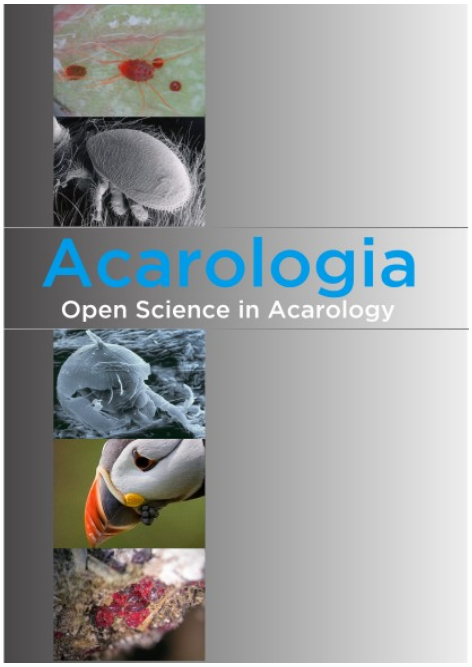

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DEVELOPMENT AND LIFE TABLE PARAMETERS OF *TETRANYCHUS TURKESTANI* (ACARINA: TETRANYCHIDAE) AT DIFFERENT CONSTANT TEMPERATURES

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ABSTRACT — Selected life history characteristics of the strawberry spider mite (*Tetranychus turkestani* Ugarov and Nikolski, Acarina: Tetranychidae) were studied at four constant temperatures (15, 20, 25 and 30 °C). Egg-to-adult developmental time of females ranged from 50.11 +/- 0.79 days at 15 °C to 7.73 +/- 0.14 days at 30 °C. An average of 140.33 +/- 5.49 degree-days was required to complete development above the lower thermal threshold (11.89 °C). Preimaginal mortality was 62.92, 16.67, 41.82 and 42.31% at 15, 20, 25 and 30 °C, respectively. Mean longevity of female *T. turkestani* ranged from 30.22 +/- 2.88 days at 15 °C to 5.78 +/- 0.10 days at 30 °C. Mean total fecundity ranged from 23.11 +/- 3.14 to 49.95 +/- 5.54 eggs / female. The sex ratio (% females) ranged from 69.00 +/- 0.04 to 83.01 +/- 0.02%. The intrinsic rate of population increase (r_m) ranged from 0.272 +/- 0.010 at 30 °C to 0.033 +/- 0.002 (female per female per day) at 15 °C. The population doubled most quickly at 30 °C (2.54 +/- 0.09 d) and most slowly at 15 °C (20.46 +/- 1.59 d). Based on these results, we can predict the presence of the different stages of the strawberry spider mite on cucumber over time. This information will therefore enable us to determine more precisely the best time to control this pest.

KEYWORDS — *Tetranychus turkestani*; biology; life table parameters; temperature; cucumber; *Cucumis sativa*

INTRODUCTION

The southwestern Khuzestan province (Iran) has a typically hot and dry climate with a mean maximum temperature of 30 °C from April to June and from September to November, a relative humidity of 35 – 40%, and a rainfall slightly above 50 mm. Cucumber is the main spring and fall vegetable crop, covering almost 50,000 ha in irrigated lands. The acreage is increasing as more land is under irrigation.

The strawberry spider mite, *Tetranychus turkestani* Ugarov and Nikolski, is a widespread pest of many agricultural crops including cotton, beans, cucurbits, alfalfa, soybean and sugar beet (Jeppson *et al.*, 1975; Kamali *et al.*, 2001; Zhang, 2003; Khanjani, 2005). Feeding and web production affect the quantity and quality of yield (Jeppson *et al.*, 1975; Sohrabi and Shishehbor, 2008).

For poikilothermal organisms, development and reproduction characteristics are affected by temperature. In the case of phytophagous arthropods, host plants are also needed to estimate parameters that are used in population models (Gutierrez *et al.*, 1977). Previous studies on the life cycle and reproduction of *T. turkestani* have been made at different temperatures on cotton (Carey and Bradley, 1982), egg-plants (Nemati *et al.*, 2005) and beans

(Sohrabi and Shishehbor, 2008; Latifi *et al*., 2010). Understanding the physiological relationship between temperature and development is important for the prediction of outbreaks and timely management of pest on crops (Jervis and Copland, 1996). The purpose of the present study was to determine the effects of temperature on preimaginal development, survival, longevity and fecundity to construct age-specific survival and fecundity curves that can be analyzed to estimate more accurately the effect of temperature on population growth rate in this species. It is the first time that cucumber has been used in such a study. Such data on thermal biology of *T. turkestani* could be useful for predicting its phenology and population dynamics in the field and also optimizing mass rearing under laboratory condition.

MATERIALS AND METHODS

Stock colony of *T. turkestani*

Tetranychus turkestani was collected from castor bean (*Ricinus communis* L.) leaves at Shahid Chamran University, Ahvaz (Iran), and used to start rearing the colony. This stock colony was maintained on cowpea (*Vigna unguiculata* L.) grown from seed and transplanted into compost in plastic pots (10 cm in diameter). Infested plants were kept in wooden-framed rearing cages (120 x 60 x 60 cm) covered with white nylon mesh of 120 μm aperture. They were maintained in the laboratory at 25 ± 1 °C, 65 ± 5% RH and 16:8 (L:D) with illumination (4000 lux) provided by fluorescent lamps. Plants were kept until they were severely damaged by the spider mites, new plants being added when needed. After 15 generations, mites from stock colony were used for the tests.

Preimaginal development and mortality

Plastic boxes (14 x 11 x 4 cm) were used as test arenas. Three layers of cotton fabric mat, with the same size, soaked in water and placed in the box. A detached cucumber leaf was placed lower side uppermost on the fabric mats in each arena. A narrow strip of tissue paper was placed on periphery of each leaflet. For individual studies, the leaf surface was subdivided into four *ca.* equal areas using the same barrier. The soaked mats and tissue papers kept the leaf moist and contained the mites in the arenas. For each experiment, one mated female adult from the stock colony was transferred with the help of a fine hair camel brush (000) to the arenas and was allowed to lay eggs. After a 24 h oviposition period, the adult and all the eggs laid but one were removed. Experiments were conducted in a temperature cabinet at 15, 20, 25 and 30 °C, 60 ± 5% RH and 14:10 (L:D). Egg to adult developmental time and mortality were checked twice daily, under a dissecting microscope at magnification up to 100 x. The presence of an exuvium was used as the criterion for a successful molting. For calculation purposes, we assumed that molting or death occurred at the midpoint between two successive observations. Individuals trapped in the wet tissue paper surrounding the leaf arena were excluded from data analysis. The immature stages were transferred to new detached leaves every three to five days.

Adult longevity and reproduction

Adults used for reproduction experiments were reared from eggs obtained from previous experiment. After emergence adults were paired and transferred into the new test arenas, so each arena contained one female and one male. Adult longevity and fecundity were recorded twice daily. Every three days, mites were transferred to a new detached leaf until the female mite died. Males that died or escaped from the experimental unit were replaced by young ones. Females trapped in the wet tissue paper or dead because of improper handling were excluded from data analysis.

During oviposition period, eggs laid by each female were collected and transferred on a new cucumber leaf. Secondary sex ratio was recorded after the mites completed their development.

Data analysis

Developmental time, longevity, fecundity and sex ratio under the different constant temperatures were analyzed using ANOVA (SAS Institute, 1997). Means were compared by Fisher's LSD method. A

series of Chi-square tests were conducted to determine if there were significant differences in preadult mortality for mites reared at different temperatures.

Lower developmental threshold temperatures (t) for preimaginal development were estimated by weighted linear regression on mean developmental rates (reciprocal of mean developmental times, the weight being the number of individuals) against the temperature, *i.e.* y = a + bx, where y is the development rate, and a and b are constants, x the temperature and t = – (a/b) is the developmental zero (Arnold, 1959). Degree-days (DD) needed for development was calculated as DD = D (T – t), where D is mean development time in days, T is temperature tested (°C), and t is lower developmental threshold temperature (°C) (Price, 1984).

Life and fertility 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 iteratively solving the equation by Birch (1948): $\sum e^{-rmx} l_x m_x = 1$, where x is the mean age class, m_x is the mean number of female progeny per female of age x and l_x is probability of surviving to age x. A trial number of values for r_m were substituted into the equation until the r_m value for which the sum of the left side of the equation approximates unity. Sex ratio of the female offspring reared at the different tested constant temperatures was estimated as described in the above-mentioned paragraph, and the results were incorporated in data analysis.

The Jackknife procedure was used to estimate SE for the female/female/day values at different constant temperatures (Maia *et al.*, 2000). Further data were also calculated for each temperature: net reproduction rate ($R_0 = \sum l_x m_x$, number of female offspring produced per female), finite rate of increase ($\lambda = e^{rm}$, number of times the population will multiply itself per unit of time), mean generation time (T = ln R_0 / r_m in days), and doubling time (DT = ln 2/r_m, number of days required for the population to double in numbers) (Birch, 1948).

RESULTS

The development of *T. turkestani* at constant temperatures revealed an inverse relationship between the duration of development and temperatures (Table 1). Analysis of variance indicated significant differences in developmental duration for females (F = 1779; df = 3,117 and *P = 0.0001*) and males (F = 1336; df = 3,31 and *P = 0.0001*). Total development duration of *T. turkestani* females from egg to adult were about seven times longer at 15 °C than at 30 °C.

The lower thermal thresholds for the development of *T. turkestani* were calculated to be 11.89 and 12.21 °C for female and male mite, respectively (Tables 2 and 3). On the basis of these thresholds, an average of 140.33 degree-days was needed for *T. turkestani* females to complete their development from egg to adult.

Juvenile mortality ranged from 16.67% at 20 °C to 62.92% at 15 °C (Table 4). Chi-square tests indicated significant differences in juvenile mortality

TABLE 1: Average duration (in days ± SE) of life stages of *Tetranychus turkestani* at different temperature.

sex	Temp.	N	Egg	Larva	Protochrysalis	Protonymph	Deutochrysalis	Deutonymph	Teliochrysalis	Egg to adult
Female	15	27	25.50 ± 0.66 a	8.16 ± 0.47 a	3.68 ± 0.23 a	3.51 ± 0.17 a	2.88 ± 0.18 a	2.75 ± 0.11 a	3.53 ± 0.20 a	50.11 ± 0.79 a
	20	30	6.79 ± 0.09 b	1.93 ± 0.07 b	1.72 ± 0.07 b	1.28 ± 0.05 b	1.38 ± 0.07 b	1.38 ± 0.05 b	1.66 ± 0.05 b	16.14 ± 0.19 b
	25	23	4.12 ± 0.06 c	1.65 ± 0.21 bc	0.88 ± 0.08 c	0.84 ± 0.08 c	0.89 ± 0.07 c	0.86 ± 0.05 c	1.00 ± 0.03 c	10.27 ± 0.28 c
	30	38	2.96 ± 0.08 d	1.06 ± 0.07 c	0.72 ± 0.05 c	0.81 ± 0.04 c	0.57 ± 0.02 d	0.92 ± 0.06 c	0.66 ± 0.04 d	7.734 ± 0.14 d
Male	15	8	26.20 ± 0.83 a	8.77 ± 1.05 a	4.00 ± 0.36 a	3.50 ± 0.56 a	3.11 ± 0.31 a	2.72 ± 0.48 a	3.27 ± 0.23 a	51.60 ± 1.07 a
	20	10	7.26 ± 0.16 b	1.80 ± 0.16 b	1.50 ± 0.10 b	1.10 ± 0.10 b	1.35 ± 0.15 b	1.25 ± 0.11 b	1.65 ± 0.07 b	15.91 ± 0.33 b
	25	9	4.30 ± 0.10 c	1.35 ± 0.21 b	1.00 ± 0.18 b	0.94 ± 0.13 b	0.72 ± 0.08 c	0.72 ± 0.08 bc	1.00 ± 0.14 c	10.04 ± 0.29 c
	30	9	2.87 ± 0.21 d	1.07 ± 0.07 b	0.64 ± 0.09 c	0.57 ± 0.07 b	0.64 ± 0.14 c	0.64 ± 0.09 c	0.92 ± 0.17 c	7.370 ± 0.32 d

Note: Mean values in a row followed by the same letters are not significantly different at 0.05%.

N: Number of mites tested

TABLE 2: Development rates (y; 1/day) regressed on constant temperature (x), estimated lower developmental thresholds (t) and mean sum of degree-days (DD) required for females of *Tetranychus turkestani*.

Stage	Rate (y) regressed on temperature (x) (°C)				$y = -a + bx$
	a	b	R^2	t (°C)	DD ± SE
Egg	0.254	0.0198	0.99	12.83	51.27 ± 1.44
Larva	0.6	0.051	0.95	11.76	20.86 ± 2.20
Protochrysalis	0.913	0.7813	0.97	11.68	12.84 ± 0.57
Protonymph	0.593	0.6516	0.91	9.1	16.22 ± 1.67
Deutochrysalis	1.092	0.0924	0.98	11.81	10.64 ± 0.56
Deutonymph	0.339	0.5216	0.84	6.5	19.88 ± 1.64
Teliochrysalis	0.992	0.8186	0.99	12.11	11.99 ± 0.66
Total	0.086	0.0073	0.99	11.89	140.33 ± 5.49

TABLE 3: Development rates (y; 1/day) regressed on constant temperature (x), estimated lower developmental thresholds (t) and mean sum of degree-days (DD) required for males of *Tetranychus turkestani*.

Stage	Rate (y) regressed on temperature (x) (°C)				$y = -a + bx$
	a	b	R^2	t (°C)	DD ± SE
Egg	0.272	0.0205	0.99	13.27	48.11 ± 1.09
Larva	0.604	0.0529	0.95	11.42	21.24 ± 3.49
Protochrysalis	1.052	0.0854	0.99	12.31	11.56 ± 0.41
Protonymph	1.049	0.0912	0.95	11.5	11.21 ± 0.77
Deutochrysalis	0.963	0.0874	0.96	11.02	11.67 ± 0.54
Deutonymph	0.848	0.0835	0.96	10.16	12.21 ± 0.53
Teliochrysalis	0.482	0.5474	0.95	8.81	18.60 ± 0.88
Total	0.094	0.0077	0.99	12.21	131.88 ± 4.31

TABLE 4: Percentage mortality within immature stages of *Tetranychus turkestani* at different constant temperatures.

Stage	15 °C	20 °C	25 °C	30 °C
Egg	31.46 (28)	4.170 (2)	3.640 (2)	0
Larva	3.270 (20)	0	3.770 (2)	2.560(2)
Protochrysalis	7.310 (3)	4.350 (2)	13.72 (7)	19.73 (15)
Protonymph	13.15 (5)	0	4.540 (2)	9.830 (6)
Deutochrysalis	0	2.270 (1)	16.67 (7)	7.280 (4)
Deutonymph	0	2.320 (1)	2.850 (1)	3.920 (2)
Teliochrysalis	0	4.760 (2)	5.880 (2)	8.160 (4)
Total (n)	62.92 (56)	16.67 (8)	41.82 (23)	42.31 (78)

Note: (n): number dying in each stage except for total which is the initial number entering the egg stage.

between temperatures ($\chi^2 = 7.81$; df = 3 and $P = 0.05$). Mortality of immature stages of *T. turkestani* showed no trends with temperature.

An inverse trend exists between temperature and mean adult longevity of *T. turkestani* across

the full temperature range investigated (Table 5). ANOVA indicated that temperature was a highly significant factor affecting the longevity of both females (F = 57.90; df = 3,117 and *P = 0.0001*) and males (F = 17.58; df = 3,31 and *P = 0.0001*).

The mean pre-oviposition period (days) decreased consistently as temperature increased across the full range of temperatures investigated (F = 29.11; df = 3,117 and *P = 0.0001*) (Table 5). The shortest observed mean pre-oviposition duration was 0.87 days at 30 °C.

ANOVA indicated no significant effect of temperature on mean daily fecundity (F = 0.6; df = 3,124 and *P = 0.6183*). However, mean total fecundity of *T. turkestani* was significantly depending on the temperature (F = 7.92; df = 3,117 and *P = 0.0001*) (Table 5). The greatest mean number of eggs was laid at 20 °C (49.9 ± 5.54 egg/ female).

The secondary sex ratio of *T. turkestani* were 72.04, 83.01, 73.48 and 69.00% of females at 15, 20, 25 and 30 °C, respectively (Table 5). Significant differences in sex ratio of strawberry spider mite progeny occurred at different temperatures (F = 2.96; df = 3,70 and *P = 0.03*). For all the temperatures tested, sex ratio of progeny was male biased in 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 (Figure 1).

Calculated daily intrinsic rates of natural increase (r_m) ranged from 0.033 female/female/day for mites held at 15 °C to a maximum peak rate of 0.272 female/female/day at 30 °C (Table 6). Mean generation time (T) decreased consistently with rising temperature across the whole temperature range tested. The time required to double the population reached a minimum of only 2.54 days at 30 °C. Age-specific survival (l_x) and fecundity (m_x) curves derived from these data for each tested temperature are illustrated in Figure 2.

TABLE 5: Female and male longevity, total fecundity, daily fecundity (Mean ± SE (n)) and secondary sex ratio of *Tetranychus turkestani* at different constant temperatures.

Stage	15 °C	20 °C	25 °C	30 °C
Preoviposition period	6.460 ± 0.90 (27) a	1.610 ± 0.25 (30) b	1.140 ± 0.13 (23) b	0.870 ± 0.09 (38) b
Oviposition period	21.44 ± 3.17 (27) a	12.31 ± 1.26 (30) b	4.950 ± 0.68 (23) c	4.560 ± 0.50 (38) c
Postoviposition period	3.310 ± 0.81 (27) a	0.975 ± 0.28 (30) b	6.600 ± 0.73 (23) b	0.360 ± 0.10 (38) b
Female longevity	30.22 ± 2.88 (27) a	14.85 ± 1.20 (30) b	6.740 ± 0.68 (23) c	5.780 ± 0.10 (38) c
Male longevity	30.38 ± 3.16 (8) a	18.28 ± 3.07 (30) b	8.340 ± 1.38 (9) c	5.210 ± 1.45 (9) c
Daily fecundity	0.591 ± 0.04 (27) a	2.430 ± 0.30 (30) a	2.000 ± 0.45 (23) a	3.310 ± 0.61 (38) a
Total fecundity	23.11 ± 3.14 (27) b	49.95 ± 5.54 (30) a	24.57 ± 3.51 (23) b	32.81 ± 3.88 (38) b
Sex Ratio (% female)	72.04 ± 0.05 (27) ab	83.01 ± 0.02 (30) a	73.48 ± 0.04 (23) ab	69.00 ± 0.04 (38) b

Note: Values in a column followed by the same letters are not significantly different at 0.05%.

Sample size (n): number of mites tested.

TABLE 6: Life table parameters of *Tetranychus turkestani* at different temperatures.

Parameters	15 °C	20 °C	25 °C	30 °C	F	df	P
r_m	0.033 ± 0.002 c	0.163 ± 0.004 a	0.185 ± 0.01 a	0.2720 ± 0.01 b	151.24	3,117	<0.0001
R_0	6.870 ± 1.008 c	32.63 ± 3.560 a	10.91 ± 1.56 bc	17.408 ± 2.06 b	21.84	3,117	<0.0001
λ	1.034 ± 0.002 a	1.177 ± 0.005 b	1.234 ± 0.01 b	1.3130 ± 0.01 c	128.52	3,117	<0.0001
T	56.92 ± 1.320 a	21.36 ± 0.380 b	12.90 ± 0.24 c	10.490 ± 0.18 d	1040.4	3,117	<0.0001
Dt	20.46 ± 1.590 a	4.249 ± 0.110 b	3.743 ± 0.22 b	2.5400 ± 0.09 b	122.74	3,117	<0.0001

Note: Values in a row followed by the same letters are not significantly different at 0.05%.

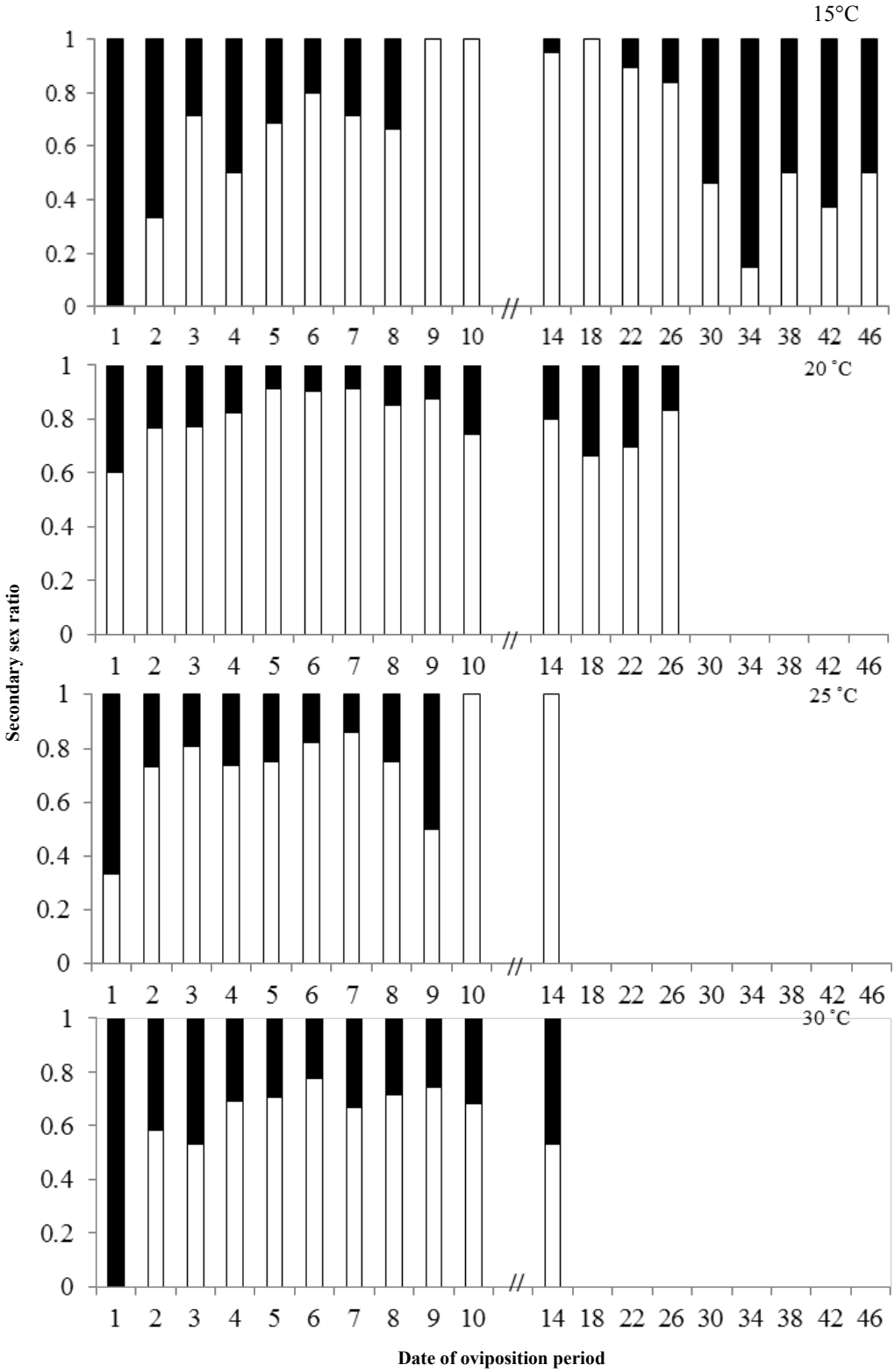

FIGURE 1: Offspring sex ratio of females of *Tetranychus turkestani* reared at different constant temperatures. Egg samples were collected at all of days throughout the oviposition period. For each sampling date, black and white bars indicate the percentages of males and females offspring, respectively.

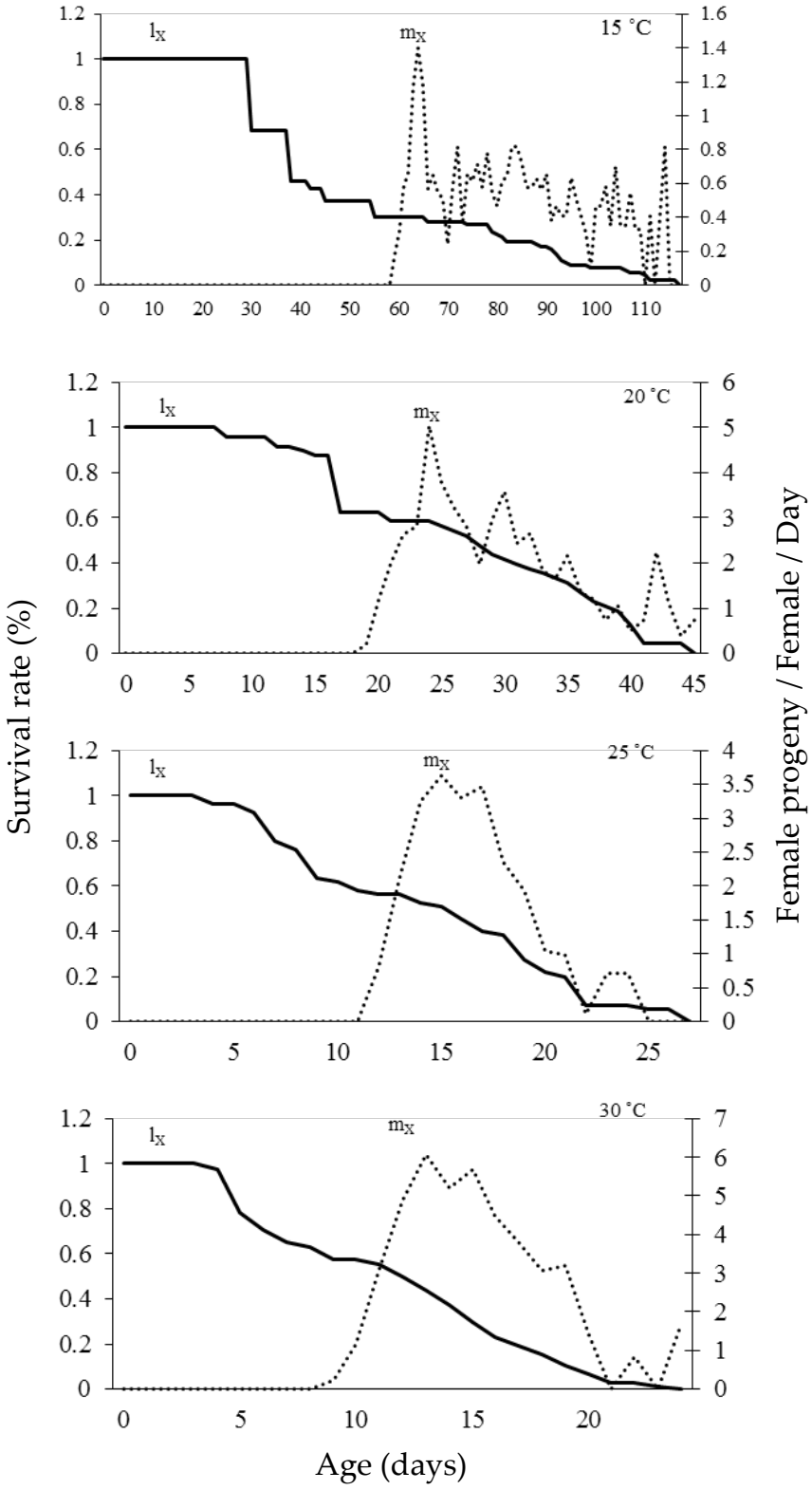

FIGURE 2: Survival rate (l_x, solid lines) and daily proportion of female progeny per female (m_x, dotted lines) of *Tetranychus turkestani* at different constant temperatures.

DISCUSSION

As in most poikilothermal animals, temperature significantly affects developmental rate, longevity and fecundity of *T. turkestani*. Immature development of *T. turkestani* was successfully completed between 15 and 30 °C. Developmental duration of *T. turkestani* females ranged from 50.11 days at 15 °C to 7.73 days at 30 °C. Similar results have been reported on various host plants (Andres, 1957; Sohrabi and Shishehbor, 2008; Latifi *et al*., 2010). Nemati *et al.* (2005) observed on eggplant developmental times of 30.32, 17.41, 9.98 and 5.71 days at 15, 20, 25 and 30 °C, respectively, which are shorter than those recorded in this study. Differences in the ecological factors, *viz*. mite strain and host plant, as well as experimental condition (photoperiod and relative humidity), may provide an explanation for longer developmental times. Nemati *et al*. used L:D 16:8 photoperiod, 45 – 65% relative humidity and eggplant as the host- plant. He also collected mites from eggplant.

The lower temperature threshold for *T. turkestani* was 11.89 °C for females and 12.21 °C for males, respectively. These values are much lower than those reported by Nemati *et al*. (2005) for female *T. turkestani* (13.4 °C) on eggplant. The mean number of degree-days required by *T. turkestani* to complete its development was 140.33 DD for females and 131.88 DD for males, respectively. These are higher than that of Nemati *et al*. (2005) for females *T. turkestani* (102.00 DD) on eggplant.

The egg to adult development duration of males of *T. turkestani* at most of the tested temperatures was similar to the respective duration of females. A similar trend has also been reported for another Iranian population of *T. turkestani* (Latifi *et al*., 2010), and other tetranychid species such as *Eutetranychus orientalis* Klein (Imani and Shishehbor, 2009), *Tetranychus urticae* Koch (Riahi, 2011) and *Tetranychus pacificus* McGregor (Carey and Bradley, 1982).

Mortality of *T. turkestani* at different constant temperatures has been documented in the literature. In a laboratory experiment with *T. turkestani* on bean, Latifi *et al*. (2010) found egg-to-adult mortalities of 19.2, 7.0 and 20.4% at 20, 25 and 30 °C which are lower than the results obtained in the present study. Sohrabi and Shishehbor (2008) conducted a study on the life history of *T. turkestani* on different host plant species and reported lower preimaginal mortality than those obtained in the current study. These dissimilarities may be explained by disparities in host plant suitability for *T. turkestani* in addition to differences in experimental conditions.

According to our results and irrespective of the tested temperatures, most of the eggs give rise to male progeny in the first 3 – 4 days of oviposition period and to female progeny throughout the rest of the oviposition period. This trend is also common in other tetranychid species such as *T. urticae* (Riahi, 2011). According to Sabelis (1985), the observed increased male progeny production in the beginning of the oviposition period could contribute to the early insemination of females that would afterwards start to disperse to find a desirable host plant.

For all four temperature regimes tested, female-biased sex ratios were consistently observed, varying from 69.00 to 83.01% among progeny produced over lifetime. Moraes and McMurtry (1987) observed an almost identical pattern in *Tetranychus evansi* at temperatures ranging from 15 to 35 °C. However, Margolies and Wrensch (1996) reported that sex ratio of *T. urticae* females exposed to a high temperature (32 °C) was more male biased (0.536) than for females exposed to a low temperature (22 °C, 0.727).

According to our results, intrinsic rate of population increase of *T. turkestani* was strongly affected by temperature, increasing gradually with temperature from 15 to a maximum at 30 °C. Similar results have been reported for this species on eggplant (Nemati *et al*., 2005) and on bean (Latifi *et al*., 2010) and for three other tetranychid speciese such as *Tetranychus urticae* and *Eotetranychus carpini borealis* (Ewing) (Bounfour and Tanigushi, 1993), and *Eutetranychus orientalis* (Imani and Shishehbor, 2009). However, in several other tetranychid species, the estimated maximum values of r_m were recorded at lower or higher temperatures; for example, at 27 °C for *T. urticae* (Riahi, 2011), and at 34 °C for *Tetranychus macdanieli* (Roy *et al*., 2003).

The results of these studies on *T. turkestani* on cucumber show that the optimal temperature for development, survival and reproduction, within the range examined, was 30 °C. This indicates that, in the absence of other mortality factors, *T. turkestani* has the greatest potential to become a serious pest when temperature is around 30 °C.

These data have several useful aspects. First, they can be used in mass-rearing projects. The optimum rearing temperature for development, survival and fecundity can be chosen from our data. Second, our data will allow the development of population and developmental models for *T. turkestani* which will use ambient temperature to predict the appearance of various life stages of this pest in the field. This information can be use in pest control programs as well as in efforts to understand the population biology of this mite.

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