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Development, reproduction and life table parameters of *Tetranychus turkestani* (Acari: Tetranychidae) on three different host plants

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Original research

ABSTRACT

The strawberry spider mite, *Tetranychus turkestani* Ugarov & Nikolski, is one of the most important pests of different field and glasshouse crops in Iran. The objectives of the current study were to determine developmental time, survival, reproduction and life table parameters of *T. turkestani* on three plant species: cowpea (*Vigna unguiculata* L.), white bean (*Phaseolus lunatus* L.) and red bean (*Phaseolus calcaratus* Roxb.) at 25 ± 1 °C, 60 ± 10 % RH and a photoperiod of 16:8 (L:D). The mean developmental time from egg to adult on cowpea, white bean and red bean were 11.99, 10.43 and 10.46 days, respectively. The total preadult survival rates varied from 75% to 80%. Females of *T. turkestani* oviposited means of 65.13, 44.03 and 32.69 eggs on cowpea, white bean and red bean, respectively, and had a mean longevity of 13.92, 9.08 and 7.23 days on the same three host plants. The intrinsic rate of increase (r_m) varied from 0.18 to 0.21. The net reproductive rate (R_0) was higher on cowpea (42.33) than on white bean (24.95) or red bean (14.16). Using these measures, *T. turkestani* performance was best on cowpea, worst on red bean, and intermediate on white bean.

Keywords strawberry spider mite; survival; longevity; fecundity; Fabaceae

Introduction

The strawberry spider mite, *Tetranychus turkestani* Ugarov & Nikolski (also known as *Tetranychus atlanticus* McGregor), is one of the most important agricultural pests in the world (Jeppson *et al.* 1975; Bolland *et al.* 1998). It is a polyphagous species and feeds on 271 plant species belonging to more than 65 plant families (Migeon and Dorkled 2020). This phytophagous mite is distributed throughout the world and causes yield losses in cultivated crops (field and glasshouse crops) by sucking the cell contents (Jeppson *et al.* 1975; Helle and Sabelis 1985; Zhang 2003; Hoy 2011).

Feeding activity of *T. turkestani* leads to the appearance of white chlorotic spots on upper side of leaves with copious webbing on the underside of the leaves. In serious infestations, leaves may drop and flowering may be noticeably reduced. The short life span and high reproductive potential cause a fast-growing population that allows the mite to attain economic injury level in appropriate condition, resulting in a rapid decline of host plant yield (Carey and Bradley 1982; Tomczyk and Kropczynska 1985; Sohrabi and Shishehbor 2008; Karami Jamour *et al.* 2012).

The effect of host plant morphological and chemical features on biological characteristics of tetranychid mite species has been indicated frequently (Tomczyk and Kropczynska 1985; Awmack and Leather 2002). Host plant species or cultivars are among the most important

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factors that affect development time, survival, longevity and fecundity of spider mites (den Boom *et al.* 2003; Vasquez *et al.* 2008). Information on the impact of Leguminosae host plants on the development and reproductive performance of *T. turkestani* is limited; in fact, the only documented report was that of Sohrabi and Shishehbor (2008), who reported that longevity of *T. turkestani* varied among three Leguminosae plant species (cowpea, green gram, pinto bean).

Several important field crops belonging to the Fabaceae, Cucurbitaceae and Malvaceae plant families are attacked by *T. turkestani*, among which Fabaceae (Leguminosae) plant species (commonly known as the legume, pea or bean) are the most important host plants for this mite pest (Jeppson *et al.* 1975). However, little is known about the development, survival, reproduction and life table parameters of *T. turkestani* on Fabaceae host plants. Development of efficient strategies for controlling strawberry spider mite will require knowledge of its biological relationships with various host plants. Among these, an important component will be an understanding of host suitability. Hence, the aim of this study was to better understand the influence of some Leguminosae plant species on life history parameters of *T. turkestani* by constructing the life tables of this spider mite on three commercial Leguminosae plants.

Materials and methods

Plant materials

Three plant species of Fabaceae were used in this study: Cowpea (*Vigna unguiculata* L.), white bean (*Phaseolus lunatus* L.) and red bean (*Phaseolus calcaratus* Roxb.). Seeds were planted in plastic pots (20 cm diameter, 10 cm height) in a mixture of compost (Nutrifood Company, Iran) and sawdust (1:1 ratio) and kept in wooden cages (120 × 60 × 60 cm) covered by white nylon mesh (with an aperture of 120 µm). Plants 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. Studies were initiated when cowpea, white bean and red bean were three, four and four weeks old, respectively. The heights of these plants at these ages were ≈ 30, 25 and 25 cm for cowpea, white bean and red bean, respectively. Only the second to fourth fully expanded leaves (from the growing terminal) were selected. The leaves were replaced every three to four days throughout the study.

Spider mite colony

Tetranychus turkestani was collected from morning glory (*Convolvulus arvensis* L.) leaves at Shahid Chamran University of Ahvaz, Ahvaz (Iran) (31°18′21″N 48°39′33″E), and used to start rearing the colony. This stock colony was separately maintained on cowpea, white bean and red bean plants. Infested plants were kept in wooden framed cages under laboratory conditions described above. Plants were maintained until they were severely damaged by the spider mites; new plants being added when needed. Synchronous colonies of *T. turkestani* were provided by rearing five generations (which lasted 80, 65 and 68 days) on cowpea, white bean and red bean, respectively.

Preimaginal developmental time, survival and sex ratio

Plastic boxes (14 × 11 × 4 cm) described by Sohrabi and Shishehbor (2008) were used as test arenas. Three layers of cotton mat, with the same size, soaked in water and placed in the box. A detached leaf of each plant species was placed lower side uppermost on the cotton mats in each arena. A narrow strip of tissue paper was placed on periphery of each leaf. For individual tests, the leaf surface was subdivided into two ca. equal areas using the same barrier. The soaked cotton mat and tissue papers kept the leaves fresh and prevented the escape of tested mites. For each experiment, one mated adult female from each stock colony was transferred with the aid of a fine camel hair brush (000) to the arenas and was allowed to lay eggs. After a 24 hours

oviposition period, only one newly laid egg was left on each leaf arena and the mite and the excess eggs were removed. Sixty eggs were used for each treatment. The plastic boxes were kept in an incubator at 25 ± 1 °C, 65 ± 5% RH and 16:8 (L:D); a new leaf was prepared and the mites were transferred at the first sign of leaf deterioration. Egg to adult developmental time, survival and sex ratio 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 successful molting. For calculation purposes, we assumed that molting or death occurred at the midpoint between two successive observations (Karami Jamour and Shishehbor, 2012). Individuals trapped in the wet tissue paper surrounding the leaf arena were excluded from data analysis.

Adult longevity and fecundity

Adults used for longevity and fecundity experiments were reared from eggs obtained from previous experiments. Newly molted adult female and male of *T. turkestani* (age < 24 h old) were paired and transferred into the new test arenas, so each arena contained one female and one male. Egg laying and longevity were recorded twice daily. Every three days, mites were transferred to a new arena containing a detached leaf until the female died. Males that died or escaped from the experimental unit were replaced by young ones. Females trapped in the wet tissue or dead because of improper handling were excluded from data analysis.

Statistical analysis

The age-stage specific survival rates (S_{xj}) (where x is the age and j is the stage), age-stage specific fecundity (f_{xj}), age-specific survival rates (l_x), age-specific fecundity (m_x), and the population parameters net reproductive rate (R_0), intrinsic rate of increase (r_m), finite rate of increase (λ) and mean generation time (T) were calculated using an age-stage, two-sex life table (Chi and Liu 1985; Chi 1988). The age-stage life expectancy (e_{xj}) was calculated according to Chi and Su (2006). The net reproductive rate (R_0) is the total number of offspring produced by an average individual during its lifetime and was calculated as:

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

The intrinsic rate of increase is estimated by using iterative bisection method from:

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

with age indexed from 0 (Goodman 1982). The mean generation time is defined as the length of time that a population needs to increase by R_0- fold of its size at the stable age-stage distribution, i.e., $e^{rT} = R_0$ or $\lambda^T = R_0$. Therefore, it is calculated as $T = (\ln R_0)/r_m$. The gross reproductive rate (GRR) is calculated as $\Sigma\, m_x$. The reproductive value (v_{xj}) considered as the expectation of future offspring of individuals of age x and stage j (Fisher 1930). To estimate the means, variances and standard errors of the population parameters of *T. turkestani*, bootstrap techniques were used (Efron and Tibshirani 1993) with 100,000 bootstrap samples for more stable and precise estimates. The computer program TWOSEX-MSChart (Chi 2017) was used to perform the analysis and estimate the life table parameters. A paired bootstrap test was also used to compare the differences in life history parameters among host plant species.

Results

The female and male immature developmental time are shown in Tables 1 and 2, respectively. Significant differences were observed between immature developmental duration of females (Table 1, $P < 0.05$). Same results obtained for males (Table 2, $P < 0.05$). Mean total development

duration of *T. turkestani* females and males from egg to adult were about 1.5 days longer on white bean and red bean compared to cowpea. However, there were no significant differences in the mean developmental time of female and male *T. turkestani* on white bean and red bean.

Host plant had no significant effect on the total preadult survivorship of *T. turkestani* ($P > 0.05$). The highest percentage of mite preadult survival was found on cowpea (80 ± 0.05), followed by white bean (76.67 ± 0.05) and red bean (75 ± 0.05). Host plant significantly affected female progeny percentage ($P < 0.05$). The highest percentage of female progeny was recorded from *T. turkestani* reared on cowpea (80% ± 0.43) followed by white bean (73% ± 0.47) and red bean (58% ± 0.65).

The mean duration of preoviposition (from adult emergence to egg laying, APOP) did

Table 1 Development time (days; mean ± SE) of immature stages of *Tetranychus turkestani* female on cowpea, white bean and red bean

Parameters	Host plants		
	Cowpea (n = 39)	White bean (n= 34)	Red bean (n = 26)
Egg incubation period	5.1±0.08a	4.51±0.01b	4.52±0.07b
Larva	1.55±0.06a	1.32±0.07b	1.27±0.08b
Protochrysalis	0.96±0.04a	0.86±0.04a	0.90±0.06a
Protonymph	1.18±0.06a	0.79±0.05b	0.77±0.05b
Deutochrysalis	0.94±0.05a	0.85±0.04a	0.88±0.04a
Deutonymph	1.09±0.04a	1.03±0.04a	1.04±0.05a
Teleiochrysalis	1.17±0.05a	1.07±0.04a	1.08±0.05a
Total preadult of female	11.99±0.13a	10.43±0.01b	10.46±0.14b

* Values in rows followed by the same small letter are not significantly different, using the paired bootstrap test at 5% significance level. n = number of individuals reaching the adult stage.

Table 2 Development time (days; mean ± SE) of immature stages of *Tetranychus turkestani* male on cowpea, white bean and red bean

Parameters	Host plants		
	Cowpea (n = 9)	White bean (n = 12)	Red bean (n = 19)
Egg incubation period	5.28±0.21a	4.50±0b	4.47±0.08b
Larva	1.17±0.06a	1.25±0.12a	1.16±0.07a
Protochrysalis	1.06±0.04a	0.92±0.06a	0.97±0.03a
Protonymph	1.17±0.06a	0.79±0.07b	0.66±0.05b
Deutochrysalis	0.94±0.05a	0.71±0.07b	0.82±0.07ab
Deutonymph	0.78±0.04b	0.75±0.08a	0.79±0.06a
Teleiochrysalis	1.17±0.05a	0.96±0.07a	1.00±0.05a
Total preadult of male	11.56±0.18a	9.88±0.18b	9.87±0.13b

* Values in rows followed by the same small letter are not significantly different, using the paired bootstrap test at 5% significance level. n = number of individuals reaching the adult stage.

not differ significantly among the three host plants (Table 3). In the mean duration of total preoviposition (from egg development to egg laying, TPOP), the difference was found only between cowpea and the two beans. However, oviposition duration (from first to last egg laid) and female and male longevity differed significantly among host plant species tested (Table 3).

The age-stage-specific survival rate (*Sxj*) shows the probability that an egg can survive to age *x* and stage *j* (Figure 1). Significant overlaps were observed between stages in all three reproductive cohort of *T. turkestani* due to variable developmental rates occurring among individuals. The ability to observe the beginning and ending of subsequent stages (i. e., egg, larva, etc. stages) in the survival curve for each stage is an advantage of using the age-stage, two sex life table. We took the non-feeding resting stages (protochrysalis, deutochrysalis and teliochrysalis) out of the figures 1-4 to avoid presenting busy charts.

The age-specific survival rate (l_x), age-specific fecundity (m_x), age-specific maternity ($l_x m_x$) and age-stage specific fecundity (f_x) were calculated and are shown in Figure 2. The age-specific survival rate demonstrates a simplified overview of the survival history when all stages are pooled (Figure 2). The l_x is affected by bean plant species. Oviposition period varied from 6.57 (red bean) to 8.50 (white bean) and 13.17 (cowpea) and differed significantly between three host plants (Table 3).

Host plant had no significant effect on mean daily fecundity. However, mean total fecundity of *T. turkestani* was significantly different among the three host plants (Table 3). The highest mean total number of eggs was laid on cowpea (65.13 ± 3.68 eggs/female).

The age-stage-specific life expectancy (e_{xj}) is the lifespan remaining for an individual of age *x* and stage *j*. The age-stage specific life expectancies of *T. turkestani* on different host plants species are plotted in Figure 3. The life expectancy of a newborn egg was about 14, 16 and 21 in mites reared on red bean, white bean and cowpea, respectively. The maximum life expectancy of all stages of *T. turkestani* was recorded in cowpea. Life expectancy decreased gradually with age, since the study was conducted in the laboratory and thus unaffected.

The age stage reproductive value (v_{xj}) of *T. turkestani* represents the contribution of an individual to the future population (Figure 4). The reproductive value of a newborn (v_{01}) is the finite rate itself. For example, a newly emerged female (age 15 d) has a reproductive value of 24.54 in cowpea. On the other hand, a 11-d old female has a lower reproductive value, 18.60 in red bean. The reproductive curve (v_{xj}) of *T. turkestani* shows the highest value in mites reared on cowpea. Life table statistics of *T. turkestani* clearly differed among host plants (Table 4). Mites reared on cowpea had a significantly higher net reproductive rate (R_0) than those reared on white bean and red bean. However, host plant species had no significant effect on intrinsic rate of increase (r_m) and finite rate of increase (Table 4).

Table 3 Adult preoviposition period (APOP), total preoviposition period (TPOP), total fecundity and female and male longevity (mean ± SE) of *Tetranychus turkestani* on cowpea, white bean and red bean

Parameters	Host plants		
	Cowpea (n = 39)	White bean (n = 34)	Red bean (n = 26)
APOP (day)	0.1795 ± 0.0617[a]	0.1176 ± 0.0557[a]	0.3077 ± 0.1073[a]
TPOP (day)	12.1667 ± 0.1472[a]	10.5441 ± 0.1119[b]	10.7692 ± 0.1997[b]
Oviposition period (day)	13.17 ± 0.6261[a]	8.5 ± 0.6140[b]	6.5769 ± 0.4780[c]
Total fecundity (day)	65.13 ± 3.68[a]	44.03 ± 3.81[b]	32.69 ± 2.82[c]
Female longevity (day)	13.92 ± 0.65[a]	9.08 ± 0.66[b]	7.23 ± 0.47[c]
Male longevity (day)	12.44 ± 0.99[a]	8.58 ± 0.7[b]	6.58 ± 0.55[c]

* Values in rows followed by the same small letter are not significantly different, using the paired bootstrap test at 5% significance level. n = number of reproducing females observed.

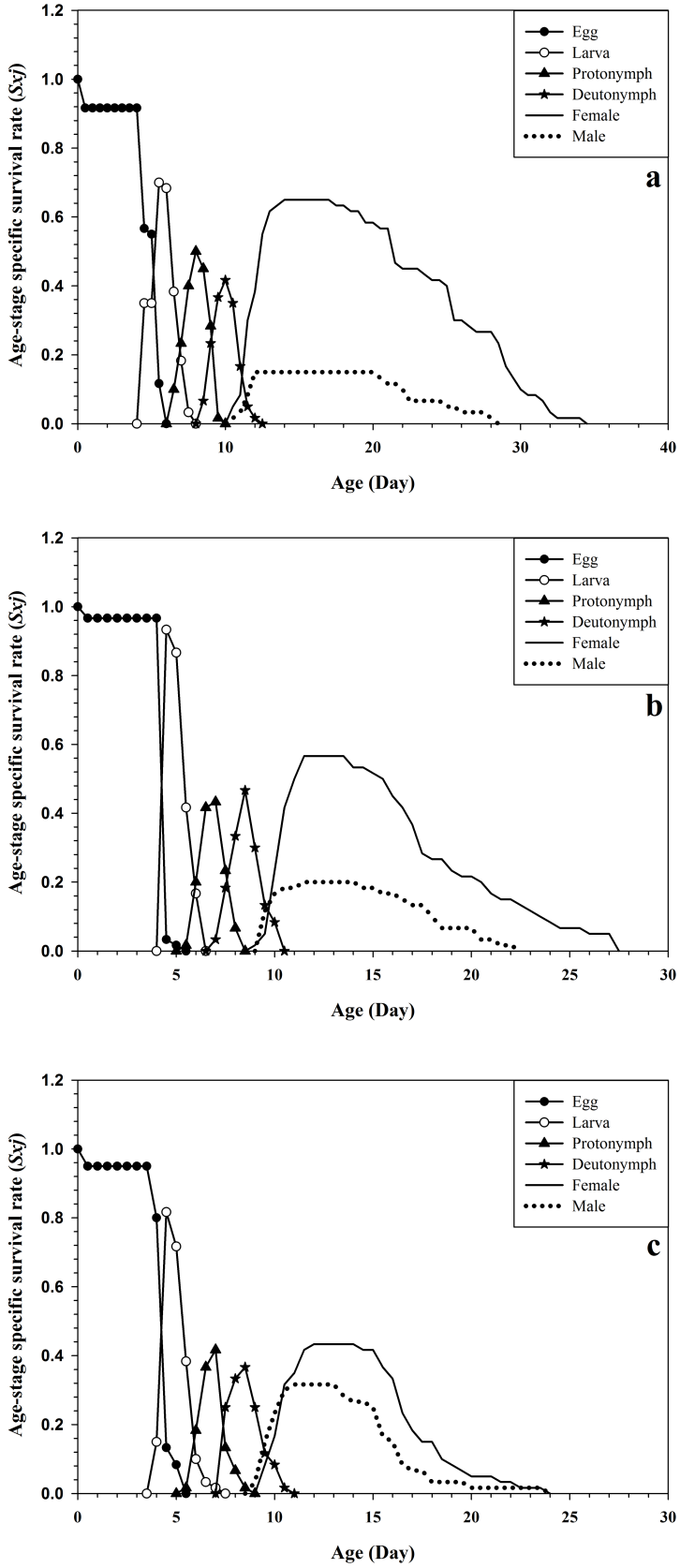

Figure 1 Age-stage-specific survival rate (S_{xj}) of *Tetranychus turkestani* on: a. cowpea, b. white bean, c. red bean.

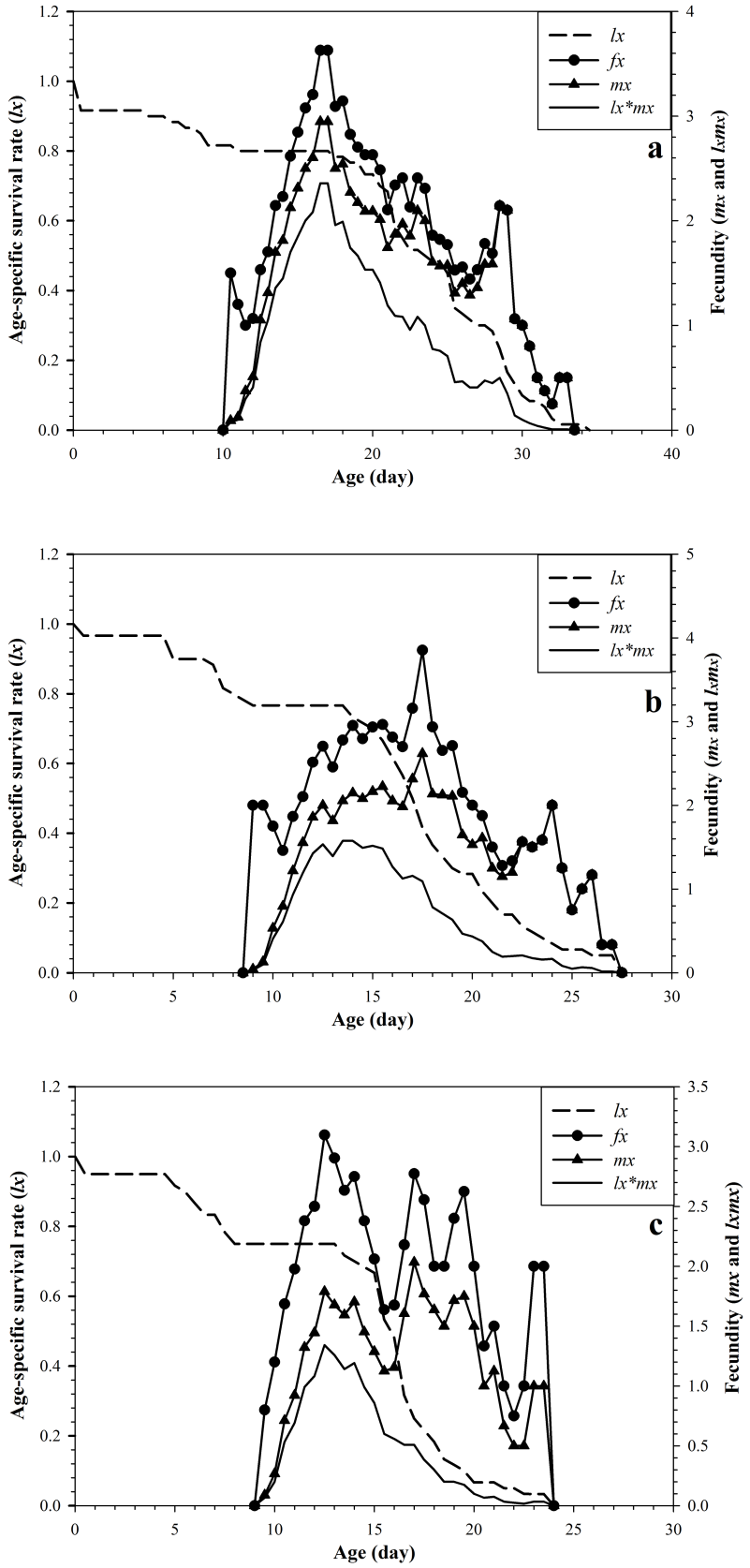

Figure 2 Age-specific survival rate (l_x), fecundity (m_x) and maternity ($l_x m_x$) of *Tetranychus turkestani* on: a. cowpea, b. white bean, c. red bean.

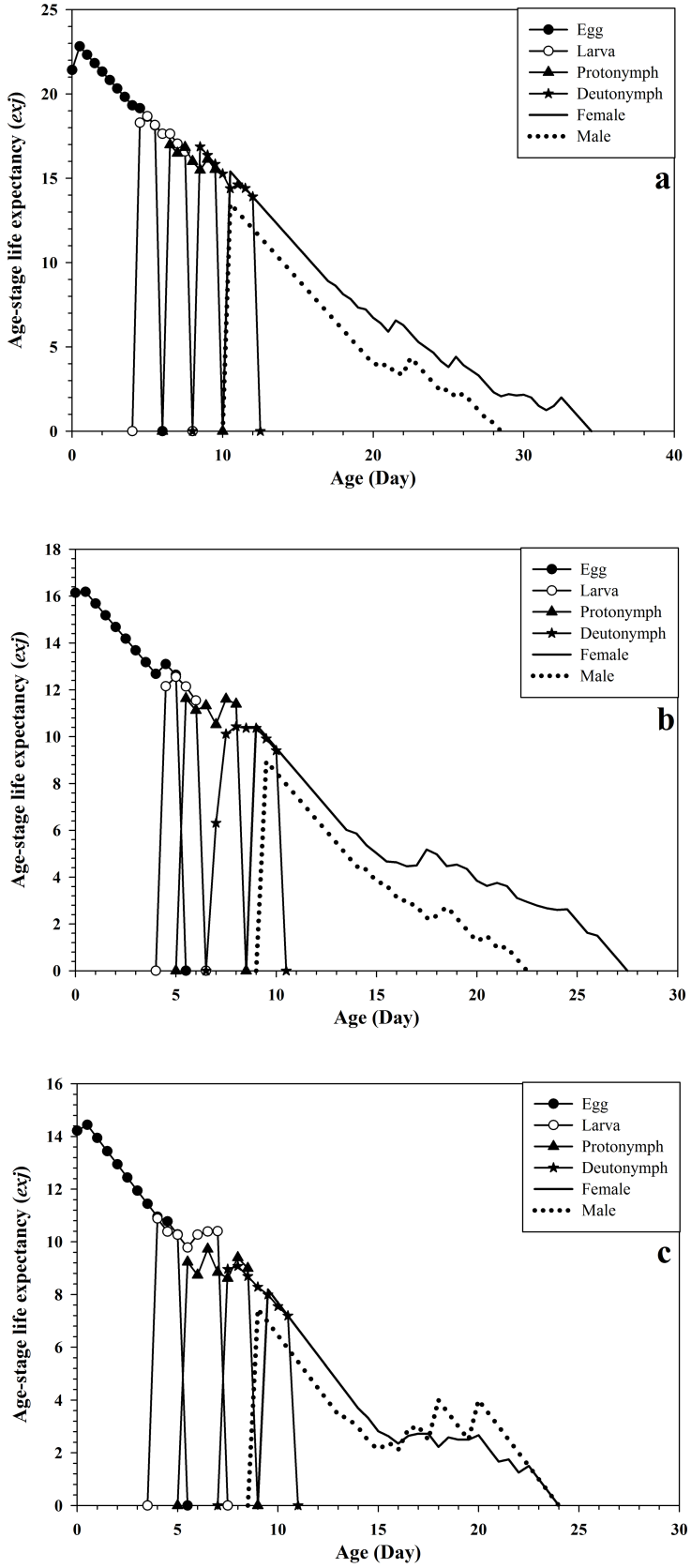

Figure 3 Age-stage-specific life expectancy (e_{xj}) of *Tetranychus turkestani* on: a. cowpea, b. white bean, c. red bean.

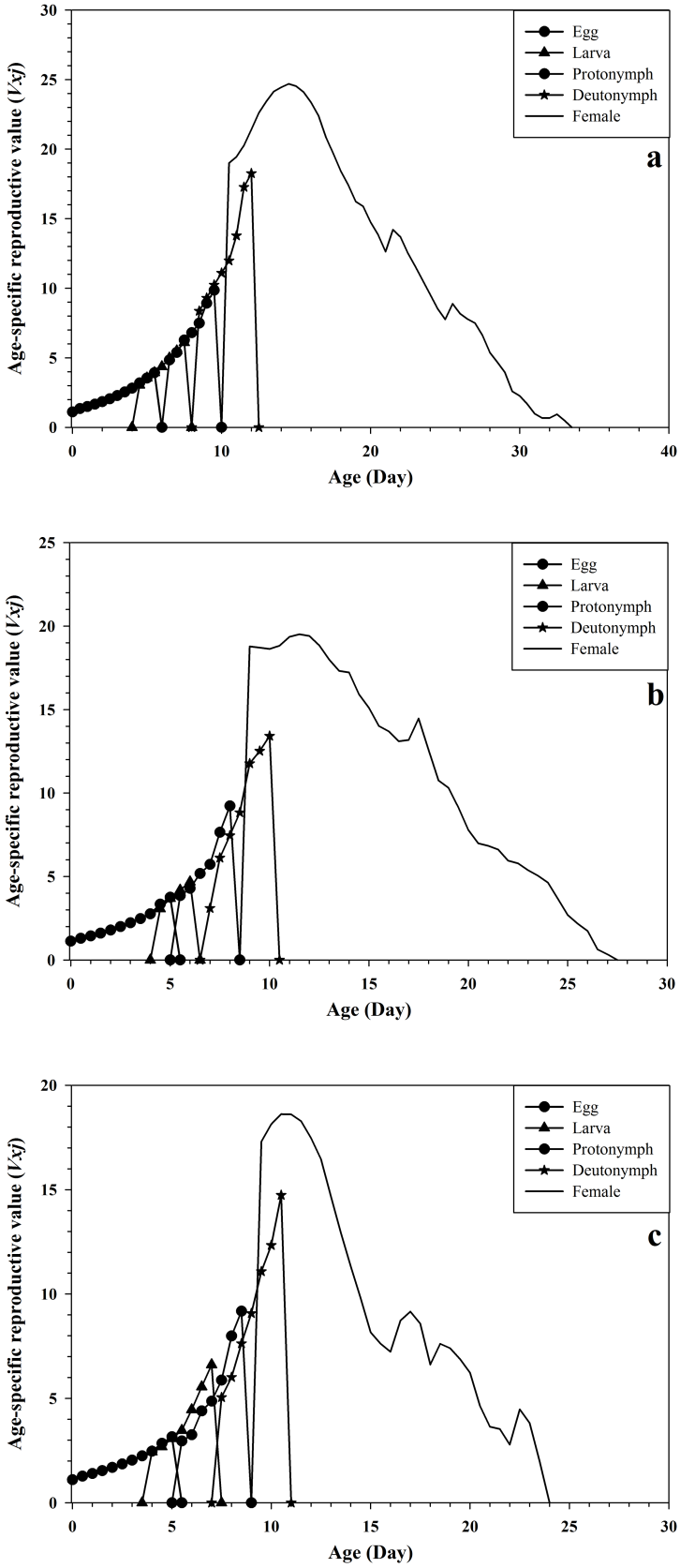

Figure 4 Age-stage-specific life expectancy (v_{xj}) of *Tetranychus turkestani* on: a. cowpea, b. white bean, c. red bean.

Discussion

Different host plants significantly affected the biology of *T. turkestani*. The strawberry spider mite was able to reproduce on all host plants studied; however, the cowpea was more suitable for its development and reproduction. Several features of the host plant, such as morphology, nutritional values, and secondary chemical compounds, may have affected the biological reaction of *T. turkestani*. However, the effect of these factors upon development and reproduction of this species need to be studied in detail. Morphological and chemical characteristics of the plants, as well as nitrogen levels, are known to be related to mite development and reproduction (Tomczyk and Kropczynska 1985).

Results of our experiment showed that host plant can affect development time of *T. turkestani.* Developmental duration of *T. turkestani* female ranged from 10.43 days on white bean to 11.99 days on cowpea. Developmental time of female *T. turkestani* was reported to be 10.80 days on alfalfa (Andres 1957), 10.70 days on cotton (Carey and Bradley 1982), 9.90 days on eggplant (Nemati *et al.* 2005), 12.17, 11.79, 10.81 days on cowpea, green gram, pinto bean, respectively (Sohrabi and Shishehbor 2008), 8.92 days on kidney bean (Latifi *et al.* 2010) and 10.27 days on cucumber (Karami-Jamour and Shishehbor 2012) which are similar to our results. However, lower developmental time of 7.70 days was reported by Cagle (1956) for *T. turkestani* on cotton at the same temperature (25 °C) (Table 5). Differences in the mite strain, host plant and experimental condition may provide an explanation for shorter developmental time.

The egg to adult development duration of males of *T.turkestani* on all of the host plant species tested was shorter than the respective duration of females. A similar trend has also been reported for *T. turkestani* on cowpea, green gram and pinto bean (Sohrabi and Shishehbor 2008), on kidney bean (Latifi *et al.* 2010) and other tetranychid species such as *Eutetranychus orientalis* (Klein) (Imani and Shishehbor 2009), *Tetranychus urticae* Koch (Riahi *et al.* 2011) and *Tetranychus pacificus* McGregor (Carey and Bradley 1982).

Survival of *T. turkestani* on different host plants has been documented in the literature. Preimaginal survival of *T. turkestani* was reported to be 82 and 89 % on cowpea and green gram, respectively (Sohrabi and Shishehbor 2008), 93 % on kidney bean (Latifi *et al.* 2010) at the same temperature (25 °C) which are similar to the results obtained in the present study. However, lower survival of 58% was reported by Karami Jamour and Shishehbor (2012) on cucumber. These disparities may be explained by dissimilarities in host plant suitability for *T. turkestani* along with differences in experimental conditions.

The sex ratio was strongly biased for females. These data are in line with the findings of Sohrabi and Shishehbor (2008) who reported 91, 80 and 84% females for *T.turkestani* on cowpea, green gram and pinto bean, respectively. Sex ratio of other genera of tetranychid mites are known to be female biased (Huffaker *et al.* 1969). Helle and Pijnacker (1985) also reported that the ratio of 1:3 male:female is often found in many amphigonic tetranychid species.

Table 4 Life table parameters (mean ± SE) of *Tetranychus turkestani* on cowpea, white bean and red bean

Parameters	Host plants		
	Cowpea	White bean	Red bean
Intrinsic rate of increase (r_m)(d^{-1})	0.2110±0.007a	0.2177±0.001a	0.1888±0.013a
Finite rate of increase (λ) (d^{-1})	1.2349±0.008a	1.2432±0.012a	1.2709±0.015a
Net reproductive rate (R_0) (offspring)	42.3333±4.648a	24.95±3.533b	14.1666±2.416c
GRR	72.14±4.961a	55.83±5.170b	35.84±6.505c
Mean generation time (T) (d)	17.747±0.241a	14.775±0.253b	14.034±0.027c

* Values in rows followed by the same small letter are not significantly different, using the paired bootstrap test at 5% significance level.

The longevity of females of *T. turkestani* on all three host plants tested was longer than the respective longevity of males. A similar trend has also been reported for *T. turkestani* on eggplant (Nemati *et al.* 2005), on cowpea, green gram and pinto bean (Sohrabi and Shishehbor 2008), on kidney bean (Latifi *et al.* 2010), on cucumber (Karami Jamour and Shishehbor 2012) (Table 5) and other tetranychid species such as *E. orientalis* (Imani and Shishehbor 2009), and *T. urticae* (Riahi *et al.* 2011).

Only a few studies have been carried out to assess the biology of *T. turkestani* on Leguminose plant species. Mean total fecundity of *T. turkestani* was reported to be 90.58, 84.14 and 53.73 eggs/female on cowpea, green gram and pinto bean, respectively (Sohrabi and Shishebor 2008) and 115 eggs/female on kidney bean (Latifi *et al.* 2010) (Table 5). The values found in both studies are higher than those found in the current study, i. e., 65.13, 44.03 and 32.69 eggs/female on cowpea, white bean and red bean, respectively. Differences in ecological factors, namely, strain of mites, host plant species, as well as measurement methods may provide an explanation for higher fecundity of *T. turkestani* reported in other studies compared to our results.

At 25 °C, intrinsic rate of increase (r_m) of *T. turkestani* was reported to be 0.20 on cotton (Carey and Bradley 1982), 0.22 on eggplant (Nemati *et al.* 2005), 0.21 on cotton (Zhang *et al.* 2006), 0.23, 0.24, 0.19 on cowpea, green gram and pinto bean, respectively (Sohrabi and Shishehbor 2008) and 0.18 on cucumber (Karami Jamour and Shishehbor 2012) which are similar to our results (Table 5). However other laboratory studies have reported a variety of r_m values for this species. The value of r_m of *T. turkestani* was found to be 0.25 on cotton (Popov 1981) and 0.29 on kidney bean (Latifi *et al.* 2010) which are higher than the values obtained in the present study, i. e., 0.21, 0.21, 0.18 on cowpea, white bean and red bean, respectively, reflecting lower juvenile mortality, higher fecundity and longer adult life span in latter studies. Differences in ecological elements, such as strain of mite and species of host plant, in addition to data analysis method, may provide an explanation for higher r_m.

The results of the current study indicated that *T. turkestani* performance was best on cowpea, worst on red bean, and intermediate on white bean. With rapid development and high survival rates, *T. turkestani* can cause significant damage to many economically important Leguminosae crops. If the ecological conditions are suitable, a female *T. turkestani* can complete its development in about 10 days, and produce up to 65 eggs. Knowledge of the biology of a mite is important for improving programs for pest management, predicting the population appearance and density, and for determining the timing of insecticide applications, as well as release of natural enemies in pest management.

Table 5 Life history and life table parameters of *Tetranychus turkestani* on different host plants at ≈ 25 °C

Host plant	Temperature °C	Developmental time (days)	Survival %	Sex ratio (female %)	Female longevity	Total fecundity	R_0	r_m	Reference
Cotton	25°C	7	-	68	-	-	-	-	Cagle, 1956
Alfalfa	24°C	10.8	-	-	-	160	124	-	Andres, 1957
Cotton	25°C	-	-	-	-	-	56.04	0.25	Popov, 1981
Cotton	23.8°C	10.7	-	62	12.46	73.5	46.7	0.2	Carey and Bradley, 1982
Eggplant	25°C	9.98	-	61	12.09	91	31.7	0.22	Nemati *et al*. 2005
cotton	25°C	-	-	85	-	-	-	0.21	Zhang *et al*. 2006
Cowpea	25°C	12.17	81	81	12.91	90.58	50.61	0.23	Sohrabi and Shishehbor, 2008
Green gram	25°C	11.79	88	84	13.22	84.14	59.79	0.24	Sohrabi and Shishehbor, 2008
Pinto bean	25°C	10.81	58	80	9.05	53.73	27.86	0.19	Sohrabi and Shishehbor, 2008
Kidney bean	25°C	8.92	93	71	11.47	115	78.27	0.29	Latifi *et al*. 2010
Cucumber	25°C	10.27	58.2	73	6.74	24.57	10.91	0.18	Karimi Jahoor and Shishehbor, 2012
Cowpea	25°C	11.99	80	80	13.92	65.13	42.33	0.21	This study
White bean	25°C	10.43	76.67	73	9.08	44.03	24.95	0.21	This study
Red bean	25°C	10.46	75	58	7.23	32.69	14.16	0.18	This study

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