Experimental and Applied Acarology (2024) 93:99–114
https://doi.org/10.1007/s10493-024-00908-5

RESEARCH

Life table parameters of *Amblyseius largoensis, Amblyseius swirskii* and *Proprioseiopsis lenis* (Acari: Phytoseiidae) fed on eggs and larvae of *Frankliniella occidentalis*

Viet Ha Nguyen[1] · **Duc Tung Nguyen**[2] · **Thomas Van Leeuwen**[1] · **Patrick De Clercq**[1]

Received: 7 November 2023 / Accepted: 15 March 2024 / Published online: 9 May 2024

Abstract

The immature development and reproduction of the predatory mites *Amblyseius largoensis* (Muma), *Proprioseiopsis lenis* (Corpuz and Rimando), and *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) were investigated using both thrips eggs and first instars of the western flower thrips, *Frankliniella occidentalis* Pergande, as prey in a controlled laboratory environment at 25 °C and 60% relative humidity. When provided with thrips eggs as food, *A. largoensis* exhibited a notably shorter immature development period for both males (7.05 days) and females (6.51 days) as compared with *A. swirskii* (8.05 and 7.19 days, respectively) and *P. lenis* (8.10 days and 7.05 days, respectively). *Amblyseius largoensis* also displayed a higher oviposition rate (2.19 eggs/female/day) than *A. swirskii* and *P. lenis* (1.79 and 1.78 eggs/female/day, respectively). Moreover, it exhibited the highest fecundity (25.34 eggs/female), followed by *P. lenis* (24.23 eggs/female) and *A. swirskii* (22.86 eggs/female). These variations led to *A. largoensis* having the highest intrinsic rate of increase (r_m) at 0.209, followed by *A. swirskii* at 0.188, and *P. lenis* at 0.165. However, when the predatory mites were provided with first instars of *F. occidentalis*, *A. swirskii* demonstrated a faster immature development period for both males (7.67 days) and females (7.59 days) as compared with *P. lenis* (9.00 days and 7.86 days, respectively) and *A. largoensis* (8.47 days and 8.61 days, respectively). While the oviposition rates of *P. lenis* (1.92 eggs/female/day) and *A. swirskii* (1.90 eggs/female/day) were similar when feeding on this prey, *A. largoensis* produced fewer eggs (1.83 eggs/female/day). Further, *A. swirskii* exhibited the highest fecundity (31.93 eggs/female), followed by *A. largoensis* (25.71 eggs/female) and *P. lenis* (23 eggs/female). Consequently, the intrinsic rate of increase (r_m) on thrips first instars was highest in *A. swirskii* (0.190), followed by *A. largoensis* (0.186), and *P. lenis* (0.176). In summary, our findings indicate that in terms of life history parameters *A. largoensis* performs optimally when feeding on thrips eggs, whereas *A. swirskii* performs best when preying on the mobile first instars of the thrips. These insights into the dietary preferences and reproductive capabilities of the studied predatory mite species have important implications for their potential use as biological control agents against *F. occidentalis* in agricultural settings.

Extended author information available on the last page of the article

Keywords *Amblyseius largoensis* · *Amblyseius swirskii* · *Proprioseiopsis lenis* · *Frankliniella occidentalis* · Life table · Biological control

Introduction

The western flower thrips, *Frankliniella occidentalis* (Pergande), represents a significant global threat to agricultural and horticultural crops. Its adverse impact includes reduced crop yields due to direct feeding damage and the transmission of tospoviruses, such as impatiens necrotic spot virus and tomato spotted wilt virus, affecting a wide array of crops (Prins and Goldbach 1998). Managing *F. occidentalis* is particularly challenging because of its propensity to develop resistance to chemical insecticides (Gao et al. 2012; Demiroz and Kumral 2022; Yuan et al. 2023). Moreover, its thigmotactic behavior complicates the effective application of chemical insecticides (Sarkar et al. 2019). In light of the environmental concerns associated with chemical insecticides, the quest for alternative methods to manage thrips infestations has become imperative, with a growing focus on biological control agents.

Vietnam, like other nations in South-East Asia, aspires to become a prominent producer and exporter of high-quality agricultural products (Nguyen et al. 2020). Over the past few years, the Vietnamese government has put considerable effort into the promotion and implementation of various campaigns aimed at reducing pesticide usage (Pham et al. 2016). Thrips, including *F. occidentalis*, which are key agricultural pests known to quickly develop resistance to pesticides, are among the focal pests in this context (Poushkova and Kasatkin 2020). Notably, thrips management in Vietnam has predominantly relied on intensive insecticide use. However, rising awareness among consumers and authorities (Mai et al. 2019) about the potential health risks associated with pesticide residues on agricultural products has prompted a shift towards biological control methods as a more sustainable alternative to chemical approaches (Pham et al. 2013). Recent studies in Vietnam have demonstrated the potential of predatory mites from the Phytoseiidae family (Acari) to serve as effective biological control agents against *F. occidentalis* (Nguyen et al. 2019a, b).

The Phytoseiidae family encompasses over 2500 valid species worldwide (Demite et al. 2014, 2020), all of which are predators. Several species within this family hold economic importance as natural enemies, extensively employed in the biological control of various insect and mite pests (McMurtry and Croft 1997; McMurtry et al. 2013). In the present study, we set out to construct life tables of three phytoseiid species capable of preying on the early immature stages of *F. occidentalis*. These include two native species to Vietnam, *Proprioseiopsis lenis* (Corpuz and Rimando) and *Amblyseius largoensis* (Muma), along with a non-native species commercially available in the region, *Amblyseius swirskii* Athias-Henriot.

Amblyseius swirskii, initially identified in Israel in 1962, has since spread to 22 countries and has been available on the market since 2005, now being sold in over 50 countries (Calvo et al. 2015; Tixier et al. 2022). This versatile generalist predator feeds on various prey species and pollen (McMurtry et al. 2013; Alipour et al. 2016; Riahi et al. 2017) and has been observed on 48 plant families, with the highest incidence on Rosaceae, Rutaceae, and Solanaceae, including both cultivated crops and wild plants (Tixier et al. 2022). *Amblyseius swirskii* is an effective biological control agent of thrips (Messelink et al. 2006; Chow et al.

2010), spider mites (Momen 2009), and whiteflies (Nomikou et al. 2001, 2004; Messelink et al. 2008). The species can be mass reared cost effectively and in the field its populations can be supplemented with cattail pollen or astigmatid mites, enhancing its usefulness for augmentative releases (Goleva and Zebitz 2013; Leman and Messelink 2015; Pijnakker et al. 2016).

Amblyseius largoensis, on the other hand, has been identified in tropical regions across the Americas, on Indian Ocean islands, and more recently in Southeast Asia (Gallego et al. 2003; Liao et al. 2013, 2021; Da Silva et al. 2015; Nguyen et al. 2019a). It has been noted as the predominant predator linked to the red palm mite *Raoiella indica* (Hirst) infesting coconuts in Florida, Puerto Rico, and Trinidad and Tobago (Peña et al. 2009). Additionally, it exhibits a diverse diet in the field, preying on various arthropods such as *Eriophyes* mites (Kamburov 1971; Galvão et al. 2007), thrips (Nguyen et al. 2019a), rice moths (Nasr et al. 2015), fruit flies (Momen et al. 2016), and whiteflies (De Alfaia et al. 2018).

Proprioseiopsis lenis, originally discovered on *Citrus nobilis* (Rutaceae) in the Philippines by Corpuz and Rimando (1966), is naturally distributed in New Zealand (Schicha and Elshafie 1980). Subsequently, it has been recorded in Australia (Navasero and Corpuz-Raros 2005), Thailand (Oliveira et al. 2012), and more recently in Vietnam (Nguyen et al. 2019a). Researchers have suggested that *P. lenis* holds the potential to effectively control outbreaks of spider mites and thrips in South-East Asia.

Previous studies on the biological control potential of phytoseiid predators against *F. occidentalis* have predominantly focused on the mobile first instars of the prey. However, the larvae of this thrips species remain in the first instar for only a brief period, typically no longer than 24 h. Thereafter, they become more difficult to exploit as prey by most phytoseiid mites. However, compared to predation on thrips larvae, relatively less attention has been directed towards predation on thrips eggs. The significance of egg predation was suggested by Vangansbeke et al. (2018); Nguyen et al. (2019b), who demonstrated that phytoseiid mites can effectively locate and feed on eggs of *F. occidentalis*. Thus, the objective of the present life table study is to compare the development and reproduction of *A. swirskii*, *A. largoensis*, and *P. lenis* when preying on eggs versus first instars of *F. occidentalis*, with a view to assessing the potential roles of these phytoseiids in managing thrips outbreaks in South-East Asia.

Materials and methods

Colony of prey

Western flower thrips, *F. occidentalis*, were reared at the Department of Plants of Crops of Ghent University (Belgium) on bean pods (*Phaseolus vulgaris* Prelude) and fresh pollen of cattail, *Typha latifolia* L. (Nutrimite, Biobest Group, Westerlo, Belgium) in plastic boxes (30 cm × 20 cm x 8 cm). The rearing containers were kept in a climate chamber (Panasonic MLR 352 H) set at 25 ± 1 °C and 65 ± 5% relative humidity (RH) and a 16:8 h (L:D) photoperiod. Bean pods and pollen were replaced weekly. First instar larvae and adults of *F. occidentalis* were used for the experiments.

Colony of predatory mites

Proprioseiopsis lenis and *A. largoensis* were collected in Vietnam, and colonies were established at Ghent University in 2016. *Amblyseius swirskii* was provided by BioBest Group NV (Westerlo, Belgium). All predatory mites were reared on arenas made from bean leaves (*P. vulgaris*). These leaves were placed upside down on a 2 cm thick layer of wet cotton in plastic trays (20×13×5 cm). To prevent mites from escaping, a thin layer of tissue paper was placed on the edges of the leaves and kept moist. First instars of *F. occidentalis* were provided as the sole prey on a daily basis. Each leaf disc was utilized for two weeks, after which the mites were transferred to fresh leaf discs. All phytoseiids were reared in a Panasonic climate chamber (MLR 352) set at 25±1 °C, 65±5% RH and a 16:8 h (L:D) photoperiod.

Experimental setup

To investigate the development and reproduction of individual predatory mites, plastic dishes (5×1.5 cm) were used as rearing microcosms. The bottom of each dish was lined with a 5×0.3 cm moist cotton layer, on top of which a 4 cm diameter bean leaf section was placed. The edges of the leaves were covered with soft paper tissue, which was moistened daily to prevent mite escape. Approximately 12 h before the start of each experiment, small pieces of white cotton thread were placed in the stock colony of predatory mites to serve as oviposition substrates. Individual eggs deposited on the cotton were transferred to the rearing microcosms, with each treatment initiated using sixty eggs. For experiments involving larvae of *F. occidentalis* as prey, 15 first instars (less than 12 h old) were introduced into each rearing microcosm using a fine brush. This process was repeated every 24 h, at which point any surviving larvae from the previous day were removed. For experiments using eggs of *F. occidentalis* as prey, five female thrips were introduced into each rearing microcosm 24 h before introducing the predator to allow for egg laying. The mites were transferred daily with a fine brush to new microcosms containing fresh thrips eggs. To gather data on the duration of each developmental stage of the predatory mites, as well as on mortality and escape rates, observations were made every 24 h until all individuals had reached adulthood. Any escaped predatory mites were excluded from data analysis. The appearance of an exuvia in the rearing microcosm marked the first day of a new developmental stage for each individual predator. Upon completing immature development, each female phytoseiid was immediately paired with a male that had been reared on the same diet. This male was removed after 24 h. Only a singly mating was allowed in order to exclude variable effects of food competition and further mating events on the female's reproductive output. Adults were observed daily to determine the preoviposition and oviposition periods, oviposition rate, and longevity. The oviposition rate was calculated by dividing the total number of eggs by the number of days during which oviposition occurred. The oviposition period was calculated as the time from the first egg laid until the last egg laid. Progeny from females of the same age were transferred to new rearing microcosms and provided with the same diet as their parents in order to determine the sex ratio. All experiments were conducted in a Panasonic climate chamber (MLR 352) set at 25±1 °C, 65±5% RH, and a 16:8 h (L: D) photoperiod.

Life table parameters

Life table parameters were calculated for *P. lenis*, *A. largoensis*, and *A. swirskii* when presented with eggs or first instars of *F. occidentalis*. The intrinsic rate of increase (r_m) was calculated using the formula developed by Lotka (1907) and Birch (1948):

$$\sum l_x m_x e^{-r_m * x} = 1$$

where x is the female age (in days), l_x is the age -specific survival of females at age x, and m_x is the number of female progeny produced per female at age x. This value is obtained by multiplying the mean number of eggs laid per female by the proportion of female offspring produced at age x. To estimate the standard error of r_m, we utilized the Jackknife procedure following the methodology of Meyer et al. (1986) and Hulting et al. (1990). The generation time (T), net reproductive rate (R_0), finite rate of natural increase (λ), and doubling time (DT) were calculated according to Maia et al. (2000). Generation time (T) signifying the time span (in days) between the first egg laid in one generation and the next, was formulated as:

$$\mathrm{T} = \frac{\sum x l_x m_x}{\sum l_x m_x}$$

The net reproductive rate (R_0) measures the mean number of female offspring produced per female (females/female) and was computed using the following formula:

$$R_0 = \sum l_x m_x$$

Finite rate of natural increase (λ) quantifies the population growth rate over a unit of time and was assessed as:

$$\lambda = \mathrm{antiloge}^{r_m}$$

Doubling time (DT) represents the number of days required for a population to double in size and was calculated using the formula,

$$\mathrm{DT} = \frac{\ln(2)}{r_m}$$

Statistical analysis

Data were subjected to statistical analysis (R_Studio, version 1.1.453, 23 April 2018) to analyse the effect of diet on the duration of the immature stages, preoviposition and oviposition period, daily and total oviposition, and adult longevity of *P. lenis*, *A. largoensis* and *A. swirskii*. Kolmogorov–Smirnov tests indicated that none of the data were normally distributed. Therefore, nonparametric Kruskal–Wallis ANOVAs were used to analyse the data and means were separated using the Mann–Whitney U test. Sex ratios of the progeny were compared by means of a logistic regression. This regression is a generalized linear model using a probit (log odds) link and a binomial error function. P-values smaller than or equal to 0.05 were considered significant.

Results

The immature survival rate of *A. largoensis*, *P. lenis*, and *A. swirskii* when provided with a diet of thrips eggs ranged from 91.67 to 96.67%, whereas when they were offered thrips larvae as prey, their survival rates showed a range from 70 to 83.33%. The survival rate of *P. lenis* on both thrips larvae and eggs (70 −91.67%) was consistently lower than that observed in the other two species. Above survival rates take into consideration both dead and escaped individuals, so we further separated effects of diet on these categories. Death rate ranged from 13.33 to 20% when the phytoseiids were offered larvae of *F. occidentalis*, which was higher than that of their counterparts fed on thrips eggs, ranging from 0 to 1.67%. When the prey was thrips larvae, the escape rate was between 3.33% and 10%, which was similar to when thrips eggs were offered as food, with a range of 3.33–6.67%. When the food consisted of thrips eggs, the overall mortality rate of the phytoseiids (0.56%) was lower compared to the escape rate (5%). However, when the prey was thrips larvae, the overall mortality rate of the predatory mites (16.67%) was higher than the escape rate (7.22%).

The total developmental time of *P. lenis* and *A. swirskii* females on either diet did not differ (Table 1). However, the protonymphal stages of these mites took comparatively more time to develop when feeding on thrips larvae than when provided with thrips eggs. Interestingly, when *A. swirskii* was fed on thrips eggs, its eggs took longer to hatch. Diet significantly influenced the immature development of *A. largoensis* females, with the exception of the larval stage. Females of *A. largoensis* that consumed thrips eggs completed the immature stages in 6.51 days, whereas it took them 8.61 days when fed on thrips larvae. Male phytoseiids maintained on larvae of *F. occidentalis* generally took longer to develop than their female counterparts. For *A. swirskii* males, there was no significant difference in development time when they were fed either thrips eggs or larvae throughout all stages of development. On the contrary, males of *A. largoensis* displayed significant differences in all stages of development except for the larval stage. Similarly, in *P. lenis* males, differences were evident in the deutonymph and total immature stages only. Males of *A. largoensis* and *P. lenis* required more time to reach the adult stage when feeding on thrips larvae (8.47 and 9.00 days, respectively) compared to when provided with thrips eggs (7.05 and 8.10 days, respectively) of *F. occidentalis*. After mating, the influence of diet extended to nearly all reproductive parameters and adult longevity (Table 2). When *A. swirskii* was fed on thrips eggs versus larvae, the preoviposition period, oviposition period, female longevity, total number of eggs, and female proportion differed significantly. On a diet of thrips larvae, *A. swirskii* exhibited a longer oviposition time (16.04 days), an extended female longevity (20.44 days), and a higher egg production rate (31.93 eggs per female) compared to when fed on thrips eggs.

In contrast, prey type had a less pronounced effect on the fecundity and longevity of *A. largoensis*. While females of this species displayed a shorter longevity (15.71 versus 17.77

Table 1 Developmental time of the immature stages of three predatory mites fed on the eggs or first-instar larvae of *F. occidentalis* at 25±1°C and 65±5% RH

	Species	Prey type (*F. occidentalis*)	N	Developmental stage (days)				
				Egg	Larva	Protonymph	Deutonymph	Total immature
Female	*A. largoensis*	Egg	35	2.03±0.03a	0.94±0.03a	1.17±0.06a	2.37±0.08a	6.51±0.09a
		Larva	31	2.35±0.09b	0.97±0.02a	1.84±0.06b	3.45±0.11b	8.61±0.12b
χ^2				11.90	0.49	26.82	31.65	50.40
P				6.65×10^{-4}	0.49	2.23×10^{-7}	1.85×10^{-8}	1.51×10^{-12}
Female	*P. lenis*	Egg	26	2.08±0.05a	0.90±0.04a	1.17±0.08a	3.35±0.11a	7.50±0.13a
		Larva	22	2.00±0.00a	0.86±0.05a	1.82±0.15b	3.18±0.14a	7.86±0.26a
χ^2				11.59	0.43	11.73	0.69	0.41
P				0.19	0.51	6.16×10^{-4}	0.41	0.52
Female	*A. swirskii*	Egg	37	2.43±0.08a	0.95±0.03a	1.03±0.05a	2.78±0.10a	7.19±0.10a
		Larva	27	2.11±0.06b	0.96±0.03a	1.78±0.09b	2.74±0.14a	7.59±0.22a
χ^2				7.60	0.21	31.81	0.02	1.78
P				5.84×10^{-3}	0.65	1.70×10^{-8}	0.88	0.18
Male	*A. largoensis*	Egg	22	2.05±0.05a	0.95±0.03a	1.27±0.09a	2.77±0.09a	7.05±0.05a
		Larva	19	2.42±0.12b	0.92±0.04a	1.82±0.08b	3.32±0.11b	8.47±0.12b
χ^2				8.19	0.42	10.99	13.62	34.02
P				4.20×10^{-3}	0.52	2.23×10^{-4}	9.18×10^{-4}	5.46×10^{-9}
Male	*P. lenis*	Egg	29	2.24±0.08a	0.93±0.03a	1.66±0.09a	3.28±0.08a	8.10±0.10a
		Larva	20	2.30±0.11a	0.93±0.04a	1.83±0.08a	3.95±0.14b	9.00±0.15b
χ^2				0.20	0.01	2.21	14.11	17.94
P				0.65	0.91	0.14	1.70×10^{-4}	2.28×10^{-5}
Male	*A. swirskii*	Egg	21	2.24±0.1a	0.95±0.03a	1.67±0.10a	3.19±0.11a	8.05±0.19a
		Larva	18	2.22±0.1a	0.97±0.03a	1.64±0.13a	2.83±0.09b	7.67±0.14a
χ^2				0.01	0.21	0.10	5.27	1.95
P				0.91	0.65	0.75	0.02	0.16

N: Number of individuals reaching the adult stage; each treatment was started with 60 eggs

Means (±SE) within a column and sex followed by the same letter are not significantly different (Mann-Whitney U test; $P > 0.05$)

χ^2, df- and P-values refer to Kruskal-Wallis ANOVAs

days) when reared on thrips eggs compared to thrips larvae, they exhibited a higher oviposition rate (2.19 versus 1.83 eggs per female per day) when consuming eggs of *F. occidentalis*. *Proprioseiopsis lenis* was the least influenced by adult diet. Among all parameters, only the oviposition rate showed a significant difference when the predatory mites were fed on thrips eggs versus larvae, with rates of 1.78 eggs per female per day and 1.92 eggs per female per day, respectively. The sex ratio of offspring was significantly influenced by diet only in *A. swirskii*, which exhibited a female proportion of 65.65% on thrips eggs compared to 59.47% on thrips larvae. Life table parameters appeared to be more strongly affected by diet in *A. swirskii* and *A. largoensis* than in *P. lenis* (Table 3). *A. largoensis* stood out with the highest value of intrinsic rate of increase (0.209) when thrips eggs were provided as food to the phytoseiids. However, when mobile first instar thrips were the prey, *A. swirskii* exhibited a higher intrinsic rate of increase (0.190) than the other two predatory mites. Conversely, *P. lenis* consistently demonstrated the lowest value of intrinsic rate of increase on both prey types.

Table 2 Fecundity and longevity of *A. largoensis, P. lenis* and *A. swirskii* fed on eggs and first-instar larvae of *F. occidentalis* at 25 ± 1°C and 65 ± 5% RH

Species	Prey type (*F. occidentalise*)	N	Preoviposition period (days)	Oviposition period (days)	Female longevity (days)	Oviposition rate (eggs/female/day)	Total number of eggs (eggs/female)	Female proportion of the progeny
A. largoensis	Egg	35	2.09±0.05a	11.80±0.73a	15.71±0.73a	2.19±0.04a	25.34±1.44a	62.55±4.73a
	Larva	31	1.94±0.09a	13.52±0.93a	17.77±0.98b	1.83±0.06b	25.71±1.99a	61.03±2.63a
χ^2			2.15	3.49	4.80	19.65	0.44	0.69
P			0.14	6.16×10^{-2}	2.84×10^{-2}	9.30×10^{-6}	0.51	0.41
P. lenis	Egg	26	2.31±0.09a	13.85±1.29a	18.04±1.35a	1.78±0.03a	24.23±2.11a	51.40±4.26a
	Larva	22	2.23±0.13a	12.09±0.9a	16.55±0.97a	1.92±0.05b	23.73±1.96a	55.03±5.18a
χ^2			1.62	0.78	0.47	5.67	0.22	2.64
P			0.20	0.38	0.49	1.72×10^{-2}	0.97	0.10
A. swirskii	Egg	37	2.24±0.07a	12.68±0.9a	17.51±0.89a	1.79±0.04a	22.86±1.68a	65.65±2.25a
	Larva	27	1.81±0.09b	16.04±1.09b	20.44±1.16b	1.90±0.07a	31.93±2.66b	59.47±2.45b
χ^2			11.27	5.46	4.33	3.78	7.97	6.85
P			7.89×10^{-4}	1.95×10^{-2}	3.75×10^{-2}	5.17×10^{-2}	4.77×10^{-3}	8.86×10^{-3}

N = number of reproducing females observed

Means (±SE) within a column and sex followed by the same letter are not significantly different ($P > 0.05$) according to a Mann-Whitney U test (preoviposition period, oviposition period, female longevity, oviposition rate, total number of eggs) or Probit (Wald Chi-square) test (female proportion of progeny). χ^2, df- and P-values refer to Kruskal-Wallis ANOVAs

Discussion

In the present study, *A. largoensis*, *A. swirskii* as well as *P. lenis* successfully developed and reproduced on both eggs and first instars of *F. occidentalis*. This finding is not in line with the outcome of an earlier study by Nguyen et al. (2019b), in which adult females of *P. lenis* were rarely observed to feed on thrips eggs. We hypothesize that the lack of exposure to thrips eggs during the immatures stages and the high density of adult predators in a small experimental arena impacted the ability of *P. lenis* females to find and feed on thrips eggs in the Nguyen et al. (2019b) study.

The statistical analysis indicated significant differences among egg incubation times, although these differences were minor. This variation in egg development time is unlikely a result of treatment effects and may be linked to slight differences in egg collection times.

When offered larvae of *F. occidentalis* in the present study, *A. swirskii* exhibited the highest intrinsic rate of increase, the highest fecundity, and the shortest juvenile developmental time, followed by *A. largoensis* and *P. lenis.* In our laboratory experiments, death and escape rates of *A. largoensis*, *P. lenis*, and *A. swirskii* preying on thrips larvae ranged from 13.33 to 20% and 3.33–10%, respectively. In previous studies using thrips larvae as prey reported survival rates varied considerably depending on the phytoseiid and thrips species involved, averaging only 13% for *Iphiseius degenerans* (Berlese) with *F. occidentalis* (Vantornhout et al. 2004), 38% for *Neoseiulus californicus* (McGregor) with *F. occidentalis* (Walzer et al. 2004), 62–88% for *Neoseiulus cucumeris* (Oudermans) with onion thrips *Thrips tabaci* (Lindeman) and *F. occidentalis*, respectively (Marisa and Sauro 1990), and 91% for *P. lenis* with *F. occidentalis* (Nguyen et al. 2019a).

The developmental time of *A. swirskii* in our study closely aligns with that reported by Wimmer et al. (2008) when the phytoseiid was offered larvae of *F. occidentalis* and *T. tabaci* under similar experimental conditions. The developmental time of *A. swirskii* males and females when fed *F. occidentalis* larvae (7.6–7.7 days) was longer than that observed when preying on the two-spotted spider mite *Tetranychus urticae* Koch (5.83–6.03 days) (Hosseininia et al. 2020) at 25 °C, but the intrinsic rate of increase and fecundity did not differ significantly. This may be related to the lower nutritional value of *F. occidentalis* larvae compared to other food sources such as pollen, whiteflies, or mixed diets (Nomikou et al. 2001, 2004; Wimmer et al. 2008), potentially influencing the life history parameters of *A. swirskii*. The duration of the *A. largoensis* juvenile stages in the current study (8.47–8.61 days) was longer than that reported on mixed stages of the red palm mites *R. indica* (5.92 days) and of *Tetranychus gloveri* Banks (7.11 days) on coconut (Carrillo et al. 2010) at 26.5 °C and 70% RH, and was shorter than that of those fed on the armored scale *Aonidiella orientalis* Newstead (11.43 days), or the mealybug *Nipaecoccus nipa* Maskell (13.5 days). On the other hand, the intrinsic rate of increase of *A. largoensis* (r_m = 0.186) was significantly higher in the present study than when it was fed on *R. indica* (r_m = 0.127) or *T. gloveri* (r_m = 0.102). Conversely, when consuming mixed life stages of *T. urticae* (4.00-4.31 days and 11.34 days, respectively) or the first and second instars of *F. occidentalis* (4.09–4.34 days and 13.47 days, respectively), *P. lenis* completed the immature stage faster and had shorter longevity (Nguyen et al. 2019a) than when preying on thrips larvae (7.86-9.00 days and 16.55 days, respectively) in this study. As temperature is a key factor affecting growth and development of predatory mites, it may be in part responsible for the differences among studies (Kolokytha et al. 2011; Stavrinides and Mills 2011).

Table 3 Life table parameters of *A. largoensis*, *P. lenis* and *A. swirskii* fed on eggs and first-instar larvae of *F. occidentalis* at 25 ± 1°C and 65 ± 5% RH

Species	Prey type (*F. occidentalis*)	N	Net reproductive rate (Ro)	Generation time (T, days)	Doubling time (DT, days)	Finite rate of increase (λ)	Intrinsic rate of increase (r_m)
A. largoensis	Egg	35	15.89 ± 0.92a	13.22 ± 0.19a	3.31 ± 0.05a	1.233 ± 0.004a	0.209 ± 0.003a
	Larva	31	15.71 ± 1.20a	15.39 ± 0.13b	3.87 ± 0.09b	1.196 ± 0.005b	0.186 ± 0.004b
χ^2			2.24	39.07	27.83	29.55	29.63
P			0.13	4.09×10^{-6}	1.33×10^{-7}	5.44×10^{-8}	5.22×10^{-8}
P. lenis	Egg	26	12.28 ± 0.98a	15.18 ± 0.26a	4.19 ± 0.08a	1.180 ± 0.004a	0.165 ± 0.003a
	Larva	22	14.21 ± 1.03a	15.15 ± 0.19a	3.94 ± 0.09b	1.192 ± 0.005b	0.176 ± 0,004b
χ^2			0.47	0.18	7.30	7.70	7.82
P			0.49	0.67	6.90×10^{-3}	5.53×10^{-3}	5.17×10^{-3}
A. swirskii	Egg	37	15.39 ± 1.04a	14.90 ± 0.18a	3.77 ± 0.07a	1.201 ± 0.004a	0.188 ± 0.003a
	Larva	27	35.80 ± 1.52b	15.79 ± 0.18b	2.63 ± 0.07b	1.274 ± 0.005b	0.190 ± 0.004a
χ^2			21.05	10.25	41.79	42.06	0.08
P			4.48×10^{-6}	1.37×10^{-3}	1.02×10^{-10}	8.83×10^{-11}	0.77

N = number of reproducing females observed

Means (± SE) within a column and sex followed by the same letter are not significantly different ($P > 0.05$) according to a Mann-Whitney U test (preoviposition period, oviposition period, female longevity, oviposition rate, total number of eggs) or Probit (Wald Chi-square) test (female proportion of progeny). χ^2, df- and P-values refer to Kruskal-Wallis ANOVAs

Jacobson et al. (2001) were the first to suggest that the phytoseiid *N. cucumeris* could prey on both thrips eggs and first instars of *F. occidentalis*, although they did not provide concrete evidence of this predation on eggs. Subsequent studies by Vangansbeke et al. (2018) proposed that *A. swirskii* could effectively control thrips eggs, substantiated by the reduced number of *F. occidentalis* larvae hatching in leaf arenas with predatory mites compared to arenas without them. This hypothesis gained further support from Nguyen et al. (2019b), who detected thrips DNA in the guts of phytoseiid mites that foraged for 2 h on bean leaves containing thrips eggs.

In our study, *A. largoensis* had the highest intrinsic rate of increase value, produced the highest total number eggs and had the shortest juvenile developmental time when offered thrips eggs, followed by *A. swirskii* and *P. lenis*. Death and escape rates of all predatory mites offered thrips eggs ranged from 0 to 1.67% and from 3.33 to 6.67%, respectively. Survival rates reported in the literature for phytoseiid mites preying on non-mobile foods such as insect eggs or pollen averaged 92% for *A. largoensis* with eggs of the coconut whitefly *Aleurodicus cocois* Curtis (De Alfaia et al. 2018), 70% for *I. degenerans* with *Ricinus communis* L. pollen (Vantornhout et al. 2004), and 93%, 80%, 97%, and 40% for *P. lenis* when fed *Typha latifolia* (Linnaeus), *Luffa aegyptiaca* (Miller), *Zea mays* (Linnaeus), and *R. communis* pollen, respectively (Nguyen et al. 2019a).The egg-to-adult development time of *A. swirskii* when preying on *F. occidentalis* eggs (7.19 days) was slightly longer than that observed when consuming eggs of *T. urticae* (6.58 days) and eggs of the cotton whitefly *Bemisia tabaci* (Gennadius) (6.01 days) (Seiedy et al. 2017) under similar experimental conditions. Additionally, the intrinsic rate of increase of *(A) swirskii* in our study (r_m = 0.188) was slightly lower than that reported when preying on eggs of *T. urticae* (r_m = 0.220) or eggs of *(B) tabaci* (r_m = 1.25) (Seiedy et al. 2017). Notably, *A. largoensis* exhibited a shorter juvenile developmental time when preying on eggs of the coconut whitefly *A. cocois* compared to thrips eggs but had a significantly lower intrinsic rate of increase ($r_m = 0.04$ versus 0.21). Nguyen et al. (2019a) reported that the intrinsic rate of increase of *P. lenis* was higher on *T. latifolia* pollen and *L. aegyptiaca* than on thrips eggs but not on *Z. mays* pollen, whereas the total fecundity of *P. lenis* was lower when feeding on pollen from *T. latifolia, L. aegyptiaca*, and *Z. mays* compared to *F. occidentalis* eggs.

Various phytoseiid mites have been tested against the first and second instars, as well as the pupal and adult stages of thrips (Ghasemzadeh et al. 2017; Khaliq et al. 2018; Ahmed and Lou 2018). However, their control effects on adult thrips and second instars have been reported to be limited (Khaliq et al. 2018). This limitation in subduing older thrips stages may arise from challenges related to the size (Saito 1986; Choh et al. 2012) and defence behaviours of the prey (Faraji et al. 2001, Magalhães et al. 2005, Wimmer et al. 2008, Choh et al. 2012, de Almeida and Janssen 2013). For instance, larvae of *F. occidentalis* have been noted to swing their abdomen to defend themselves from predation attempts, and to produce anal droplets as an alarm signal for conspecifics (Bakker and Sabelis 1989; Teerling et al. 1993, de Bruijn et al. 2006). In the present laboratory trials, immature mortality rates were higher when the studied phytoseiids were given thrips larvae as prey compared to when they were provided with thrips eggs. Higher mortality rates on *F. occidentalis* larvae can be explained by the difficulty of the larval and protonymphal stages of the three phytoseiids to attack larval thrips, demonstrating the ability of this prey to resist attack and cause harm to the predator. On the other hand, higher overall escape rates as compared to death rates on thrips eggs (5% versus 0.56%, respectively) whereas the inverse was noted for thrips larvae, may suggest that thrips eggs are a less preferred type of prey. Whether the studied phytoseiids prefer thrips larvae over eggs should be the subject of further experiments in which both prey types are offered simultaneously.

In summary, both eggs and larvae of *F. occidentalis* proved to be suitable prey to support development and reproduction of *A. largoensis*, *P. lenis*, and *A. swirskii*. The intrinsic rate of increase of *A. largoensis* was higher on *F. occidentalis* eggs than on thrips larvae, whereas in *P. lenis* the opposite trend was observed. *Amblyseius swirskii*, on the other hand, showed little or no difference in its development time and intrinsic rate of increase when feeding on either type of prey. These findings confirm the potential of the studied phytoseiid mites as biological control agents against both eggs and larvae of the Western flower thrips, extending the window for effective predation on *F. occidentalis* populations. Nevertheless, further research is warranted to explore the performance of these phytoseiid species under diverse temperature regimes, which is crucial for their practical implementation in South-East Asia. Future studies conducted on whole plants and under more field-realistic conditions will provide a more comprehensive understanding of the field establishment and predation potential of these phytoseiid mites. In regions like Vietnam, where pesticide usage often prevails as the primary method of pest control, these findings present an encouraging alternative that can safeguard the health of farmers, consumers, and the environment. Conserving populations of predatory mites in agricultural ecosystems or incorporating them into augmentative biological control programs could thus have a positive impact on agricultural production in South-East Asia and beyond.

Acknowledgements This research was supported in part by a scholarship of the Vietnamese government, and in part by a project funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED), and the Research Foundation– Flanders (FWO) (grant number FWO.106.2020.01 and G0E1221N).

Author contributions Viet Ha Nguyen were responsible for conceptualization, methodology, experimental activities, statistical analysis, and writing of the manuscript. Duc Tung Nguyen contributed by providing advice on methodology, statistical analysis and assisting in revising the manuscript. Patrick De Clercq and Thomas Van Leeuwen were responsible for supervision, funding acquisition, project administration, resources and revision of the manuscript.

Funding This research was supported in part by a scholarship of the Vietnamese government, and in part by a project funded by the Vietnam National Foundation for Science and Technology Development (NAFOSTED), and the Research Foundation– Flanders (FWO) (grant number FWO.106.2020.01 and G0E1221N).

Data availability The data and materials generated or analyzed during this study are available upon reasonable request. Researchers interested in accessing the dataset or materials can contact the corresponding author, Patrick De Clercq, through his ORCID profile (https://orcid.org/0000-0003-0664-1602) at patrick.declercq@ugent.be. Access to the data and materials will be provided in accordance with ethical and legal considerations, ensuring participant confidentiality and privacy. This availability aligns with our commitment to fostering transparency and facilitating future scientific inquiries.

Declarations

We confirm that all the listed authors have read and approved the manuscript, and there are no other authors who haven't been mentioned. We assure that the order of authors listed in the manuscript has been approved by all of us.
We confirm that all of the research mentioned in this manuscript that has involved experimental animals subject has been conducted with the approval of all relevant authorities and that such approvals are recognized in the manuscript.
We understand that the Corresponding Author is the primary contact for the Editorial process. The Corresponding Author is responsible for communicating with the other authors about progress, submitting revisions and final approval of proofs. We confirm that we have provided a current, accurate email address that the Corresponding Author can access.

Ethical approval There are no human subjects in this article; hence, the research project does not require ethical approval, as all experimental work was conducted with known invertebrate species.

Consent to participate I understand the general purposes, risks and methods of the research project titled " Life table parameters of *Amblyseius largoensis, Amblyseius swirskii* and *Proprioseiopsis lenis* (Acari: phytoseiidae) fed on eggs and larvae of *Frankliniella occidentalis*". I have obtained the informed consent from all individual participants enlisted in the study.

Consent to publish I hereby grant permission for the researchers involved in the project titled " Life table parameters of *Amblyseius largoensis, Amblyseius swirskii* and *Proprioseiopsis lenis* (Acari: Phytoseiidae) fed on eggs and larvae of *Frankliniella occidentalis*" to use, publish, and disseminate the results of this research.

Competing interests The authors declare no competing interests.

References

Ahmed N, Lou M (2018) Efficacy of two predatory phytoseiid mites in controlling the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on cherry tomato grown in a hydroponic system. Egypt J Biol Pest Co 28:1–6

Alipour Z, Fathipour Y, Farazmand A (2016) Age-stage predation capacity of *Phytoseiulus persimilis* and *Amblyseius Swirskii* (Acari: Phytoseiidae) on susceptible and resistant rose cultivars. Int J Acarol 42:224–228. https://doi.org/10.1080/01647954.2016.1171797

Bakker FM, Sabelis MW (1989) How larvae of *Thrips tabaci* reduce the attack success of Phytoseiid predators. Entomol Exp Appl 50:47–51. https://doi.org/10.1111/j.1570-7458.1989.tb02313.x

Birch LC (1948) The intrinsic rate of natural increase of an insect population. J Anim Ecol 17:15–26. https://doi.org/10.2307/1605

Calvo FJ, Knapp M, Van Houten YM, Hoogerbrugge H, Belda JE (2015) *Amblyseius Swirskii*: what made this predatory mite such a successful biocontrol agent? Exp Appl Acarol 65:419–433. https://doi.org/10.1007/s10493-014-9873-0

Carrillo D, Peña JE, Hoy MA, Frank JH (2010) Development and reproduction of *Amblyseius largoensis* (Acari: Phytoseiidae) feeding on pollen, *Raoiella indica* (Acari: Tenuipalpidae), and other microarthropods inhabiting coconuts in Florida, USA. Exp Appl Acarol 52:119–129. https://doi.org/10.1007/s10493-010-9360-1

Choh Y, Ignacio M, Sabiles MW, Janssen A (2012) Predator-prey role reversals, juvenile experience and adult antipredator behaviour. Sci Rep 2:1–6

Chow A, Chau A, Heinz KH (2010) Compatibility of *Amblyseius (Typhlodromips) swirskii* (Athias-Henriot) (Acari: Phytoseiidae) and *Orius insidiosus* (Hemiptera: Anthocoridae) for biological control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on roses. Biol Control 53:188–196. https://doi.org/10.1016/j.biocontrol.2009.12.008

Corpuz LA, Rimando L (1966) Some Philippine *Amblyseiinae* (Phytoseiidae: Acarina). Philipp Agric Sci 50:114–136. https://www.researchgate.net/publication/307598333

Da Silva RR, Teodoro AV, De Sousa Silva MDJ, Reis PR, Silva SS (2015) Compatibility of pesticides with the generalist predatory mite *Amblyseius largoensis* (Acari: Phytoseiidae). Rev Colomb Entomol 41:76–80

De Alfaia JP, Barros MEN, Melo LL, Lima DB, Dias-Pini NDS, Melo JWS (2018) Biological performance of the predatory mites *Amblyseius largoensis* and *Euseius concordis* fed on eggs of *Aleurodicus cocois*. Syst Appl Acarol 23:2099–2103. https://doi.org/10.11158/saa.23.11.2

De Almeida AA, Janssen A (2013) Juvenile prey induce antipredator behaviour in adult predators. Exp Appl Acarol 59:275–282. https://doi.org/10.1007/s10493-012-9601-6

De Bruijn PJA, Egas M, Janssen A, Sabelis MW (2006) Pheromone-induced priming of a defensive response in western flower thrips. J Chem Ecol 32:1599–1603

Demiroz D, Kumral NA (2022) Research of resistance of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) populations to different insecticide groups. Balkan Agric Congr 4:824–830

Demite PR, McMurtry JA, De Moraes GJ (2014) Phytoseiidae Database: a website for taxonomic and distributional information on phytoseiid mites (Acari). Zootaxa 3795:571–577. https://doi.org/10.11646/zootaxa.3795.5.6

Demite PR, De Moraes GJ, McMurtry JA, Denmark HA, Castilho RC (2020) Phytoseiidae Database www.lea.esalq.usp.br/phytoseiidae (accessed 02/06/2022)

Faraji F, Janssen A, Sabelis MW (2001) Predatory mites avoid ovipositing near counterattacking prey. Exp Appl Acaro 25:613–623

Gallego CE, Aterrado ED, Batomalaque CG (2003) Biology of the false spider mite, *Rarosiella Cocosae* Rimando, infesting coconut palms in Camiguin, northern Mindanao (Philippines). Philippine Entomol 17:187–192

Galvão A, Gondim MG, De Moraes GJ, De Oliveira JV (2007) Biology of *Amblyseius largoensis* (Muma) (Acari: Phytoseiidae), a potential predator of *Aceria Guerreronis* Keifer (Acari: Eriophyidae) on coconut trees. Neotrop Entomol 36:465–470

Gao Y, Lei Z, Reitz SR (2012) Western flower thrips resistance to insecticides: detection, mechanisms and management strategies. Pest Manag Sci 68:1111–1121

Ghasemzadeh S, Leman A, Messelink GJ (2017) Biological control of *Echinothrips americanus* by phytoseiid predatory mites and the effect of pollen as supplemental food. Exp Appl Acarol 73:209–221. https://doi.org/10.1007/s10493-017-0191-1

Goleva I, Zebitz CPW (2013) Suitability of different pollen as alternative food for the predatory mite *Amblyseius Swirskii* (Acari, Phytoseiidae). Exp Appl Acarol 61:259–283. https://doi.org/10.1007/s10493-013-9700-z

Hosseininia A, Khanjani M, Asadi M, Soltani J (2020) Life-history of the predatory mite *Amblyseius Swirskii* (Athias-Henriot) (Acari: Phytoseiidae) on *Tetranychus Urticae* Koch (Acari: Tetranychidae), *Carpoglyphus lactis* Linnaeus (Acari: Carpoglyphidae) and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae). J Ornam Plants 10:155–166

Hulting FL, Orr DB, Obrycki JJ (1990) A computer program for calculation and statistical comparison of intrinsic rate of increase and associated life table parameters. Fla Entomol 73:601–612. https://doi.org/10.2307/3495274

Jacobson RJ, Croft P, Fenlon J (2001) Suppressing establishment of *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) in cucumber crops by prophylactic release of *Amblyseius Cucumeris* Oudemans (Acarina: Phytoseiidae). Biocontrol Sci Technol 11:27–34. https://doi.org/10.1080/09583150020029718

Kamburov SS (1971) Feeding, development, and reproduction of *Amblyseius largoensis* on various food substances. J Econ Entomol 64:643–648

Khaliq A, Afzal M, Raza AM, Kamran M, Khan AA, Aqeel MA, Ullah MI, Khan BS, Kanwal H (2018) Suitability of *Thrips tabaci L*. (Thysonaptera: Thripidae) as prey for the phytoseiid mite, *Neoseiulus barkeri Hughes* (Acari: Phytoseiidae). Afr Entomol 16:131–135. https://doi.org/10.4001/003.026.0131

Kolokytha PD, Fantinou AA, Papadoulis G Th (2011) Temperature and diet effects on immature development of predatory mite *Typhlodromus Athenas* Swirski and Ragusa (Acari: Phyotseiidae). Environ Entomol 40:1577–1584. https://doi.org/10.1603/EN11098

Leman A, Messelink GJ (2015) Supplemental food that supports both predator and pest: a risk for biological control? Exp Appl Acarol 65:511–524

Liao JR, Ho CC, Ko CC (2013) Checklist of Phytoseiidae (Acari: Mesostigmata) from Taiwan. Formos Entomol 33:67–90

Liao JR, Ho CC, Ko CC (2021) Predatory mites (Acari: Mesostigmata: Phytoseiidae) intercepted from samples imported to Taiwan, with description of a new species. Zootaxa 4927:301–330. https://doi.org/10.11646/zootaxa.4927.3.1

Lotka AJ (1907) Relation between birth rates and death rates. Science 26:21–22

Magalhães S, Janssen A, Montserrat M, Sabelis MW (2005) Prey attack and predators defend: counterattacking prey trigger parental care in predators. Proc R Soc Lond Ser B-Biol Sci 272:1929–1933. https://doi.org/10.1098/rspb.2005.3127

Mai HT, Shamim S, Pham DKH (2019) Consumer concern about food safety in Hanoi. Vietnam Food Control 98:238–244. https://doi.org/10.1016/j.foodcont.2018.11.031

Maia ADN, Luiz AJB, Campanhola C (2000) Statistical inference on associated fertility life table parameters using jackknife technique. Computational aspects. J Econ Entomol 93:511–518. https://doi.org/10.1603/0022-0493-93.2.511

Marisa C, Sauro S (1990) Biological observations and life table parameters of *Amblyseius Cucumeris* (Oud.) (Acarina: Phytoseiidae) reared on different diets. Redia 73:569–583

McMurtry JA, Croft BA (1997) Lifestyles of phytoseiid mites and their roles in biological control. Annu Rev Entomol 42:291–321. https://doi.org/10.1146/annurev.ento.42.1.291

McMurtry JA, De Moraes GJ, Sourassou NF (2013) Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Syst Appl Acarol 18:297–320. https://doi.org/10.11158/saa.18.4.1

Messelink GJ, Van Steenpaal EF, Ramakers PMJ (2006) Evaluation of phytoseiid predators for control of western flower thrips on greenhouse cucumber. Biocontrol 51:753–768. https://doi.org/10.1007/s10526-006-9013-9

Messelink GJ, Van Maanen R, Van Steenpaal EF, Janssen A (2008) Biological control of thrips and whiteflies by a shared predator: two pests are better than one. Biocontrol 44:372–379. https://doi.org/10.1016/j.biocontrol.2007.10.017

Meyer JS, Ingersoll CG, McDonald LL, Boyce MS (1986) Estimating uncertainty in population growth rates: jackknife vs. bootstrap techniques. Ecology 67:1156–1166. https://doi.org/10.2307/1938671

Momen FM (2009) Potential of three species of predatory phytoseiid mites as biological control agents of the peach silver mite, *Aculus fockeui* (Acari: Phytoseiidae and Eriophyidae). Acta Phytopathol Hun 44:151–158

Momen FM, Nasr A, El-Rady K, Metwally AM, Mahmoud YA (2016) Performance of five species of Phytoseiid mites (Acari: Phytoseiidae) on *Bactrocera zonata* eggs (Diptera: Tephritidae) as a factitious food. Acta Phytopathol Hun 51:123–132

Nasr A, Momen FM, Metwally AM, Gesraha MA, Abdallah A, Saleh KM (2015) Suitability of *Corcyra Cephalonica* eggs (Lepidoptera: Pyralidae) for the development, reproduction and survival of four predatory mites of the family Phytoseiidae (Acari: Phytoseiidae). Gesunde Pflanzen 67:175–181. https://doi.org/10.1007/s10343-015-0350-4

Navasero M, Corpuz-Raros L (2005) Functional response of three predatory phytoseiid mites (Phytoseiidae: Acari) to two-spotted mite, *Tetranychus Urticae* Koch (Tetranychidae: Acari). Philippine Entomol 19:168–181

Nguyen DT, Than TA, Jonckheere W, Nguyen VH, Van Leeuwen T, De Clercq P (2019a) Life tables and feeding habits of *Proprioseiopsis Lenis* (Acari: Phytoseiidae) and implications for its biological control potential in Southeast Asia. Syst Appl Acarol 24:857–865. https://doi.org/10.11158/saa.24.5.9

Nguyen VH, Jonckheere W, Nguyen DT, De Moraes GJ, Van Leeuwen T, De Clercq P (2019b) Phytoseiid mites prey effectively on thrips eggs: evidence from predation trials and molecular analyses. Biol Control 137:104012

Nguyen VS, Nguyen TMP, Ho NC, Nguyen XD, Do TD, Vu NH, Vuong TKH, Nguyen CT, Tran TTT (2020) Vietnamese agriculture before and after opening economy. Mod Econ 11:894–907. https://doi.org/10.4236/me.2020.114067

Nomikou M, Janssen A, Schraag R, Sabelis MW (2001) Phytoseiid predators as potential biological control agents for *Bemisia tabaci*. Exp Appl Acarol 25:271–291. https://doi.org/10.1023/A:1017976725685

Nomikou M, Janssen A, Schraag R, Sabelis MW (2004) Vulnerability of *B. Tabaci* immatures to Phytoseiid predators: consequences for oviposition and influence of alternative food. Entomol Exp Appl 110:95–102. https://doi.org/10.1111/j.0013-8703.2004.00114.x

Oliveira DC, Charanasri V, Kongchuensin M, Konvipasruang P, Chandrapatya A, De Moraes GJ (2012) Phytoseiidae of Thailand (Acari: Mesostigmata), with a key for their identification. Zootaxa 3453:1–24. https://doi.org/10.11646/Zootaxa.3453.1.1

Peña JE, Rodrigues JCV, Roda A, Carrillo D, Osborne LS (2009) Predator-prey dynamics and strategies for control of the red palm mite (*Raoiella indica*) (Acari: Tenuipalpidae) in areas of invasion in the neotropics. Proceedings of the 2nd meeting of IOBC/WPRS Bull 50:69–79

Pham VH, Mol A, Oosterveer P (2013) State governance of pesticide use and trade in Vietnam. NJAS-Wagen J Life Sc 67:19–26. https://doi.org/10.1016/j.njas.2013.09.001

Pham VH, Mol A, Oosterveer P, Van den Brink PJ, Pham TMH (2016) Pesticide use in Vietnamese vegetable production: a 10-year study. Int J Agr Sustain 14:325–338. https://doi.org/10.1080/14735903.2015.1134395

Pijnakker J, Arijs Y, de Souza A, Cellier M, Wäckers F (2016) The use of Typha angustifolia (cattail) pollen to establish the predatory mites Amblyseius Swirskii, Iphiseius degenerans, Euseius Ovalis and Euseius Gallicus in glasshouse crops. Integr Control Plant-Feeding Mites IOBC/WPRS Bull 120:47–52

Poushkova SV, Kasatkin DG (2020) Materials to the knowledge of the fauna of thrips (Thysanoptera) in Vietnam as a result of the expedition of FGBU VNIIKR. Plant Quarantine Nr 2(2):55–68. https://www.researchgate.net/publication/343474393

Prins M, Goldbach R (1998) The emerging problem of tospovirus infection and non-conventional methods of control. Trends Microbiol 6:31–35

Riahi E, Fathipour Y, Talebi AA, Mehrabadi M (2017) Linking life table and consumption rate of *Amblyseius Swirskii* (Acari: Phytoseiidae) in presence and absence of different pollens. Ann Entomol Soc Am 110:244–253. https://doi.org/10.1093/aesa/saw091

Saito Y (1986) Prey kills predator: counter-attack success of a spider mite against its specific phytoseiid predator. Exp Appl Acarol 2:47–62

Sarkar SC, Wang E, Zhang Z, Wu S, Lei Z (2019) Laboratory and glasshouse evaluation of the green lacewing, *Chrysopa pallens* (Neuroptera: Chrysopidae) against the western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae). Appl Entomol Zool 54:115–121. https://doi.org/10.1007/s13355-018-0601-9

Schicha E, Elshafie M (1980) Four new species of phytoseiid mites from Australia, and three species from America redescribed (Acari: Phytoseiidae). Aust J Entomol 19:27–36. https://doi.org/10.1111/j.1440-6055.1980.tb00957.x

Seiedy M, Soleymani S, Hakimitabar M (2017) Development and reproduction of the predatory mite *Amblyseius Swirskii* Athias-Henriot (Acari: Phytoseiidae) on *Tetranychus Urticae* Koch (Acari: Tetranychidae) and *Bemisia tabaci* Gennadius (Heteroptera: Aleyrodidae). Int J Acarol 43:160–164. https://doi.org/10.1080/01647954.2016.1248486

Stavrinides MC, Mills NJ (2011) Influence of temperature on the reproductive and demographic parameters of two spider mite pests of vineyards and their natural predator. Biocontrol 56:315–325. https://doi.org/10.1007/s10526-010-9334-6

Teerling CR, Gillespie DR, Borden JH (1993) Utilization of western flower thrips alarm pheromone as a prey-finding kairomone by predators. Can Entomol 125:431–437

Tixier M-S, Douin M, Lopes I, Migeon A, Fossoud A, Navajas M (2022) Genetic diversity of the predatory mite *Amblyseius Swirskii* Athias-Henriot (Acari: Phytoseiidae) with an overview of its distribution and implications for biological control. Biol Control 168:104841. https://doi.org/10.1016/j.biocontrol.2022.104841

Vangansbeke D, Pijnakker J, Arijs Y, Wäckers F (2018) Thrips egg predation by phytoseiids: an overlooked pest control mechanism. IOBC/WPRS Bull 124:184–189

Vantornhout I, Minnaert HL, Tirry L, De Clercq P (2004) Effect of pollen, natural prey and factitious prey on the development of *Iphiseius degenerans*. Biocontrol 49:627–644. https://doi.org/10.1007/s10526-004-5280-5

Walzer A, Paulus W, Schausberger P (2004) Ontogenetic shifts in intraguild predation on thrips by Phytoseiid mites: the relevance of body size and diet specialization. Bull Entomol Res 94:577–584. https://doi.org/10.1079/BER2004329

Wimmer D, Hoffmann D, Schausberger P (2008) Prey suitability of western flower thrips, *Frankliniella occidentalis*, and onion thrips, *Thrips tabaci*, for the predatory mite *Amblyseius Swirskii*. Biocontrol Sci Technol 18:533–542

Yuan J, Zheng X, Wang J, Qian K, Feng J, Zhang Y, Zhang K, Liang P, Wu Q (2023) Insecticide resistance of western flower thrips, *Frankliniella occidentalis* (Pergande) in China. Crop Prot 172:106339. https://doi.org/10.1016/j.cropro.2023.106339

Authors and Affiliations

Viet Ha Nguyen[1] · Duc Tung Nguyen[2] · Thomas Van Leeuwen[1] · Patrick De Clercq[1]

✉ Patrick De Clercq
patrick.declercq@ugent.be

[1] Laboratory of Agrozoology, Department of Plants and Crops, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

[2] Entomology Department, Vietnam National University of Agriculture, Trau Quy, Gia Lam, Hanoi, Vietnam