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Egyptian Journal of Biological Pest Control (2023) 33:92
https://doi.org/10.1186/s41938-023-00738-4

Egyptian Journal of Biological Pest Control

RESEARCH Open Access

A comparative study of two-sex life table parameters of *Orius laevigatus* fieber (Hemiptera: anthocoridae) on two mealybug species, *Planococcus citri* Risso, and *P. solenopsis* Tinsley (Hemiptera: Pseudococcidae)

Dogancan Kahya[1*]

Abstract

Background Augmentative biological control is a crucial component of Integrated Pest Management, and *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) is an important predator used commercially. However, the two-sex life table parameters of *O. laevigatus* on *Planoccocus citri* Risso, and *P. solenopsis* Tinsley (Hemiptera: Pseudococcidae) have not been fully characterised. This study aimed to assess the potential of *P. citri* and, *P. solenopsis* as prey for mass-rearing the predatory bug. To accomplish this, three different prey items (individuals of *P. citri*, *P. soleneopsis*, and eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae)) were used to determine the life table parameters of the minute pirate bug.

Results Daily and total fecundity, adult longevity, APOP, TPOP, and pre-adult periods were calculated in this study. The results showed that daily fecundity was 7.4 ± 0.10, 4.41 ± 0.08, 3.47 ± 0.08, and adult longevity was 20.9 ± 0.47, 15.17 ± 0.31, 14.03 ± 0.39 on *E. kuehniella*, *P. solenopsis* and *P. citri*, respectively. Net reproduction rate (R_0) was 57.23 ± 11.35, 17.27 ± 3.57, 11.05 ± 2.30, and the intrinsic rate of increase (*r*) was 0.172 ± 0.009, 0.084 ± 0.006, 0.069 ± 0.006 on *E. kuehniella*, *P. soleneopsis*, and *P. citri*, respectively. Additionally, finite rate of increase (*λ*), gross reproductive rate (GRR), and mean generation time (*T*) were calculated on the three tested prey.

Conclusion Overall, the results showed that eggs of *E. kuehniella* were the most suitable prey for the mass-rearing of *O. laevigatus*. Although *P. citri* and *P. solenopsis* had worse results than *E. kuehniella*, *P. solenopsis* may still have potential, and *O. laevigatus* could potentially be used against this pest with further studies in laboratory and field conditions.

Keywords Demographic analysis, *Orius laevigatus*, *Phenacoccus solenopsis*, *Planococcus citri*, *Ephestia kuehniella*

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Background

Biological control is one of the most effective and successful control methods in greenhouses and fields in Integrated Pest Management (IPM) programs since the 1900s (Van Lenteren and Godfray 2005). The application methods of biological control are classical, augmentative and conservation. In the augmentative biological control, the natural enemies have to be commercially mass reared in bio-factories prior its release in the agroecosystem (De

Puysseleyr 2014). This method is generally used in greenhouses, fruit orchards, vineyards, cotton, maize, and soybean and can be environmentally friendly control instead of chemical control (Uygun et al. 2016). More than 170 predators and parasitoids are commercially used globally, and 100 are applied with augmentative biological control. Especially professional production, new mass-rearing techniques, quality control protocols, shipment, and developed release methods help to spread the augmentative biological control and reach farmers adequately (Cock et al. 2010).

The *Orius* genus is considered as important generalist predators of many small soft-body arthropod pests which widely uses in augmentative biocontrol programs in various agroecosystems, especially greenhouses (Gerling et al. 2001). In addition, it can feed not only on thrips but also whiteflies, mites, aphids, and lepidopteran eggs (van Lenteren and Bueno 2003). Many studies indicated that the predatory bugs can be integrated with other biocontrol agents including some parasitoid wasps (Pirzadfar et al. 2020). Moreover, this predator is the zoo-phytophagous, which can feed on pollen and sap for survival (Armer et al. 1998). The minute pirate bug, *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) is one of the most effective biological control agents commercially used in augmentative biological control programs in Europe.

Orius laevigatus is a successful predator that can feed on a wide range of prey. Alternative prey can be supplementary during the mass rearing of natural enemies, and nutritional contents of the preference of different prey by beneficial organisms are one of the critical factors (Evans et al. 1999). Some researchers have studied different prey preferences and life table parameters of *Orius* species (Arnó et al. 2008; Zuma et al. 2022). Generally, prey preferences and life table parameters of *Orius* species were done on different aphids, thrips, whitefly, or interactions of these prey species. In addition, Ballal et al. (2012) studied the predatory potential of two anthocorid species on two different mealybug species, *Paracoccus marginat*us Williams and Granara de Willink and *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). In addition, different prey preferences (Aphids, mealybugs, and *E. kuehniella*) on *Orius albidipennis* were studied by Amer et al. (2021). Limited studies have been done on mealybugs and other potential prey preferences of *O. laevigatus.*

This study focused on the two-sex life table parameters of *O. laevigatus* on different prey of *P. solenopsis*, *P. citri* and *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). The alternative prey potential of mealybugs was observed in the laboratory conditions during this study. Number of daily and total laid eggs, APOP (Adult Pre-ovipositional period), TPOP (Total pre-ovipositional period), Ovipositional, and post-ovipositional periods, fecundity, and longevity of *O. laevigatus*, in addition, life table parameters were calculated on two-sex life table analysis (Chi et al. 2020). The primary aim of this study was to estimate the potential use of mealybugs in the mass-rearing of *O. laevigatus*. Moreover, fundamental studies on the potential use of *O. laevigatus* against two different mealybug species were determined at this study.

Methods

Planococcus citri and *Phenacoccus solenopsis* cultures

Mealybug cultures were lasted in climate rooms separately at 25 °C, 65 ± 10% R.H and 16: 8 (L: D) in the Biological Control Research Institute. Potato sprouts were used for the stock culture of the two mealybug species.

Orius laevigatus culture

The predatory bug culture was obtained from Biological Control Research Institute, *E. kuehniella* eggs and sugary water soaked in cotton were used as a food source in the mass rearing of this predator and *Kalanchoe blossfeldiana* Poelln. (Rosales: Crassulaceae) leaves were used as an ovipositional substrate in controlled climate rooms with above mentioned conditions. In addition, *O. laevigatus* was reared on *P. citri* and *P. solenopsis* for using in life table experiments.

Design of the experiment

Experiments were carried out with *P. citri*, *P. solenopsis*¸ and eggs of *E. kuehniella* separately. The newly hatched nymphs, which were reared on each prey separately, were placed into 9 mm Petri dishes and egg-hatching duration and immature stages of *O. laevigatus* (N1, N2, N3, N4, and N5) were recorded for each prey individually. After that, *O. laevigatus* individuals, one day age female and male, which completed their immature stages, were placed into plastic containers together. Each container included one female and one male of *O. laevigatus*. Moreover, mixed nymphs and adults of *P. citri* and *P. solenopsis* were given as prey daily for each experiment separately, and *K. blossfeldiana* leaves as ovipositional substrate were used for oviposition. In addition, the same experimental design was carried out for *E. kuehniella* eggs.

Experiments were done with 40 replications in controlled climate cabinets with above mentioned conditions for each prey separately. Counting was recorded daily for life table parameters of *O. laevigatus* on the three prey.

Life table analysis

The life table parameters of *O. laevigatus,* reared on *P. solenopsis*, *P. citri*, and *E. kuehniella,* were analysed by the computer program TWOSEX-MS Chart (Chi and Liu 1985; Chi 1988, 2018). The age-stage-specific fecundity

Table 1 Parameters and equations in the life table analysis (Chi et al. 2022; Wei et al. 2020)

$s_{xj} = \frac{n_{xj}}{n_{01}}$	Sxj: The age-stage-specific survival rate
$l_x = \sum_{j=1}^{m} s_{xj}$	l_x: the age-specific survival rate
$m_x = \left(\sum_{j=1}^{m} s_{xj}/f_{xj}\right)/\sum_{j=1}^{m} s_{xj}$	m_x: age-specific fecundity
$R_0 = \sum_{X=0}^{\infty}\sum_{j=1}^{m} s_{xj}f_{xj} = \sum_{X=0}^{\infty} l_x m_x$	R_0: The net reproduction rate
$T = (\ln R_0)/r$	T: Mean generation time
$\lambda = e^r$	λ: finite rate of increase, r: the intrinsic rate of increase

(*fxj*), age-stage-specific survival rate (*Sxj*), age-specific fecundity (m_x) and age-specific survival rate (*lx*), were calculated from the daily records of the survival and fecundity of all individuals. net reproduction rate (R_0), finite rate of increase (λ), the intrinsic rate of increase (r), mean generation time (T), gross reproductive rate (GRR), and the number of female adults (N_f) were calculated in this study (Table 1). 100,000 bootstrap method was used for the calculation of means and standard errors. In addition, statistical differences between prey were determined with the "Paired bootstrap method" ($p < 0.05$) (Chi et al. 2022). All formulas used for analysis are given below in table (1):

Results

In this study, life table parameters of *O. laevigatus* were determined using three different prey species. The pre-adult period of *O. laevigatus* was 25.13 ± 0.26, 26.67 ± 0.33, and 13.17 ± 0.20 days when reared on *P. solenopsis*, *P. citri*, and *E. kuehniella*, respectively [df = 2,117; $p = 0.0003$]. The pre-adult duration was longer for *O. laevigatus* reared on mealybug species than for *E. kuehniella*. The egg-hatching period was shorter for *O. laevigatus* reared on *E. kuehniella*, and the duration of nymphal stages was longer for *O. laevigatus* reared on *P. citri,* and *P. solenopsis*. Additionally, this study revealed a shorter pre-adult period and longer adult longevity for *O. laevigatus* when reared on *E. kuehniella*. (Table 2, Figs. 1, 2, and 3). The immature and mature stages of *Orius laevigatus* showed statistically significant differences between three different prey in this study ($p < 0.05$) (Table 2).

Table 2 The immature and mature stages of *Orius laeivgatus* on different prey

Prey	Egg (Day ± SE)	1st instar nymph (Day ± SE)	2nd instar nymph (Day ± SE)	3rd instar nymph (Day ± SE)	4th instar nymph (Day ± SE)	5th instar nymph (Day ± SE)	Total (Day ± SE)
Phenacoccus solenopsis	4.49 ± 0.08a*	4.22 ± 0.07a	4.32 ± ,0.09a	4.0 ± 0.11a	3.83 ± 0.13a	4.30 ± 0.09a	25.13 ± 0.26a
Planococcus citri	5.24 ± 0.13a	4.44 ± 0.10a	4.39 ± 0.10a	3.97 ± 0.11a	3.87 ± 0.10a	4.70 ± 0.10a	26.67 ± 0.33a
Ephestia kuehniella (Control)	2.53 ± 0.09b	2.24 ± 0.07b	2.30 ± 0.09b	2.29 ± 0.11b	1.50 ± 0.11b	2.33 ± 0.12b	13.17 ± 0.20b

*Means followed by the same letters in the same column are not significantly different based on the paired bootstrap test at the 5% significance level

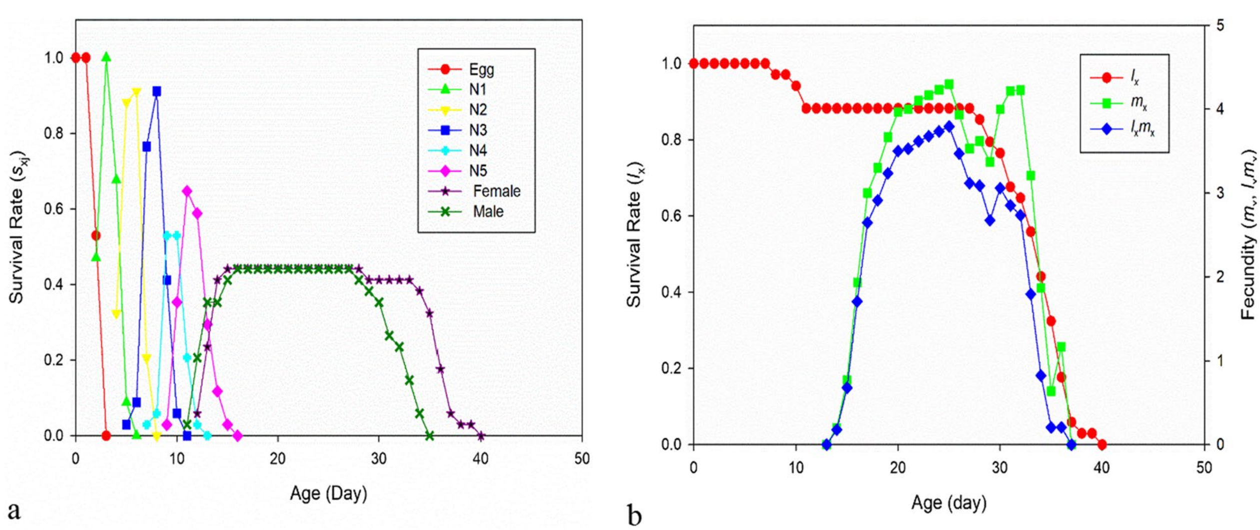

Fig. 1 (**a** Age-stage specific survival rate (s_{xj}), **b** Age-specific survival rate (l_x), age-specific fecundity ($_{mx}$), and age-specific maternity ($l_x m_x$) of *O. laevigatus* reared on *E. kuehniella*

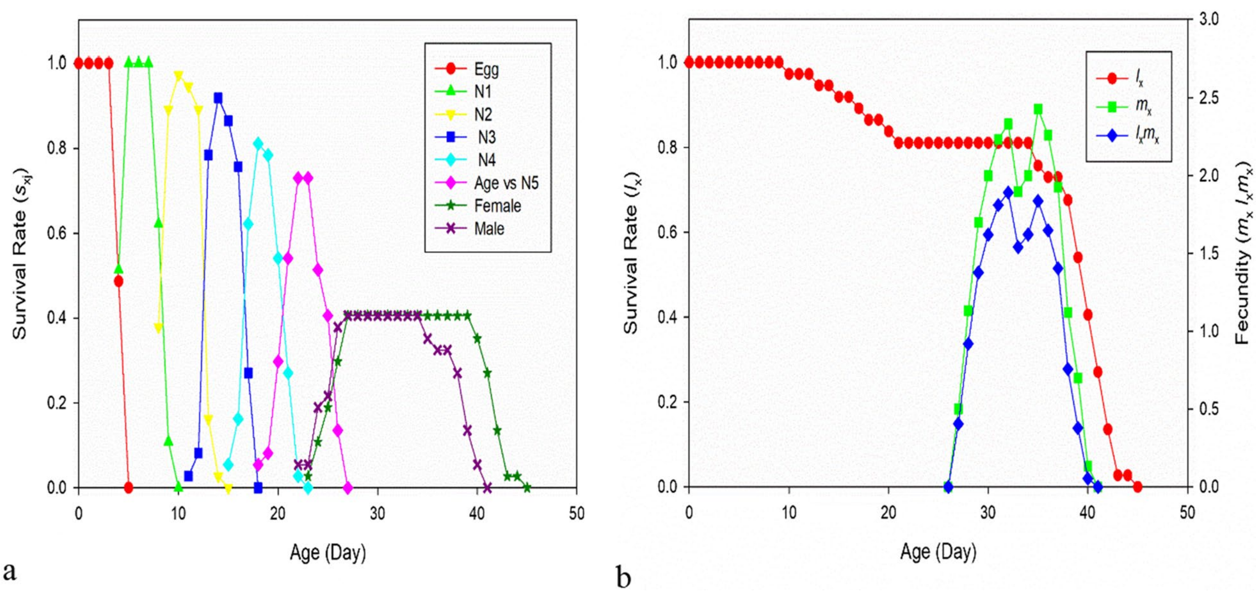

Fig. 2 (**a** Age-stage specific survival rate (s_{xj}), **b** Age-specific survival rate (l_x), age-specific fecundity ($_{mx}$), and age-specific maternity ($l_x m_x$) of *Orius laevigatus* reared on *P. solenopsis*

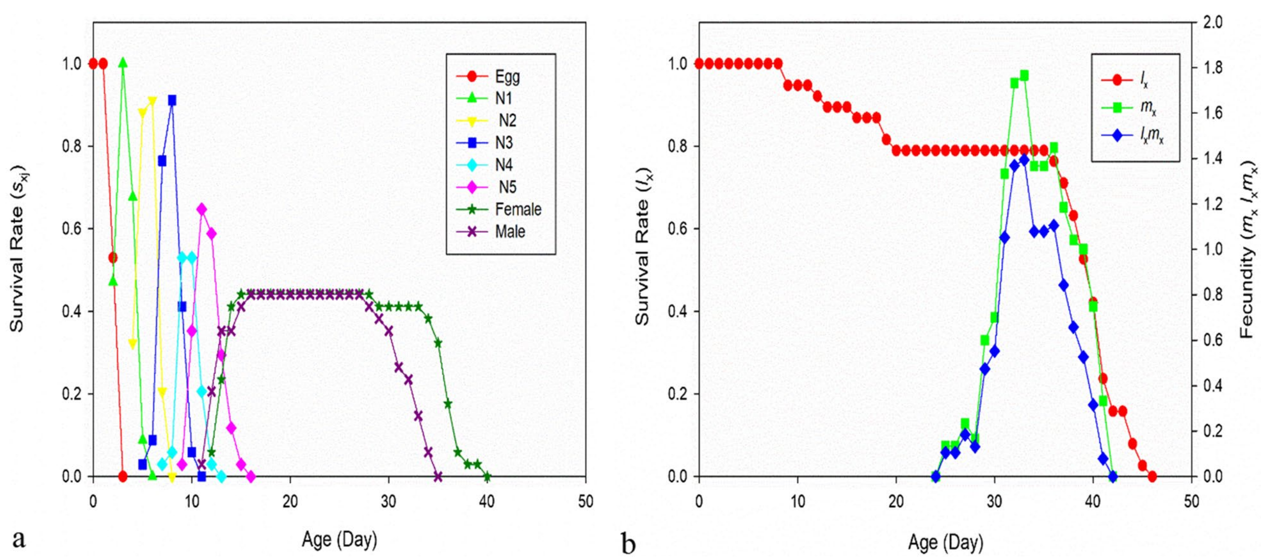

Fig. 3 (**a** Age-stage specific survival rate (s_{xj}), **b** Age-specific survival rate (l_x), age-specific fecundity ($_{mx}$), and age-specific maternity ($l_x m_x$) of *Orius laevigatus* reared on *P. citri*

This study showed that the APOP (Adult pre-ovipositional period) and TPOP (Total pre-ovipositional period) of *O. laevigatus* were longer when fed on *P. citri* and *P. solenopsis* than on *E. kuehniella*. Furthermore, the ovipositional period was twice as long as when *E. kuehniella* was used as a prey compared to *P. solenopsis* and *P. citri*. The worst performance in terms of oviposition was observed when *P. citri* was used as prey. The total fecundity of *O. laevigatus* was 129.73 ± 5.98, 42.6 ± 2.47, and 28.00 ± 1.69 [df = 2,117; p = 0.0001], and daily fecundity was 4.41 ± 0.08, 3.47 ± 0.08, and 7.4 ± 0.10 [df = 2,117; p = 0.0001] on *E. kuehniella*, *P. solenopsis*, and *P. citri*, respectively. Additionally, the adult longevity was 20.9 ± 0.47, 15.17 ± 0.31, and 14.03 ± 0.39 [df = 2,117; p = 0.0091] on *E. kuehniella*, *P. solenopsis*, and *P. citri*, respectively (Table 3). Based on these results, *E.*

Table 3 APOP ((Adult preoviposition period), TPOP (Total preoviposition period), Oviposition, Postoviposition period, Total and daily fecundity of *Orius laevigatus* on different prey

Prey	APOP (Day ± SE)	TPOP (Day ± SE)	Oviposition period (Day ± SE)	Post-oviposition period (Day ± SE)	Total fecundity (Day ± SE)	Daily fecundity (Day ± SE)	Adult Longevity (Day ± SE)
Phenacoccus solenopsis	3.2 ± 0.17a*	28.67 ± 0.33a	9.67 ± 0.40b	3.66 ± 0.18a	42.6 ± 2.47b	4.41 ± 0.08b	15.17 ± 0.31b
Planococcus citri	3.33 ± 0.13a	30.13 ± 0.52a	8.07 ± 0.41b	3.46 ± 0.16a	28.00 ± 1.69c	3.47 ± 0.08c	14.03 ± 0.39b
Ephestia kuehniella (Control)	2.67 ± 0.12b	16.07 ± 0.26b	17.53 ± 0.54a	2.33 ± 0.12b	129.73 ± 5.98a	7.4 ± 0.10a	20.9 ± 0.47a

*Means followed by the same letters in the same column are not significantly different based on the paired bootstrap test at the 5% significance level

kuehniella was the most suitable prey for mass-rearing of *O. laevigatus*. Mealybug species were found to be ineffective for mass-rearing, but *O. laevigatus* may still be used as an alternative option in augmentative biological control against *P. solenopsis*. APOP, TPOP Oviposition, Postoviposition period, Total and daily fecundity of *O. laevigatus* showed statistically significant differences between three different prey in this study ($p < 0.05$) (Table 3).

Life table parameters of *O. laevigatus* were determined on the two different mealybug species and *E. kuehniella*. The net Reproduction rate (R_0) was 57.23 ± 11.35, 17.27 ± 3.57, and 11.05 ± 2.30 [df = 2,117; $p = 0.0005$] on *E. kuehniella*, *P. solenopsis*, and *P. citri*, respectively. In addition, the intrinsic rate of increase (r) and finite rate of increase values (λ) was better on *P. solenopsis* (0.084 ± 0.006, 1.088 ± 0.007) than *P. citri*. Moreover, the mean generation time was 23.41 ± 0.30, 33.56 ± 0.30, and 34.42 ± 0.59 [df = 2,117; $p = 0.0001$] on *E. kuehniella*, *P. solenopsis*, and *P. citri*, respectively (Table 4). According to the results of this study, *E. kuehniella* showed the best performance in terms of life table parameters, and *P. solenopsis* may be used as a prey for mass-rearing of *O. laevigatus,* or this predator may be applied as an alternative biological control agent in greenhouses in the augmentative biological control against *P. solenopsis*. The age-specific survival rates (lx), age-specific fecundities of the total population (m_x), and age-specific maternity ($l_x m_x$) of *O. laevigatus* reared on *E. kuehniella, P. solenopsis,* and *P.*citri, respectively were shown in Figs. (1, 2 and 3).The life table parameters of *O. laevigatus* showed statistically significant differences between three different prey in this study ($p < 0.05$) (Table 4).

Discussion

Prey choice is one of the most critical factors in the mass-rearing of predators. studies were conducted to determine the most suitable prey for the mass-rearing of *O. laevigatus*. Arnó et al. (2008) studied two different *Orius* species on *Bemisia tabaci* Genn. (Hemiptera: Aleyrodidae) and *Franklinella Occidentalis* Pergande. (Thysanoptera: Thripidae) for prey preference. The study showed that *O. laevigatus* and *O. majusculus* could feed on whitefly nymphs and eggs but prefered thrips when presented with whiteflies and thrips. Zuma et al. (2022) researched the effect *of E. kuehniella* eggs as an alternative prey and alyssum as a companion plant against *Macrosiphum euphorbiae* Thomas (Hemiptera: Aphididae) (aphid). According to the results of the study, *E. kuehniella* eggs and alyssum, a companion plant, can positively affect *the O. laevigatus* population. They suppressed the aphid population easily with this alternative option. In addition, different larval diets for *E. kuehniella* and their effects on *O. laevigatus* performance were studied, the CY diet (95% cornmeal + 5% yeast) for *E. kuehniella,* and the best results were obtained when *O. laevigatus* was fed with these eggs, regarding fecundity, longevity, and nymphal development (Pehlivan 2021). Prey preference of *Orius niger* Wolff (Hemiptera: Anthocoridae) was studied on *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), *Aphis gossypii* Glover (Hemiptera: Aphididae) and *Tetranychus urticae* Koch (Acari: Tetranychidae) under laboratory

Table 4 Life table parameters of *Orius laevigatus* on different prey

Prey	The intrinsic rate of increase (r)(day^{-1})	Net reproduction rate (R_0) (offspring/female)	Finite rate of increase (λ) (day^{-1})	Gross reproductive rate (GRR) (offspring/female)	Mean generation time (T) (day)
Phenacoccus solenopsis	0.084 ± 0.006b*	17.27 ± 3.57b	1.088 ± 0.007b	22.37 ± 4.09b	33.56 ± 0.30a
Planococcus citri	0.069 ± 0.006b	11.05 ± 2.30c	1.072 ± 0.006b	15.29 ± 2.83b	34.42 ± 0.59a
Ephestia kuehniella (Control)	0.172 ± 0.009a	57.23 ± 11.35a	1.188 ± 0.011a	71.42 ± 12.32a	23.41 ± 0.30b

*Means followed by the same letters in the same column are not significantly different based on the paired bootstrap test at the 5% significance level conditions. The numbers of prey consumed recorded were: 0.54, 0.35 and 0.089 for *T. tabaci*, *A. gossypii* and *T. urticae*. (Salehi et al. 2011). Moreover, the predator–prey interactions for *O. laevigatus* and *O. majusculus* on three thrips species were studied, and the results showed that the reproductive parameters of two *Orius species* were positive. However, leaf-inhabitant thrips was more suitable than *F. occidentalis* (Rahman et al. 2022). Effects of three different temperatures (15, 25, and 35 °C) on life table parameters of *O laevigatus* and *O. albidipennis* on *F. occidentalis* were studied. Although the best performance for fecundity was obtained at 25 ℃ for both predators, predation activity was better at 35 ℃, and *O. laevigatus* consumed more individuals than *O. albidipennis* (Cocuzza et al. 1997). In addition, life table parameters of *O. laevigatus* on *B. tabaci* were observed and finite rate of increase (λ): 1.12 females/female/day, net reproduction rate (R_o): 20 females/female/generation, r_m: 0.12, mean generation time (T): 25.7 days, gross reproductive rate (GRR): 46 insects/female/generation was found in this study (Hamdan 2012). Many studies conducted on different prey preferences and life table parameters of *Orius* species, and *E. kuehniella,* showed one of the best performances in terms of the mass-rearing of this predator. The results showed similar results for *E. kuehniella* with our study.

Furthermore, there are limited studies about using mealybug species as prey for anthocorid predators. Fabres and Ferrero (1980) detected the predation activity for *Cardiastethus exiguus* Poppius (Hemiptera: Anthocoridae) on the Cassava Mealybug (*Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)). Tohamy et al. (2008) determined *O. albidipennis* as a predator of *Saccharicoccus sacchari* Cockerell (Hemiptera: Pseudococcidae) (The pink sugarcane mealybug). Elbahrawy et al. (2020) conducted a study about the monitoring and management of *P. solenopsis* on green bean plants, and they found many predators and parasitoids during their surveys. *O. laevigatus* was recorded as a predator of *P. solenopsis* with other coccinellids and chrysopids predators. In addition, *Orius* species was recorded as a predator of mealybugs in studies (El Aalaoui and Sbaghi 2021). The predatory potential of *Anthocoris muraleedharani* Yamada and *Blaptostethus pallescens* Poppius (Hemiptera: Anthocoridae) on *P. marginatus* and *P. solenopsis* was studied under laboratory conditions. *A. muraleedharani* can feed with *P. solenopsis* but cannot feed with *P. marginatus*. *B. pallescens* fed with both *P. solenopsis* and *P. marginatus*. The longevity of *B pallescens* was reduced when fed with *P. marginatus*. Regarding higher adult longevity, shorter nymphal duration, and predatory potential, *A. muraleedharani* was better than *B. pallescens* (Ballal et al. 2012). The effects of different prey on *O. albidipennis* were studied, and *E. kuehniella, A. craccivora, and P. citri* were used as alternative prey and the results showed that the highest total fecundity was 112.7, 96.4, 55.42, and daily fecundity was 8.18, 5.24, and 3.06 on *E. kuehniella, A. craccivora, and P. citri,* respectively (Amer et al. 2021).

In general, aphids, mites, and whiteflies were used as an alternative prey for *Orius* species above studies (Venzon et al. 2002; Van Lenteren and Bueno 2003). In addition other anthocorid predators were studied by some researchers (Ballal et al. 2012). Mealybugs were not common prey for this predator. However, the results of this study showed that *P. solenopsis* may be better than *P. citri* in terms of life table parameters. In addition, the results of the life table parameters of *O. laevigatus* on *P. citri* were similar and matched up with Amer et al. (2021). The findings regarding the life table parameters of *O. laevigatus* feeding on *E. kuehniella* were consistent with previous studies conducted by Zuma et al. (2022). Moreover, it was determined that *E. kuehniella* emerged as the most suitable prey choice for mass-rearing purposes. Moreover, *P. solenopsis* was invasive and established in Türkiye since 2012 (Kaydan et al. 2013) therefore *O. laevigatus* may be an alternative predator for this mealybug species and it may be combined with other natural enemies after conducting further studies about the interactions between *O. laevigatus* and *P. solenopsis.*

Conclusion

This study determined the life table parameters of *O. laevigatus* on *P. citri* and *P. solenopsis* for the mass-rearing of the predator. Generally, *E. kuehniella* eggs were used for the mass-rearing of *O. laevigatus.* The most suitable prey was eggs of *E. kuehniella*. Although mealybug species had a lower potential when used as prey for *O. laevigatus*, *P. solenopsis* had better results than *P. citri*. Therefore, *O. laevigatus* may be used against *P. solenopsis* by combining with other predators and parasitoids in augmentative biological control programs. Further studies should be done to determine the predatory potential of *O. laevigatus* against *P. solenopsis* in laboratory and field conditions for the contribution to biological control in integrated pest management.

Abbreviation

SE Standard error

Acknowledgements

I would likte to thank Assoc. Prof. Dr.Refik BOZBUGA for reviewing this manuscript.

Author contributions

Author read and controlled final version of manuscript.

Funding
Not applicable.

Availability of data and materials
All datasets are presented in the manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for Publication
Not applicable.

Competing interests
The author declare that they have no competing interest.

Received: 15 May 2023 Accepted: 9 September 2023
Published online: 15 September 2023

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