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Article

Biology and life table parameters of *Proprioseiopsis lindquisti* on three eriophyid mites (Acari: Phytoseiidae: Eriophyidae)

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ABSTRACT
The predatory mite *Proprioseiopsis lindquisti* completed its development and reproduced successfully on three eriophyid mites, *Aculops lycopersici*, *Aceria mangiferae*, and *Aculus fockeui*, under laboratory conditions. Feeding on *A. mangiferae* and *A. fockeui* resulted in short developmental and long oviposition periods and was a suitable food for predator oviposition as it resulted in high fecundity, gross and net reproductive rates. Feeding on *A. lycopersici* elongated the developmental period and was less favorable for the predator as it gave the lowest rate of oviposition and net reproductive rates. Higher intrinsic rates of increase, and finite rates of increase for *P. lindquisti* were recorded on *A. mangiferae* while *A. lycopersici* and *A. fockeui* produced lower values.

KEY WORDS: *Aceria mangiferae*; *Aculops lycopersici*; *Aculus fockeui*; intrinsic rates of increase; laboratory conditions; predatory mite.

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INTRODUCTION

Phytoseiid mites are important natural enemies of several phytophagous pests (Bounfour and McMurtry 1987). They are important biological control agents of other mite groups, thrips, whiteflies, small arthropods and nematodes. They have been used to control pests in biological control programs (Lindquist *et al.* 1996; Sabelis and Van Rijn 1997; McMurtry and Croft 1997; Gerson *et al.* 2003). *Proprioseiopsis* species are common in different parts of the world (Moraes *et al.* 2004), but few papers refer to the biology of these mites and their ability to consume mites (Ball 1980; Momen and El-Borolossy 1999; Momen 2009). The predatory mite *Proprioseiopsis lindquisti* (Schuster and Pritchard) was found in Egypt on olive leaves at Faywam (Momen 1999). *Proprioseiopsis lindquisti* can survive and reproduce on eriophyid mites, but failed to sustain oviposition on nymphs of *T. urticae*, eggs and adults of *Parlatoria zizyphus* (Lucas) and liquid diets such as molasses and honey (Momen 1999).

Eriophyid mites are obligate plant parasites with several economically important species mainly on perennial plants. The tomato russet mite *Aculops lycopersici* (Massee), is a serious pest; it is present where Solanaceae crops are grown (Jeppson *et al.* 1975). *Aculops lycopersici* tolerates different climatic conditions and completes several generations per year causing alterations in

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leaves, stems and fruits, often up to plant death (Duso *et al.* 2010). It causes silvering of under surface of leaves which later become bronze, wither and die. The mango bud mite *Aceria mangiferae* Sayed was described from Egypt, but currently is found everywhere mango is grown (Sayed 1946; Denmark 1983; Doreste 1984). *Aceria mangiferae* attack buds and inflorescences of mango, *Mangifera indica* L. (Keifer *et al.* 1982; Ochoa *et al.* 1994). This mite induces witches broom causing bud proliferation and play a role in carrying fungal pathogen *Fusarium mangiferae* Britz, which causes mango malformation (Varma *et al.* 1974; Freeman *et al.* 2004). The peach silver mite, *Aculus fockeui* (Nalepa & Trouessort), is a pest of plum, peach, nectarine and almond (Jeppson *et al.* 1975; Kadono 1985). In Egypt, it was firstly found by Attiah (1970) and later became a serious pest, reaching a high level of economic threat. *Aculus fockeui* injures young leaves, causing yellow spots; later in season leaves show silvering and rolling. The damaged trees have lower vigor because of post-harvest defoliation which results in lower fruit quality in the next year (Kondo and Hiramatsu 1999).

The morphological characters of host plants, such as plant structure, leaf hairiness, and type and density of trichomes, have been found to affect the searching efficiency of natural enemies through the interaction between the pest and its predator (Krips 2000; Raghu *et al.* 2004). The leaf structure also affects mating, oviposition, growth and development of the predatory mites (Kreiter *et al.* 2002).

The objective of this study was to evaluate nutritional value of *Aculops lycopesici*, *Aceria mangiferae* and *Aculus fockeui* as natural food for the predatory mite *P. lindquisti*. Reproductivity and demographic parameters of *P. lindquisti* were evaluated and compared using different mobile stages of these eriophyid mites under laboratory conditions.

MATERIAL AND METHODS

Predatory mite culture

The predatory mite, *P. lindquisti*, was collected from the leaves of mango, peach, and rarely tomato plants. The stock culture was maintained on the mobile stages of *Aculus fockeui* in the laboratory at 28 ± 1 °C, 70 ± 5% relative humidity and a photoperiod of 12:12 h (light: dark). Females of *P. lindquisti* were transferred into leaf discs (4 cm in diameter) of acalypha *Acalypha wilkesiana* Müll. Arg. (Eupharbiaceae) on water-saturated cotton provided with mobile stages of *Aculus fockeui* and allowed to oviposit for 24 h. The newly deposited eggs were used for experiments.

Tested Preys

The effect of different preys on biological parameters of *P. lindquisti* was studied using three eriophyid mites, *Aceria mangiferae* from infested mango buds *Mangifera indica* L., *Aculus fockeui*, from infected peach leaves *Prunus persica* (Stokes) (Rosaceae) and *Aculops lycopersici* from tomato leaves *Lycopersicon esculentum* Mill. (Solanaceae).

Experiments

The experiments were conducted under laboratory conditions at 28 ± 1 °C, 70 ± 5% RH and a photoperiod of 12:12 h (light: dark). Leaf discs (2 cm in diameter) of acalypha were placed upside-down on wet cotton pads in Petri dishes. Forty eggs of *P. lindquisti* (for each prey) were individually transferred to each leaf disc, and the newly hatched larvae were supplied with a small leaf disc (0.25 cm in diameter) that was heavily infested with the tested eriophyid mites or one outer bract infested with mango bud mite as food. The developmental periods of different life stages of the predator were recorded every 12 h. Newly emerged females were copulated with males within 24 h, and they were confined individually on leaf discs. All biological parameters were observed daily. The leaf substrate was replaced with a fresh one every 5 days.

Statistical analysis

A total of 27, 22, and 26 females (replicates) of *P. lindquisti* per *Aceria mangiferae*, *Aculops lycopersici* and *Aculus fockeui* (respectively) were analyzed using one-way ANOVA; means were compared by Tukey HSD at a 5% probability level using SPSS computer program (version 25).

Age-stage, two-sex life table

Developmental time of all individuals, including male and female, and female fecundity were analyzed according to the Age-Stage, Two- Sex life table theory (Chi and Liu 1985) and the method described by Chi (1988). Population parameters (*r, λ, R0, T* and *GRR*) were calculated by using the TWOSEX-MSChart program (Chi 2017). The bootstrap method was used to estimate the standard errors of the population parameters (Huang and Chi 2012); the differences of the bootstrap values between treatments were compared using the paired bootstrap test based on the confidence interval of difference (Efron and Tibshirani 1993).

RESULTS

Effect of preys on development and reproduction

The predatory mite *P. lindquisti* successfully developed and reproduced when fed on three eriophyid mites, *Aculops lycopersici*, *Aceria mangefirae*, and *Aculus fockeui* (Table 1). Tested preys significantly affected the preadult development of *P. lindquisti* ($F = 100.51$, $df_{2.72}$, $P = 0.000$). The longest oviposition period (27.22 and 22.12 days) was recorded when *Aceria mangefirae* and *Aculus fockeui* were used as prey where *Aculops lycopersici* resulted in shortest oviposition period (18.41 days) ($F = 121.93$, $df_{2.72}$, $P = 0.000$). The longest female longevity ($F = 11.06$, $df_{2.72}$, $P = 0.000$) was recorded on *Aceria mangiferae* and *Aculus fockeui*. Total fecundity and daily fecundity were significantly affected by different prey species ($F = 517$, $df_{2.72}$, $P = 0.000$; $F = 34.24$, $df_{2.72}$, $P = 0.000$ respectively). They were the highest on *Aceria mangiferae* (38.56 eggs, 1.42 egg/female/ day) (Table 2).

Table 1. Mean developmental period (± SE) of *Propriopseiopsis lindquisti* fed on active stages of *Aculops lycopersici*, *Aceria mangiferae* and *Aculus fockeui*.

Developmental stages /Periods	*Aceria mangiferae* (27)	*Aculus fockeui* (26)	*Aculops lycopersici* (22)
Egg	1.89 ± 0.06	1.81 ± 0.08	1.64 ± 0.11
Larva	1.00 ± 0.00b	1.00 ± 0.00b	1.14 ± 0.08a
Protonymph	1.37 ± 0.10c	1.89 ± 0.10b	2.64 ± 0.12a
Deutonymph	1.56 ± 0.10c	2.27 ± 0.11b	3.27 ± 0.14a
Preadult	5.82 ± 0.12c	6.96 ± 0.12b	8.68 ± 0.19a
Preoviposition period	1.26 ± 0.09b	2.65 ± 0.11a	2.86 ± 0.15a
Oviposition period	27.22 ± 0.38a	22.12 ± 0.37b	18.41 ± 0.45c
Postoviposition period	2.04 ± 0.13c	3.89 ± 0.19b	6.00 ± 0.28a
Female longevity	30.52 ± 0.42a	28.65 ± 0.44b	27.27 ± 0.61b
Life span	36.33 ± 0.39a	35.62 ± 0.45a	36.00 ± 0.57a
Total fecundity	38.56 ± 0.45a	26.77 ± 0.36b	20.36 ± 0.38c
Daily number of eggs/females	1.42 ± 0.02a	1.22 ± 0.03b	1.12 ± 0.03c

Numbers in parentheses represent the number of replicates. The means in each row with the same letters are not significantly different (Tukey-HSD test: $P \leq 0.05$).

Table 2. Population parameters (mean ± SE) of *Propriopseiopsis lindquisti* fed on mobile stages of *Aculops lycopersici*, *Aceria mangiferae* and *Aculus fockeui*.

Life table parameters	*Aceria mangiferae* (27)	*Aculus fockeui* (26)	*Aculops lycopersici* (22)
Intrinsic rate of increase (*r*)	0.208 ± 0.013a	0.175 ± 0.012ab	0.142 ± 0.011b
Finite rate of increase (*λ*)	1.231 ± 0.016a	1.191 ± 0.014ab	1.152 ± 0.012b
Net reproductive rate (R_0)	19.222 ± 2.623a	13.385 ± 1.861ab	10.182 ± 1.552b
Mean generation time (*T*)	14.242 ± 0.256b	14.825 ± 0.225b	16.361 ± 0.249a
Gross reproductive rate (*GRR*)	20.445 ± 2.875a	13.750 ± 1.979b	10.554 ± 1.678b

Numbers in parentheses represent the number of replicates. Mean values in a row followed by different letters are significantly different (Paired bootstrap test, at 5% significance level).

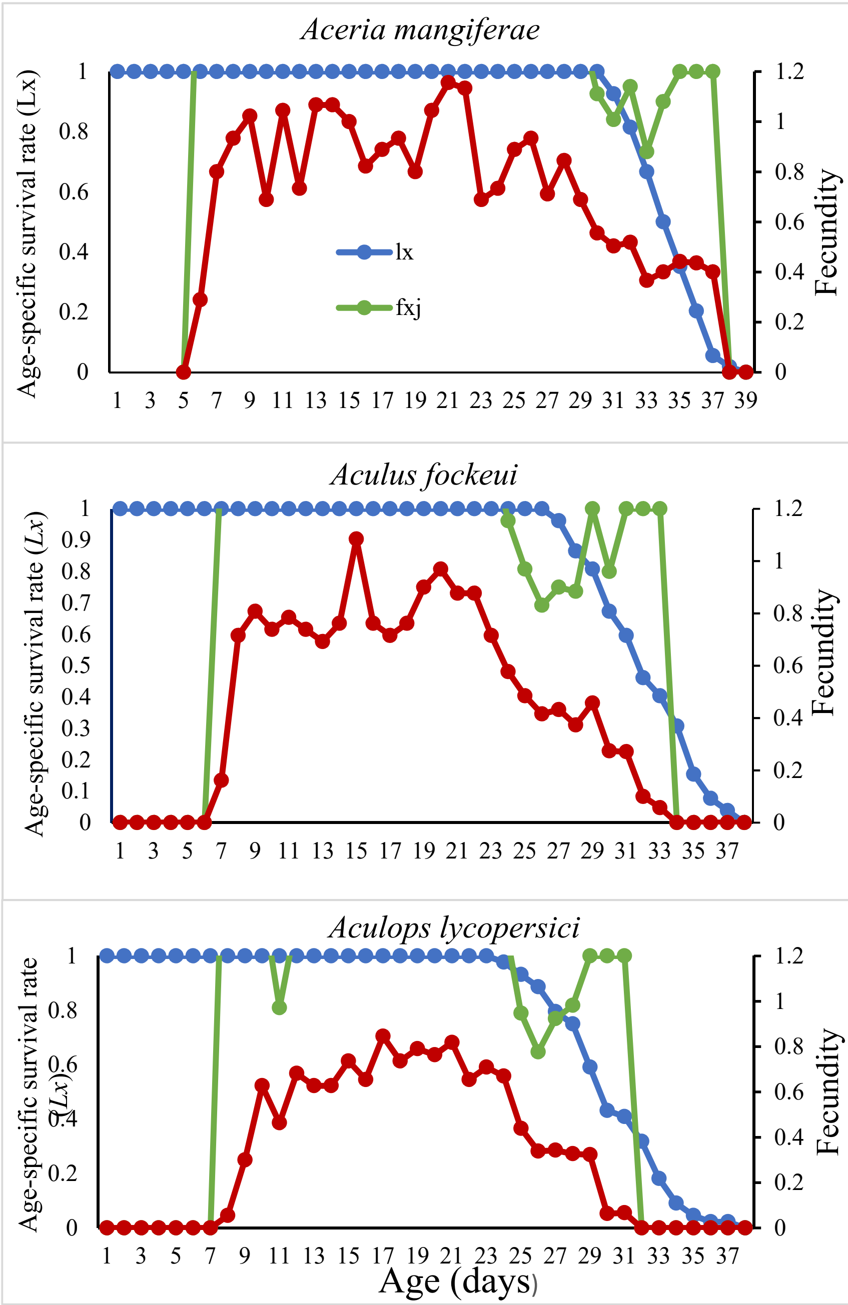

Figure 1. Age-specific survival rate (l_x), age-stage specific fecundity of female (f_{xj}) and age-specific fecundity rate (m_x) of *Propriopseiosis lindquisti* on three eriophyid mites.

Population parameters

The effect of mobile stages of the tested preys on population parameters of *P. lindquisti* is summarized in Table 2. Predatory mite on *Aceria mangiferae* and *Aculus fockeui* showed short mean generation time (T = 14.24 and 14.82 days) while *Aceria lycopersici* value was longer (16.36 days). The highest value of net reproductive rate was on *Aceria mangiferae* and *Aculus fockeui*, whereas a lower value was recorded for *Aculops lycopersici*. The intrinsic rate of increase (r), finite rate of increase (λ) and gross reproductive rate (*GRR*) showed a similar trend. Age-specific survivorship (lx), age and age-stage-specific fecundity (mx) of *Propriopseiopsis lindquisti* when fed on eriophyid mites are shown in Figure 1. The curves show that *P. lindquisti* completed its development and reproduced on the tested preys. The mean number of offspring produced by *P. lindquisti* individuals of the age x and stage j per day is shown with the age-stage-specific fecundity (f_{xj}). The start of oviposition of the first female on *Aceria mangiferae*, *Aculops lycopersici* and *Aculus fockeui* occurred at the age 5, 7 and 6 days, respectively. The highest daily fecundity of the females of the predator on the three mentioned eriophyid mites was 0.96, 0.70 and 0.90 eggs/female/day, that occurred at the age of 21, 17 and 15 days, respectively.

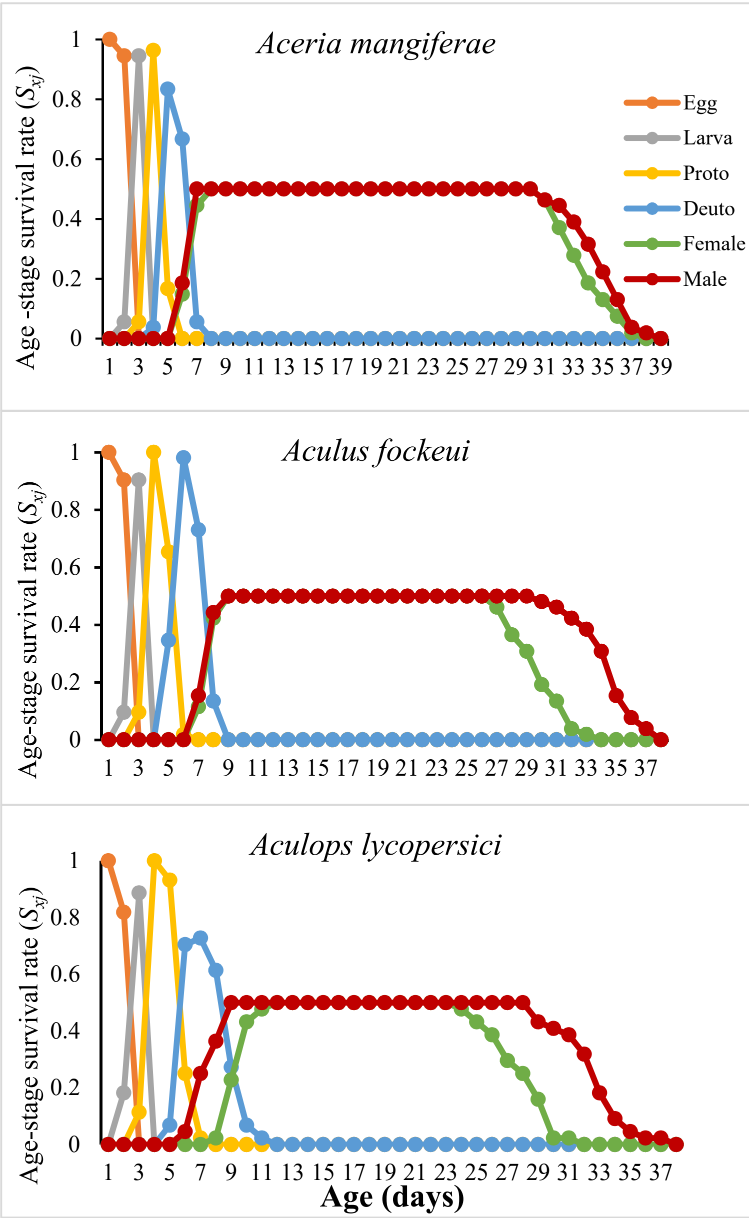

Figure 2. Age-stage survival rate (S_{xj}) of *Propriopseiosis lindquisti* on three eriophyid mites.

Age-stage, two-sex life table

The age-stage specific survival rates (S_{xj}) of *P. lindquisti* show the probability that a newborn will survive to age *x* and develop to stage *j* (Fig. 2). Curves also show the survivorship, and stage differentiation and the variable developmental rate.

DISCUSSION

The eriophyid mites *Aceria mangiferae*, *Aculus fockeui* and *Aculops lycopersici* provide commensurate nutritional effects for the development and reproduction of *P. lindquisti.* The longest preadult development, mean generation time and lowest fecundity for *P. lindquisti* were recorded on *Aculops lycopersici*, while *Aceria mangiferae* and *Aculus fockeui* showed faster development, shorter mean generation time (*T*), and higher fecundity of the predator. Preadult developmental periods in our study ranged from 5.82 to 8.68 days and the oviposition rate was 38.56, 26.77 and 20.36 eggs on *Aceria mangiferae*, *Aculus fockeui* and *Aculops lycopersici*, respectively. When *P. lindquisti* was offered other prey such as *Eriophyes olivi* Zaher and Abou-Awad, *Tetranychus urticae* Koch and pollen grains of *Phoenix dactylifera* (L.), the eriophyid mite *E. olivi* allows faster development (6.38 days) and higher fecundity (35.00 eggs) while no eggs were produced on *T. urticae* which was unsuitable prey for *P. lindquisti* (Momen 1999). Similarly, eriophyid mites contributed to faster development and high fecundity of *Propioseiopsis badri* (Yousef and El-Borolossy) (Momen *et al.* 2014), *Typhlodromus transvaalensis* (Nesbitt) (Momen and Hussein 1999) and *Amblyseiella denmarki* (Zaher and El-Borolossy) (Momen *et al.* 2004) while *T. urticae* elongated the developmental period these predators. Compared with our results, *Typhlodromips swirskii* (Athias-Henriot) and *Typhlodromus mangiferus* Zaher and El-Brolossy fed on *Aceria mangiferae* showed longer developmental periods (8.24 and 7.32 days) and higher fecundity (2.15 and 2.30 egg/female/day, respectively), at 30 °C (Abou-Awad *et al*. 2010 a, b). When *T. swirskii* and *Typhlodromus athiasae* Porath & Swirski were offered *Aculops lycopersici* the development was faster (7.00 and 8.00 days, respectively), and the reproduction rate of *T. swirskii* was higher (1.7 egg/female/day) than the value recorded for *P. lindquisti* in our study (Momen and Abdel-Khalek 2008). For *P. badri*, *Aculops lycopersici* diet gave lower fecundity (16.95 eggs) than that of females of *P. Lindquisti* (20.36 eggs) in our study. *Aculus fockeui* elongates the developmental times and gave high reproduction rate for *Typhlodromips swirskii* (6.57 day, 43.00 eggs), *Typhlodromus negevi* Swirski & Amitai (8.64 day, 32.35 eggs), and *Amblyseiella denmarki* (8.07 day, 49.40 eggs) compared with our results (Momen 2009). James (1989) reported that *Aculus fockeui* allows good survival and oviposition (1.2 eggs/day) for *Amblyseius victoriensis* (Womersley).

Our results showed that the tested eriophyid mites significantly affected population parameters of the phytoseiid mite *P. lindquisti* (Table 2). *Aculops lycopersici* was not a favorable food source for oviposition of the predator; feeding on this prey resulted in the lowest values of R_0, *r*, and λ while *Aceria mangiferae* and *Aculus fockeui* gave the higher values. Momen and Abdel-Khalek (2008) found that *Amblyseius swirskii* and *T. athiasae* successfully reproduced when fed with *Aculops lycopersici* and the R_0 = (26.79 and 19.84 offspring/individual, respectively) and *r* = (0.24 and 1.18day^{-1} respectively), were higher than our results. *Proprioseiopsis badri* showed lower value of R_0 = 9.83 (offspring/individual) and higher intrinsic rate of increase 0.17 (day^{-1}) on *Aculops lycopersici* than our results. In comparison with our results, when *T. mangiferus* and *T. swirskii* preyed on *Aceria mangiferae* higher values of R_0 = (23.72 and 24.94 offspring/individual, respectively) and *r* = (0.18 and 0.18day^{-1}, respectively) were observed (Abou-Awad *et al.* 2010a, b). The net reproductive rate of *Amblyseiella denmarki* (35.57 day^{-1}) and *T. swirskii* (28.97day^{-1}) and the intrinsic rate of increase of *Amblyseiella denmarki* (0.22day^{-1}), *T. swirskii* (0.24day^{-1}) and *T. negevi* (0.16 day^{-1}) were higher compared with our results (Momen 2009b).

The intrinsic rate of increase (*r*) of a predacious mite is an important factor for its evaluation as a biological control agent against phytophagous mites. *Aceria mangiferae* and *Aculus fockeui* gave the higher (*r*) values for *P. lindquisti*, whereas *Aculops lycopersici* showed the lowest value. Generally, eriophyid mites favored the reproductive potential of the specialist predator, *P. lindquisti*.

The mobile stages of the eriophyid mites provided commensurate nutritional effects on survivorship, longevity and fecundity of the predator, *P. lindquisti*. Some eriophyid mites are characterized by a favorable protein content. On the contrary, Sabelis (1996) reported that eriophyids had a low nutritional quality when compared with other prey. Also, the toxins in eriophyids may be repellent to some phytoseiid predators.

Predators can be affected by the host plant directly, differences in the structure of the leaves and other plant attributes can affect prey finding, or in nutrients provided, e.g. in exudates (Krips *et al.* 1999; Skirvin and de Courcy Williams 1999). The host plant has indirect effects on the predators, such as the concentration of nutrients available to the phytophagous mites, which reflects their nutritive value to the predator, or differences in population growth and stage structure of the prey (Sabelis 1991; Krips *et al*. 1998). Therefore, the predator's efficiency, establishment and persistence are reduced as direct and indirect consequences of the host plant. It should be noted that under laboratory conditions, where the predators are confined with their prey on small leaf discs, prey location was much simpler than field conditions.

CONCLUSION

The tested eriophyid mites, *Aculops lycopersici*, *Aceria mangiferae*, and *Aculus fockeui* provide a commensurate nutritional effect for *P. lindquisti* to survive and reproduce. Results obtained in this study suggest that *P. lindquisti* has potential as an effective biological control agent of the mango bud mite, peach silver mite and tomato rust mite. The above discussed results may help to provide a better understanding of the effectiveness and possibilities of the utilization of *P. lindquisti* as a specialized predator of eriophyid mites in the biological control programs.

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زیست‌شناسی و آماره‌های جدول زیستی *Proprioseiopsis lindquisti* با تغذیه از سه کنهٔ اریوفید (Acari: Phytoseiidae: Eriophyidae)

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چکیده

کنهٔ شکارگر *Proprioseiopsis lindquisti* رشد خود را با تغذیه از سه کنه به نام‌های *Aculops lycopersici* ،*Aceria mangiferae* و *Aculus fockeui* در شرایط آزمایشگاهی تکمیل و با موفقیت تولیدمثل کرد. تغذیه از *A. mangiferae* و *A. fockeui* به دوره‌های رشد کوتاه و طولانی مدت تخم‌گذاری منجر شد و غذای مناسبی برای تخم‌گذاری شکارگر بود که منجر به باروری، مقدار ناخالص و خالص تولید مثل زیاد شد. تغذیه از *A. lycopersici* دوره رشد را طولانی کرد و برای شکارگر کمتر مطلوب بود، به طوری‌که کمترین میزان تخمگذاری و مقدار خالص تولید مثل را داشت. نرخ ذاتی افزایش بیشتر و نرخ متناهی افزایش برای *P. lindquisti* با تغذیه از *A. mangiferae* ثبت شد در حالی‌که با تغذیه از *A. lycopersici* و *A. fockeui* مقادیر کمتری تولید شد.

واژگان کلیدی: *Aceria mangiferae* ؛ *Aculops lycopersici* ؛ *Aculus fockeui* ؛ نرخ ذاتی افزایش؛ شرایط آزمایشگاهی؛ کنهٔ شکارگر.

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