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Original Article

Estimation of predation rate and handling time of boll weevil larvae by *Marava arachidis* (Dermaptera: Labiidae) using different mathematical methods

Estimativa da taxa de predação e tempo de manuseio de larvas do bicudo do algodoeiro por *Marava arachidis* (Dermaptera: Labiidae) utilizando diferentes métodos matemáticos

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Abstract

Anthonomus grandis grandis (Coleoptera: Curculionidae) is a pest with a large potential for destruction in cotton crops, causing damage to the cotton reproductive structures. The earwig *Marava arachidis* (Dermaptera: Labiidae), is an important reference as a predator in several crops and being easy to rear in the laboratory. To analyze the potential biocontrol of *M. arachidis* of *A. grandis grandis* larvae, a study of predatory capacity was conducted using a functional response model. *A. grandis grandis* larvae were exposed to the predator at densities 1, 2, 4, 6, and 8 larvae (= prey/predator / Petri dish), with 30 replications at each density. Contact between the predator and the prey occurred for 24 hours; after this period, the level of predation of *M. arachidis* was assessed based on the proportion of preyed larvae. The linear logistic regression coefficient was used with a beta-binomial generalized linear model to determine the functional response. The negative signal of the linear coefficient and the goodness-of-fit tests revealed a quadratic or type II functional response, with the number of prey varying from 1.00 larva (density of 1 larva/predator) to 6.50 larvae (density of 8 larvae/predator). Therefore, the results of the present study demonstrate a high predatory capacity of *M. arachidis* on *A. grandis grandis* larvae.

Keywords: earwig, cotton boll weevil, biological control.

Resumo

Anthonomus grandis grandis (Coleoptera: Curculionidae) é uma praga com grande potencial de destruição nas lavouras de algodão, causando danos às estruturas reprodutivas do algodoeiro. A tesourinha *Marava arachidis* (Dermaptera: Labiidae), é uma importante referência como predador em diversas culturas agrícolas, além de ser de fácil criação em laboratório. Com o objetivo de analisar o potencial biocontrole de larvas de *A. grandis grandis* por *M. arachidis*, foi realizado um estudo de capacidade predatória utilizando um modelo de resposta funcional. Larvas de *A. grandis grandis* foram expostas ao predador nas densidades: 1, 2, 4, 6 e 8 larvas (= presa/predador/placa de Petri), com 30 repetições em cada densidade. O contato entre o predador e a presa ocorreu durante 24 horas; após esse período, o nível de predação de *M. arachidis* foi avaliado com base na proporção de larvas predadas. O coeficiente de regressão logística linear foi utilizado com um modelo linear generalizado beta-binomial para determinar a resposta funcional. O sinal negativo do coeficiente linear e os testes de ajuste revelaram uma resposta funcional quadrática ou tipo II, com o número de presas variando de 1,00 larva (densidade de 1 larva/predador) a 6,50 larvas (densidade de 8 larvas/predador). Portanto, os resultados do presente estudo demonstram uma alta capacidade predatória de *M. arachidis* sobre larvas de *A. grandis grandis*.

Palavras-chave: tesourinha, bicudo do algodoeiro, controle biológico.

1. Introduction

The cotton boll weevil, *Anthonomus grandis grandis* (Coleoptera: Curculionidae) is one of the most important pests in cotton today, as it is a pest with great potential for destruction, infesting crops from the reproductive phase to harvest, feeding on fibers and seeds, causing injuries to the plant's floral buds, causing the plant's reproductive organ to become infertile and fall to the ground (Faustino et al., 2023; Silva et al., 2023). Studies show that the boll weevil

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has a lower mortality rate than other cotton pests due to natural enemies (Ramalho and Malaquias, 2015). This reinforces the need to explore new biological measures to control this important pest in cotton farming.

Biological control is one of the sustainable agriculture strategies that has become increasingly important in terms of pest management on a sustainable basis (Abbas et al., 2022). It is generally used with other control methods, such as chemicals, and aims to use natural enemies, such as predators, parasitoids, or entomopathogens, to control specific crop pests (Abbas et al., 2022). Among biocontrol agents, dermapterans have attracted attention due to their voracity in predation and diverse feeding capacity, particularly eggs and immature stages of insects that permeate the orders Lepidoptera, Hymenoptera, Diptera, and Coleoptera (Souza et al., 2019). *Marava arachidis* (Yersin) (Dermaptera: Labiidae) has been an important reference as a dermapteran predator in several crops (Ferreira et al., 2022). In addition to its predatory potential, *M. arachidis* is easy to rear in the laboratory with high reproductive capacity, generating many specimens for release in the field, further reinforcing its potential as a biological controller in the face of integrated pest management (Aboelhadid et al., 2022).

In order to use a biological control agent in a production system, several aspects must be investigated, one of the most important being the functional response. This can provide information about the predatory capacity that a natural enemy has, which is classified into three types (Malaquias et al., 2014). For example, in a predator that presents a type I functional response, its attack rate is constant and does not depend on the density of prey; in type II, the attack rate declines gradually, having an inverse correlation with the density of prey and the type III the attack rate increases with increasing density and the decrease is gradual thereafter (Malaquias et al., 2015).

These types are classified according to the general characteristics of predatory behavior, such as attack rate and handling time the predator takes to attack, kill, and consume the prey (Nunes et al., 2019). Given the presented context, this study aimed to analyze the predatory capacity of *M. arachidis*, through a functional response model, in which different methods of estimating parameters were used, using 3rd instar larvae of *A. grandis grandis* as prey. The study tested the following hypothesis: There will be a quadratic functional response, that is, type II, in *M. arachidis* in cotton boll weevil larvae. The functional response parameters were estimated by four methods, Method I: Gauss-Newton Algorithm; Method II: Bias corrected and accelerated intervals; Method III: Studentized; and Method IV: Percentile.

2. Material and Methods

The research was conducted at the Entomology Laboratory (LEN) at the Federal University of Paraíba (UFPB), Campus II, Areia, Paraíba, Brazil. The experiment was carried out using specimens of *M. arachidis* from the rearing colony maintained at the Invertebrate Zoology Laboratory (Campus II), as well as the use of *A. grandis grandis* larvae from the Embrapa Algodão rearing colony Predators were reared with an artificial diet (Lemos et al. 2003), which was changed every 2 d.

The predatory capacity of *M. arachidis* was evaluated using the functional response model. For this, 2nd instar larvae of *A. grandis grandis* were exposed to the female of the predator (< 2 days old). The newly emerged *M. arachidis* female adults were fasted for 24 h and were then individually transferred to Petri dish at the following densities: 1, 2, 4, 6, and 8 larvae (preyed by a predator) per 90x15mm Petri dish, with 30 replications at each density. Contact between the predator and the prey occurred for 24 hours; after this period, the level of predation of *M. arachidis* was assessed based on the proportion of preyed larvae. The arenas were maintained in a room climate-controlled at 26 ± 1 °C, 70 ± 10% RH and a 12-h photophase. The linear logistic regression coefficient was used with a beta binomial generalized linear model to determine the functional response. Using non-linear regression (Holling, 1959), it was possible to determine the parameters such as attack rate (a), which corresponds to the type II functional response (Equation 1), and the constant (b), when the response is type III (Equation 2), and the handling time (T_h), being adopted for both cases (type II and type III). For the type II model, the following equation was used:

$$Ne = aNT / \left(1 + aNT_h\right) \tag{1}$$

where, Ne is the number of preyed larvae; N is the number of larvae offered; a is the attack rate; T is the total time available for the predator to feed on the prey; and T_h is the handling time. In certain cases, the attack rate can increase linearly (a=bN), with b being a constant, which results in a type III functional response model:

$$Ne = bN^2T / \left(1 + bN^2T_h\right) \tag{2}$$

The parameters, attack rate (a), and handling time (T_h) were estimated through a non-linear regression, and the coefficient of determination (R^2) was calculated as the uncorrelated sum of squares. The parameters were estimated by four methods, Method I: Gauss-Newton Algorithm, with the non-linear least squares method (weighted) using the mentioned non-linear model. The nls function from the R base was used (R Core Team, 2023). Despite being a bootstrap model (with 'automatic initial values'), the value 0.99 was used initially for the parameter a (attack rate). To facilitate model convergence, the following format was adopted to estimate handling time: 2*log (2) / initial value of a; Method II: Bias Corrected and accelerated intervals – BCa method – to account for bias, skew, and bounded parameters (a and h > 0); Method III: Studentized; and Method IV: Percentile. Parameter estimates by methods II, III, and IV were conducted using the frair_fit function from the frair package (Pritchard et al., 2017).

3. Results

The average number of insects preyed ranged from 1 larva (with a capture efficiency of 1.0) at a density of

1.00 larva/predator to 6.50 larvae (capture efficiency of 0.8125) at 8 larvae/predator. Therefore, the predatory capacity of *M. arachidis* is considered satisfactory, as the daily predation rate can exceed 6.00 larvae of *A. grandis grandis* per day (Table 1).

The negative signal of the linear coefficient of the logistic regression reveals a quadratic or type II functional response for the average number of *A. grandis grandis* larvae predated by *M. arachidis*, during a 24-hour period (Table 2).

The values of parameters *a* and *Th* are presented in Table 1, confirming the type II functional response. The attack rate (*a*) of the predator estimated by the least squares method using the Gauss-Newton algorithm at 0.0374 (95% CI= 0.0290 – 0.0457). The prey handling time for the female *M. arachidis* (T_h) was estimated at 0.3794 h (95% CI = 0.0793 – 0.6794 h), that is, a time of 22.20 minutes, with intervals of asymmetric confidence ranging from 4.75 to 40.76 minutes (Table 3).

Table 1. Results of the polynomial logistic regression analysis of the proportion of third-instar larvae of *Anthonomus grandis grandis* (Coleoptera: Curculionidae) predated by *Marava arachidis* (Dermaptera: Labiidae).

Coefficients	Estimate	SE
Intercept	2.05	±1.64
Linear	-8.63	±6.92
Quadratic	5.38	±4.32
Cubic	-1.96	±1.57

SE = Standard error.

Table 2. Average number of *Anthonomus grandis grandis* (Coleoptera: Curculionidae) larvae predated by *Marava arachidis* (Dermaptera: Labiidae), during a 24-hour period.

Density	Na	SE	E
1	1.00	±0.00	1.00
2	2.00	±0.00	1.00
4	1.80	±0.58	0.45
6	4.00	±0.57	0.67
8	6.50	±1.50	0.81
μ	3.06	±0.53	-

Density = preys offered; Na = preys consumed; SE = Standard error; E = Search efficiency.

Comparing the methods adopted to estimate the functional response parameters, it was noticed that the Percentile and BCa methods estimated the attack rate and handling time with high variability – according to confidence interval values. On the other hand, the confidence intervals predicted by the Studentized method were narrower. This method would be one of the most recommended due to both the lower variability concerning the Percentile and BCa methods and the asymptotic format represented by the predation predicted by this model (Figure 1), a fact not found in the curve predicted when the Gaussian algorithm was adopted-Newton (Figure 1).

4. Discussion

The predatory capacity of *M. arachidis* is considered satisfactory, as the daily predation rate can exceed 6.00 larvae of *A. grandis grandis* per day. This indicates that *M. arachidis* has great potential to be used as a biocontrol agent for this boll weevil larvae. The type II functional response indicates that the number of ingested prey increases with increasing density until saturation of prey consumption occurs (Gholamzadeh-Chitgar et al., 2014). This was confirmed through the negative values found for the linear coefficient and goodness of fit of the type II functional response model. In other dermapterans, this type of functional response was found by Nunes et al. (2019), with the dermapteran *Euborellia annulipes* (Lucas) (Dermaptera: Anisolabididae) in specimens of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) and by Souza et al. (2019), with the same predator under *Diatraea saccharalis* Fabr. (Lepidoptera: Crambidae). This functional response type is ideal for biological control because biocontrol agents can detect and attack their prey at low densities (Reeves et al., 2023).

In addition to the negative values for linear coefficients mentioned above, the verification of the type of functional response of a predator can be observed by the slope of a curve of this response, being determined by the attack rate (α) and the handling time (Th) (Coelho et al., 2023). The attack rate is responsible for showing predation intensity due to increased prey density (Khan and Yoldas, 2018). Handling time refers to the predator's cumulative time to recognize, attack, kill, and consume prey (Jiang and Kajimura, 2020). It is worth highlighting that the handling time of 22.20 minutes observed in this study is within the average limit for other dermapterans. Being lower than that observed by (Ramos et al., 2019), who

Table 3. Attack rate (*a*) and Handling time (T_h) and 95% confidence intervals (95% CI) for *Marava arachidis* (Dermaptera: Labiidae) preying on third-instar larvae of *Anthonomus grandis grandis* (Coleoptera: Curculionidae), over 24 hours.

Parameters	Gauss-Newton[1]	Studentised[2]	Percentile[2]	BCa[2]
a	0.0374 (0.029 – 0.045)	0.069 (0.033 – 0.105)	1.982 (0.048 – 3.916)	0.071 (0.036 – 1.165)
T_h	0.3794 (0.079 – 0.679)	1.844 (0.000 – 3.688)	5.599 (0.146 – 11.052)	1.855 (0.000 – 9.903)
T	24.000	24.000	24.00	24.000

[1]estimatives from nonlinear (weighted) least-squares (nls function in R); [2]estimatives from frair_fit function in R.

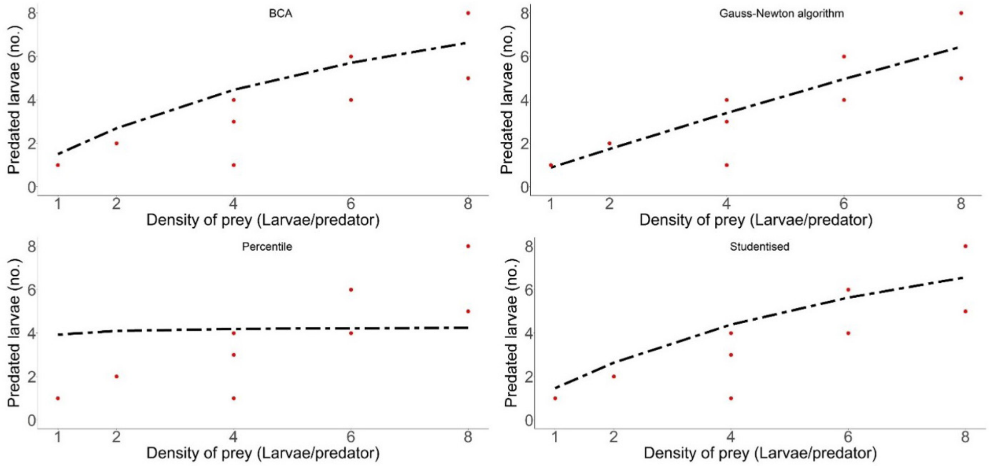

Figure 1. Functional response of *Marava arachidis* (Dermaptera: Labiidae) adults to third -instar larvae of *Anthonomus grandis grandis* (Coleoptera: Curculionidae).

found an average handling time of 31.75 minutes by the species *Chelisoches morio* (Fabricius, 1775) (Dermaptera: Chelisochidae) using the coconut leaf beetle, *Brontispa longissima* (Gestro) (Coleoptera: Chrysomelidae) as prey.

The answer found in this study for the species *M. arachidis* can be associated with the voracity of dermapterans as predators. This characteristic contributes to the success of a predator in the face of Integrated Pest Management (IPM). In this way, through the functional response, we can classify the predator *M. arachidis* as a potential biological controller of the larval stage of *A. grandis grandis*. Thus, knowledge of possible interactions between predator and prey through their biological behavior is essential to determine strategies for control. It is pertinent to highlight that several factors can interfere with the number of preys consumed, the mode of creation, the local plant of prey development, the size of the prey compared to the predator, and the related density (Oliveira-Filho et al., 2023).

In the present study, a consistent amount of consumed prey was recorded. It is important to highlight that other factors can affect predation behavior, such as the predator phase, the size of the prey, the mobility, and the characteristics of its integument, promoting greater or lower predation. Therefore, the movement of prey attracts the predator, thus influencing its consumption preference, which may or may not be nutritionally less adequate (Malaquias et al., 2014). Furthermore, the age of the prey can cause a decrease in predation, just as the variation in cuticle types provides different protection mechanisms for the prey, influenced by the proportion of chitin, degree of sclerotization, and types of constituent proteins (Souza et al., 2022). Due to the limited information in the literature about the activity of *M. arachidis* predators in Brazil, knowledge about these aspects of its predatory performance becomes essential for developing research aimed at adopting biological control strategies associated with integrated management.

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