, 17.95, 14.3, 8.4, 7.00, 5.77, 5.75, and 5.75 days at each temperature, which was statistically significant at 1% ($P< 0.01$). At 10 and 35°C, the longest and shortest pupal durations were 23.00 and 5.75 days, respectively. The pupal period was also influenced by temperature, decreasing from 23.00 days at 10°C to 5.75 days at 35°C.

In general, the immature stages total time (from egg to adult appearance) at temperatures of 10, 14, 20, 25, 27, 30, 33 and 35°C were 108.63, 91.95, 80.1, 41.67, 38.2, 32.95, 29.27 and 27.17 days, respectively ($P< 0.01$). The highest and minimum lengths of the immature stage were recorded at 10 and 35°C, respectively (Table 1).

Lifespan of the adults at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35 °C lasted for 12.58, 9.2, 8.72, 6.35, 6.35, 6.58, 5.57, and 5.57 days, respectively (Table 1). Furthermore, this research findings revealed that, like other insects, the growth rate of this species was affected by the temperature, so, increasing the temperature from 10 to 35°C decreased the duration of growth periods in all stages of development from egg to adult (Table 1).

Tables 1-3 show the length of a generation from egg to adult at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C. At these temperatures, one generation lasts 121.22, 101.15, 88.82, 48.02, 44.55, 39.53, 34.83 and 32.73 day, respectively. At 10 and 35°C, the maximum and minimum lengths of a generation period were 121.22 and 32.73 days, respectively. Furthermore, when the temperature increased from 10 to 35°C, the length of the generation time was reduced (Table 1).

At temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C, the Adult Pre-Oviposition Period (APOP) was 1.75, 1.93, 1.14, 1.06, 1.06, 1.09, 0.68, and 0.68 days, respectively. The greatest duration before oviposition was recorded at 10°C, and the shortest period was seen at 35°C (Table 2). At 10, 14, 20,

[DOI: 10.22034/jast.25.5.1101]

Table 1. Biological parameters (Mean±SE) of the carob moth, *E. ceratoniae,* at constant laboratory temperatures. ^{a}

Developmental stage↓/Temperature→	10	14	20	25	27	30	33	35
Incubation period (Day)	11.00±0.00^{a}	9.00±0.00^{b}	7.68±0.06^{c}	6.2±0.052^{d}	6.2±0.051^{de}	2.95±0.05^{f}	2.42±0.076^{gh}	2.42±0.075^{h}
Larval development time (Day)	74.63±0.07^{a}	65.00±0.00^{b}	58.12±0.42^{c}	27.07±0.04^{d}	25.00±0.00^{e}	24.23±0.06^{f}	21.1±0.03^{g}	19.00±0.00^{h}
Pupal period (Day)	23.00±0.00^{a}	17.95±0.05^{b}	14.3±0.068^{c}	8.4±0.064^{d}	7.0±0.00^{e}	5.77±0.065^{fg}	5.75±0.056^{g}	5.74±0.05^{gh}
Pre-adult (Day)	108.63±0.071^{a}	91.95±0.05^{b}	80.01±0.111^{c}	41.67±0.091^{d}	38.2±0.052^{e}	32.95±0.099^{f}	29.27±0.085^{g}	27.17±0.079^{h}
Adult longevity (Day)	12.58±0.064^{a}	9.2±0.052^{b}	8.72±0.059^{c}	6.35±0.071^{d}	6.35±0.071^{d}	6.25±0.064^{e}	5.57±0.065^{f}	5.56±0.065^{f}
Life cycle (Day)	121.22±0.109^{a}	101.15±0.062^{b}	88.82±0.131^{c}	48.02±0.122^{d}	44.55±0.96^{e}	39.53±0.125^{f}	34.83±0.107^{g}	32.73±0.1^{h}

^{a} (a-h) Different letters in each row indicate a significant difference ($P< 0.01$).

Table 2. Duration (Mean±SE) of oviposition periods and life span of male and female carob moth, *E. ceratoniae,* at constant laboratory temperatures. ^{a}

Stage↓/Temperature→	10	14	20	25	27	30	33	35
APOP (Day) ^{b}	1.75±0.125^{a}	1.93±0.189^{a}	1.14±0.069^{b}	1.066±0.081^{bd}	1.066±0.080^{cb}	1.00±0.0994^{be}	0.68±0.1102^{fg}	0.68±0.109^{g}
TPOP (Day) ^{c}	110.56±0.15^{a}	93.82±0.21^{b}	81.59±0.14^{c}	42.8±0.16^{d}	39.3±0.12^{e}	33.96±0.17^{f}	30.00±0.14^{g}	27.96±0.13^{h}
Adult longevity (Male)	12±0.05^{a}	9±0.052^{b}	9±0.05^{b}	6±0.071^{d}	6±0.071^{d}	7±0.064^{c}	6±0.065^{e}	6±0.065^{e}
Adult longevity (Female)	13±0.05^{a}	10±0.05^{b}	9±0.05^{c}	8±0.071^{d}	8±0.071^{d}	7±0.064^{e}	6±0.065^{f}	5±0.065^{g}
RepF/Fn	0.9143±0.0477^{a}	0.8286±0.0639^{b}	0.7714±0.0713^{c}	0.9091±0.0505^{a}	0.9091±0.0505^{a}	0.7576±0.0752^{d}	0.7576±0.0748^{d}	0.7576±0.0752^{d}

^{a} (a-h) Different letters in each row indicate a significant difference ($P< 0.01$). ^{b} Adult pre-oviposition period, ^{c} Total pre-oviposition period.

25, 27, 30, 33, and 35°C, Total Pre-Oviposition Period (TPOP) was 110, 93, 81, 42, 39, 33, 30 and 27 days, respectively. In Table 2, the highest male and female insect lifespans were computed at 10°C and the minimum at 35°C.

Life History Parameters under Different Thermal Regimes

Population growth parameters at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C are listed in Table 3. These results show that population indices, such as intrinsic population growth rate of increase (r), finite rate of population increase (λ), net Reproductive rate (R_0), mean generation Times (T), and Gross Reproductive Rate (GRR) of carob moth were significantly influenced by temperature. The net reproductive rate describes the population growth rate of each generation. At 10, 14, 20, 25, 27, 30, 33, and 35°C, this parameter was 0.83, 1.08, 1.1, 1.03, 1.03, 1.35, 1.03 and 0.78, respectively. The highest and minimum temperatures recorded for this parameter were 30 and 10°C, respectively. As the temperature rose, the net reproduction rate increased until it dropped to between 33 and 35°C (Table 3). This indicator, determined by multiplying the survival rate by the age-specific fertility (l_xm_x) rate, shows the population's reproductive capacity.

The most significant biological effect examined in insects is the intrinsic rate of population increase. This includes a variety of characteristics, such as Reproductive potential (R_0), age of first oviposition, and percentage of immature stage residues. The intrinsic birth rate is the population's per capita birth rate, while the intrinsic death rate is the population's per capita death rate. The intrinsic rate of population increase calculates the difference between birth and death rates. As a result, it may be considered the essential biological parameter for determining the suitability of habitat temperature for population development.

Table 3. Population growth parameters (Mean±SE) of the carob moth, *E. ceratoniae*, at constant laboratory temperatures. [a]

Population growth parameters↓/Temperature→	10	14	20	25	27	30	33	35
r (d^{-1})	-0.0016±0.001[ab]	0.00084±0.0016[a]	0.0011±0.0021[a]	0.00074±0.0037[a]	0.00081±0.0040[a]	0.0085±0.0052[a]	0.00106±0.0063[a]	-0.0084±0.006[ab]
λ (d^{-1})	0.9983±0.0012[a]	1.00084±0.0016[a]	1.0011±0.0021[a]	1.0007±0.0037[a]	1.0008±0.0040[a]	1.0086±0.0052[a]	1.0010±0.0063[a]	0.9915±0.0067[ab]
R_0 (Offspring/Individual)	0.8333±0.1132[b]	1.0833±0.1635[a]	1.1±0.1928[a]	1.0333±0.1643[a]	1.0333±0.1654[a]	1.35±0.2389[a]	1.0233±0.1971[a]	0.7833±0.1514[ab]
GRR (Female offspring)	0.83±0.113[a]	1.08±0.164[a]	1.1±0.193[a]	1.03±0.164[a]	1.03±0.165[a]	1.35±0.239[a]	1.03±0.197[a]	0.78±0.151[ab]
T (Day)	111.56±1.41[a]	94.76±1.18[b]	82.5±1.29[c]	44.03±0.98[d]	40.46±1.04[e]	34.91±0.54[f]	30.90±0.88[g]	28.87±0.59[h]
Nf/N	0.583±0.635[a]	0.5833±0.635[a]	0.5833±0.635[a]	0.55±0.0642[b]	0.55±0.0644[b]	0.55±0.0644[b]	0.55±0.0642[b]	0.55±0.0644[b]
f	1.43±0.117[c]	1.86±0.196[b]	1.89±0.26[b]	1.88±0.205[b]	1.88±0.205[b]	2.45±0.329[a]	1.88±0.285[b]	1.42±0.22[c]

[a] (a-g) Different letters in each row indicate a significant difference (P< 0.01).

The findings revealed that temperatures 10 and 30°C were the most adverse and favorable temperatures for increasing carob moth populations. This parameter's low value at 10°C is due to the low R_0 and lengthy Total Pre-Oviposition Period (TPOP). The intrinsic rate of increase in the carob moth population at various temperatures was significantly different (P< 0.0001), with the minimum intrinsic rate of population increase being -0.0016±0.001 d^{-1} at 10°C. The maximum value was 0.008±0.005 d^{-1}, calculated at 30°C (Table 3).

The finite rate of population growth refers to a daily rise in population over the previous day. Based on the analysis of the variance of estimated values for this population index, it was found that the values of this parameter at the examined temperatures differed significantly (P< 0.0001). At temperatures of 30 and 10°C, the highest finite rate of population increase was 1.008±0.005, and the minimum value was 0.998±0.001, respectively (Table 3).

Analysis of the variance of estimated values for the average generation length (T) indicated that there was a significant difference among the values computed for this parameter at different temperatures (P< 0.0001). Contrary to the intrinsic rate of population increase and net reproductive rate, the value of this parameter decreases with increasing temperature, until it reaches its minimum value (28.87) at 35°C (Table 3).

Temporal Patterns of the Life History Correlate

The age-stage survival rate (s_{xj}) depicts the pattern of developmental changes in various organisms and provides a complete description of the survival rate, helpful in adjusting developmental stages throughout the developmental period. It also illustrates the time spent by the carob moth in each development stage, one of the benefits of the age-growth-specific bisexual life table over standard table techniques. In general, these curves depict the probability of, for example, a newly-hatched larvae surviving at every age and stage of development, with the survival rate shown individually for distinct biological phases in these curves. The survivorship curves (s_{xj}) of the carob moth subjected to various treatments are shown in Figure 1. The final fatality at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C on days 121, 101, 88, 48, 46, 39, 34, and 32, respectively (Figure 1). These curves also revealed that the maximum survival rate was recorded at 10 °C and the minimum at 35 °C, suggesting that this temperature leads to an increase in immature mortality.

Figure 2 shows the age-specific survival rate (l_x) of the carob moth at various temperatures or the probability of survival of individuals up to age x. In addition to age-specific survival rates, this graph also shows age- stage-specific fertility (f_x) and age-specific fertility (m_x). The findings revealed that the carob moth could complete its life span at all tested temperatures and that oviposition occurs at various intensities (Figure 2). At age x and growth stage j, f_x depicts the offspring. Based on the data from this curve, oviposition started at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C on days 108, 91, 80, 41, 38, 32, 29, and 27, respectively.

The life expectancy (e_{xj}) curve depicts the total time an individual is expected to live up to age x and stage j, while life expectancy decreases as age increases. Changes in life expectancy and mortality rate are inversely associated; therefore, life expectancy is greatest in the initial days of life when the death rate is minimum. Figure 3 depicts age-specific life expectancy based on the development stage at various temperatures. The life expectancy in the adult stage at temperatures of 10, 14, 20, 25, 27, 30, 33, and 35°C for male insects is 12, 9, 9, 6, 6, 7, 6, and 6 days according to the data in this chart. Female insects lasted 13, 10, 9, 8, 8, 7, 6, and 6 days, respectively.

[DOI: 10.22034/jast.25.5.1101]

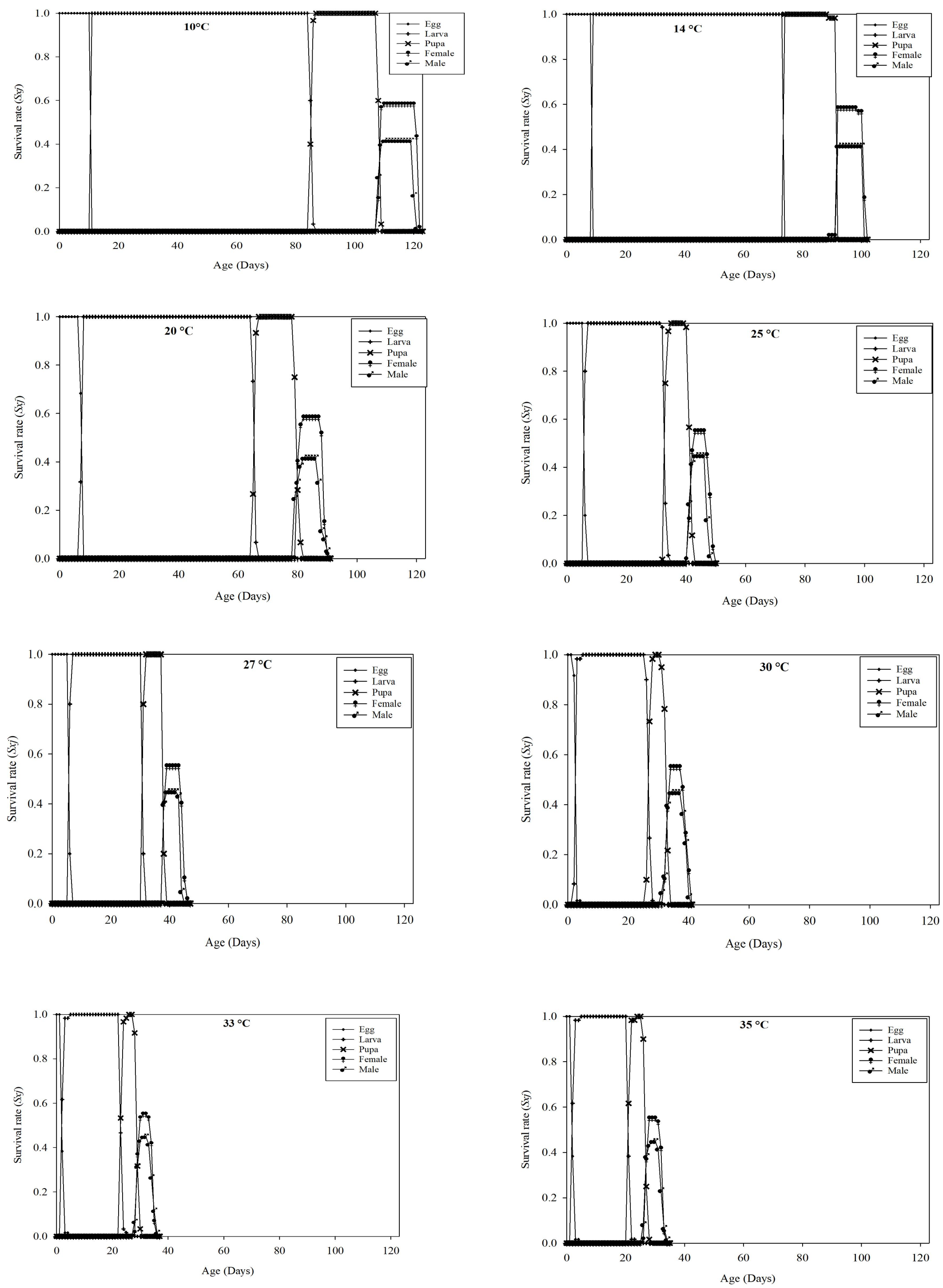

Figure 1. Age-stage survival rate (sxj) of the carob moth at different constant temperatures in the laboratory.

[DOI: 10.22034/jast.25.5.1101]

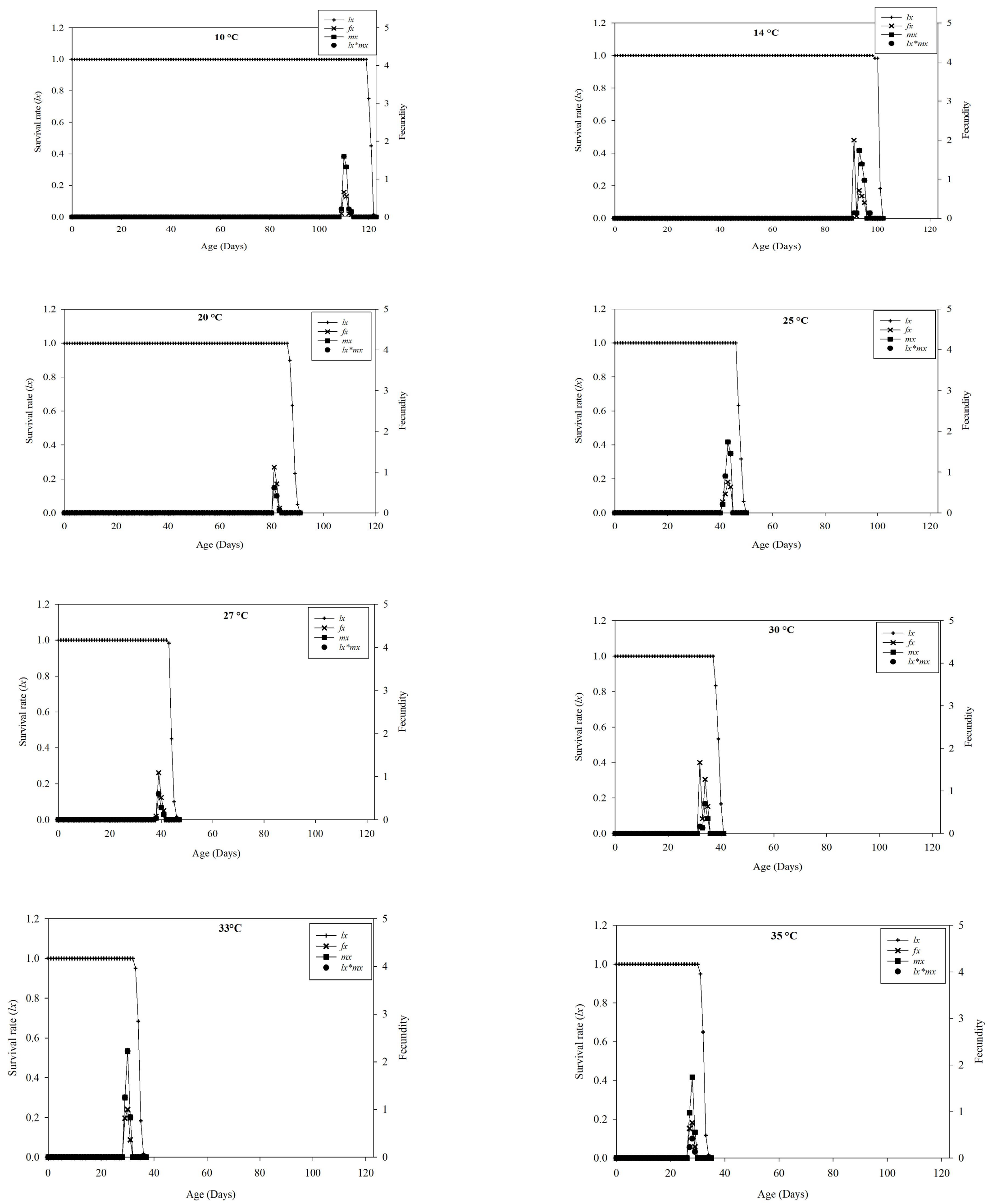

Figure 2. Age-specific survival rate (l_x), age-specific fertility (f_{xj}), fertility (m_x), and age-specific maternity (l_xm_x) of the carob moth (*E. ceratoniae*), at different temperatures in the laboratory.

[DOI: 10.22034/jast.25.5.1101]

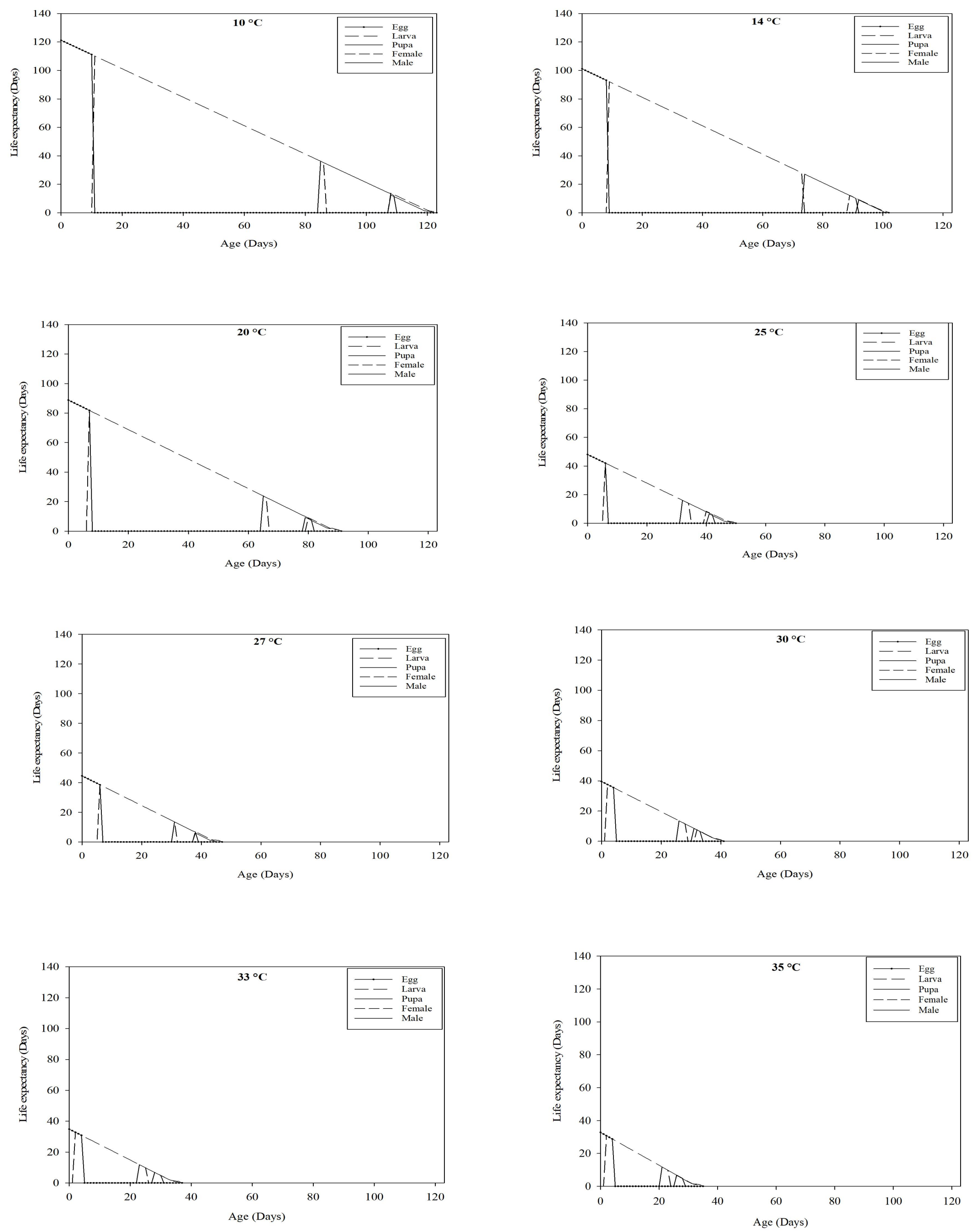

Figure 3. Age-stage specific life expectancy (e_{xj}) of the carob moth (*E. ceratoniae*), at different temperatures in the laboratory.

[DOI: 10.22034/jast.25.5.1101]

DISCUSSION

Temperature is crucial in the survival, growth, reproduction, mobility, and population dynamics of living organisms, particularly in poikilothermous species, such as insect pests (Price, 1997). Slight temperature variations may induce significant changes in the pace of arthropod biological processes (Ranjbar Aghdam and Mortazavi, 2019). As a result, a more precise assessment of temperature indices on insects and mites' growth and development is critical. The carob moth is a worldwide pest first detected and introduced in Iran from pomegranate trees in the Fars Province, Iran's most significant pomegranate production site (Kishani-Farahani *et al*., 2012). Most of the biological characteristics of E. ceratoniae and population growth parameters assessed here differed significantly among the experimental temperatures.

The incubation period of the carob moth' eggs decreased as the temperature increased from 10 to 35°C, with the largest incubation period of 11.00 days at 10 °C and the smallest at 35°C at 2.42 days. Similarly, Yousefi *et al*. (2002) found that the average time of incubation period was 8.6, 6.7, 3.6, and 2.4 days [10:14 hours (D: L) and 65.5% RH] at four temperatures of 20, 25, 30, and 35 °C. The present study showed that larval development time at different temperatures differed significantly (P< 0.01), and its value decreased by increasing temperature from 14 to 35°C. The maximum and minimum length of the larval development time were recorded under 10 and 35°C for about 94 and 18 days, respectively. Yousefi *et al*. (2002) found the mean larval period to be 69, 33.4, 22.9, and 19.1 days at four temperatures of 20, 25, 30, and 35°C. Corresponding findings of our investigations vary from those of Yousefi *et al*. (2002) but are consistent with those of Cox (1976). According to this difference, however, it can be concluded that variations in relative humidity, length of the light period, and quality of food provided to developing larvae are all determinants.

Results of the present study showed that the pupal period was also affected by temperature, decreasing from 28.78 days at 10°C to 4.95 days at 35°C. Cox (1976) measured the pupal period of the carob moth at 20, 25, and 30°C for 15, 9, and 6 days, respectively. The carob moth pupal stage was also observed to last for 7.2 days at 29°C and 8 and 5.2 days at two constant temperatures of 25 and 30°C, respectively (Cox, 1976; Al Iziz, 1985; Mehrnejad, 2002). This study, compared with previous studies, clearly showed that the length of the pupal stage is reduced when the temperature increases. The total length of the immature period differed significantly with the eight temperatures tested (P< 0.01). The maximum and minimum lengths of the immature stage were recorded at 10 and 35°C, respectively. Also, by increasing the temperature from 10 to 35°C, the total length of the immature developmental period of the carob moth is reduced.

One of the factors that can indicate appropriate environmental conditions for an insect is the reduction of the growth period of the immature stages. The short length of this period causes the population to mature earlier, and as a result, oviposition begins earlier in the next generation. This issue can have a direct impact on the population growth potential of the insects. Current results showed that the maximum and minimum longevity of adult insects occur between 10 and 35°C thermal regimes, respectively. Results of this study showed that the life span of this species, as in other insects, depends on temperature. By increasing the temperature from 10 to 35°C, the length of its growth period in all stages decreased significantly (P< 0.01). Some studies showed that adult insects lived for 6-7 days at 25°C on natural hosts and 7.4, 10-12, and 6.6 days at temperatures of 25, 27, and 30°C under artificial diets (see Al Aziz, 1985; Mehrnejad, 2002). Adult longevity on pistachio kernels was also observed to be 11.47 days (Mart and Kilincer, 1993). The

[DOI: 10.22034/jast.25.5.1101]

present results showed that the maximum and minimum lengths of a generation take place at 10 and 35°C, respectively. Also, the length of a complete generation decreased by increasing the temperature from 10 to 35°C. Yousefi *et al.* (2002) showed that the mean length of one generation of the carob moth at four temperatures of 20, 25, 30, and 35 °C equals 98.1, 53.1, 35.9, and 28.5 days, respectively. The adult pre-oviposition period (APOP), at temperatures of 10, 14, 20, 25, 27, 30, 33 and 35 °C were 1.75, 1.93, 1.14, 1.06, 1.06, 1.00, 0.68 and 0.68 days, with Total Pre-Oviposition Period (TPOP) of 110, 93, 81, 42, 39, 33, 30 and 27 days, respectively, showing a significant difference for all temperatures. Yousefi *et al*. (2002) showed that the mean adult pre-oviposition period of the carob moth at four temperatures of 20, 25, 30 and 35°C is 2.3, 1.6, 1.3 and 0.9 days, respectively. The average length of the oviposition period is equal to 4.8, 4.2, 3.6 and 2.8 days, respectively, and the average length of the post- oviposition period is 4.3, 3.3, 2.7 and 1.8 days. The current results showed that the longevity of adult male and female moths was significantly different ($P< 0.01$) under various thermal regimes. The maximum longevity of male and female insects was calculated at 10°C (13±0.05 day^{-1}) and the minimum at 35°C (6±0.06 day^{-1}). In general, the longevity of adult male and female insects decreases by increasing temperature. According to research conducted at four temperatures of 20, 25, 30, and 35°C, inside the growth chamber, the average egg hatching rate was 71, 78, 93, and 84%, respectively (Yousefi *et al*., 2004). However, the latter workers found that the average length of the incubation period was 8.6, 6.7, 3.6, and 2.4 days, the mean length of the larval period was 69, 9.4, 22.33, and 19.1 days and the mean length of the pre-pupal period was 2.2, 1.7, 3, and 1.1 days, respectively. They also showed that the mean length of a generation was 1.3±1.98, 58±1.53, 98±9.35, and 56±5.28 days, respectively. The average length of oviposition period was 2.3, 1.6, 1.3 and 0.9 days, respectively. The average length of post- oviposition period was 4.3, 3.3, 2.7, and 1.8 days, and the total laying of eggs was 71.7, 74.2, 86.9, and 73.6, respectively (Yousefi *et al*., 2004).

Our results of the effect of temperature on all parameters of the population increase of E. ceratoniae are also well indicated here. The intrinsic population growth rate (r) is a combination of information obtained from developmental period, survival, and fertility of the whole cohort. It is one of the most important determinants in population dynamics knowledge. A comparison of eight different temperatures in this study shows no significant difference in r between all temperatures but 10°C. The minimum r value was -0.0016 d^{-1} at 10°C, and the highest was 0.0085 d^{-1} at 30°C (Table 3). An investigation of the effect of six temperatures of 14, 20, 25, 27, 30, and 33 °C on demographic parameters of the codling moth showed that the minimum r-value was 0.0330 d^{-1} at 20°C and the highest was 0.078 d^{-1} at 27°C (Ranjbar Aghdam *et al.,* 2009). Other growth parameters of E. ceratoniae, such as the finite population growth rate (λ) and mean generation Times (T), were significantly different under the studied temperature regimes ($P< 0.0001$). The highest finite rate of population increase was 1.008±0.005, and the minimum was 0.991±0.006, observed at 30 and 35°C, respectively. The mean generation time decreased with increasing temperature until it was estimated at the minimum value (28.87) days at 35°C, which is more than the case obtained at 20 and 27°C, estimated for the codling moth by Ranjbar Aqdam *et al.* (2009).

Two-sex life table age-stage studies provide interesting information for different stages of development separately. Although the patterns of the survival curves, life expectancy, and fecundity of E. ceratoniae are similar to many other moth species (see, e.g. Rangbar Aghdam *et al.,* 2009; Soufbaf *et al*., 2010), there are slight differences between individual species. The intrinsic population growth rate (r) indicates the

[DOI: 10.22034/jast.25.5.1101]

potential of a population to grow but does not provide quantitative or factual information about predicting the number of individuals at different stages of growth over time. In order to show detailed information about population growth, demographic simulation and forecasting population growth over time can be significant (Ebrahimi *et al*., 2013). However, in the current study, we did not do those simulations because our final objective was to depict phenological and thermal models as a follow-up to our investigations.

In general, the results of this research are consistent with the results of other researchers, and slight differences can be attributed to the type of diets and some other environmental conditions such as rearing units' physical characteristics, variations in relative humidity, and thermal tolerances of the germinators. According to the current study, temperature has critical effects on biological indicators and life table parameters of the carob moth. Life table parameters of the carob moth at different temperatures provide more accurate and comprehensive information to adopt appropriate thermal models. So, the next phase of this research fits the above laboratory data to the existing thermal models in the field of thermal biology of insects, and the best model describing the phenology of the carob moth will be presented. After validating under natural conditions, these models can be used in modified integrated pest management programs.

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پارامترهای زیستی و جدول زندگی دو جنسی کرم گلوگاه انار *Apomyelois (=Ectomyelois) ceratoniae (Zeller, 1839) (Lep.: Pyralidae)* در دماهای ثابت مختلف

ک.عیدوزهی، س. رون، م. سوف باف، م. ر. رزوان، و ع. خانی

چکیده

پارامترهای زیستی و جدول زندگی برای مقایسه سازگاری یک جمعیت نسبت به شرایط محیطی و تغذیه‌ای مناسب‌ترین ملاک هستند. در این پژوهش اثر دماهای ۱۰، ۱۴، ۲۰، ۲۵، ۲۷، ۳۰، ۳۳ و ۳۵ درجه در شرایط آزمایشگاهی (۱۰: ۱۴ ساعت (تاریکی: روشنایی) و رطوبت نسبی ۵±۶۵ درصد) بر پارامترهای زیستی و جدول زندگی کرم گلوگاه انار (*Ectomyelois ceratoniae* Zeller) بررسی شد. نتایج بدست آمده از آزمایشات انجام گرفته در دماهای مختلف بر اساس تئوری جدول زندگی دوجنسی مورد تجزیه قرار گرفتند. نتایج نشان داد که میانگین طول دوره انکوباسیون تخم‌ها، لاروی، شفیره گی، کل دوره نابالغی و طول زندگی حشره بالغ اختلاف معنی‌داری را نشان دادند. طول دوره‌های قبل از تخم‌گذاری حشرات کامل (APOP)، به ترتیب ۱/۷۵ ،۱/۹۳، ۱/۱۴، ۱/۰۶، ۱/۰۶، ۱/۰۹، ۰/۶۸ و ۰/۶۸ روز، مجموع طول دوره قبل از تخمگذاری (TPOP)، به ترتیب ۱۱۰/۵۶، ۹۳/۸۲،۸۱/۵۹ ، ۴۲/۸، ۳۹/۳، ۳۳/۹۶،۳۰ و ۲۷/۹۶ روز و طول یک نسل در دماهای مذکور به ترتیب ۱۲۱/۲۲، ۱۰۱/۱۵، ۸۸/۸۲، ۴۸/۰۲، ۴۴/۵۵ ،۳۹/۵۳، ۳۴/۸۳ و ۳۲/۷۳ روز تعیین شد. کمترین مقدار نرخ ذاتی افزایش جمعیت (r) ۰/۰۰۱۶- بر روز در دمای ۱۰ درجه و بیشترین مقدار آن ۰/۰۰۸۵ بر روز در دمای ۳۰ درجه سلسیوس برآورد شد. بیشترین مقدار نرخ متناهی (λ) افزایش جمعیت ۱/۰۰۸۶ و کمترین مقدار آن ۰/۹۹۱۵ بود که به ترتیب در دماهای ۳۰ و ۳۵ درجه سلسیوس مشاهده شد. کمترین مقدار (۲۸/۸۷) متوسط یک نسل (T) در دمای ۳۵ درجه سلسیوس مشاهده شد. نرخ خالص تولید مثل(R_0) به ترتیب ۰/۸۳، ۱/۰۸،۱/۱، ۱/۰۳، ۱/۰۳،۱/۳۵،۱/۰۲ و ۰/۷۸ نتاج ماده برآورد شد. بیشترین بقای ویژه سنی (s_{xj}) در دمای ۱۰ درجه و کمترین آن در دمای ۳۵ درجه سلسیوس مشاهده شد.

[DOI: 10.22034/jast.25.5.1101]