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BIOLOGICAL CONTROL

Predator–Prey Interaction Between *Xylocoris sordidus* (Hemiptera: Anthocoridae) and *Enneothrips enigmaticus* (Thysanoptera: Thripidae)

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Abstract

The peanut thrips, *Enneothrips enigmaticus* (Thysanoptera: Thrypidae), is an important pest of the peanut (*Arachis hypogaea*) in South America. Due to concerns about the environment and human health induced by the extensive use of pesticides in the management control of pests, environmentally and friendlier tactics must be targeted. Thus, this study investigates, for the first time, the behavior of *Xylocoris sordidus* (Hemiptera: Anthocoridae) as a biological control agent for *E. enigmaticus.* The methodology included no-choice tests to assess whether the predation rate varies according to the developmental stage of the prey, as well as the predator's developmental stage with the highest predation capacity. Additionally, an analysis of the functional response of adult and 5th instar nymphs of *X. sordidus* exposed to different densities of *E. enigmaticus* nymphs (1, 2, 4, 8, 16, and 32) was conducted. The results confirm the predation of peanut thrips by *X. sordidus*, with a higher predation rate in the nymphal stages of the prey. There was no difference in predation capacity between predator nymphs and adults, and exhibiting a type II functional response. Therefore, the potential of *X. sordidus* as a biological control agent for *E. enigmaticus* is confirmed, showing the importance of adopting measures to preserve this predator in peanut crops.

Keywords Biological control · Peanut · Thrips,·natural enemies · Predation · Functional response

Introduction

Peanut, *Arachis hypogaea* L. (Fabales: Fabaceae), is a globally significant oilseed crop. In Brazil, the 11th largest producer worldwide, the state of São Paulo is the leading producer (Farinelli et al. 2018; Santos et al. 2019), where a significant portion of the production is obtained in areas used for sugarcane crop (Fernandes and Michelotto 2022). In these areas, where peanut crops are usually secondary, it is mainly aimed at the recovery of the soil exploited by sugarcane crops; pest control is often neglected, which potentially reduces its production.

The peanut thrips are one of the most significant pests in South America's peanut production, which was formerly known as *Enneothrips flavens* Moulton (Thysanoptera: Thrypidae). However, detailed studies involving morphological, biological, and molecular analyses revealed that this species has, in fact, a new denomination: *Enneothrips enigmaticus* Lima, Alencar, Nanini, Michelotto and Correa (Thysanoptera: Thrypidae) (Lima et al. 2022). These thrips exhibit a behavior of scraping the inner part of the closed

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peanut leaflets, causing abnormal leaf development with silver lesions on the adaxial leaves surface. This impairs the plant's photosynthetic area and the development of new shoots (Almeida and Arruda 1962; Fernandes and Michelotto 2022). Consequently, damage to the crop can result in yield reductions ranging from 19.5 to 62.7% (Moraes et al. 2005).

In Brazil, the most common method for the management of peanut thrips is the use of chemical control (Calore et al. 2015; Michelotto et al. 2017). However, due to the adverse effects of chemical pesticides on the environment, and human health, also in addition to the efficiency of control, more sustainable pest management options are required (Barzman et al. 2015; Baker et al. 2020; Deguine et al. 2021). In this regard, biological control is a promising tactic that needs to be prioritized (Naranjo et al. 2015; van Lenteren et al. 2018).

Among arthropods, predators and parasitoids can act as biological control agents, in which specialist individuals are normally prioritized. This situation occurs because generalist natural enemies often attack a wide diversity of prey species, including pests and non-target organisms, which can generate uncertainty about their effectiveness in pest management (Koss and Snyder 2005; Krey et al. 2017; Kheirodin et al. 2020). Still, there are studies that support the use of generalist natural enemies or even indicate that biocontrol effectiveness tends to be greater by generalist agents (Stiling and Cornelissen 2005; Doğramaci et al. 2011; Messelink and Janssen 2014). The advantage of generalist natural enemies is their persistence even when the target pest is reduced. When using alternative food sources, the presence of these arthropods in the crop before the target pest becomes abundant makes it possible to suppress the pest before it can cause economic damage (Clercq 2002; Pijnakker et al. 2020; Andow et al. 2021). However, it is important to take into account that each species is different, and that their responses to various conditions will differ according to their specific characteristics, so each situation must be evaluated based on adapted criteria and parameters (Pilkington et al. 2010; Diehl et al. 2013; Loomans 2021).

Bugs from the Anthocoridae family are considered promising biological control agents, as they are generalist predators that feed on small arthropods such as aphids, psyllids, scale insects, and thrips (Saulich and Musolin 2009; Perdikis et al. 2011). The action of these insects against economically important pests has been reported, including the predation of *Orius niger* (Wolff) (Hemiptera: Anthocoridae) on *Frankliniella* spp. (Thysanoptera: Thripidae), *Orius strigicollis* (Poppius) (Hemiptera: Anthocoridae) on *Tetranychus urticae* (Koch) (Acarina: Tetranychidae), and the predation of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) by *Xylocoris* sp. (Heteroptera: Anthocoridae) (Miranda et al. 1998; Atakan 2006; Tuan et al. 2016). Additionally, anthocorids are considered thrips control agents, already used for this purpose in greenhouses (Yang et al. 2014; van Lenterem et al. 2018).

Xylocoris sordidus (Reuter) (Hemiptera: Anthocoridae) is a potential control agent for pests such as *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae), and *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae) (Santos et al. 2020; Santos and Bortoli 2018). The occurrence of this species has already been reported in peanut crops (Arbogast et al. 1983), although its role in the agroecosystem remains unknown. Hence, it is necessary to determine whether this species can act as a potential biological control agent for *E. enigmaticus*.

Information about the interactions between predator and prey, as well as the behavioral characteristics of the predator, is essential to advance the appropriate management of the target pest. One of the most used tests that allows us to understand the predator's feeding behavior is the functional response test, which evaluates the consumption rate by a predator according to the variation in the density of the prey (Holling 1959, 1966; Dawes and Souza 2013). There are three types of functional responses: type I, with increase foraging linearly according to the prey densities; type II, where the predators must pay a cost in time for each resource used individually and the result is an asymptotic response; and type III, with a sigmoidal response according to the prey densities. Being to predator insects, the response types II and III are the most common, and several factors can influence the response example the stage of the prey or others (Albashir et al. 2004; Uiterwaal and DeLong 2018). The parameters of the functional response estimated are attack rate and handling time, describing some predatory behavior (Kalinoski and DeLong 2016). The functional response of some anthochorids has already been investigated in previous studies, such as *Amphiareus constrictus* (Stal), *Blaptostethus pallescens* Poppius, and *Orius tristicolor* (White) (Hemiptera: Anthocoridae) when preying on *T. absoluta* (Queiroz et al. 2015), *Orius sauteri* (Poppius) (Hemiptera: Anthocoridae) preying on *Dendrothrips minowai* Priesner (Thysanoptera: Thripidae) (Zhang et al. 2021), and *Orius similis* Zheng (Hemiptera: Anthocoridae) preying on *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) (Zeng et al. 2021). Furthermore, other studies have demonstrated that anthochorid predators have different preferences regarding the stage of development of their prey, which reinforces the need to know the behavior of the control agent according to the target pest and thus make management more efficient (Baez et al. 2004; Tavares et al. 2013; Rashedi et al. 2020).

Therefore, to evaluate the potential of *X. sordidus* in the biological control of peanut thrips, this study investigates, for the first time, the predatory capacity of *X. sordidus* through predation rate and functional response at different densities of nymphs and adults of *E. enigmaticus* sp.

Therefore, this study is based on the following hypotheses: (1) *X. sordidus* preys on peanut thrips and is able to find them in the peanut leaflet; (2) the developmental stage of *X. sordidus* affects predation and functional response when feeding on *E. enigmaticus* sp.; and (3) the developmental stage of *E. enigmaticus* sp. affects predation by *X. sordidus*.

Materials and methods

The experiments were conducted in the Laboratory of Applied Ecology (ApEcoLab) and the Laboratory of Insect Biology and Rearing (LBCI) of the Department of Agricultural Production Sciences, Faculty of Agricultural and Veterinary Sciences, São Paulo State University (UNESP), Jaboticabal, SP, Brazil.

Obtaining the prey *Enneothrips enigmaticus*

Closed peanut (*A. hypogaea* L.) leaflets were collected from experimental fields at FCAV/Unesp (Jaboticabal, São Paulo, Brazil), at coordinates – 21.238286 latitude and – 48.284388 longitudes. Subsequently, the leaflets were examined using a stereoscopic magnifying glass to locate individuals of *E. enigmaticus*. The thrips found were counted, and the leaflets were separated for later use in the tests. Thrips were differentiated into nymphs or adults, with adults identified by the complete development of wings.

Obtaining the predator *Xylocoris sordidus*

The insects used were obtained from a rearing maintained at the Laboratory of Biology and Insect Rearing (LBIR) in Jaboticabal, SP (Brazil). The rearing follows the methodology described by Santos et al. (2020), with adaptations.

To establish a suitable environment for *X. sordidus*, oviposition small cotton rolls (approximately 3 cm in diameter × 10 cm in length), premoistened with deionized water, were placed in 25-ml glass vials containing 20 ml of deionized water. These vials were placed inside glass containers (11 cm in diameter, 17 cm in height), referred to as cages, containing folded paper towels shaped like "W," which acted as shelters to prevent cannibalism. The cages were adapted with a lid opening (diameter of 5 cm) covered with voile fabric to improve internal air circulation.

After oviposition, the eggs present in the cotton were transferred to glass Petri dishes (14 cm in diameter, 2 cm in height) lined with moistened paper towels and cotton, preventing desiccation and the death of *X. sordidus* embryos and nymphs. Two-day-old eggs of *D. saccharalis* (obtained from the São Martinho Biofactory, Pradópolis, São Paulo, Brazil) were provided every 2 days for predator feeding. The plates were sealed with polyvinyl chloride film (PVC) film, and the nymphs were regularly observed until they reached adulthood. Subsequently, the insects were removed using fine-tipped brushes and transferred to cages for mating and oviposition. Container cleaning and maintenance of the rearing were performed every 2 days.

Predation rate on nymphs and adults of the prey

A no-choice test was conducted to evaluate whether the predation rate of *X. sordidus* differs when feeding on nymphs or adults of *E. enigmaticus*. Peanut leaflets containing 15 preys were placed in disposable polystyrene Petri dishes (6 cm in diameter), and the predators were transferred to these plates using a fine brush. Each plate contained a filter paper at the base along with a damp cotton ball, peanut leaflets with thrips, and only one unfed adult predator for 24 h. The insects were kept in a BOD (Biochemical Oxygen Demand) chamber at a temperature of 25 ± 2 °C and a 12-h photophase. After 24 h, the number of surviving thrips per plate was counted. The number of consumed preys was assessed by estimating the mean percentage of consumption 24 h after exposure to the prey. Twelve replications were performed for each treatment.

Predation rate of predator nymphs and adults

Another test was carried out to assess whether the predation rate of *X. sordidus* differs according to its developmental stage (adult or immature). Fifth instar nymphs and adults of *X. sordidus* were used in a no-choice test condition, being this test carried out under the same conditions as the previous predation rate test. Fifteen prey nymphs were offered to each predator on peanut leaflets placed in Petri dishes. Fifteen replications were conducted for different predator stages, and after 24 h, the number of surviving thrips per plate was counted. The insects were kept in a BOD (Biochemical Oxygen Demand) chamber at a temperature of 25 ± 2 °C and a 12-h photophase.

Functional response

For the analysis of the functional response, adults and 5th instar nymphs of *X. sordidus* were exposed to different densities of *E. enigmaticus* nymphs (1, 2, 4, 8, 16, and 32). Peanut leaflets with the predetermined number of each density were placed in disposable polystyrene Petri dishes (6 cm in diameter), and the predators were transferred to these plates using a fine brush. Each plate contained a filter paper at the base along with a damp cotton ball, peanut leaflets with thrips, and only one predator. The insects were kept in a BOD (Biochemical Oxygen Demand) chamber at a temperature of 25 ± 2 °C and a 12-h photophase. After 24 h of exposure, the number of *E. enigmaticus* nymphs consumed was counted. The predators were kept without food for a period of 24 h prior to tests starting, and 10 replications were conducted for each prey density.

Analysis of data

The frequency data from the choice tests were analyzed using Proc FREQ and interpreted using the chi-square test ($\chi2$), where the null hypothesis assumed a 1:1 ratio, indicating that predation has no difference between prey types.

The survival rate of *X. sordidus* adults was compared between treatments using the log-rank test from the Kaplan–Meier method, utilizing Proc LIFETEST (SAS Institute 2022). Manly's index was estimated using the following equation:

$$\beta = \frac{loglog\left(\frac{e_j}{A_j}\right)}{\sum_j^3 log\left(\frac{e_j}{A_j}\right)}$$

where β = represents the prey preference, j = refers to the number of treatments to which the prey was subjected, e = is the number of preys consumed during the exposure period (24 h), and A represents the total number of preys fed by the predator. This index produces values between 0 and 1. A value of 0.5 indicates that predation has no difference between prey types. Values above 0.5 indicate a difference in predation between types for prey. This method considers the decrease in prey density due to predation during the experimental evaluation (Sherratt and Harvey 1993). The difference between the number of preys consumed in predation tests under different choice conditions and those obtained by the Manly preference index was determined using the Student–Newman–Keuls and *t*-tests ($P < 0.05$) using Procs GLM or TTEST for comparison. The means of the percentage of prey consumed depending on the selection conditions were compared by the Student–Newman–Keuls test ($P < 0.05$) using Proc GLM (SAS Institute 2022). The type of functional response was determined by nonlinear logistic regression using Proc CATMOD (SAS Institute 2022). The polynomial function describing the relationship between N_a/N_0 and N_0 was obtained using the equation:

$$\frac{N_a}{N_0} = \frac{exp\ exp\left(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3\right)}{1 + exp\ exp\left(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3\right)}$$

Here, N_a = represents the number of preys consumed, N_0 = represents the number of preys provided, and P_0, P_1, P_2, and P_3, are the constant, linear, quadratic, and cubic coefficients, respectively, related to the curve's slope. All parameters were estimated by maximum likelihood. When $P_1 > 0$ and $P_2 < 0$, the proportion of prey consumed is positively related to density, indicating a type III functional response. When $P_1 < 0$, the proportion of prey consumed decreases monotonically with the initially offered number, describing a type II functional response (Juliano 2001). First, the cubic model was tested, but the equation terms were reduced until significance was achieved. The type of functional response was determined using nonlinear logistic regression based on a random equation proposed by Rogers (1972):

$$N_a = N_0\left\{1 = exp\ exp\left[a\left(\mathrm{T_h}N_a - T\right)\right]\right\}$$

where N_a = is the number of preys consumed, N_0 = is the number of preys provided, a = is the attack rate, Th = is the handling time, and T = is the time the predator is exposed to the preys (24 h). The attack rate (a') and handling time (Th) parameters were analyzed by nonlinear regression, as suggested by Rogers (1972), using Proc NLIN (SAS Institute 2022), and compared based on the generated confidence intervals (CI); if the CIs do not overlap, the difference between the means is significant ($P < 0.05$) (Di Stefano 2005). The maximum predation rate T/Th was also estimated.

Results

Predation rate on nymphs and adults of the prey

The no-choice test showed that *X. sordidus* adults consumed a significantly higher number of nymphs than adults of *E. enigmaticus* ($\chi2 = 27.4163$; $P < 0.0001$), being 60.64% and 39.36% respectively (Fig. 1a).

Predation rate of predator nymphs and adults

The results demonstrate that both adults and nymphs of *X. sordidus* consume a statistically equivalent number of *E. enigmaticus* ($\chi2 = 2.2786$; $P = 0.1312$), accounting for 52.99% and 47.01% of adults and nymphs, respectively (Fig. 1b). In other words, both nymphs and adults of *X. sordidus* can prey on *E. enigmaticus* nymphs.

Functional response of *X. sordidus* on *E. enigmaticus* nymphs

Xylocoris sordidus showed predatory ability in both nymph and adult stages. The results of the logistic regression analysis for the nymphs were significant ($P < 0.05$), with a negative linear coefficient ($P1$) of − 0.0428, indicating a type II functional response to the nymphs of the prey, *E. enigmaticus* (Table 1). Similarly, *X. sordidus* adults showed a type II functional response ($P < 0.05$; $P1 - 0.0361$) in relation to the prey.

The functional response curves for nymphs and adults of *X. sordidus* on *E. enigmaticus* at different densities are

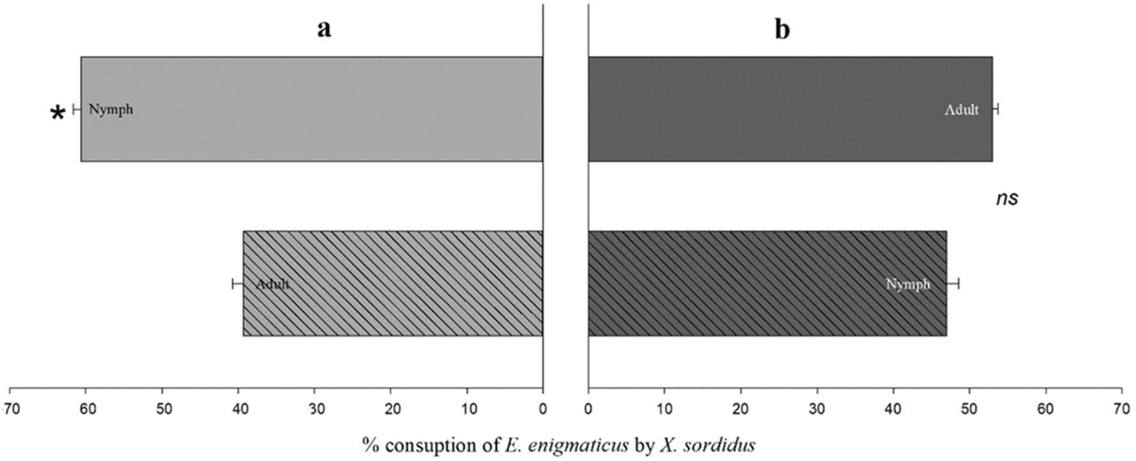

Fig. 1 **a** Percentage of consumption of nymphs and adults of *Enneothrips enigmaticus* by adults of *Xylocoris sordidius* in 24 h. **b** Percentage of consumption of *Enneothrips enigmaticus* nymphs and adults by nymphs of *Xylocoris sordidius*, after 24 h. ns, not significant. * = significant

shown in Fig. 2a and b. The number of thrips consumed by the nymphs and adults of *X. sordidus* increased with the increase in prey density but tended to stabilize from density 16. At the subsequent density 32, neither adults nor nymphs were able to prey on more than 20 thrips.

Nymphs and adults of *X. sordidus* showed a higher percentage of prey consumption when provided with four nymphs of *E. enigmaticus*. When exposed to four thrips nymphs, *X. sordidus* nymphs consumes on average three nymphs per day (representing 75% of the preys). However, when offered 32 nymphs, the consumption average was 14.2 nymphs (equivalent to 44.5% of the prey), suggesting that the predator nymphs are more efficient in locating the preys at lower prey densities. A similar trend was observed with *X. sordidus* adults, with consumption of 3.4 and 20 nymphs (86.6% and 62.7% of the preys) when exposed to 4 and 32 nymphs of *E. enigmaticus*, respectively.

The attack rate (a') of *X. sordidus* preying nymphs of *E. enigmaticus* did not vary between the predator's stages, with fifth instar nymphs and adults showing statistically equal (a') values. The handling times (Th) were lower for adults (1.0650 h) than fifth instar nymphs (1.5878 h) and the maximum predation rate (T/Th) was higher for *X. sordidus* adults (Table 2).

Discussion

It was confirmed the potential of *X. sordidus* as a biological control agent to *E. enigmaticus*, being the predator able to locate the prey hidden in peanut leaflets. The predation capability of the bug increased as the number of thrips increased, and there was no difference in predation capability between nymphs and adult of the predators. However, *X. sordidus* adults showed a higher predation rate when feeding on prey nymphs.

The predation capability of *X. sordidus* was expected since several species from the Anthocoridae family are studied and commercialized to use in biological pest control. As an example, we can mention *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) which is sold in several countries, including Brazil. The same happens with *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae) in North America where the major focus is the pest control of stored products. Furthermore, the fact that *X. flavipes* can locate and attack larvae that feed internally on stored grains, confirming the genus' ability to prey in complex habitats (Donnelly and Phillips 2001).

Previous studies analyzing the action of anthocorids against thrips species also found functional response type II (Tavares et al. 2013; Liu et al. 2018). Predators that show

Table 1 Results of logistic regression for nymphs and adults of *Xylocoris sordidus* with different prey densities

Predator	Parameters	Estimates		S. error		χ^2		*P-value*	
		Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult
Xylocoris sordidus	Intercept	1.174	1.706	0.154	0.177	57.71	92.3	< 0.0001	< 0.0001
	Linear	− 0.042	− 0.036	0.006	0.006	47.78	27.6	< 0.0001	< 0.0001

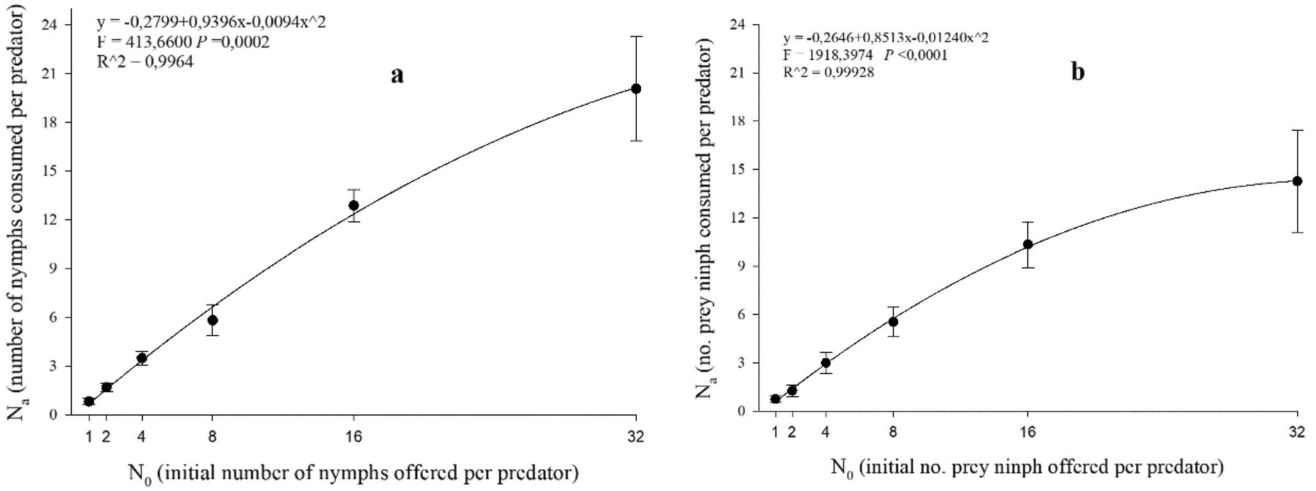

Fig. 2 Functional responses of adults (**a**) and nymphs (**b**) of *Xylocoris sordidius* preying *Enneothrips enigmaticus* nymphs under different densities over a 24-h period

Table 2 Mean values (95% confidence interval) of attack rate [*a*′(h – 1)] and handling time [Th(h)] for *Xylocoris sordidu*s preying on nymphs of *Enneothrips enigmaticus* estimated number of prey attacked during the observation period (*T* = 24 h/Th)

Treatments	Attack rate [a′(h – 1)]	Handling time [Th(h)]	T/Th
Nymph	0.0104 (0.00453–0.0162) a	1.5878 (1.3523–1.8234) a	15.11
Adult	0.0111 (0.00600–0.0162) a	1.0650 (0.9299–1.2001) b	22.53

functional response type II can be used in augmentative biological control programs. In this case, many predators should be released in the area to reduce the estimated prey population (van Lenteren et al. 2016).

Predators with a low handling time (Th) and a high attack rate (*a*′) are considered more effective as biological control agents (Salehi et al. 2016). In this study, *X. sordidus* adults demonstrated a lower handling time than fifth instar nymphs, indicating greater efficiency in capturing and consuming *E. enigmaticus* nymphs. This difference in handling time may be related to a variety of factors, such as voracity variation, satiation time, digestive capacity, and walking speed (Pervez and Omkar 2005; Seko and Miura 2008; Rahman et al. 2022). On the other hand, the attack rate remained constant between predator stages, suggesting that prey capture effectiveness is an intrinsic characteristic of the species, established in nymphs and maintained in adults.

Regarding the higher predation rate by nymphs compared to adult thrips, it may probably be due to adults being more mobile than nymphs and being able to escape predator attack more easily (Gitonga et al. 2002). Similar observations were made for *Orius. insidiosus* preying on thrips of the genus *Frankliniella* and *Orius albidipennis* Reuter (Hemiptera: Anthocoridae) preying on *Aphis fabae* Scopoli (Homoptera: Aphididae) (Baez et al. 2004; Rashedi et al. 2020). Furthermore, it is important to note that predation of immature nymphs is advantageous in reducing the pest population before individuals reach the reproductive stage, potentially reducing the next generation of the pest in the area.

Most anthocorids are predators in the nymphal and adult stages (Ballal and Yamada 2016). However, it is important to note that the prey consumption pattern can vary considerably among the different predator development stages. Sarker et al. (2016) found that the consumption of eggs of *Cryptolestes pusillus* (Schon.) (Coleoptera: Cucujidae) by *X. flavipes* increases with the nymphs’ age. Additionally, in other investigations, it was observed that predation by *O. insidiosus* on *Caliothrips phaseoli* (Hood) (Thysanoptera: Thripidae) was more effective in the adult stage compared to the immatures nymphs (Silva et al. 2023). This situation may occur because larger predatory arthropods usually move faster, detect prey at greater distances, and subdue prey easier (Uiterwaal and DeLong 2018).

However, in this study, a different pattern from the one described above was observed. Predation of *E. enigmaticus* by fifth instar nymphs and adults showed no statistical difference. Supporting these results, LeCato (1976) identified a similar predation pattern in *X. flavipes* when consuming larvae of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), and Arnó et al. (2008) in *Orius laevigatus* (Fieber) (Hemiptera: Anthocoridae) preying on immatures of *F. occidentalis*. These studies converge to emphasize the importance of understanding variations in predatory behavior among the different predator development stages and different prey species. Additionally, it is possible to note that predator behavior can vary according to the predator and prey species, even within the same family.

It is important to consider that while analyses of predator functional responses are useful, results in field conditions may differ from responses in laboratory conditions. This is because the foraging effectiveness of the predator can be affected by a combination of many factors, such as temperature and prey availability, among others (Ge et al. 2018; Hassanzadeh-Avval et al. 2019). Thus, the results of this study serve as a basis for the use of *X. sordidus* in biological control programs. However, field experiments are still necessary to elucidate the interactions between *X. sordidus* and *E. enigmaticus* (Ge et al. 2018).

Although the potential of *X. sordidus* as a biological control agent is confirmed, it is worth mentioning that better pest control results can be achieved by preserving populations of the natural enemies. For this purpose, some tactics can be used, such as reducing the use of insecticides or using selective insecticides (Torres and Bueno 2018; Lin et al. 2021). Additionally, planting polycultures and selecting non-agricultural host plants in the crop areas can also contribute to increasing and sustaining natural enemies in the region (Perdikis; Peñalver-Cruz et al. 2019; Atakan and Pehlivan 2020).

In conclusion, this study provides evidence that *X. sordidus* has the potential to be an effective predator against *E. enigmaticus* by contributing to the reduction of pests' populations. Conservation tactics that favor the presence of natural enemies in crops should be prioritized to ensure the persistence of the predators in crop area, and the use of augmentative biological control should also be evaluated. The information reported here can help improve peanut pest management and contribute to the development of sustainable agriculture.

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Data Availability The data that support the findings of this study are available from the first author upon reasonable request.

Declarations

Conflict of Interest The authors declare no competing interests.

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