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ORIGINAL ARTICLE

Functional response and biological characteristics of *Orius vicinus* (Ribaut) (Hemiptera: Anthocoridae) on *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae)

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Abstract

This study evaluated the functional response and life table parameters of the predator *Orius vicinus* (Ribaut) (Hemiptera: Anthocoridae) when fed on immature stages of the polyphagous pest *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae). Biological and life table parameters, including development, survival, reproduction, and population growth rates, were assessed using two-sex age–stage life table analysis. Functional responses of adult *O. vicinus* to the egg, larval, and pupal stages of *B. tabaci* were determined separately under controlled conditions of 26 ± 1 °C, 60 ± 10% relative humidity (RH), and a 16:8 h light: dark (L: D) photoperiod. Results showed that egg development lasted 4.67 ± 0.06 days, total nymphal development was 13.65 ± 0.13 days with a survival rate of 77.32%, and mean fecundity per female was 60.89 ± 2.76 eggs. Female and male adult longevities were 16.95 ± 0.55 and 12.27 ± 0.54 days, respectively. Adult preoviposition period (APOP) and total preoviposition period (TPOP) were 4.14 ± 0.12 and 22.7 ± 0.23 days, respectively, while the oviposition period lasted 11.23 ± 0.53daysThe estimated life table parameters were the intrinsic rate of increase (r) of 0.113 day^{-1}, the net reproductive rate (R_0) of 24.8 offspring, the finite rate of increase (λ) of 1.12 day^{-1}, and the mean generation time (T) of 28.4 days. Functional response analysis revealed a Type III response to eggs and larval stages, and a Type II response to pupae. These results indicate that *O. vicinus* could be effectively integrated into Biological control programs against *B. tabaci*.

Keywords Biological control · Life table · Predator-prey interaction · Whitefly

Introduction

Bemisia tabaci is a highly polyphagous pest distributed across tropical and subtropical regions, with more than 900 reported host plant species. In the absence of control measures, *B. tabaci* can cause severe yield losses (Frohlich et al. 1999; De Barro et al. 2000; Sugiyama et al. 2013). It is ranked among the world's 100 most invasive species and considered one of the most destructive agricultural pests globally (Dinsdale et al. 2010; Kontsedalov et al. 2012). All developmental stages of *B. tabaci* feed on phloem sap, which weakens host plants, while the excretion of honeydew promotes sooty mold development. Moreover, *B. tabaci* acts as a vector of plant viruses, transmitting Tomato Yellow Leaf Curl Virus (TYLCV genus *Begomovirus*) in a persistent manner, causing indirect damage (Chen et al. 2018).

Chemical insecticides have long been the main strategy against *B. tabaci*. However, the pest has developed resistance to multiple classes of insecticides, including chlorinated hydrocarbons, organophosphates, carbamates, pyrethroids, neonicotinoids, and insect growth regulators (Nauen et al. 2002; Horowitz et al. 2005; Yükselbaba and Alı 2022). Consequently, long-term control has become increasingly difficult under both open-field and greenhouse conditions (Palumbo et al. 2001; Horowitz et al. 2005). Insecticide resistance not only raises control costs but also poses risks to human health and the environment, as pesticide residues can contaminate air, water, soil, and precipitation (Nauen et al. 2002; Yükselbaba and Alı 2022). To mitigate the adverse effects of chemical control, alternative strategies such as

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biological control are increasingly emphasized (Boatman et al. 2007).

Among natural enemies of *B. tabaci*, several predators such as *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Nabis pseudoferus* Remane (Hemiptera: Nabidae), *Macrolophus caliginosus* (Rambur) (Hemiptera: Miridae), and species of *Orius*, have been reported as effective biological control agents (Gerling et al. 2001). The Anthocoridae family, comprising nearly 600 species worldwide, includes small predators (1.4–4.5 mm) that feed on a broad range of prey, including aphids, psyllids, thrips, scales, mites, lepidopteran larvae, and insect eggs (Pericart 1972; Lattin 1999). Species of *Orius* are particularly valued for suppressing thrips in greenhouse crops (Tavella et al. 1991) and are commercially mass-produced as biocontrol agents (Hernandez 1999; Sanchez and Lacasa 2002; Van Lenteren et al. 2018, 2020).

Previous studies have reported that some *Orius* species also prey on *B. tabaci* and may be suitable candidates for biological control in cotton and other crops (Gerling et al. 2001). *Orius vicinus*, in particular, has demonstrated faster development and reproduction in laboratory conditions compared to other *Orius* species (Wearing and Lariviere 1994; Pehlivan et al. 2017). This predator typically produces two generations per year, occasionally three in warmer years, and has been recognized as a potential biological control agent in both orchards and greenhouse crops (Wearing and Attfield 2002). Before using predators (e.g., *Orius* spp.) in biological control programs, it is essential to examine their biological characteristics, including life table parameters, under controlled experimental conditions. Such studies help demonstrate the effectiveness of the predator against the target species prior to field application and provide valuable insight for regulating prey populations. Two-sex life table studies enable us to better understanding of the ecology and effectiveness of an organism, as they account for both sexes to construct accurate population curves. These studies are crucial for understanding predator–prey relationships (Fathipour et al. 2006; Hamdan 2015). The effectiveness of predators depends not only on their ability to survive and reproduce on alternative hosts but also on their functional response to different life stages of the target pest (Holling 1959; Rahman et al. 2022). Functional response, defined as the relationship between prey density and the number of prey consumed per predator per unit time (Holling 1959), is a key determinant of predator–prey dynamics and a critical parameter for assessing the potential of biological control agents (Ingegno et al. 2019). Holling (1959) described three principal forms of functional response: Type I, a linear increase as prey density rises; Type II, a response that begins linearly but eventually levels off; and Type III, a sigmoidal pattern characterized by a slow initial increase followed by acceleration. The functional response of *O. vicinus* on *B. tabaci* eggs has been reported (Pehlivan et al. 2020). Life cycle studies have also been conducted on *T. urticae* (Bilecen and Yükselbaba 2025) and *E. kuehniella* eggs (Pehlivan et al. 2017). Previous studies have examined the life cycle and functional response of different *Orius* species on *B. tabaci* (Arno et al. 2008; Hamdan 2015; Shahpouri et al. 2019). Despite the importance of *Orius* species in integrated pest management, studies focusing on their life table parameters and functional response to *B. tabaci* remain limited. To the best of our knowledge, no study has yet investigated the life cycle and larval stage functional response of *O. vicinus* on *B. tabaci*.

The present study investigates the life cycle of *O. vicinus* on *B. tabaci* and evaluates its functional response to different developmental stages of the pest. The results are expected to provide valuable insights into the potential of *O. vicinus* as a biological control agent against *B. tabaci*.

Materials and methods

Insect cultures

Orius vicinus individuals were collected from *Ficus microcarpa* (L.f.) (Rosales: Moraceae) trees in Antalya, Turkey, and identified according to Pericart (1972). Stock cultures were maintained in two L plastic canisters under controlled conditions (26 ± 1 °C, 60 ± 10% R.H., 16:8 h L: D). *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs, previously stored at −20 °C for at least 48 h, were provided as food. Fresh pepper plants were placed in the canisters as oviposition substrates and replaced every two days. Fruits containing predator eggs were transferred to new canisters. Thin cardboard strips were added to reduce cannibalism (Staubli and Pasquier 1988; Blümel et al. 1996). A colony of *B. tabaci* was established on sweet pepper *Capsicum annuum* L. (Solanaceae) in Plexiglas cages under the same environmental conditions. New plants were added weekly, and old plants were removed. Plants were grown in 180 ml plastic pots containing a peat–perlite mixture without insecticide treatment.

Life table studies

To determine the biological parameters of *O. vicinus* on *B. tabaci*, predator eggs from a stock culture reared for one generation on *B. tabaci* were used. A total of 172 predator eggs were collected for the experiments.

Experiments were conducted at 26 ± 1 °C, 60 ± 10% R.H., and 16:8 h L: D, using 3.5 cm pepper leaf discs placed upside-down on 1.5% agar in Petri dishes. A pair of adults

(one male and one female) was introduced onto each disc for 24 h for oviposition, and eggs were marked under a stereomicroscope. Eggs were checked every 8 h to record embryonic development duration and hatching rate.

Newly hatched nymphs were carefully transferred individually to fresh leaf discs containing *B. tabaci* immature stages using a fine brush (Fig. 1). Leaf discs were replaced every two days to ensure food availability and leaf freshness. Nymphs were observed every 8 h under a stereomicroscope to determine molting, development time, and survival for each instar.

The total nymphal development period was calculated from egg hatch to adult emergence. Adults were sexed under a stereomicroscope based on the presence of an ovipositor, and the female-to-male ratio was recorded.

For adult lifespan and other biological data, paired adults (one female, one male) were maintained on discs containing *B. tabaci* immature stages. Discs were checked every 8 h to record the adult pre-ovipositional period (APOP), the total pre-oviposition period (TPOP), and the oviposition period. APOP is the period between the emergence of an adult female and first oviposition, while TPOP is the time interval from birth to the beginning of oviposition. Adult longevity was also recorded. Female fecundity was determined by counting eggs laid at 8-hour intervals until the females' death.

Functional response experiments

Functional response experiments were conducted on 3.5 cm diameter pepper leaf discs placed in Petri dishes. The *O. vicinus* individuals used in these experiments were collected at the 4th–5th nymphal instars and reared on pepper leaf discs containing different developmental stages of *B. tabaci* until adult emergence. One to five day old females were starved for 24 h on clean leaf discs before the trials (Shahpouri et al. 2019).



Fig. 1 *Orius vicinus* nymph fed on *Bemisia tabaci* larva

For each prey stage (egg, 1st, 2nd, and 3rd larval stages, and pupa), pepper leaf discs were separately infested with only one stage of *B. tabaci* at densities of 2, 4, 8, 16, 32, 64, and 128 individuals per disc. Leaf discs infested with specific developmental stages and densities were prepared as follows. Unsexed *B. tabaci* adults were collected from the stock culture using a mouth aspirator and transferred into clip cages. The clip cages were then attached to pepper leaves to allow oviposition for 24 h. After this period, the adults were removed (Yükselbaba and Alı 2022). The plants were subsequently maintained at 26 °C for one day to obtain eggs; seven days for first-instar nymphs; ten days for second instars; twelve days for third instars; and fourteen days for the pupal stage. After the required duration for each developmental stage, excess individuals and any non-target stages were carefully removed. For each stage, the number of individuals on the leaf discs was adjusted to 2, 4, 8, 16, 32, 64, and 128.

After infestation, a single starved female *O. vicinus* was introduced into each Petri dish. The dishes were sealed with Parafilm to prevent escape while allowing ventilation through small pinholes. After 24 h of exposure, the predators were removed and the number of prey consumed was recorded under a stereomicroscope.

Each prey density × prey stage combination was replicated 10 times. Thus, the functional response of *O. vicinus* was evaluated separately for eggs, 1 st, 2nd and 3rd larval stages, and pupae of *B. tabaci*.

Data analysis

Life table parameters, including age and stage specific survival rate (s_{xj}), age-specific survival rate (l_x), intrinsic rate of increase (r), net reproductive rate (R_0), mean generation time (T), and finite rate of increase (λ), were calculated using the TWOSEX-MSChart program (Chi 1988; Chi and Su 2006).

Statistical analysis was conducted to determine whether there were differences in the predator's consumption among prey stages in the functional response analysis. The normality of the data was assessed using the Shapiro–Wilk test to evaluate whether the data followed a Gaussian distribution (Shapiro and Wilk 1965), and homogeneity of variances was checked using Levene's test. The data were analyzed using Generalized Linear Mixed Models (GLMMs) with a binomial distribution and a logit link function, followed by Tukey–Kramer post hoc tests for multiple comparisons. Statistical analyses were performed using SPSS version 23.0 (Chicago, IL, USA). Differences were considered statistically significant at $P<0.05$.

Table 1 Development time of egg and nymph stages of *Orius vicinus* fed on *Bemisia tabaci*

Stage	*N*	Mean (day)	S.E (±)	Max	Min	Survival (%)
Egg	172	4.67	0.06	7	2.33	96.51
1 st Nymph	166	2.38	0.05	4.66	0.66	97.59
2nd Nymph	162	1.94	0.05	3.66	0.66	95.06
3rd Nymph	154	2.73	0.05	7	1	96.75
4th Nymph	149	2.67	0.07	5	0.67	96.64
5th Nymph	144	4.02	0.09	8	1	93.75
Total	135	18.32	0.14	24.33	15	78.49

N: Number of individuals

The functional response type was determined in two steps. First, we used logistic regression to analyze the proportion of prey consumed (Ne/N_0) as a function of the initial prey density (N_0), following Juliano (2001). Here, *Ne* represents the number of prey consumed and N_0 is the initial number of prey offered.

$$\mathrm{Ne}/N = \frac{Exp(P_0 + P_1 N_0 + P_1 N_0^1 + P_2 N_0^2 + P_3 N_0^3 +)}{1 + Exp(P_0 + P_1 N_0 + P_1 N_0^1 + P_2 N_0^2 + P_3 N_0^3 +)}$$

In the logistic regression equation, P_0, P_1, P_2, and P_3 correspond to the intercept and the linear, quadratic, and cubic coefficients, respectively. A type II functional response is indicated when $P_1 < 0$, whereas a type III response is indicated when $P_1 > 0$ and $P_2 < 0$ (Juliano 2001). All parameters were estimated using the CATMOD procedure in SAS (SAS 2007).

Handling time (*Th*) and attack rate (α) for the type II functional response were estimated using the Holling disc equation (Holling 1959), as follows:

$$Ne = \frac{aNT}{(1 + aThN)}$$

For the type III functional response, parameters were estimated using the Hassell equation (Hassell et al. 1976), as follows:

$$Ne = N_0 \frac{1 - Exp\left[(d + bN_0)(ThNe - T)\right.}{1 + cN_0}$$

Where *Ne* is the number of prey consumed, N_0 is the initial prey density, *T* is total time, *Th* is handling time, *a* is attack rate, and *b*, *c*, *d*, are model-specific constants. Parameters and their Standart errors (±S.E) were estimated using the non-linear least squares regression (NLIN) procedure in SAS (SAS 2007).

Table 2 Lifespan of *Orius vicinus* adults

Parameters	*N*	Mean±SE.	Min	Max
APOP	68	4.14±0.12	1.33	6
TPOP	68	22.7±0.23	18.33	27.67
Female	70	16.95±0.55	6	26
Male	65	12.27±0.54	5.25	22.66
Oviposition days	70	11.23±0.53	2	20.67

N: Number of individuals

Results

Life table parameters of *Orius vicinus*

In this study, the hatching rate and development time of *O. vicinus* egg deposited on pepper leaf discs were determined based on a total of 172 eggs. Six eggs failed to hatch, resulting in a hatching rate of 96.51% (Table 1).

Survival rates for each instar were high. Survival was highest during the first instar (97.6%), followed by the third instar, and then the fourth and second instars. The lowest survival rate was observed in the fifth instar (93.75%). Different developmental durations were observed among the instars. The longest development time was recorded in the fifth instar, while the shortest development times (0.66 days) were observed in the second and third instars (Table 1). These values reflect the more precise measurements made possible by observations at 8-hour intervals.

From the total 166 nymphs, 135 nymphs completed development to adulthood. The total nymphal development duration was 13.65±0.14 days with 81% survival rate and including the egg stage, overall development time was 18.32±0.13 days. The overall survival rate from egg to adult was 78.49%, with a mortality rate of 21.51% (Table 1).

Among the adults, 70 were females and 65 were males, resulting in a sex ratio of 51.85% females and 48.15% males. The APOP, TPOP, average adult longevity, and average oviposition days were shown in Table 2. While the adult lifespan of female individuals was 16.95±0.55 days, the APOP and TPOP were 4.14±0.12 days and 22.7±0.23 days, respectively. The average lifespan of the male was observed as 12.27±0.54 days.

The maximum lifetime fecundity of a female was 116 eggs, with a maximum of 9 eggs laid per day. On average, each female laid 60.8 ± 2.77 eggs during her lifetime (Table 3).

Using the TWOSEX-MSChart program, the demographic parameters of *O. vicinus* fed on immature stages of *B. tabaci* were estimated as follows: The (r) was 0.11 day^{-1}, the (λ) was 1.11 day^{-1}, the (R_0) was 24.84 offspring, and the (T) was 28.4 days (Table 3).

The (*Sxj*) curve showed the probability of survival to age x and stage j (Fig. 2). The highest survival was observed during the egg stage, while the lowest survival occurred at the fourth nymphal instar. Among the nymphal stages, survival was highest in the first instar.

The (*Vxj*) indicated the expected contribution of individuals at age x and stage j to future population growth. The highest reproductive contribution occurred during the adult stage, reaching a peak of 30.06 eggs at day 23 (Fig. 3).

The (*exj*) curve, representing the expected remaining lifespan at age x and stage j, was estimated as 28.55 days for eggs. The mean life expectancies for the first to fifth instars were 25.8, 23.05, 23.55, 20.91, and 18.76 days, respectively (Fig. 4).

The age-specific survival rate (*lx*), fecundity (*mx*), and maternity rate (*lx***mx*) curves are presented in Fig. 5. The

Table 3 Life table population parameters of *Orius vicinus* on *Bemisia tabaci*

Parameters	Estimate
r	0.113 day^{-1}
λ	1.12 day^{-1}
R_0	24.74 offspring
T	28.36 days
F	60.8 eggs/female
DT	7.24 day

lx curve declined steadily from the egg to the adult stage, mainly due to mortality at hatching and during nymphal development. The maternity rate (*lx***mx*) increased from day 56, peaked around day 104, and declined to zero by day 134. The fecundity curve (*mx*) showed a similar trend, with maximum reproduction at day 104.

Functional response of *Orius vicinus* to *Bemisia tabaci* stages

The functional response of *O. vicinus* adult to *B. tabaci* eggs, 1 st, 2nd, and 3rd instars, and pupae was evaluated at prey densities of 2, 4, 8, 16, 32, 64, and 128 individuals per disc, and mean prey consumption was also determined (Table 4).=

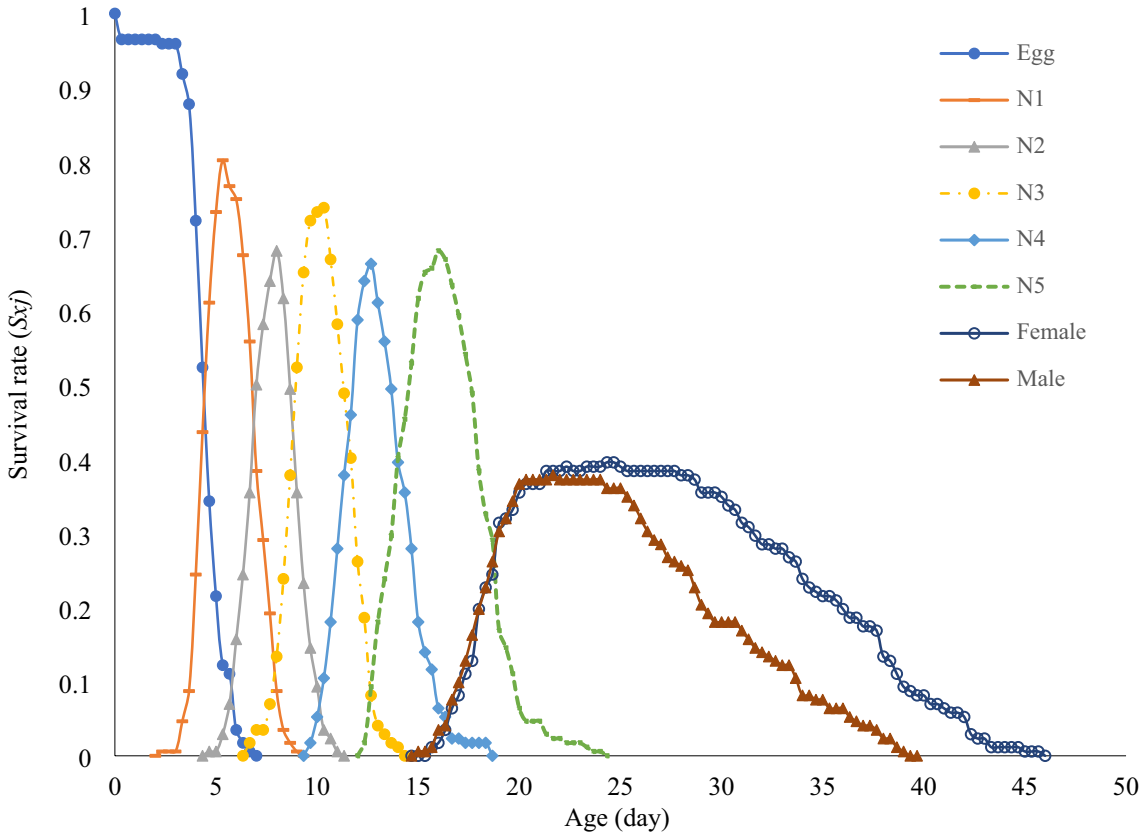


Fig. 2 Age and stage specific survival rates of *Orius vicinus* and the rates and durations of *inter*-stage transitions (*Sxj*)

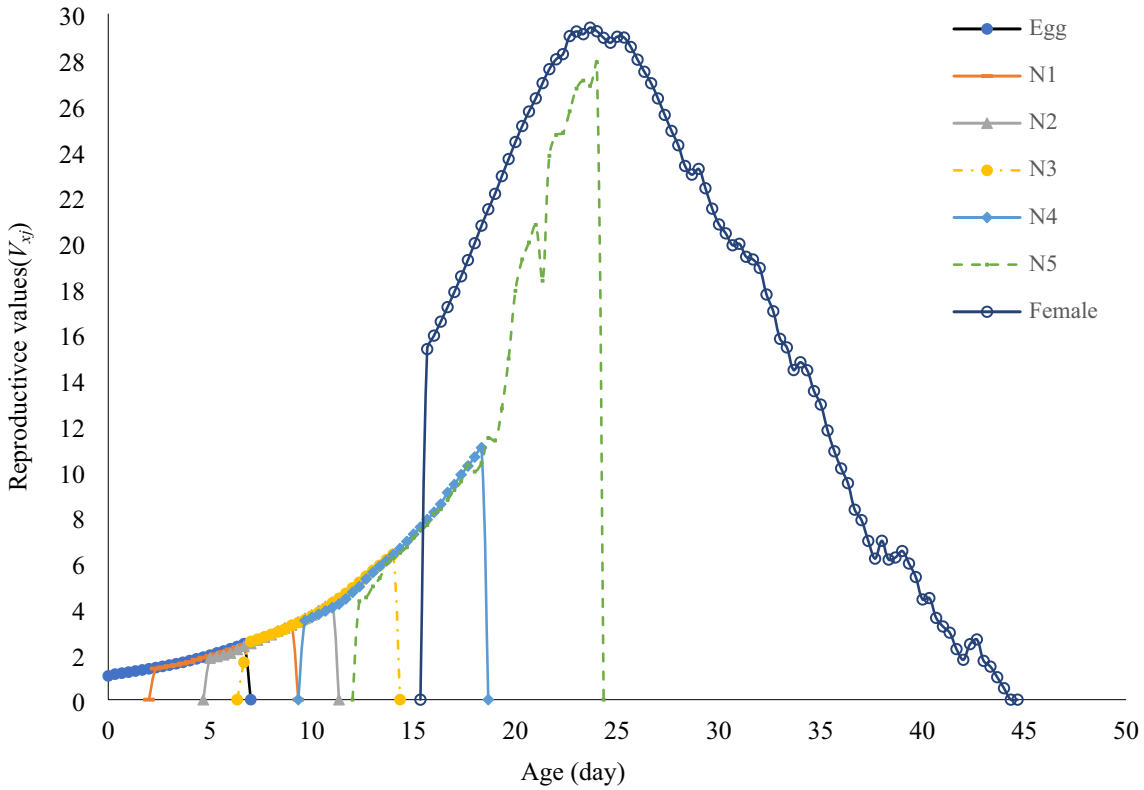


Fig. 3 Age and stage specific reproductive curves of *Orius vicinus* fed on *Bemisia tabaci* (*Vxj*)

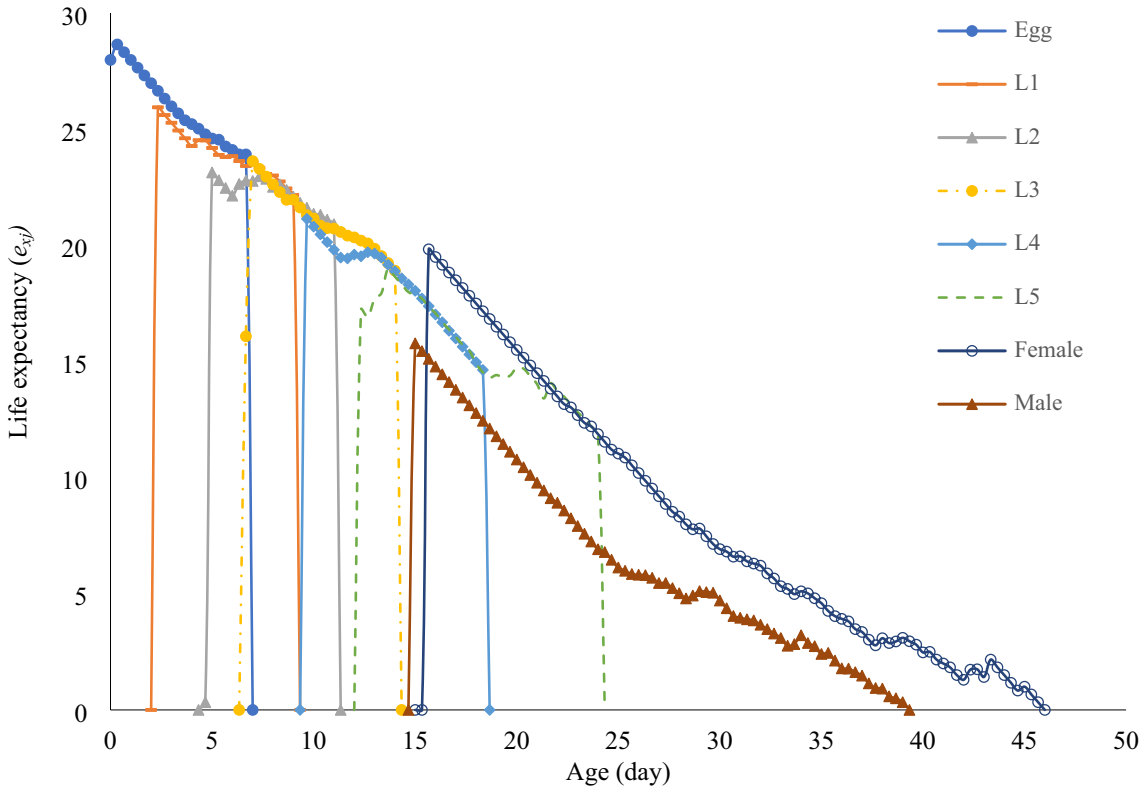


Fig. 4 Age and stage specific life expectancy (*exj*) of *Orius vicinus* fed on *Bemisia tabaci*

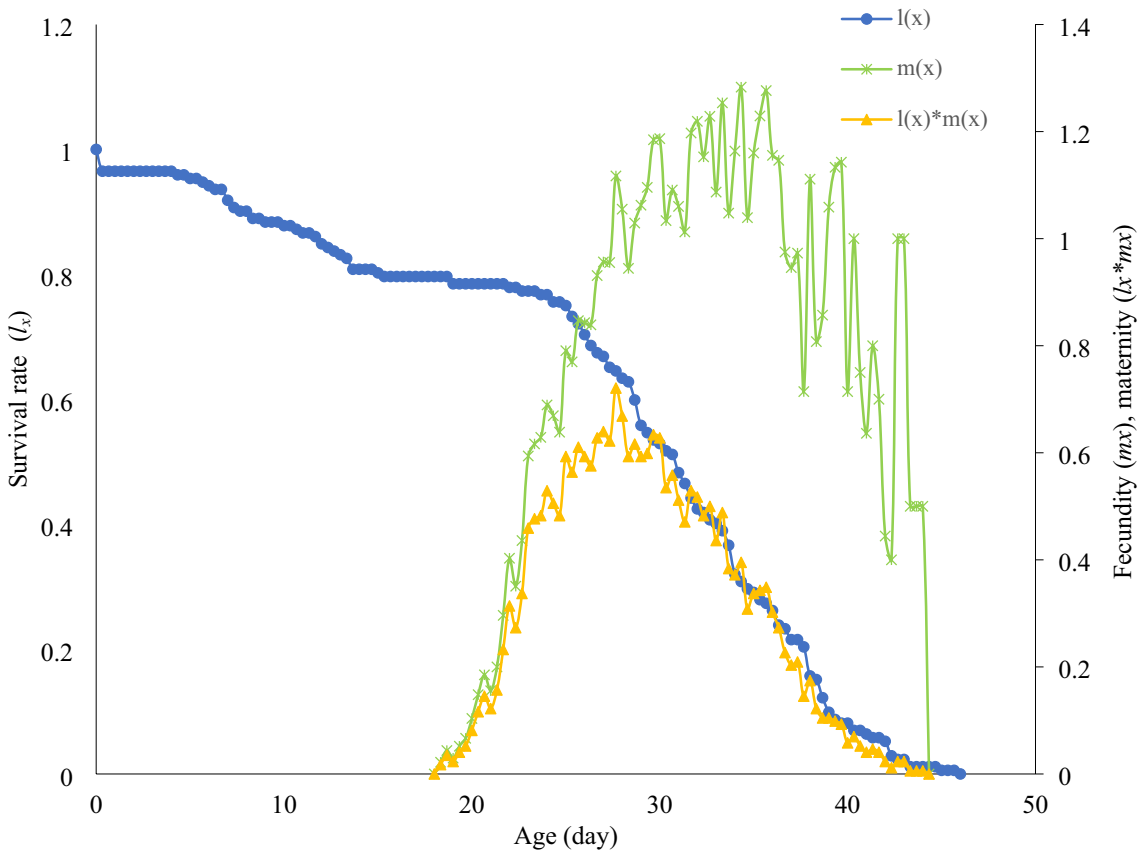


Fig. 5 Age-specific survival rate (*lx*), fecundity (*mx*), and maternity (*lx*mx*) curves of *Orius vicinus* fed on *Bemisia tabaci*

Table 4 Mean consumed prey at functional response experiments

	2±SE	4±SE	8±SE	16±SE	32±SE	64±SE	128±SE
Egg	0.42^{b}±0.18	0.75^{b}±0.28	1.33^{d}±0.33	3.08^{c}±0.51	7.92^{d}±0.87	14.33^{c}±1.41	28.58^{c}±2.61
L1	1.4^{a} ±0.2	2.5^{a}±0.31	6.1^{a}±0.37	11.9^{a}±0.56	26.4^{a}±0.95	54.8^{a}±1.54	72.2^{a}±2.86
L2	1.36^{a}±0.19	2.36^{a}±0.3	4.36^{b}±0.35	10.36^{a}±0.53	20.27^{b}±0.91	37.45^{b}±1.47	62.18^{b}±2.73
L3	1.13^{a}±0.22	2.25^{a}±0.35	3.5^{bc}±0.41	10.25^{a}±0.63	18.75^{b}±1.07	35.13^{b}±1.72	58.63^{b}±3.2
Pupae	1.18^{a}±0.19	1.64^{a}±0.3	2.55^{c}±0.35	5.82^{b}±0.53	11.36^{c}±0.91	17.54^{c}±1.47	28.54^{c}±2.73
df:4	F:4.68 P:0.001	F:6.07 P:0.001	F:26.57 P:0.001	F:47.51 P:0.000	F:64.62 P:0.000	F:121.9 P:0.001	F:53.78 P:0.000

Different letters within the same row are significantly different ($P<0.05$) df: degrees of freedom. L : larvae stage of *B. tabaci*

Logistic regression analysis revealed that *O. vicinus* exhibited a Type III functional response to eggs and nymph stages (1st–3rd instars), while a Type II functional response was observed against pupae (Table 5).

According to the functional response model, the estimated attack rate (*a*) and handling time (*Th*) of *O. vicinus* stages are presented in Table 6. The attack rate of *O. vicinus* on *B. tabaci* pupae was 0.43, with a handling time of 8.51 h, whereas for eggs these values were 0.009 and 16.84, respectively. The maximum number of pupae predicted to be attacked within 24 h was 64.86, compared to 1.43 for eggs (Table 6).

Discussion

Orius species are considered important beneficial insects in various agricultural ecosystems (Van Lenteren et al. 2018). Determining parameters such as life cycle, reproductive capacity, longevity, developmental duration, and mortality rates of predatory insects on alternative hosts is crucial for assessing the effectiveness of a biological control agent. Functional response studies are also conducted to evaluate the predation capacity of predators.(Van Lenteren et al. 2018).

Previous studies have shown that the developmental and reproductive traits of *Orius* species vary when feeding on *B. tabaci*. Hamdan and Awad (2008) reported that when *O. laevigatus* fed on egg and larvae of *B. tabaci* on tomato, the

Table 5 Logistic regression analysis parameters of *Orius vicinus* on *Bemisia tabaci* stages

Prey Stage	Parameters	Estimate	SE	X^2	*P*
Egg	Intercept	−1.40	0.28	23.82	<0.0001
	Linear	0.01	0.02	0.24	0.62
	Quadratic	−0.00018	0.000444	0.18	0.66
	Cubic	8.263E-7	2.192E-6	0.15	0.69
1 st Larva	Intercept	0.76	0.24	8.36	0.0038
	Linear	0.02	0.01	2.92	0.22
	Quadratic	−0.00006	0.000432	2.33	0.89
	Cubic	−1.74E-6	2.172E-6	2.11	0.42
2nd larva	Intercept	0.24	0.23	1.08	0.29
	Linear	0.02	0.01	1.57	0.20
	Quadratic	−0.00048	0.000362	1.79	0.18
	Cubic	2.205E-6	1.795E-6	1.51	0.21
3rd Larva	Intercept	0.11	0.23	0.22	0.63
	Linear	0.02	0.02	0.93	0.33
	Quadratic	−0.00037	0.000355	1.10	0.29
	Cubic	1.697E-6	1.762E-6	0.93	0.33
Pupa	Intercept	−0.38	0.26	5.93	0.01
	Linear	−0.01	0.02	2.88	0.08
	Quadratic	0.000074	0.000431	0.43	0.51
	Cubic	−4.04E-7	−2.166E-6	0.02	0.89

egg hatching time was 4.26 days, total development time from egg to nymph was 16.46 days, and nymphal mortality rate was 40%. The oviposition period was 18.33 days. female longevity and fecundity were 25.6 days and 71.5 eggs, respectively, while male longevity was 22.3 days. Arno et al. (2008) found that the nymphal developmental durations and nymphal survival of *O. laevigatus* and *Orius majusculus* (Reuter) (Hemiptera: Anthocoridae) feeding on dead third-instar larvae and pupae of *B. tabaci* on melon were 13.5 and 12.4 days, and %76.9 and %90, respectively. Efe and Çakmak (2013) reported that the egg development period of *Orius niger* Wolff (Hemiptera: Anthocoridae) feeding on second instar larvae of *B. tabaci* as 6 days, and the nymphal development time was 15.45 days. They further noted that females lived 68 days and produced 209 eggs. Efe et al. (2015) reported that the preoviposition period of *Orius minutus* (L.) (Hemiptera: Anthocoridae) feeding on second instar larvae of *B. tabaci* on cotton was 3.84 days, and the oviposition period was 34.20 days. The maximum fecundity was 180 eggs, the egg hatching time was 5.60 days, and the nymphal survival rate was approximately 77%. In the present study, the egg hatching time of *O. vicinus* feeding on *B. tabaci* was 4.67 days, with an egg hatching rate of 96.53%. When fed on the pre-adult stages of *B. tabaci*, the nymphal development period was 13.65 days, and the total development time from egg to adult was 18.33 days. The nymphal survival rate was 77.32%. Taken together, these studies indicate that *O. vicinus*, *O. laevigatus*, *O. majusculus*, and *O. niger* exhibit different development times when feeding on *B. tabaci*. *Orius vicinus* had a developmental period similar to that of *O. laevigatus*, longer than *O. majusculus*, but shorter than *O. niger*. These differences may primarily be related to the predator species, possibly due to morphological and physiological variations among species. Additional variation may arise from the prey stage, potentially reflecting differences in prey size and nutritional composition, particularly protein content. Moreover, host plant interactions may also contribute, especially structural leaf traits such as hairiness and trichome density. Mortality rates of *O. vicinus* were higher than those of *O. laevigatus* when both fed on *B. tabaci*. This difference may be due to the host plant, as well as the use of the dead whitefly stage offered to the predator.

Several studies have evaluated the developmental traits and survival rates of *O. vicinus* when reared on different prey and diets. Wearing and Colhuon (1999) reported that at 20 °C, the nymphal survival rate of *O. vicinus* on five different hosts ranged between 74% and 100%. Pehlivan et al. (2017) determined that when fed on *E. kuehniella* eggs, the nymphal mortality rate was 3.33%, the nymphal developmental period was 13.24 days, the female ratio was 51.12%, male and female longevities were 32.28 and 35.93 days, respectively, and the preoviposition period was 5.14 days. Bilecen and Yükselbaba (2025) reported that when *O. vicinus* fed on *T. urticae*, the egg hatching time, nymphal developmental period, and nymphal survival rate were 4.07 days, 13.53 days, and 76.99%, respectively, with male and female longevities of 12.50 and 15.33 days, and a fecundity of 31.28 eggs. When *E. kuehniella* eggswhich are not natural pests in the field—are provided as food, the longevity of *Orius* species tends to be extended. Furthermore, *O. vicinus* exhibited the lowest mortality rate when fed on *E. kuehniella* eggs. However, considering that this food is not naturally available, it is more relevant to know the lifespan of *Orius* species when feeding on actual pests. Examining both previously reported data and the results of the present

Table 6 Estimated functional response parameters of *Orius vicinus* on *Bemisia tabaci* stages

Prey stage	α ± SE	%95 CI	T_h ± SE	%95 CI	T/T_h	R^2
Egg	0.009 ± 0.001	0.005–0.012	16.84 ± 1.302	14.24–19.45	1.43	0.999
L1	0.022 ± 0.003	0.016–0.028	2.91 ± 0.28	2.347–3.4656	8.24	0.999
L2	0.017 ± 0.002	0.017–0.0213	4.35 ± 0.457	3.445–5.268	5.52	0.999
L3	0.015 ± 0.002	0.011–0.019	4.49 ± 0.393	3.707–5.2766	5.35	0.999
Pupa	0.017 ± 0.002	0.012–0.021	0.37 ± 0.079	0.216–0531.216	64.86	0.975

CI: Confidence intervals, L : larvae stage of *B. tabaci*

study, it is evident that the longevity of *O. vicinus* varies depending on the prey provided.

Efe et al. (2015) reported that when *O. minutus* fed on *B. tabaci*, the life table parameters were: $r=0.121$ day^{-1}, $T=33.89$ days, $R_0=60.44$ offspring, and $\lambda=1.129$ day^{-1}. Efe and Çakmak (2013) reported that when *O. niger* fed on *B. tabaci*, the life table parameters were $R_0=87.2$ offspring, $r=0.12$ day^{-1}, and $T=37.2$ days. Bilecen and Yükselbaba (2025) reported that when *O. vicinus* fed on *T. urticae*, the life table parameters were $r=0.095$ day^{-1}, λ 1.1 day^{-1}, $R_0=12.04$ offspring, and $T=26$ days. In our study, when *O. vicinus* fed on *B. tabaci*, the life table parameters were $R_0=24.84$ offspring, $r=0.113$ day^{-1}, $\lambda=1.119$ day^{-1}, and $T=28.40$ days. Comparing the net reproductive rates reported in the above studies, the ranking from lowest to highest is: *O. vicinus*, *O. minutus*, and *O. niger*. The net reproductive rate of *O. vicinus* obtained in our study was lower than those of *O. niger* and *O. minutus*. When comparing reproductive rates, *O. vicinus*, *O. niger*, and *O. minutus* exhibited almost similar values.

Regarding mean generation time among *Orius* species feeding on *B. tabaci*, the ranking from shortest to longest was *O. vicinus*, *O. minutus*, and *O. niger*. The intrinsic rates of increase of *O. vicinus*, *O. niger*, and *O. minutus* feeding on *B. tabaci* were similar. Mean generation time represents the time required for a population to complete one generation. Predators with shorter generation times generally exhibit higher population growth rates compared to those with longer generation times. The intrinsic rate of increase is an important parameter defining the potential growth of a population. It reflects the overall effects of temperature and diet on development and reproduction and provides insight into population survival characteristics (Chi 1988; Chi and Su 2006). Additionally, *O. vicinus* feeding on *B. tabaci* exhibited better life table parameters compared to when feeding on *T. urticae*. Differences in life cycle parameters may be thought to result from the predator species, the prey stage offered, and host plant morphology.

Orius species generally exhibit a type II functional response when feeding on different prey species and at various prey densities (Isenhour et al. 1989; Zhang et al. 2024). Van Den Meiracker and Sabelis (1999) reported that *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) showed a type II functional response when feeding on *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae). Shahpouri et al. (2019) reported that *Orius albidipennis* (Reuter) (Hemiptera: Anthocoridae) exhibited type II and type III functional responses when fed on whitefly eggs and third-instar nymphs, respectively.

In the present study, *O. vicinus* exhibited a type III functional response when feeding on the eggs and first, second, and third larval stages of *B. tabaci*, and a type II functional response during the pupal stage. The results indicate that when feeding on *B. tabaci* eggs, larvae, or pupae, the functional response type and estimated parameters vary depending on the predator speciesand prey stage consumed. This variation is likely due to differences in prey size. Similarly, Shahpouri et al. (2019) found that *O. albidipennis* exhibited different functional response types on *B. tabaci* eggs and third-instar nymphs, attributing the difference to prey size. In contrast to our study, Pehlivan et al. (2020) reported that *O. vicinus* shows a type II response to *B. tabaci* eggs. Prey size is an important factor determining the type and parameters of a predator's functional response (Hassell et al. 1976). A type II response generally indicates high efficiency at low prey densities but potential saturation at higher densities where as type III functional response in *Orius* species suggests that predators can increase their attack rate as prey density increases (Holling 1965; Hassell et al. 1976; Hassell and Comins 1978). Predators exhibiting a type III functional response are also thought to learn how to overcome obstacles when capturing their prey (Schenk and Bacher 2002). Functional response patterns provide important insights for the integration of natural enemies into IPM programs, as they reflect how predation efficiency changes across varying prey densities (Holling 1959, 1965). In the context of our findings, the functional response of *O. vicinus* demonstrates its potential as an effective biological control agent against *B. tabaci*, particularly under fluctuating prey densities. The increased predation rate at moderate prey densities implies that this predator can suppress population growth before increases occur, which is a desirable characteristic in IPM strategies. Therefore, the observed functional response supports the suitability of *O. vicinus* for incorporation into integrated pest management programs aimed at reducing reliance on chemical control (Barrios-O'Neill et al. 2016; DeLong et al. 2014).

Conclusions

The results of this study indicate that *O. vicinus* is an effective predator of *B. tabaci*. This study provides the first report of the functional response of *O. vicinus* to the larval stages of *B. tabaci* and the first report of a Type III functional response, indicating that predation efficiency increases with prey density at low prey abundances. Functional response experiments revealed stage-specific differences in predation efficiency, highlighting the predator's adaptability to different prey stages. These findings not only expand our understanding of the biology and functional response of *O. vicinus*, but also provide practical insights for optimizing its use as a biological control agent. In particular, knowledge of predation efficiency can guide field-level implementation in

IPM programs, ensuring effective suppression of *B. tabaci* populations under varying environmental conditions. Future studies should evaluate its efficacy under greenhouse conditions to optimize integrated pest management strategies, including assessing its effectiveness and determining optimal release rates of *O.vicinus* on *B. tabaci* on pepper plants.

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Authors' contributions MÖ and UY conceived and designed the research. MÖ and UY conducted experiments. MÖ and UY wrote, reviewed, and edited the manuscript. UY performed the formal analysis and curated the data. UY supervised the work. All authors read and approved the final manuscript.

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Declarations

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