RESEARCH

Foraging behaviors of *Amblyseius swirskii* Athias-Henriot and *Euseius scutalis* (Athias-Henriot) (Acari: Phytoseiidae) feed on the invasive pest, *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae)

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Abstract

Background Recent population outbreaks of citrus brown mite, *Eutetranychus orientalis* (Klein) (Acari: Tetranychidae), were observed in the Çukurova region, a region that supplies approximately 80% of total citrus production in Turkey. Therefore, to obtain preliminary data, regarding biological control of this pest, functional and numerical responses of two commonly found predatory mites, *Amblyseius swirskii* Athias-Henriot and *Euseius scutalis* (Athias-Henriot) (Phytoseiidae) in citrus orchards, to egg and protonymph stages of *E. orientalis* were determined under laboratory conditions.

Results In the experiments, six different prey densities (1, 5, 10, 20, 40 and 80) for each selected biological stage of the prey were provided to the predatory mite for 24 h. According to results, the proportion of prey consumed by *A. swirskii* decreased with increasing egg and protonymph stages of the prey densities. Similarly, the proportion of protonymph consumption of *E. scutalis* decreased with increasing prey densities, but egg consumption of the predator showed no discernible response to increasing densities. *A. swirskii* exhibited a type II functional response in both prey stages, whereas *E. scutalis* showed a type II response only for the protonymph stage of the prey. The attack rate (*a*) and the handling time (*Th*) varied between the biological stages and also predatory mite species. The highest *a* (0.066 h^{-1}) and the lowest *Th* (0.536 h) values were determined when the *A. swirskii* was fed on protonymph stage of *E. orientalis*. The numerical response curves were found to be similar to those of Type II functional response. The efficiency of conversion of ingested food (ECI) of the both predatory mite species females decreased on both tested stages when prey density increased. The highest and the lowest average daily mean number of eggs laid by *E. scutalis* was found as 0.20 and 1.40 when it fed on eggs and protonymphs of its prey, respectively.

Conclusion Both predatory mite species were evaluated as potential and promising biological control agents in the sustainable control of *E. orientalis* in citrus orchards.

Keywords *Eutetranychus orientalis*, *Amblyseius swirskii*, *Euseius scutalis*, Citrus, Functional and numerical responses, Biological control

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Yalçın *et al. Egyptian Journal of Biological Pest Control*   (2023) 33:18

Page 2 of 8

Background

Numerous phytophagous mite species have enlarged their distribution in recent decades as a result of widespread and intensive pesticide use, the unprecedented impact of global warming and the transportation of plant materials between countries and continents (Yalçın et al. 2022). One of these species that has spread throughout the world in recent years is the citrus brown mite, *Eutetranychus orientalis* Klein (Acari: Tetranychidae) which was first identified from materials collected from citrus in the Middle East (Klein 1936). This species is currently considered in the context of invasive mite species and a threat to citrus and other groups in more than 40 countries (Migeon and Dorkeld 2021).

Although *E. orientalis* causes similar damage to other phytophagous mites, the mite primarily colonizes the upper leaf surface and feeds by sucking leaf sap. Heavy infestations may result in fruit and leaf drop, and loss of an entire plants when no convenient control measures are applied (El-Halawany 2019).

The existence of *E. orientalis* in Turkish mite fauna was first mentioned by Jeppson et al. (1975). Following studies confirmed the presence of *E. orientalis* based on the samples collected from lemon trees in southern Turkey (Yalçın et al. 2022). Subsequent surveys revealed that *E. orientalis* has become one of the most frequently seen phytophagous mite species along with *Panonychus citri* (McGregor) (Acari: Tetranychidae) and *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae) in citrus-growing areas in the Eastern Mediterranean region of the country (Yalçın et al. 2022).

Nowadays, as in the control of many other phytophagous mite species, management of this pest is mainly depended on chemical control which is based on the use of acaricides. However, it has become essential to develop an environmentally friendly pest control methods to the side effects of chemical control on the consumer and the environment. In contrast to the intensive use of acaricides, sustainable control of these pests primarily depends on the presence of natural enemies in the ecosystem, in the context of integrated pest management. Among them, the predatory mites of the family Phytoseiidae (Acari: Mesostigmata) are acting as an important role as a density-dependent limiting factor for those mite pests as well as the other small soft bodied insects.

A series of phytoseiid species have been reported in association with *E. orientalis* in the Mediterranean citrus orchards, such as *Amblyseius chilenensis* Dosse, *A. swirskii*, *Euseius scutalis* (Athias-Henriot), *Iphiseius degenerans* (Berlese) and *Typhlodromus talbii* Athias-Henriot (Stathakis et al. 2021). In these studies, the biological characteristics of predatory mites as efficient predators of the pest were partially revealed, and no information

was given on their functional and numerical responses, except for *I. degenerans* and *E. scutalis*. In addition to the information provided here, *A. swirskii* and *E. scutalis* are the two most prevalent predatory mite species observed in citrus-growing areas in the Mediterranean region. Kazak et al. (2016) reported that these predatory mite species constitute at least 50% of the predatory mite species in citrus orchards in Çukurova, Turkey.

The functional and the numerical responses play a crucial role to comprehending the foraging behaviors of natural enemies and their potential on preys. While the former describes the predators capacity to consume as a function of increasing prey density, the latter explains the reproductive potential of the predators with increasing prey density. Despite the fact that both predatory mite species are common in the Mediterranean citrus ecosystem, limited number of studies has been conducted on their foraging behaviour in relation to the different biological stages of *E. orientalis* (Stathakis et al. 2021). Furthermore, this seems the first study on foraging behaviour of *A. swirskii* to early biological stages of *E. orientalis*. In this regard, there is an urgent need to search for potential predators to establish environmentally friendly pest management systems against *E. orientalis* in citrus orchards.

Therefore, through the functional and numerical responses of *A. swirskii* and *E. Scutalis,* which are commonly present in Mediterranean citrus agroecosystems, this study aimed to gain information about their possible roles on suppressing the *E. orientalis* in the early biological stages.

Methods

Collection, identification and rearing of *A. swirskii*, *E. scutalis* and *E. orientalis*

The *E. orientalis* population used in the experiments was obtained from a culture reared on potted beans, (*Phaseolus vulgaris* L.) (Fabaceae) in a laboratory, originally collected from lemon trees (*Citrus lemon* var. Kutdiken (Rutaceae)) (Döker et al. 2021). The stock cultures of the two predatory mite species, *A. swirskii* and *E. scutalis*, were established from citrus leaves collected from experimental orchard located in Cukurova University, Faculty of Agriculture, Adana, Turkey. Later, the leaf samples were examined under a stereo-binocular microscope, and predatory mite females were transferred individually to bean leaf discs placed on cotton soaked in water in Petri dishes using a thin-tipped brush. After this stage, *Typha latifolia* L. (Typhaceae) pollen was provided to the leaf discs as food for the predatory mites. In order to ensure the continuity of populations, the eggs laid by the predatory mites were collected at 1–2-day intervals and transferred to clean bean leaves and new mites colonies were established. After establishment of predatory

Yalçın *et al. Egyptian Journal of Biological Pest Control*   (2023) 33:18

Page 3 of 8

mite cultures, adult females were individually collected from the colonies for each predatory mite species were kept in 60% lactic acid for 10 h and then their permanent preparations were mounted in Hoyer medium. Predatory mite species were identified using the identification key recommended by Döker et al (2016) for species of the Phytoseiidae family of Turkey, according to Chant and McMurtry (2007). Both predatory mite species were reared on *T. latifolia* pollen. All the mite species were reared under laboratory conditions of 25 ± 2 °C and $65 \pm 10\%$ RH conditions throughout the experiments.

Functional and numerical responses of *A. swirskii* and *E. scutalis* to eggs and protonymphs of *E. orientalis*

The functional and numerical responses of adult females of *A. swirskii* and *E. scutalis* to eggs, and protonymphs of *E. orientalis* were studied under laboratory conditions (25 ± 1 °C and $70 \pm 5\%$ RH and 16:8 h L:D). The experimental arenas were constructed by placing bean leaf discs (*P. vulgaris* cv. Roma 3 cm in diameter) adaxial side up on water-saturated cotton pads in Petri dishes (5 cm in diameter). Depending on the required prey densities, 5–20 adult females of *E. orientalis* were transferred to the leaf discs and kept for oviposition for 24 h. To obtain a cohort of eggs, females were removed from the experimental test units after 24 h, and eggs were counted and adjusted using insect pins under stereo binocular microscope. Other biological stage was obtained from the same age of rearing units that were previously established by transferring adult females to bean leaves on water-saturated cotton pads. Six different prey densities (1, 5, 10, 20, 40 and 80) each with at least 15 replications, for each egg and protonymph stage of the prey, were provided to the predator. Five-day-old gravid females of *A. swirskii* and *E. scutalis* obtained from the rearing units were individually starved in Eppendorf® tubes for 12 h (Yazdanpanah et al. 2022). One starved predator was transferred to the experimental test units and kept under controlled conditions described earlier. Finally, the number prey consumed by the predatory mites, and the number of laid eggs by each predator was recorded after 24 h.

Data analyses

The data obtained for the functional response were evaluated in two steps. In the first step, the functional response type of the predator mite species depending on prey type was determined by a logistic regression of the proportion of prey consumed (N_a/N_0) in relation to initial prey density (N_0) (Juliano 2001).

$$\frac{N_a}{N_0} = \frac{\exp\left(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3\right)}{1 + \exp\left(P_0 + P_1 N_0 + P_2 N_0^2 + P_3 N_0^3\right)} \tag{1}$$

Equation (1) was used to determine the type of the functional response curve. In the equation, P_0, P_1, P_2, and P_3 are the constant, the linear, the quadratic, and the cubic coefficients, respectively. If N_0^3 was nonsignificant ($p > 0.05$), cubic coefficients were removed from the formula, and the data were re-subjected to the logistic regression. Significantly negative linear coefficients (P_1) were used to determine the Type II functional response (Juliano 2001). The functional response type of *E. scutalis* for egg consumption was not determined because there was no increase in predator consumption at low and high prey densities against increasing egg prey density.

In the second step, the handling time (*Th*) and the attack rate (α) coefficients of a Type II response were estimated using the Holling's disc equation (Eq. (2)), because Type II functional response was determined for both prey types (Holling 1959).

$$\frac{N_a}{P} = \frac{\alpha TN}{(1 + aThN)} \tag{2}$$

In the equation, N_a defines the number of prey consumed, *P* is the number of predators, *N* is the number of prey provided, α is the search rate, *Th* is the handling time (*h*), and *T* is the experimental period (24 h). The functional response of the predatory mite *E. scutalis* to *E. orientalis* egg densities was not determined because there was no change in *E. scutalis* consumption as a result of increased *E. orientalis* egg densities.

The number of eggs deposited by the predator and the initial prey density was used in a linear regression analysis to determine the numerical response. The efficiency of conversion of ingested food (ECI) to egg biomass of *A. swirskii* and *E. scutalis* at varying prey densities was determined using Eq. (3), as proposed by Omkar and Pervez (2004). Linear regression was used to fit the data collected on egg production and ECI vs prey density.

$$\text{ECI} = \frac{\text{number of eggs laid}}{\text{prey density}} \tag{3}$$

Data on food consumption and fecundity were analyzed using nonparametric Mann–Whitney *U* test following homogeneity of variances (Levene's test) and normality test (Shapiro–Wilk). All analyses were performed in SPSS (ver. 25.0) package program (Chicago IL, USA).

Results

Prey consumption and functional response of *A. swirskii* and *E. scutalis* to *E. orientalis*

Amblyseius swirskii consumed a statistically higher numbers of eggs than *E. scutalis* did in all prey densities, when *E. orientalis* eggs were offered as prey. The

prey consumption of *A. swirskii* increased with increasing *E. orientalis* egg densities. The highest consumption of the predator occurred at a density of 80 eggs (Table 1). In contrast, the egg consumption of *E. scutalis* did not show an increase with increasing prey densities. When predators were fed on *E. orientalis* protonymphs, *A. swirskii* consumed substantially more prey than *E. scutalis* at high prey densities (10, 20, 40, 80) and the difference was determined to be statistically significant. According to the results, linear coefficients (P1 values) were found to be significantly negative when *A. swirskii* was fed on both prey stages and *E. scutalis* was fed on only protonymph (Table 2). The proportions of prey consumptions of both predatory mite species decreased with increasing prey densities for both selected biological stages of the prey, except egg consumption for *E. scutalis* (Fig. 1). Significantly negative P1 values and the shape functional response curves confirm that *A. swirskii* and *E. scutalis* showed a Type II functional response to prey *E. orientalis*.

The highest search rate (α) was determined for *A. swirskii* on protonymph (0.066 h^{-1}) of its prey, while the lowest one was determined for *E. scutalis* in the egg stage (0.015 h^{-1}) of its prey (Table 3). Only the search rate of *E. scutalis* on eggs was statistically different from all other search rates based on the CL. Similar to the search rate, the lowest handling time (*Th*) was also found for *A. swirskii* when protonymph (0.536 h) was given as prey. This was followed by the egg stage (0.699 h) of the prey given to the same predatory mite species as prey. When the egg and protonymph stages were given as prey to *E. scutalis*, the handling times were determined as 18.10 (h) and 0.784 (h), respectively.

Reproduction and numerical response of *A. swirskii* and *E. scutalis* on *E. orientalis*

In general, the daily mean number of eggs laid by *A. swirskii* and *E. scutalis* was found to be statistically similar

Table 2 Estimated logistic regression coefficients for adult female *Amblyseius swirskii* and *Euseius scutalis* feeding on *Eutetranychus orientalis* egg and protonymph after 24 h at varying prey densities

Predator	Prey stages		Coefficients (SE)	χ^2	*p* value
A. swirskii	Egg	P_0	1.5793 (0.175)	81.83	< 0.001
		P_1	− 0.0351 (0.009)	15.85	< 0.001
		P_2	0.0004 (0.000)	0.42	= 0.513
	Protonymph	P_0	4.8547 (0.475)	104.41	< 0.001
		P_1	− 0.1208 (0.020)	37.58	< 0.001
		P_2	0.0015 (0.000)	14.67	< 0.001
E. scutalis	Protonymph	P_0	2.1675 (0.384)	31.38	< 0.001
		P_1	− 0.1258 (0.042)	8.79	= 0.003
		P_2	0.0035 (0.001)	4.59	= 0.032
		P_3	0.0005 (0.000)	4.18	= 0.041

at increasing *E. orientalis* egg and protonymph densities (Table 4). *Euseius scutalis* continued to lay egg despite low prey consumption with increasing *E. orientalis* egg density, but in all densities it laid fewer eggs than *A. swirskii*. Although *E. scutalis* consumed less prey than *A. swirskii* when the predatory mites were fed on *E. orientalis* protonymph, the average number of eggs laid was higher than *A. swirskii* at all densities. However, the difference in means was not statistically significant.

The numerical response curves were found to be similar to those of Type II functional responses (Fig. 2). The relationship between the mean number of eggs laid by the predators and initial prey density was significantly different when *A. swirskii* fed on egg ($R^2 = 0.973$; $p < 0.01$) and protonymph ($R^2 = 0.980$; $p < 0.01$) of *E. orientalis*. However, the relationships were nonsignificantly different when eggs ($R^2 = 0.730$; $p = 0.13$) were provided as prey for *E. scutalis*, but it was significant when the predator was fed on protonymph ($R^2 = 0.860$; $p < 0.05$). The data on the efficiency of conversion of ingested food (ECI) at different prey densities also showed curved shapes, but in

Table 1 Daily numbers of *Eutetranychus orientalis* egg and protonymph consumed by *Amblyseius swirskii* and *Euseius scutalis* at varying prey densities (Mean ± SE)

Prey density	Egg			Protonymph		
	A. swirskii	*E. scutalis*	*p*	*A. swirskii*	*E. scutalis*	*p*
1	0.93 ± 0.06*	0.13 ± 0.09	< 0.001	1.00 ± 0.00	0.80 ± 0.10	= 0.073
5	4.22 ± 0.28*	0.80 ± 0.22	< 0.001	4.80 ± 0.10	4.40 ± 0.19	= 0.098
10	7.66 ± 0.47*	1.11 ± 0.21	< 0.001	9.66 ± 0.21*	7.40 ± 0.33	< 0.001
20	13.76 ± 0.65*	1.13 ± 0.19	< 0.001	19.20 ± 0.27*	12.75 ± 0.55	< 0.001
40	23.06 ± 0.74*	1.05 ± 0.21	< 0.001	29.93 ± 1.47*	21.00 ± 0.98	< 0.001
80	23.61 ± 0.68*	1.33 ± 0.25	< 0.001	30.80 ± 0.75*	21.60 ± 0.74	< 0.001

*Significant differences between each pair of prey consumption by *A. swirskii* and *E. scutalis* for the same prey densities (Mann–Whitney *U* test; *t* test)
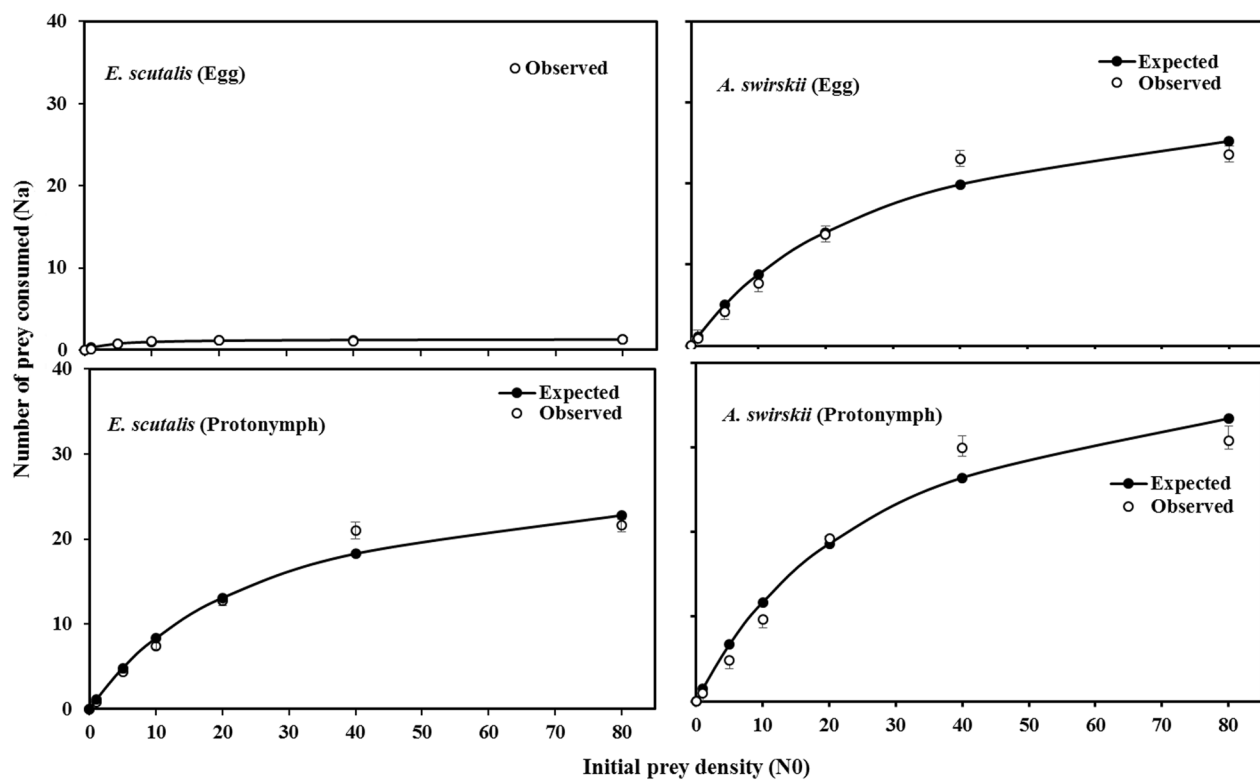
Fig. 1 Functional response curves of *Amblyseius swirskii* and *Euseius scutalis* to different egg, and protonymph densities of *Eutetranychus orientalis* (filled and nonfilled circles indicate expected and observed predation rates, respectively)

Table 3 Search rate (*a*) and capture time (*Th*) of *Amblyseius swirskii* and *Euseius scutalis* on egg and protonymph stages of *Eutetranychus orientalis*

Predator	Prey stage	$a \pm$ SE (h^{-1})	95% CL* (h^{-1})	$Th \pm$ SE (h)	95% CL* (h)	R^2
A. swirskii	Egg	0.049 ± 0.003a**	0.042–0.055	0.699 ± 0.034	0.633–0.766b**	0.90
	Protonymph	0.066 ± 0.006a	0.054–0.077	0.536 ± 0.032	0.472–0.600c	0.88
E. scutalis	Egg	0.015 ± 0.008b	0.001–0.032	18.10 ± 2.310	13.51–22.560a	0.17
	Protonymph	0.048 ± 0.004a	0.041–0.055	0.784 ± 0.040	0.705–0.863b	0.90

*CL: Confidence limits, **Means within the same columns with different letters are significantly different based on nonoverlap 95% CLs

Table 4 Number of eggs laid by *Amblyseius swirskii* and *Euseius scutalis* at different prey densities (Mean $\pm$ SH)

Prey density	Prey *E. orientalis* (Egg)			Prey *E. orientalis* (Protonymph)		
	A. swirskii (no. of laid eggs)	*E. scutalis*'in (no. of laid eggs)	*p*	*A. swirskii* (no. of laid eggs)	*E. scutalis* (no. of laid eggs)	*p*
1	0.66 ± 0.12*	0.20 ± 0.10	0.011	0.53 ± 0.13	0.86 ± 0.19	0.214
5	0.66 ± 0.12	0.33 ± 0.14	0.099	0.73 ± 0.18	1.13 ± 0.19	0.140
10	0.80 ± 0.13	0.72 ± 0.13	0.658	0.86 ± 0.16	1.20 ± 0.14	0.140
20	1.04 ± 0.12	0.73 ± 0.15	0.658	1.06 ± 0.15	1.31 ± 0.11	0.238
40	1.18 ± 0.13	0.76 ± 0.16	0.055	1.26 ± 0.15	1.40 ± 0.13	0.562
80	1.16 ± 0.12*	0.73 ± 0.15	0.034	1.20 ± 0.15	1.40 ± 0.13	0.337

*Significant differences between each pair of laid eggs by *A. swirskii* and *E. scutalis* for the same prey densities (Mann–Whitney U test; t test)
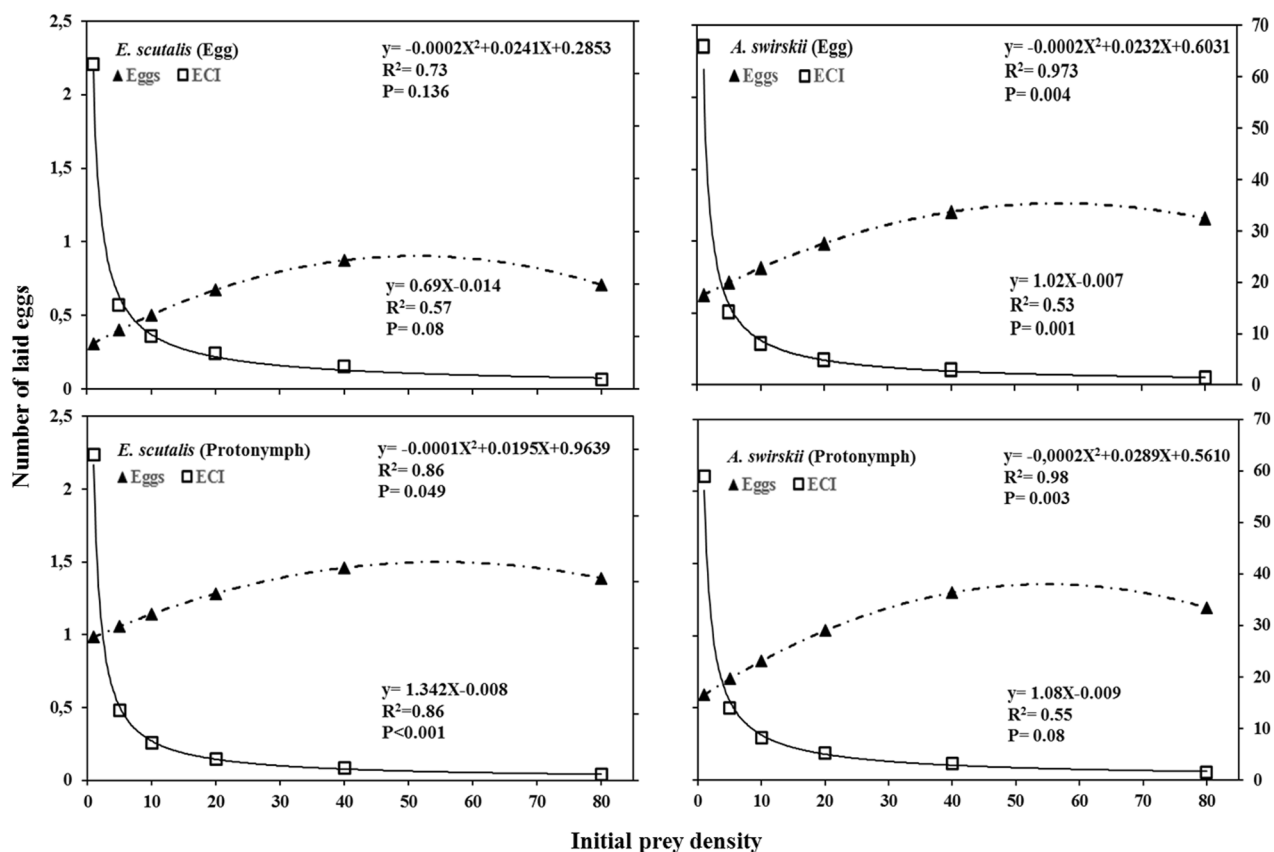
Fig. 2 Numerical response and ECI factor curves of *Amblyseius swirskii* and *Euseius scutalis* and their relationship with different egg and protonymph densities of *Eutetranychus* orientalis

the opposite direction to the functional response curves. The ECI of females *A. swirskii* and *E. scutalis* decreased on both egg and protonymph stages when prey density increased. The relationship between ECI and initial prey density was only significant when *A. swirskii* and *E. scutalis* fed on egg ($R^2 = 0.530$; $p < 0.01$) and protonymph ($R^2 = 0.860$; $p < 0.01$) stages of the prey, respectively (Fig. 2). Both predatory mite species laid the highest mean number of eggs when they fed on the protonymph stage of the prey, and these values were determined as 1.26/day and 1.40/day for *A. swirskii* and *E. scutalis* at prey densities of 40 and 80 protonymphs, respectively.

Discussion

Although the presence of *E. orientalis* in Turkey was first reported in the 1970s, remarkable populations of the pest were encountered in 2014, and since then its causes apparent damage in citrus orchards throughout the Eastern Mediterranean Region of Turkey (Yalçın et al. 2022). Different biotic and abiotic factors are thought to have contributed to the inclusion of *E. orientalis* among the most common mite pest species in citrus in the last

10 years. When these factors were evaluated separately, it is possible that *E. orientalis* developed resistance to some acaricides used in citrus production and expanded its population in the region, as experienced with another tetranychid mite species, *P. citri* (Döker et al. 2021).

Amblyseius swirskii and *E. scutalis* are classified as Subtype III-b generalist predators living on glabrous leaves and Type IV lifestyle-pollen feeding generalist predators, respectively. Both predatory mite species feed on tetranychid mites, soft-bodied arthropods and pollen (McMurtry et al. 2013). Among them, *A. swirskii* has been widely used in greenhouses to control thrips and whiteflies (Tellez et al. 2020). Similarly, *E. scutalis* has been reported to be a promising predator of tetranychid mites, scale insects and whiteflies (Al-Shammery 2010). Previous studies indicated that *A. swirskii* showed a Type II functional response when it fed on various mite species such as *Aculops lycopersici* (Massee), *Cenopalpus irani* Dosse, *Eotetranychus frosti* (McGregor), *Suidasia medanensis* Oudemans, *T. urticae* and *T. turkestani* Ugarov and Nikolskii, but also some insect species such as *Bemisia tabaci* (Gennadius) and *Thrips tabaci* (Lindeman)

(Rahmani et al. 2021). Similarly, *E. scutalis* also showed a Type II functional response when it fed on various biological stages of *T. urticae* and *E. orientalis* (Elmoghazzy 2022). In this study, *A. swirskii* exhibited Type II functional responses to egg and protonymph stages of *E. orientalis,* while *E. scutalis* showed the same response only to protonymph stage of the prey. The attack rate and the handling time are other two important parameters and used to determine efficacy of natural enemies on their prey (Pervez and Omkar 2006). The results obtained in this study revealed that attack rate and handling time varied among predatory mite species. The highest attack rate and the shortest handling time for both predatory mite species were obtained when they were fed on the protonymph stage of their prey. This may be explained by the relative size of the prey stage as indicated by Li and Zhang (2020). Due to the larger size of the protonymph, the predator may spend less time for finding and capture of a protonymph than an egg (Ali et al. 2011). Similarly, when the same predatory mite, fed on egg and protonymph stages of *T. urticae* and *T. evansi*, the attack rates were also found to be higher on protonymph than on eggs stage of the prey (Shirvani et al. 2023). In contrast, Bazgir et al. (2020) found that the attack rates of *A. swirskii* were higher on the egg stage of *E. frosti* and *C. irani* compared to the their protonymphs. The handling time of *A. swirskii*, on the other hand, was found to be shortest in the protonymph stage of the prey in the current study.

In the case of *E. scutalis*, the lowest attack rate and the longest handling time were determined when it fed on eggs of its prey. This may be due to the feeding type of the predator as it is already known as a pollen feeding generalist predatory mite species belonging to Type IV group (McMurtry et al. 2013). Blackwood et al. (2001) reported that prey stage preferences of generalist and specialist phytoseiid predatory mites vary considerably, and specialist predators mostly prefer the egg stage over other stages of their prey.

Stathakis et al. (2021) studied functional response of a Greek population of *E. scutalis* to protonymphs of *E. orientalis*. The attack rate determined by the respective authors (0.745) is more or less similar to that found in the present study (0.784). The handling time (0.136) found by Stathakis et al. (2021), however, was much higher than that determined in the present study (0.048). Although it was not specifically mentioned whether the protonymph or deutonymph stages of the prey were used by Stathakis et al. (2021), this discrepancy may be explained by the interpopulation differences or one of the predator mite populations is more specialized to its prey than the other.

Similar to prey consumption rates, the highest mean number of eggs laid by *A. swirskii* and *E. scutalis* was also determined when they were fed on protonymph. In

general, there was an increase in the oviposition rates of both species with increasing prey densities, except for *E. scutalis* when it fed on eggs. However, oviposition rates of the predatory mite species showed a slowed pattern of an increase due to the nutrition satiation required for egg production, at higher prey densities (Döker et al. 2021). Moreover, the ECI values of both species reported in this study indicated that the conversion of the prey to predator biomass was the highest at lower prey densities. This results pointed out that both predator species may spent plenty of energy for survival instead of egg production at low prey densities. These results were in agreement with those found by Cuellar et al. (2001) who determined the oviposition rates of *N. californicus* were highly related to predation rates. In the study, despite the low prey densities, *E. scutalis* continued to lay eggs.

Since both predatory mite species generally coexist in citrus orchards, intra- and extraguild predation behaviours of both predator species and their effect on the success of biological control should also be examined. Momen and Abdel-Khalek (2009) reported that *Typhlodromips swirskii* showed stronger heterospecific predation than *E. scutalis* in laboratory conditions. For this reason, it should not be ignored that *T. swirskii* may result in pressure on *E. scutalis* in conditions where the prey density is low in natural conditions (Momen and Abdel-Khalek 2009).

Conclusions

Both predatory mite species were evaluated as potential biological control agents in the sustainable control of *E. orientalis* in citrus crops. In this study, *E. scutalis* reproduced by feeding only on the protonymph stage of the prey, while *A. swirskii* continued to reproduce by feeding on both stages of the prey. This suggests that *E. scutalis* may play a role in suppressing the pest in the early immature stages of infestation. In order to obtain detailed knowledge with regard to the performance of both predatory mite species on *E. orientalis*, life table parameters and other biological characteristics of the predators on the prey should also be studied in further studies.

Author contributions
KY conducted experiments—investigations and statistical analyses. İD conducted statistical analyses, contributed material and writing—original draft. CK helped in conceptualization, methodology, contributed material, secured study supervision, writing—original draft, writing—review and editing. All authors read and approved the final manuscript.

Yalçın *et al. Egyptian Journal of Biological Pest Control*   (2023) 33:18

Page 8 of 8

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors here declare that there are no competing interests.

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