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BIOLOGY, LIFE TABLE, AND PREDATION OF *ZETZELLIA MALI* (ACARI: STIGMAEIDAE) ON *TETRANYCHUS URTICAE* (ACARI: TETRANYCHIDAE)

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ABSTRACT: Biology, life table parameters and predation rate of the predatory mite *Zetzellia mali* (Ewing) (Acari: Stigmaeidae) feeding on eggs of *Tetranychus urticae* Koch (Acari: Tetranychidae) on apple leaves were studied at 25±1ºC, 65±5% RH and a photoperiod of 16:8 (L:D) hours. The following average parameters were obtained: Female longevity is 10±0.73 days, fecundity is 1.42 eggs/female/day, egg mortality is 21%, preoviposition period is 1.81±0.2 days, oviposition period is 5.4±0.6 days, post oviposition period is 1.3±0.4 days, juvenile development time is 12.18±0.34 days, juvenile mortality is 22%, sex ratio is 0.72 (female/female plus male). Life table parameters were estimated as net reproductive rate (R0) 7.25, intrinsic rate of increase (rm) 0.146 days-1, finite rate of increase (λ) 1.15, mean generation time (T) 12.88 days and doubling time (DT) 4.71 days. Average daily predation of *Z. mali* females on *T. urticae* eggs was 3.14. Thus it is concluded that *Z. mali* can be considered as a valuable addition to the existing IPM methods for spider mites control.

KEY WORDS: biology, life table, Stigmaeidae, *Zetzellia mali*

INTRODUCTION

Tetranychus urticae Koch (Acari: Tetranychidae) is one of the most important pest mites on fruit trees and woody ornamental plants in the World. The mobile stages of this mite feed on the leaf surface and young terminal shoots of plants with their piercing-sucking mouthparts and cause yellow spots on the leaves. Besides, it also causes indirect damage by laying eggs on the leaf surface and covering them with silky thread. At high population levels, it may cause defoliation (Kafil et al. 2007). A major problem in controlling these spider mites is their ability to develop rapid resistance to miticides after only a few applications. Farmers responded to this by increasing the dosage and frequency of sprays, but this irrational use of pesticides only speed up the development of pesticide resistance in *T. urticae*.

To reduce pesticide input and associated risks and costs, biological control of spider mites is widely used world wide (Mo and Liu 2006). The family Stigmaeidae includes potentially important predaceous mite species found throughout the World on plants and in the soil feeding on tetranychids, tenuipalpids and eriophyids (Nelson et al. 1973; Santos and Laing 1985; Villanueva and Harmsen 1998; Kheradmand et al. 2007). After phytoseiid mites, stigmaeids, specially the genera *Agistemus* Summers and *Zetzellia* Oudemans, are considered the most important spider mite predators (Santos and Laing 1985; Kheradmand et al. 2007). *Zetzellia mali* (Ewing) is a predator of both apple rust mites and spider mites and occurred throughout the apple orchards of Iran (Jamali et al. 2001; Zahedi-Golpayegani et al. 2007). In eastern North America, it can adequately assist in the control of mite pests, especially early in the spring and from mid-summer until fall (Kain and Nyrop 1995).

Zetzellia mali by itself is the least likely mite to provide effective biological control. It doesn't have phytoseiids' potential for rapid population growth and may compete with them by consuming their eggs and competing for common prey. However, *Z. mali* has many attributes that contribute to biological mite control. It can survive on a variety of alternative foods and persist for long periods without prey and eventually reach densities capable of controlling pest mites. *Z. mali* can also complement biological control by phytoseiids by feeding on stationary forms of pest mites (Kain and Nyrop 1995). Clements and Harmsen (1992) showed that a combination of stigmaeids and phytoseiids have greater efficacy than either predator alone over a wide range of prey densities.

Life table and development rate of *Z. mali* feeding on *Aculus schlechtendali* Nalepa (Acari: Eriophyidae) were studied by White and Laing (1977) in laboratory conditions. Santos (1991) suggested that *Z. mali* in natural ecosystems, respond more to the density of *A. schlechtendali* than to the density of *Panonychus ulmi* Koch. Lawson and Walde (1993) showed that *Z. mali* increased patch residence time in response to the presence of *P. ulmi* eggs. Walde et al. (1995) determined that in laboratory choice trials, prey preference of *Z. mali* varies with the relative but not absolute density of its prey. Jamali et al. (2001) studied the biology of *Z. mali* in Karaj, Iran.

Demographic studies have several applications: analyzing population stability and structure; estimating extinction probabilities; predicting life history evolution; predicting outbreak in pest spe-

cies and examining the dynamics of colonizing or invading species (Haghani et al. 2006). There is a little information about *Z. mali* and its efficacy as a biological control agent of spider mites. To explore the potential of using *Z. mali* in controlling spider mites more information is needed. The objective of this study was to determine all major biological parameters of *Z. mali* feeding on eggs of *T. urticae* on apple, including development, reproductive and fecundity, life table parameters and predation under laboratory conditions.

MATERIALS AND METHODS

Mite cultures

Adult females of *Z. mali* were collected from an apple orchard located in the vicinity of Maragheh city (Northwestern Iran) in June 2007. Modified apple leaf arenas consisting of a water saturated foam pad placed in a plastic box (10×20×0.5 cm^3). A water saturated layer of cotton was placed over the foam pad, 4–5 mature apple leaves were placed on cotton layer with the upper surface facing down. Each leaf petiole was covered with a saturated cotton strip. Approximately 40 or more *Z. mali* adults were transferred using a fine brush to individual apple leaf arenas infested with eggs of *T. urticae*. Additional *T. urticae* females were added to each arena before all of their eggs were consumed. About 20 leaf arenas (4 per plastic box) were maintained in an individual growth chamber (WTB Binder Labortechnik GmbH, Tuttlingen, Germany) that provide constant temperature of 25±1ºC and air circulation. The relative humidity inside the chamber ranged between 60% and 70%. *T. urticae* stock colony initiated with specimens collected from bean fields and maintained on apple leaf arenas. The mites were transferred to new arenas every 10 days.

Experimental design

To follow the different stages of *Z. mali*, females were isolated in 2 cm^2 arenas of apple tree leaf prepared as previously described but a layer of filter paper was used instead of cotton layer. Every 4 arenas were kept in a 10 cm Petri dish containing water. The trays with mites were maintained in rearing chamber at 25±1ºC temperature, 65±5% RH and 16:8 L:D photophase. After oviposition the females were removed as well as all but one egg per arena. By using a stereomicroscope to determine the developmental times of the larval, protonymphal and deutonymphal stages, individuals were observed every 24 h until they reached the adult stage. At the adult stage, sexes were determined (male is less robust and idiosoma tapering posteriorly) and only females were used for determination of developmental times. Following Jamali et al. (2001) results, ten *T. urticae* eggs were used as prey, every 24 h the number of consumed eggs was counted and the remaining eggs were replaced by new ones to avoid their hatching. Developmental stages, sex ratio, survival rate, predation rate and the number of eggs deposited were recorded daily. The study was initiated with 100 eggs which resulted in 11 females reaching to the end of experiment. Female longevity and fecundity were measured and the following table parameters were calculated :

— The age specific survival (l_x)

— The age specific fecundity (m_x) = born female/female

— The net reproductive value (R_0) = $\sum(l_x m_x)$ (Birch 1948)

— The intrinsic rate of increase (r_m) which is calculated by iteratively solving the Euler equation,

$$\sum(e^{-r_m \cdot x} l_x m_x) = 1 \text{ (Birch 1948)}$$

— The mean generation time (T) = $\frac{\ln R_0}{r_m}$ (Birch 1948)

— The finite rate of increase (λ) = e^{r_m} (Birch 1948)

— The doubling time (DT) = $\frac{\ln 2}{r_m}$ (Kairo and Murphy 1995)

— The life expectancy $(e_x) = \frac{T_x}{l_x}$, $T_x = \sum_{y=x}^{w} L_y$, $L_x = \frac{l_x + l_{x+1}}{2}$ (Carey 1993)

— The stable age distribution (C_x) = $\frac{l_x . e^{-r_m . x}}{\sum_{x=0} (l_x . e^{-r_m . x})}$ (Birch 1948)

— Gross reproductive rate (GRR) = $\sum m_x$

RESULTS

Z. mali had 5 developmental stages: egg, larva, protonymph, deutonymph and adult with every active immature stage followed by a quiescent one. The average life time was 22.18±1.07 days (Table 1) with 9.62% of lifespan corresponding to adulthood. The egg stage had the longest duration

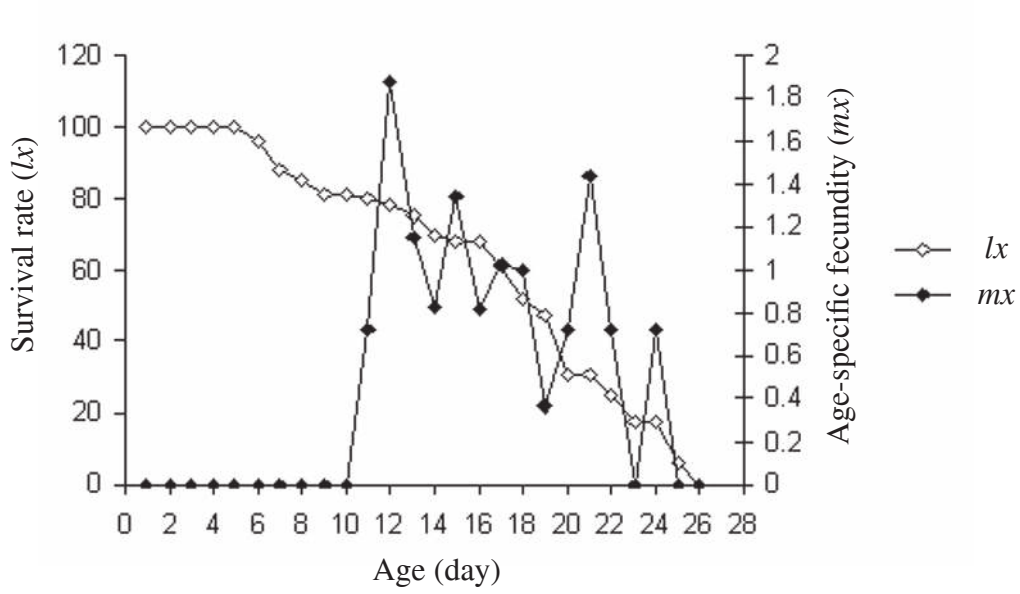

Fig 1. The age specific survival (*lx*) and age-specific fecundity (*mx*) (♀/♀) of *Zetzellia mali* on apple tree leaves.

Table 1.
Duration (days) of *Z. mali* life-history stages on apple tree leaves at 25±1ºC, 65±5% RH and 16:8 L:D photophase

Life stage	Daily predation on *T. urticae* eggs	Average±SE	N
Egg	–	4.84±0.1	79
Larva	0.38±0.1	1.9±0.1	65
Protochrysalis	0	1.04±0.02	50
Protonymph	1.38±0.14	1.28±0.07	47
Deutochrysalis	0	1±0	43
Deutonymph	2.05±0.16	1.12±0.05	40
Teleiochrysalis	0	1±0	31
Immature combined	–	12.18±0.34	–
Pre-ovipositing female	3.76±1.01	1.81±0.2	11
Ovipositing female	4.26±0.15	5.4±0.6	11
Post-ovipositing female	1.42±0.23	1.3±0.4	11
Adult female	–	10±0.73	11
Overall life stage	–	22.18±1.07	–

of immature stages (59.95% of life time). These developmental periods combined with the daily survival and oviposition rate in Fig. 1. The net reproductive rate (R_0) was 7.25, the intrinsic rate of increase (r_m) was 0.146 day^{-1}, the finite rate of increase (λ) was 1.15, the mean generation time (*T*) was 12.88 days and the doubling time (*DT*) was 4.71. Calculated L_x, T_x, e_x and C_x are shown in Table 2.

Z. mali females started to lay eggs when they were 1.81±0.2 days old. The oviposition period lasted 5.4±0.6 days (n=11) and postoviposition period was 1.3±0.4 days. In this experiment the mean life time of females was found to be 10±0.73 days, the oviposition period thus amounting to 54% of female entire life time. The total number of eggs produced by *Z. mali* females fed on *T. urticae* eggs was 7.7±0.75 per female. During the oviposition period the number of eggs laid daily by a female varied from 0–4 with the average being 1.42 eggs/ day. Totally, 79% of eggs hatched and 72% of hatched eggs were female. This species is arrhenotokous, with unfertilized eggs resulting in male progenies. Mean predation rate of *Z. mali* feeding on eggs of *T. urticae* in each stage is presented in Table 1.

Table 2.
Calculated values of *Lx*, *Tx*, *ex* and *Cx* for *Z. mali* at 25±1ºC, 65±5% RH and 16:8 L:D photophase

x	*Lx*	*Tx*	*ex*	*Cx*
1	1	16.09	16.09	0.157
2	1	15.09	15.09	0.135
3	1	14.09	14.09	0.117
4	1	13.09	13.09	0.101
5	0.98	12.09	12.09	0.087
6	0.92	11.11	11.57	0.072
7	0.86	10.19	11.57	0.057
8	0.83	9.32	10.97	0.048
9	0.81	8.49	10.48	0.039
10	0.80	7.68	9.48	0.034
11	0.79	6.88	8.6	0.029
12	0.76	6.09	7.8	0.024
13	0.72	5.32	7.1	0.020
14	0.69	4.6	6.57	0.016
15	0.68	3.91	5.75	0.013
16	0.64	3.23	4.75	0.011
17	0.56	2.58	4.23	0.009
18	0.49	2.02	3.88	0.006
19	0.39	1.52	3.24	0.005
20	0.31	1.13	3.66	0.003
21	0.28	0.82	2.66	0.002
22	0.21	0.54	2.18	0.001
23	0.18	0.33	1.83	0.001
24	0.12	0.15	0.83	0.0009
25	0.03	0.03	0.5	0.0002
26	0	0	0	0

DISCUSSION

Data of *Z. mali* feeding on *T. urticae* eggs were used to analyze all major life table parameters. There is no published information on the life table parameters for *Z. mali* feeding on *T. urticae* eggs. We showed that *Z. mali* can develop and reproduce on *T. urticae* eggs in laboratory conditions. White and Laing (1977) reported that the larvae of *Z. mali* can not feed on *P. ulmi* eggs and develop into protonymphs but we found that all mobile developmental stages of *Z. mali* feed on *T. urticae* eggs. Our results on the mean generation time and sex ratio of *Z. mali* were very close to those of White and Laing's (1977) using the apple rust mite as prey at 24±1ºC and 51% RH. The mean generation time and sex ratio of *Z. mali* on *T. urticae* eggs at 21°C, 75% RH, and 16:8 L:D photoperiod reported by Jamali et al. (2001) were 20.75 days and 2.1 females/males respectively. The difference might result from different laboratory conditions.

In this research, the egg stage had the longest duration (59.95% of the total life time), followed by the larval stage (13.03%), adult (9.62%), protochrysalis (4.8%), protonymph (3.9%), deutochrysalis (3.4%), deutonymph (2.9%), and teleiochrysalis (2.4%). The approximate proportions of the population at each stage reported by White and Laing (1977) at 19°C temperature and 56% RH were as follows: egg 59%, larvae 15%, protonymph 7%, deutonymph 5% and adult 13%. Adult females laid eggs in 1.5–2 days (average 1.8 days) after emergence. However considering all imma-

ture stages it was estimated that it takes 14.0 days for a newly laid egg to develop into adults and initiate laying eggs. Each *Z. mali* female deposited 4–11 eggs over an oviposition period of 3–9 days. Preovipositional and ovipositional periods of *Z. mali* reported by White and Laing (1977) were 1.5 and 9.4 days respectively and each female laid an average of 15 eggs during the oviposition period. Jamali et al. (2001) showed that the average preoviposition and oviposition periods lasted 4.6±0.14 and 11.7±2.14 days respectively and adult females laid 1.05±0.1 eggs per day.

Natural mortality (22%) over all immature stages of *Z. mali* in our study was relatively low. The survival rate of *Z. mali* adults sharply decreased immediately after the reproductive period, indicating that most individuals survived to the end of their life cycle and died at their maximal age. We found that each the adult female of *Z. mali* consumed an average of 3.14 eggs per day and was the most voracious during their oviposition period (4.26 eggs/day). Jamali et al. (2001) reported that each adult consumed 2.22 (1–4) *T. urticae* eggs per day. It seems that high temperatures can cause an increase in the predation rate. Adult females of *Z. mali* consume an average of 12.5 motile *Aculus schlechtendali* per day (White and Laing, 1977).

The intrinsic rate of increase (r_m) is the most important parameter for describing the growth potential of a population under given climatic and food conditions, because r_m reflects an overall effect on development, reproduction and survival (Southwood and Handerson 2000). In theory, a predator that has a population growth rate lower than its prey can not control its prey. In biological control the r_m value is one of the most important criteria in selecting biological control candidates on the basis of its reproductive potential and to predict the outcome of interaction of the pest and the beneficial agent once a beneficial agent is introduced into a crop system. The r_m value of *Z. mali* feeding on *T. urticae* eggs found in this study (0.146 day^{-1}) was greater than those determined by White and Laing (1977). A comparison of some intrinsic characteristics of *Z. mali* and phytophagous mite *T. urticae* can help to visualize the relative potential of *Z. mali* to regulate tetranychid mites. The intrinsic rate of increase (r_m) of *T. urticae* is 0.143 day^{-1} (Laing 1969) is slightly lower than that found in this study for *Z. mali*. Other stigmaeid predators such as *Agistemus industani, A. cyprius and A. floridanus* had lower intrinsic rate of increase when provided with *P. citri* eggs and ice plant pollen at 25ºC (Goldarazena et al. 2004).

There are several advantages of using *Z. mali* as a biological control agent of spider mites because it can survive on several alternative foods when its preferred prey is not present and thus can live for long periods without prey. Santos (1982) observed that *Z. mali* can survive 23.6 days without any food on leaves. Because of its feeding versatility, *Z. mali* can eventually reach population densities capable of controlling pest mites. Pesticides that are considered moderately toxic to predators may have little or no long term effect on their populations when applied in low quantities, but if they are used too often they will have a negative effect. It may take up to three years to establish a population of predators high enough to control pest mites. Integrated pest management strategies can help establish colonies of predatory mites (Kain and Nyrop 1995).

The results of the current study provide information that will help facilitate the more effective control of spider mites by the stigmaeid predator. Additional research is needed to identify viable and improved pollen sources, if available, for the development of *Z. mali* and other stigmaeid species.

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