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Research Article

Functional response and selectivity of chemical insecticides to the predator *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) fed with contaminated prey

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Abstract. This study evaluated the functional response of the predator *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) when fed with *Corcyra cephalonica* (Stainton, 1863) (Lepidoptera: Pyralidae) eggs contaminated with the insecticides Altacor® (chlorantraniliprole) and Match® (lufenuron). The experiments assessed both direct and indirect toxicity, as well as the predator behavior under varying prey densities. Logistic regression indicated a type II functional response in all treatments, with prey consumption significantly reduced when insecticides were present. Despite the toxicity observed after prolonged direct exposure, leading to 100% mortality by the sixth day, indirect exposure through feeding did not negatively affect predator longevity, and in the Match® treatment, longevity even exceeded that of the control. Attack rate and handling time varied among treatments, with Altacor® showing the lowest attack rate and shortest handling time. These results suggest that *X. sordidus* can contribute to pest control in integrated pest management strategies, particularly during the initial 72 hours following release, even in environments where chemical insecticides are applied. The findings highlight the potential compatibility of selective insecticides with biological control agents.

Keywords: Biological control, Functional response analysis, Predator–prey interaction, Selective insecticides, Toxicological effects.

Introduction

Xylocoris sordidus (Reuter, 1871) (Hemiptera: Anthocoridae) is considered an efficient predator of stored grain pests in subtropical regions. They have the ability for high breeding capacity, high search efficiency, grouping in habitat with abundance of prey, as well as the ability to survive in low prey density (Oliveira et al. 2024).

In a possible associative management between natural enemies and chemical molecules, there is a need to understand the control efficiency and selectivity of products to natural enemies (Torres & Bueno 2018). For the *X. sordidus,* little is known about the effects of chemical molecules on their biological aspects. In crops where chemical molecules and natural enemies have been used together or with short time intervals, it is important to study these relationships.

The objective was to study the predation behavior of *X. sordidus*, based on its predatory capacity and functional response, using *Corcyra cephalonica* (Stainton, 1863) (Lepidoptera: Pyralidae) eggs treated and non-treated with Altacor® (chlorantraniliprole) and Match® (lufenuron) insecticides. Additionally, the study examined the direct and indirect toxicity of the insecticides on the predator after contamination.

Material and Methods

Local. The experiment was conducted at the Laboratory of Biology and Insect Rearing (LBCI) located in Jaboticabal-SP.

Experimental insects. *Xylocoris sordidus* and *C. cephalonica* came from a rearing at the LBCI, kept in an air-conditioned environment with a temperature of 25 ± 2°C; relative humidity of 70 ± 10%; and a photoperiod of 12 hours light/12 hours dark.

Bioassays

Toxicity by contact and ingestion of insecticides. To assess the acute toxicity by contact and ingestion of the products to the adults of *X. sordidus*, the dry residue methodology adapted from Desneux et al. (2006) and Ko et al. (2015) was used with the maximum dosages recommended by the manufacturers of the commercial products. Five mL aliquots of each suspension were transferred to flat bottom test tubes (8.0 cm high × 2.0 cm diameter). The tubes were kept with the open surface facing downwards, on a paper towel, at room temperature until completely dry. Subsequently, adults of *X. sordidus* up to 24 hours old were placed in the tubes. After 1 and 24 hours of exposure, mortality was evaluated.

Functional response of *X. sordidus* using *C. cephalonica* eggs contaminated with insecticides. The tests used 210 adults *of X. sordidus*, aged up to 24 hours. They were kept without food for 24 hours before the start of the tests. As prey, cartons with eggs of *C. cephalonica* with a maximum of 24h of age were used, in the densities of 1, 2, 4, 8, 16, 32 and 64 eggs/plate and with 10 replications for each density in all treatments, Control (T1), Altacor® (chlorantraniliprole) (T2) and Match® (lufenuron) (T3).

In each acrylic plate (6.0 cm × 2.0 cm) one adult of *X. sordidus* and a paper card containing the eggs were introduced. Evaluations of predation behavior were performed 24 hours after the beginning of the experiment, counting the number of prey consumed per replication in each treatment and density.

Statistical analysis. The survival rate of *X. sordidus* adults was compared between treatments using the logrank test of the Kaplan-Meyer method, using the Proc LIFETEST (SAS Institute Inc. 2024). Differences in the Manly preference index were assessed with the Student–Newman–Keuls (SNK) test ($P < 0.05$)" using the Procs GLM and TTEST, respectively. Mean values of the percentage of prey consumed as a function of choice conditions were compared by the Student-Newman-Keuls test ($P < 0.05$) using Proc GLM. The type of functional response was determined by non-linear logistic regression using Proc CATMOD (SAS Institute Inc. 2024). The polynomial function describing the relationship between N_a/N_0 e N_0 was obtained using the equation:

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

Where N_a represents the number of preys consumed; N_0 represents the number of preys provided, and P0, P1, P2, and P3 are the constant, linear, quadratic, and cubic coefficients, respectively, related to the curve's slope.

All parameters were estimated by maximum likelihood. When P1 > 0 and P2 < 0, the proportion of prey consumed is positively related to density, indicating a Type III functional response. When P1 < 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):

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

Where N_a is the number of preys consumed; N_0 is the number of preys provided; a is the attack constant, Th is the handling time, and T is the time the predator is exposed to the preys (24 hours).

The attack rate (a') and handling time (T_h) parameters were analyzed by nonlinear regression, as suggested by Rogers (1972), using Proc NLIN (SAS Institute 2024), 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 et al. 2005). The maximum predation rate T/Th was also estimated.

Results and Discussion

The logistic regression analysis describing the proportion of *C. cephalonica* eggs attacked by *X. sordidus* at prey densities ranging from 1 to 64 eggs revealed significant differences among treatments (Tab. 1). In the control, all parameters of the model (intercept, linear, quadratic, and cubic) were significant (p < 0.0001), indicating a good fit of the regression to the predation data. In contrast, predation in the presence of Match® and Altacor® simplified the polynomial structure of the regression, with only the intercept and linear components retained in the models. This pattern suggests that predation in the absence of insecticides follows a more complex dynamic, while exposure to insecticide-treated eggs reduces the functional variability, constraining predator–prey interactions. Similar simplifications of functional responses under chemical exposure have been reported in other biological control agents, where pesticide interference reduced the flexibility of predator behavior (Torres et al. 2004).

Table 1. Estimated parameters of the logistic regression between the proportion of *Corcyra cephalonica* (Stainton, 1863) (Lepidoptera: Pyralidae) eggs attacked by *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae), after the application of Match® and Altacor® with prey densities of 1 to 64 eggs.

Treatments	Parameters	Estimates ± SE	df	X²	P
Control	Intercept	4.2646 (± 0.5778)	1	54.47	< 0.0001
	Linear	-0.6010 (± 0.0834)	1	51.88	< 0.0001
	Quadratic	0.0186 (±0.00305)	1	37.06	< 0.0001
	Cubic	-0.00017 (±0.000030)	1	31.73	< 0.0001
Match®	Intercept	1.5471 (± 0.2330)	1	44.08	< 0.0001
	Linear	-0.1052 (± 0.0154)	1	46.88	< 0.0001
	Quadratic	0.0000896 (± 0.000196)	1	20.90	< 0.0001
Altacor®	Intercept	0.2752 (± 0.1238)	1	4.94	0.0262
	Linear	-0.0254 (± 0.00276)	1	84.88	< 0.0001

Both attack rates and handling times, which are key parameters for describing functional responses, differed significantly among treatments (Tab. 2). The lowest attack rate was observed in the Altacor® treatment (0.00445 h^{-1}), indicating reduced efficiency in prey location and attack. However, this treatment also resulted in the shortest handling time (1.79 h), suggesting that once prey was contacted, consumption was not impaired. Conversely, in the control treatment, predators displayed a higher attack rate but also required more time to handle prey (3.46 h). These differences reveal that insecticide residues may alter the balance between searching and processing behavior in *X. sordidus*. Comparable results were obtained by Dastjerdi et al. (2009), who reported changes in parasitoid efficiency in the presence of chemical residues, although maintaining a type II response.

Table 2. Mean values (95% confidence interval) of attack rate [a'(h^{-1})] and handling time [*Th*(h)] for *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) preying on *Corcyra cephalonica* (Stainton, 1863) (Lepidoptera: Pyralidae) eggs and estimated number of prey attacked during the observation period (T=24h/Th)[1].

[2]Treatments	Attack rate [a' (h^{-1})]	Manipulation time [$Th_{(h)}$]	T/Th
Control	0.00740 (0.00246-0.00249) a	3.4687(0.3927-2.6851) a	6.93
Match®	0.00675 (0.00252-0.00172) a	2.1429(0.1842-1.7754) b	11.21
Altacor®	0.00445 (0.00152-0.00141) b	1.7922(0.1467-1.4996) c	13.40

[1] Means followed by the same letter in the column do not show a significant difference at 95%, when the confidence intervals do not overlap. [2] Treatments. Control: *C. cephalonica* eggs untreated; Match® and Altacor®: *C. cephalonica* eggs dipped in product solution.

The type II functional response observed in all treatments is consistent with expectations for predatory heteropterans, which typically show a decelerating rate of prey consumption as prey density increases (Hassell et al. 1977). In this study, the curves generated through logistic regression confirmed this trend, with predation increasing with prey density until reaching a plateau (Fig. 1). This behavior indicates that *X. sordidus* maintains its regulatory potential even under exposure to Altacor® and Match®, although with some reduction in efficiency compared to the control.

Regarding direct toxicity, exposure to both insecticides at recommended doses led to complete predator mortality by the sixth day (Fig. 2). Interestingly, mortality was not immediate, with high levels only reached after 72 hours. This delay is ecologically relevant, as it allows predators to continue consuming prey shortly after release, providing a window of effectiveness in pest suppression before chemical effects become lethal. Similar delayed toxic effects have been noted in studies with other predators exposed to insect growth regulators (Stecca et al. 2017), reinforcing the potential for integrating selective chemicals with biological control strategies.

When evaluating indirect toxicity, *X. sordidus* adults feeding on contaminated eggs did not show reduced longevity compared to the control, and in the Match® treatment, survival was even longer (Fig. 3). This finding indicates that sublethal exposure through prey consumption may not compromise predator performance. Stecca et al. (2017) similarly observed that lufenuron had low toxicity to *Podisus nigrispinus* (Dallas, 1851) (Hemiptera: Pentatomidae), corroborating the present results for *X. sordidus*. Thus, selective insecticides such as Match® can be compatible with predator activity in integrated pest management (IPM).

Overall, the data demonstrate that *X. sordidus* retains its predatory capacity under exposure to Altacor® and Match®, especially during the first 72 hours post-release. Although direct contact with insecticides eventually reduces survival, indirect exposure through contaminated prey does not impair predation or longevity. These results highlight the importance of considering both direct and indirect pathways of pesticide exposure when assessing selectivity. The functional response results, combined with the delayed mortality observed, suggest that *X. sordidus* can contribute to pest suppression in sugarcane systems even in areas where insecticides are applied, supporting its integration into

IPM programs.

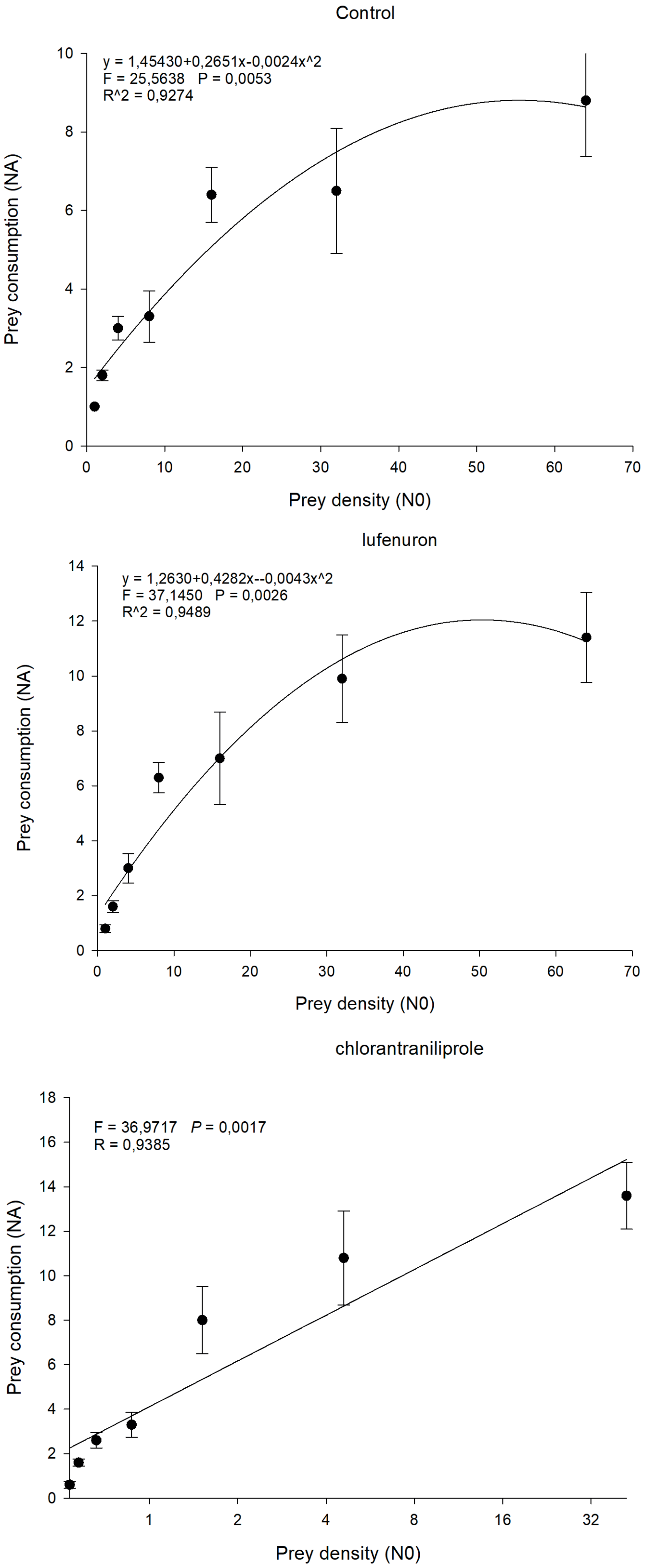

Figure 1. Average number of *Corcyra cephalonica* (Stainton, 1863) (Lepidoptera: Pyralidae) eggs preyed on by *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) adults after application of Match® and Altacor® insecticides, as a function of initial prey density during 24 hours of exposure. 1) Adults preying on *C. cephalonica* eggs non-contaminated (Control); 2) Adults preying on *C. cephalonica* eggs contaminated with Match® (lufenuron); 3) Adults preying on *C. cephalonica* eggs contaminated with Altacor® (chlorantraniliprole).

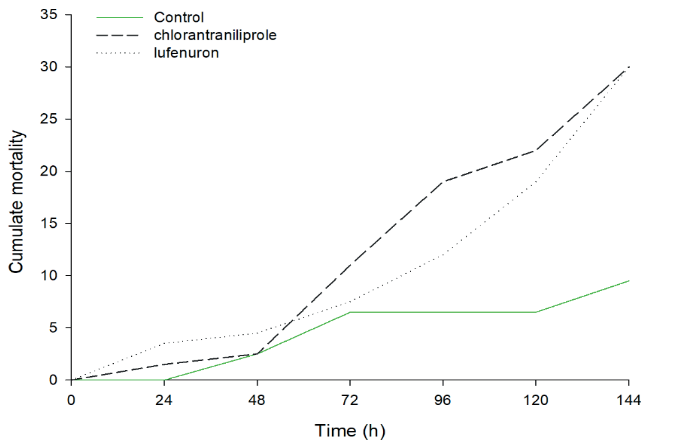

Figure 2. *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) mortality via direct contamination with Match® (lufenuron) and Altacor® (chlorantraniliprole) insecticides.

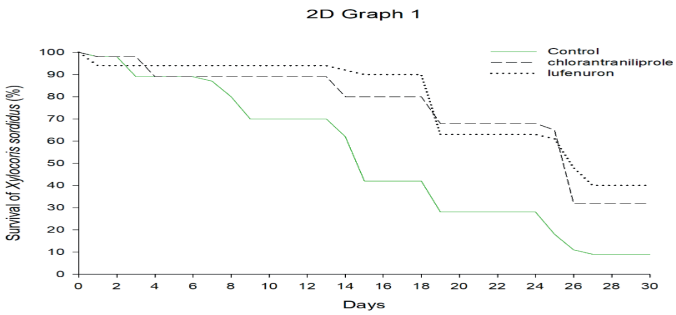

Figure 3. Longevity of *Xylocoris sordidus* (Reuter, 1871) (Hemiptera: Anthocoridae) via indirect contamination by Match® (lufenuron) and Altacor® (chlorantraniliprole) insecticides.

Conclusion

Xylocoris sordidus, when fed with *C. cephalonica* eggs, presents a type II functional response for the treatments (control, Altacor®, and Match®).

When exposed to chemical products indirectly, through consuming eggs, they exhibit similar longevity to the control treatment. In direct contact, there was no immediate effect, allowing the insect to feed on the prey.

The association between the predator *X. sordidus* and the products tested suggests positive effects and could be a strategy employed in biological control.

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Authors' Contributions

SCS: Conceptualization, Investigation, Writing – original draft; AA: Investigation; VF: Investigation; LBL: Investigation; NMLO: Investigation; LB: Investigation; DGR: Formal analysis, Methodology, Validation, Writing – review & editing; SADB: Supervision, Validation, Writing – review & editing.

Conflicts of Interest Statement

The authors declare that they have no conflicts of interest or competing interests.

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