Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252024v3712178rc

Scientific Article

Chrysoperla externa (Neuroptera: Chrysopidae) predate eggs of *Duponchelia fovealis* (Lepidoptera: Crambidae), a pest of strawberry

Chrysoperla externa (Neuroptera: Chrysopidae) preda ovos de *Duponchelia fovealis* (Lepidoptera: Crambidae), uma praga do morangueiro

Rodrimar B. Gonçalves[1], Emily S. Araujo[2]*, Bruno R. de Moraes[1], Ida C. Pimentel[1], Joatan M. da Rosa[1], Daniel Bernardi[3], Maria A. C. Zawadneak[1]

[1]Department of Basic Pathology, Universidade Federal do Paraná, Curitiba, PR, Brazil. [2]Department of Agricultural Systems; Forestry and Environment, Centro de Investigación y Tecnología Agroalimentaria de Aragón, Zaragoza, Spain. [3]Postgraduate Program in Plant Health, Universidade Federal de Pelotas, Pelotas, RS, Brazil.

ABSTRACT - *Duponchelia fovealis* is an important pest in strawberry crops. In search of an alternative biological control method, the objective of this study was to assess the effects of a diet composed of *Ephestia kuehniella* or *D. fovealis* eggs offered to *Chrysoperla externa* larvae on their subsequent development and survival under controlled conditions. Biological and reproductive parameters of *C. externa* were assessed. Additionally, the daily predation of *D. fovealis* eggs by *C. externa* was analyzed. Finally, a fertility life table was constructed. The egg-to-pupa development time differed significantly between diets. The weights of first- and second-generation male *C. externa* pupae were significantly higher when fed on *D. fovealis* eggs. Males tended to live longer on a diet based on *D. fovealis* eggs, but females presented no significant differences between diets. The oviposition period tended to be longer for *C. externa* fed on *D. fovealis* eggs. The time between generations and the net reproductive rate were greater for *C. externa* fed on *D. fovealis* eggs. The results showed that *D. fovealis* eggs are a suitable diet for the development of *C. externa*. This information is important for developing protocols for the use of *C. externa* as a biocontrol agent against this pest.

Keywords: *Fragaria* × *ananassa*. Lacewings. Biocontrol agent. Prey quality. Insect rearing.

RESUMO – *Duponchelia fovealis* é uma praga severa no cultivo do morangueiro. Na busca de uma alternativa de agente de controle biológico, avaliamos o impacto de uma dieta composta por ovos de *Ephestia kuehniella* ou *D. fovealis* oferecidas às larvas de *Chrysoperla externa* em seu subsequente desenvolvimento e sobrevivência, sob condições controladas. Foram avaliados os parâmetros biológicos e reprodutivos de *C. externa* e a predação diária de ovos de *D. fovealis* por *C. externa*. Por fim, foi construída a tabela de vida de fertilidade. A duração do período do ovo à pupa diferiu significativamente entre as dietas. O peso das pupas de *C. externa* foi significativamente maior quando alimentadas com ovos de *D. fovealis* para machos de primeira e segunda geração. Os machos tenderam a viver mais tempo com uma dieta baseada em ovos de *D. fovealis*, mas não foram detectadas diferenças significativas entre as dietas para as fêmeas. O período de oviposição tendeu a ser mais longo em *C. externa* alimentada com ovos de *D. fovealis*. A predação média diária da primeira geração de *C. externa* foi afetada pela dieta. O tempo entre cada geração e a taxa líquida de reprodução foram maiores para *C. externa* alimentada com ovos de *D. fovealis* do que quando alimentada com ovos de *E. kuehniella*. Nossos resultados comprovaram que os ovos de *D. fovealis* são uma dieta adequada para o desenvolvimento de *C. externa*. Esta informação é valiosa no desenvolvimento de protocolos para o uso de *C. externa* como agente de controle desta praga.

Palavras-chave: *Fragaria* × *ananassa*. Crisopídeos. Agente de controle biológico. Qualidade de presas. Criação de insetos.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: September 7, 2023.
Accepted in: January 30, 2024.

***Corresponding author:**
<esilva@cita-aragon.es>

INTRODUCTION

Strawberry (*Fragaria* × *ananassa*, Duchesne ex Weston) production has been increasing in Brazil in recent years; however, the attack by arthropod pests challenges the achievement of profitable yields (BAENA et al. 2023). Strawberry crops are sensitive to attack by several pest species, including mites (ARAUJO et al., 2022), aphids (BENATTO et al., 2019), thrips (SOUZA et al., 2019), spotted-wing drosophila (*Drosophila suzukii)* (Matsumura) (Diptera: Drosophilidae) (BAENA et al., 2022), and the European pepper moth *Duponchelia fovealis* (Zeller) (Lepidoptera: Crambidae) (GONÇALVES et al., 2022). The European pepper moth is native to the Mediterranean region and the Canary Islands but has spread to different regions of the world, including Brazil. Larvae can feed on all plant organs except roots, causing reductions in leaf area, weakening the stem, facilitating the entry of pathogens that can lead to plant death, and undervaluing strawberry fruits (ZAWADNEAK et al., 2016).

Despite the necessity for controlling *D. fovealis* populations, there are no approved chemical insecticides in Brazil for controlling this moth in strawberry crops (AGROFIT, 2023), increasing the need for adopting biological control practices, such as the release of commercially produced predators (DHANDAPANI et al., 2016). Research studies conducted over the last decade under laboratory conditions have identified several organisms with potential to be

used as biocontrol agents against *D. fovealis*, including entomopathogenic fungi (BAJA et al., 2020), parasitoids (ARAUJO et al., 2020a), and predators (ARAUJO et al., 2020b). However, these studies have indicated that the egg stage of *D. fovealis* is the most challenging to control, thus requiring further investigation to identify potential biocontrol agents against this pest at this life stage.

Lacewings (Chrysopidae: Neuroptera) are among the most efficient predators; they form a highly diverse family, totaling 150 species in Brazil (FREITAS; PENNY, 2001). They are polyphagous predators during the larval stage, feeding on several economically important pests (CARVALHO et al., 2023). Their larvae are particularly attracted to eggs and young larvae of lepidopterans, aphids, and spider mites (DHANDAPANI et al., 2016). Moreover, they have interesting characteristics for utilization as natural enemies in integrated pest management (IPM) programs, including good mobility, voracity, and high rates of survival and reproduction (CARVALHO; SOUZA, 2009). Successful cases of using lacewings for controlling lepidopteran pests in fruit production have been reported in Brazil (FERREIRA et al., 2006). However, it is essential to consider that the quantity and quality of larval prey may influence their immature developmental stages, as well as the reproductive potential of adults (CARVALHO et al., 2023). First-instar lacewing larvae are highly demanding in terms of the nutritional quality of consumed prey, which varies from one species to another (BEZERRA et al., 2017). Thus, the affinity with the target prey should be considered when planning IPM programs involving the release of lacewings. Practices such as releasing lepidopteran eggs are recommended for a successful establishment of Chrysopidae populations as biological control (PAPPAS; BROUFAS; KOVEOS, 2011).

In large-scale laboratory rearing of lacewings, larvae are fed with eggs of *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae), which is a diet considered suitable for *Chrysoperla externa* (Neuroptera: Chrysopidae) (RIBEIRO; CARVALHO, 1991; DIAS et al., 2018). However, rearing practices using eggs of the target pest may improve the subsequent performance of lacewings in the field. Therefore, considering the potential of *C. externa* for use in IPM programs for strawberry crops in Brazil, the current study aimed to assess the effects of a diet composed of *D. fovealis* eggs on biological and reproductive parameters and predatory ability of *C. externa* under laboratory conditions. A diet consisting of *E. kuehniella* eggs was used as a control for comparison purposes.

MATERIALS AND METHODS

Rearing of *Duponchelia fovealis*

Specimens of *D. fovealis* were obtained from a laboratory colony (Universidade Federal do Paraná, Curitiba, Paraná, Brazil) established from locally collected wild insects and reared as described by Zawadneak et al. (2017): at 25 ± 2 °C, 70±10% RH, and 14-hour photoperiod. Adults were kept in plastic cages (15 × 15 × 12.5 cm) and fed on an artificial solution consisting of 0.5 g nipagin, 0.5 g sorbic acid, 30.0 g sugar, 10 mL honey, 170 mL beer, and 500 mL distilled water (ZAWADNEAK et al., 2017). The walls of these cages were lined with paper towels for egg deposition. Larvae were fed on an artificial diet. Pupae were transferred to sterile Petri dishes (15 × 2 cm) with moist filter paper until adult emergence. Voucher specimens were deposited in the "Coleção Entomológica Padre Jesus Santiago Moure" (DZUP) at the Universidade Federal do Paraná Curitiba, Paraná, Brazil.

Origin and rearing *of Chrysoperla externa*

Chrysoperla externa eggs were purchased from Biocert® Produtos Biológicos Ltda. (Curitiba, Paraná, Brazil). The species was confirmed by characterizing the adults, as proposed by Freitas and Morales (2009). Voucher specimens were deposited in DZUP.

The lacewing larvae were fed ad libitum with sterile eggs of *D. fovealis* or *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae), the latter acquired from the Promip® Manejo Integrado de Pragas Ltda. (Engenheiro Coelho, São Paulo, Brazil). They were kept in round plastic pots (17 cm height × 15 cm diameter) until pupation. Emerged adults were placed in cages (25 cm height × 40 cm length) covered with filter paper for mating, and fed on a solution of honey and beer yeast (1:1; v:v) on cotton (CARVALHO; SOUZA, 2009), changed every 2 days.

The detailed bioassays described below were conducted under laboratory conditions (25±2 °C, 70% ± 10% RH, 14-hour photoperiod) in a completely randomized design with two diets: a) *E. kuehniella* eggs and b) *D. fovealis* eggs. The first diet was used as a control because *C. externa* populations are commonly fed on this species when reared under laboratory conditions (TAUBER et al., 2000).

Biological parameters of the first and second generations of *Chrysoperla externa*

A total of 120 *C. externa* eggs (from either the first or second generation), no more than 24 hours old, were selected from each diet. They were individually placed in flat-bottomed glass tubes (8.5 cm height × 2.5 cm in diameter), each egg considered a replication (n=120), and sealed with a cotton swab, following similar methods to those described in Ribeiro et al. (2011). A 1 mL micro-Eppendorf tube containing cotton moistened with distilled water was replaced every 2 days in these tubes using tweezers. Filter paper strips containing either *D. fovealis* or *E. kuehniella* eggs glued onto cards with a honey-based solution diluted in water in a 1:1 ratio (v:v) for egg fixation were provided ad libitum to the *C. externa* larvae until pupation. These strips were replaced every 2 days to the first, second, and third instar larvae until pupation. The stages from egg to pupa (days), pupal weight (mg), viability (%), male and female longevity (days), and sex ratio [sr = number of females / (number of females + number of males)] for this first or parental generation were evaluated daily, with each molt of ecdysis or exuviae counted as an instar.

Reproductive parameters of *Chrysoperla externa*

Ten 24-hour-old pairs of *C. externa* (n = 10) from each treatment were placed in a round plastic cage (6.5 cm in height × 12 cm in diameter) lined with filter paper, which was replaced every 24 hours. These individuals were fed on a solution of honey and beer yeast (1:1, v:v) (CARVALHO;

SOUZA, 2009) replaced every 2 days using tweezers. Micro-Eppendorf tubes with moistened cotton, replaced every 2 days, were used for providing water to the insects. Data on incubation, pre-oviposition, oviposition, and post-oviposition periods (days), daily and total oviposition, viability (%), and longevity (days) of the pairs were recorded. The eggs were packed in Ziploc bags (15 cm × 10 cm) and appropriately labeled; their incubation period and viability were monitored daily.

Daily predation

Thirty 24-hour-old eggs from the first generation of *C. externa* were selected from each treatment. They were individually placed in flat-bottomed glass tubes (8.5 cm high × 2.5 cm in diameter), each egg considered a replication (n = 30), and sealed with a cotton swab; water was provided every 2 days using micro-Eppendorf with moistened cotton. *C. externa* larvae were fed either on *D. fovealis* eggs (on filter paper strips) or *E. kuehniella* eggs pasted onto cards with a honey-based solution diluted in water at a 1:1 ratio (v:v). The food cards containing *D. fovealis* or *E. kuehniella* eggs were replaced every 24 hours to assess the daily consumption by first, second, and third instar larvae of *C. externa* (50, 100, and 250 eggs; and 50, 150 and 300 eggs, respectively). The number of predated eggs was counted daily until pupation.

Considering the differing weight and size of *D. fovealis* and *E. kuehniella* eggs, counts of predated eggs were transformed using the mean weight of eggs to compare the *C. externa* predation between these two diets. Therefore, four 100-egg samples from each species were weighed to obtain mean weights, which were 2.45 ± 0.17 mg and 8.36 ± 0.50 mg for *E. kuehniella* and *D. fovealis* eggs, respectively.

Fertility life table

From the biological parameters of *D. fovealis*, fertility life tables were constructed (SOUTHWOOD, 1978). The following indices were estimated for each treatment: the maximum rate (mr) of increase achieved by a population with a fixed age distribution, over any timespan, under optimum space and feeding conditions, and without the influence of other factors (ANDREWARTHA; BIRCH, 1954); the mean interval between generations (T), which represents the mean time between the oviposition of a given generation and the oviposition of the following generation; the net reproductive rate (R_0), which is the total of female offspring per female during the reproduction period that arrive to the next generation; the finite rate of increase (λ), which is the number of times that the population multiplies in a given time. The number of generations per year was obtained by dividing T by 365 days.

Statistical analysis

The incubation period (days), duration of larval and pupal stages (days), weight of 24-hour-old pupae (mg), adult longevity, duration of pre-oviposition, oviposition, and post-oviposition periods (days), and daily and total fecundity (number of eggs) were checked for normality and homoscedasticity using the Shapiro-Wilk and Bartlett tests, respectively. Then, data were subjected to a one-way analysis of variance (ANOVA), using the diet as a factor. Data not meeting the normality and homoscedasticity assumptions were subjected to analysis of non-transformed data using the Kruskal-Wallis test. These analyses were performed using the package Dunn.test. All statistical analyses were conducted using the software R.

Fertility life table parameters were estimated by the Jackknife method (MEYER et al., 1986), using Lifetable programming SAS® (MAIA et al., 2000), and the means were compared through the two-sided t test ($P \leq 0.05$) using the software SAS®.

RESULTS AND DISCUSSION

Biological parameters of the first and second generations of *Chrysoperla externa*

Considering the first generation of *C. externa*, the duration of egg incubation and first instar and pre-pupa stages presented no significant differences between diets (Table 1). However, significant differences were found for the duration of the second instar (p-value = 0.001), third instar (p-value < 0.001), and first to third instar stage (p-value < 0.001). *C. externa* larvae fed on *E. kuehniella* eggs completed their life cycle approximately 1 day earlier than those fed on *D. fovealis* eggs.

Table 1. Biological parameters, including mean duration of each instar stage and incubation period of eggs for the first (F1) and second (F2) generations of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, 14-hour photoperiod).

Generation	Diet (eggs)		Incubation of eggs		----- 1st instar -----		----- 2nd instar -----		----- 3rd instar -----		-- 1st to 3rd instar --	
			N	days	*n*	days	*n*	Days	*n*	days	*n*	days
F1	*E. kuehniella*		120	6.01 ± 0.03	117	3.20 ± 0.04	115	2.90 ± 0.02	114	2.86 ± 0.04	114	8.97 ± 0.06
	D. fovealis		119	6.05 ± 0.04	118	3.21 ± 0.04	117	2.77 ± 0.04	115	4.13 ± 0.08	115	10.13 ± 0.07
	Statistics	H	0.30159		0.00		62.495		112.43		95.07	
		p-value	0.5829		1		0.01242		< 0.001		< 0.001	
F2	*E. kuehniella*		119	5.21 ± 0.04	116	3.55 ± 0.04	113	3.00 ± 0.04	111	3.61 ± 0.05	111	10.16 ± 0.06
	D. fovealis		120	5.42 ± 0.05	115	3.55 ± 0.05	113	3.34 ± 0.06	110	3.62 ± 0.05	110	10.46 ± 0.07
	Statistics	H	12.234		0.0087894		20.983		0.083908		86.227	
		p-value	< 0.001		0.9253		0.004633		0.7721		0.00332	

Data are presented as mean ± standard error obtained from the Kruskal-Wallis test, with significant p-values in bold.

The biological parameters observed for *C. externa* fed on eggs of *D. fovealis* are similar to those found for *C. externa* fed on *E. kuehniella* eggs (BEZERRA et al., 2017). Specifically, the incubation period of eggs was slightly longer when *C. externa* fed a diet based on *D. fovealis* eggs, but only for the second generation; nonetheless, the difference from the *C. externa* population fed on *E. kuehniella* eggs was only 0.2 days (Table 1). Considering both evaluated diets, the durations found for this period were similar to those reported in other studies evaluating different species as diets (AUAD et al., 2005; RIBEIRO et al., 2011).

Similarly, the duration of the larval stage (from the first to third instar stage) was longer when *C. externa* was fed on *D. fovealis* eggs compared to the diet with *E. kuehniella* eggs: 1.16 and 0.3 days longer for the first and second generations, respectively (Table 1). However, these periods were shorter when compared to those reported in a study evaluating biological parameters of *C. externa* fed on eggs of *Bonagota salubricola* (RIBEIRO et al., 2011). Contrastingly, the larval stage duration found in our study was similar to those reported by Carvalho et al. (2023) when feeding *C. externa* with *E. kuehniella* eggs (8.5 days). Our results indicate no effects of a diet based on *D. fovealis* eggs on the duration of the larval stage of *C. externa*, mainly for the second generation, which can complete its larval cycle within 10 days. This should be considered for the mass rearing of this predator and for its use in integrated pest management (IPM) strategy.

The pupal stage duration varied significantly (p-value < 0.001) between diets. The egg-to-pupa development time was significantly different between diets (p-value < 0.001); however, the mean difference was less than one day (Table 2).

Table 2. Biological parameters, including the mean duration of the pupal and egg-to-adult stages for the first (F1) and second (F2) generations of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, and 14-hour photoperiod).

Generation	Diet (eggs)		------- Pre-pupa -------		---------- Pupa ----------		------- Egg to pupa -------	
			n	days	*n*	days	*n*	days
F1	*E. kuehniella*		114	1.03 ± 0.017	112	9.79 ± 2.71	112	25.72 ± 0.09
	D. fovealis		115	1.00 ± 0.086	113	9.41 ± 0.08	113	26.64 ± 0.09
	Statistics	H		1.9134		13.804		60.69
		p-value		0.1666		< 0.001		< 0.001
F2	*E. kuehniella*		111	1.00 ± 0.00	110	10.06 ± 0.04	110	26.91 ± 0.08
	D. fovealis		110	1.00 ± 0.00	109	10.06 ± 0.06	109	27.01 ± 0.00
	Statistics	H		11.667		0.098472		17.694
		p-value		0.2801		0.7537		0.02595

Data are presented as mean ± standard error obtained from the Kruskal-Wallis test, with significant p-values in bold.

Four biological parameters in the second generation of *C. externa* differed significantly between diets (Tables 1 and 2): egg incubation, second instar larval stage, first-to-third instar stage, and egg-to-pupa development; all these parameters had longer duration when *C. externa* fed on *D. fovealis* eggs (Table 1). However, the range of these differences was small, varying from 0.4% to 11% for the durations of egg-to-pupa development and second instar larval stage, respectively (Table 2). This indicates that using *C. externa* as a predator of *D. fovealis* may require complementary biocontrol agents to compensate for the slow life cycle development of *C. externa*. However, further research is required to confirm this hypothesis.

The pupal stage was slightly longer for *C. externa* fed on *E. kuehniella* eggs (9.79 days) than when fed on *D. fovealis* eggs (9.41 days), which are similar results to those reported in previous studies (MURATA; BORTOLI, 2009; RIBEIRO et al., 2011).

Male pupal weight was significantly greater when *C. externa* fed on *D. fovealis* eggs for both generations (Table 3). However, females from both generations presented no significant differences between diets (Table 3). This indicates that a diet based on *D. fovealis* eggs may enhance the viability of *C. externa* pupae, which is essential for their survival.

No malformed *C. externa* individuals were found in the first generation. However, the second generation had three malformed individuals: one for the diet with *D. fovealis* eggs and two for that with *E. kuehniella* eggs (Table 4). The sex ratio results for both diets showed a larger number of females than males in the first generation, whereas the second generation had more males (Table 4). Additionally, males tended to live longer under a diet based on *D. fovealis* eggs (p-value = 0.056), while females showed no significant differences (Table 4).

Interestingly, both pupal weight and longevity, desirable characteristics for biological control agents, were higher for males under the diet with *D. fovealis* eggs (Table 3). The longevity of both male and female pupae was longer than those found in other studies evaluating different diets for *C. externa* (RIBEIRO et al., 2011; CARVALHO et al., 2023).

Table 3. Pupal weight (males and females) for the first (F1) and second (F2) generations of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, 14-hour photoperiod).

Generation	Diet (eggs)		Pupal weight			
			---------- Male ----------		---------- Female ----------	
			n	mg	*n*	mg
F1	*E. kuehniella*		50	0.0058 ± 0.0001	62	0.0077 ± 0.0001
	D. fovealis		49	0.0066 ± 0.0001	64	0.0077 ± 0.0001
	Nonparametric statistics	H		13.044		
		p-value		0.0003042		
	Parametric statistics	F-value				0.064
		p-value				0.8
F2	*E. kuehniella*		55	0.0072 ± 0.0001	52	0.010 ± 0.001
	D. fovealis		56	0.0079 ± 0.0001	53	0.008 ± 0.0001
	Nonparametric statistics	H		9.4481		1.7455
		p-value		0.002114		0.1864

Data presented as mean ± standard error obtained from the Kruskal-Wallis and ANOVA tests, with significant p-values in bold.

Table 4. Biological parameters, including number of malformed individuals, sex ratio, and male and female longevity for the first (F1) and second (F2) generations of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, and 14-hour photoperiod).

Generation	Diet (eggs)		Longevity				
			---- Malformed ----		Sex ratio	Male	Female
			N	*n*		days	days
F1	*E. kuehniella*		112	0	0.55	72.77 ± 4.97	84.72 ± 4.52
	D. fovealis		113	0	0.56	84.22 ± 3.43	87.73 ± 4.12
	Nonparametric statistics	H					0.47357
		p-value					0.4914
	Parametric statistics	F-value				3.736	
		p-value				0.0562	
F2	*E. kuehniella*		107	2	0.48		
	D. fovealis		109	1	0.48		

Data are presented as mean ± standard error obtained from the Kruskal-Wallis and ANOVA tests, with significant p-values in bold.

Reproductive parameters of the first generation of *Chrysoperla externa*

The incubation period of *C. externa* was significantly shorter (by approximately 0.7 days) when fed on *E. kuehniella* eggs (p-value = 0.007) (Table 5). However, pre-oviposition period presented no significant difference between diets. The diet with *D. fovealis* eggs tended to extend the oviposition period by 16 days (p-value = 0.058). No significant difference was found for mean daily oviposition, total oviposition, and male and female longevity (Table 6).

The diets had no significant effects on reproductive parameters of *C. externa* (Table 5), except for oviposition and incubation periods, which were longer for the diet *with D. fovealis* eggs. The oviposition period was significantly longer than those reported in previous studies (RIBEIRO et al., 2011; CARVALHO et al., 2023). A long oviposition period is desirable for biological control agents; the diet based on *D. fovealis* eggs led to a 92-day oviposition period, on average, which is significantly longer than diets based on aphids (COSTA et al., 2012), hemipterans (CARVALHO et al., 2023), and other Lepidoptera species (RIBEIRO et al., 2011). Therefore, the use of *C. externa* against *D. fovealis* in the field should be cautious; its combination with other biocontrol agents may contribute to the achievement of an efficient IPM strategy against this pest, as commonly reported for Chrysopidae species (PAPPAS; BROUFAS; KOVEOS, 2011).

Table 5. Duration of incubation, pre-oviposition, oviposition, and post-oviposition periods for the first (F1) generation of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, and 14-hour photoperiod).

Diet (eggs)	*n*	Period (days)			
		Incubation	Pre-oviposition	Oviposition	Post-oviposition
Ephestia kuehniella	10	5.63 ± 0.07	2.89 ± 0.20	75.80 ± 5.96	8.10 ± 3.24
Duponchelia fovealis	10	6.35 ± 0.19	2.80 ± 0.29	92.20 ± 4.02	3.00 ± 1.19
Statistical analysis					
H		72.059	0.026389	35.985	17.053
p-value		0.007	0.871	0.05783	0.1916

Data are presented as mean ± standard error obtained from the Kruskal-Wallis test, with significant p-values in bold.

Table 6. Reproductive parameters, including daily and total oviposition, viability, and longevity of pairs for the first generation of *Chrysoperla externa* fed on eggs of *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, and 14-hour photoperiod).

Diet (eggs)	*n*	Oviposition			Longevity (days)	
		Daily average oviposition	Total	Viability (%)	Male	Female
Ephestia kuehniella	10	22.42 ± 0.78	1731.3 ± 150.0	87.8	111.30 ± 3.47	86.70 ± 7.27
Duponchelia fovealis	10	20.72 ± 1.52	1888.4 ± 89.8	84.3	107.60 ± 5.01	98.00 ± 4.13
Statistical analysis						
H			0.28063		0.20696	
p-value			0.5963		0.6492	
F-value		0.991				1.825
p-value		0.333				0.193

Data are presented as mean ± standard error obtained from the Kruskal-Wallis and ANOVA tests, including p-values.

Daily predation

The daily mean predation for the first generation of *C. externa* was significantly affected by the diets (Figure 1). Significant differences (p-value < 0.001) were found for the first, second, and third larval instars of *C. externa*. The larval weight or eggs consumed was approximately 2.6 times higher when *D. fovealis* eggs was the diet, for all larval instars (Figure 1). This denotes a potential preference of *C. externa* for *D. fovealis* eggs compared to those from other species which are smaller; however, further experiments are needed to confirm this hypothesis.

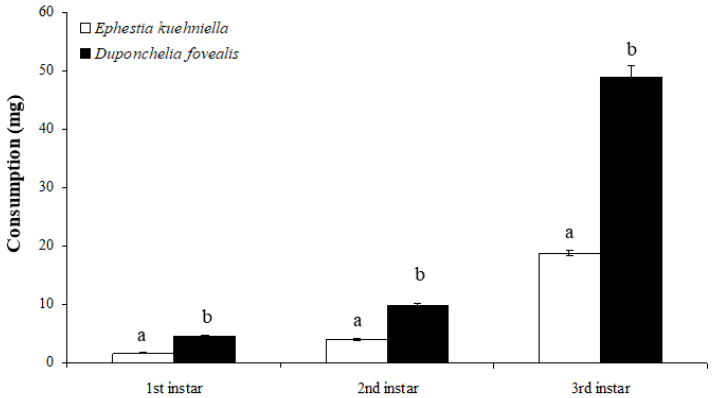

Figure 1. Daily mean predation of the first generation of *Chrysoperla externa* during the 1st, 2nd, and 3rd larval instars for diets with eggs of *Duponchelia fovealis* or *Ephestia kuehniella*. Error bars represent standard errors. Bars with the same letter are not significantly different from each other.

Fertility life table

The time between generations (T) and net reproductive rate (Ro) significantly differed between diets (Table 7), presenting greater values for *C. externa* fed on *D. fovealis* eggs. However, the intrinsic rate of increase (r_m) and population doubling time (TD) showed no significant difference between diets (Table 7).

These population parameters were greater than those reported by Carvalho et al. (2023) for *C. externa* larvae fed on *E. kuehniella* and *Planococcus citri,* Palomares-Pérez et al. (2020) for *C. externa* fed on *Melanaphis sacchari*, and Ribeiro et al. (2011) using *B. salubricola* as diet. These variations may be attributed to differences in prey species and experimental methodologies used in each study (SUJII et al., 2020). Nonetheless, these findings are essential information for developing effective IPM programs using *C. externa* against *D. fovealis*.

Table 7. Parameters of population growth: time between generations (T), net reproductive rate (Ro), intrinsic rate of increase (rm), and population doubling time (λ) for *Chrysoperla externa* fed on eggs of from *Ephestia kuehniella* or *Duponchelia fovealis* under controlled conditions (25 ± 2 °C, 70% ± 10% RH, and 14-hour photoperiod).

Diet (eggs)	T (days)	Ro (♀ / ♀)	r_m (♀ / ♀*day)	λ
Ephestia kuehniella	44.73 ± 0.74 b	885.56 ± 76.73 b	0.152 ± 0.001 a	1.164 ± 0.002 a
Duponchelia fovealis	46.38 ± 0.15 a	1004.63 ± 47.78 a	0.150 ± 0.001 a	1.160 ± 0.001 a

Data are presented as mean ± standard error obtained through the Jackknife method. Means followed by the same letter in the columns are not significantly different from each other (p-value > 0.05).

Therefore, the findings of our study proved that *D. fovealis* eggs are a suitable diet for the larval and pupal development of *C. externa*, as well as for its reproductive period. Previous reports have indicated that the immature development time of *C. externa* varies depending on the larval nutrition quality (YILMAZ et al., 2020); therefore, our findings confirm that the quality of *D. fovealis* eggs is as good as that of *E. kuehniella* eggs, which is the most common diet used for *C. externa* feeding under controlled conditions (RIBEIRO; CARVALHO, 1991; DIAS et al., 2018). Therefore, *D. fovealis* has potential as a suitable diet for mass rearing programs of *C. externa*, and importantly, *C. externa* is a promising biocontrol agent against this invasive lepidopteran pest.

CONCLUSIONS

Seeking an alternative biological control method, this study showed that using *Duponchelia fovealis* eggs as diet contributed to the development of *Chrysoperla externa* during its immature and reproductive stages*;* therefore*,* they have potential to be used for rearing this natural enemy. The results indicate that *C. externa* has potential as a biocontrol agent targeting *D. fovealis* eggs, but further research is needed to assess its viability under field conditions and investigate its combination with other control agents.

REFERENCES

AGROFIT - Ministério da Agricultura, Pecuária e Abastecimento. **Consulta de praga**. Disponível em: http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons. Acesso em: 4 Jul. 2023.

ANDREWARTHA, H. G., BIRCH, C. **The distribution and abundance of animals**. Chicago, USA: Chicago University Press, 1954. 782 p.

ARAUJO, E. S. et al. Compatibility between entomopathogenic fungi and egg parasitoids (Trichogrammatidae): A laboratory study for their combined use to control *Duponchelia fovealis*. **Insects**, 11: 630, 2020a.

ARAUJO, E. S. et al. Combining biocontrol agents with different mechanisms of action to control *Duponchelia fovealis*, an invasive pest in South America. **Crop Protection**, 134: 105184, 2020b.

ARAUJO, E. S. et al. Acarofauna present in organic strawberry fields and associated weeds species in southern Brazil. **Experimental and Applied Acarology**, 86: 91-115, 2022.

AUAD, A. M. et al. Desenvolvimento das fases imaturas, aspectos reprodutivos e potencial de predação de *Chrysoperla externa* (Hagen) alimentadas com ninfas de *Bemicia tabaci* (Gennadius) biotipo B em tomateiro. **Acta Scientiarum: Agronomy**, 27: 327-334, 2005.

BAENA, R. et al. Ripening stages and volatile compounds present in strawberry fruits are involved in the oviposition choice of *Drosophila suzukii* (Diptera: Drosophilidae). **Crop Protection**, 153: 105883, 2022.

BAENA, R. et al. Cold chain storage for quality maintenance of strawberry fruits attacked by *Drosophila suzukii* (Matsumura) (Diptera: Drosophilidae). **Postharvest Biology and Technology**, 197: 1-6, 2023.

BAJA, F. et al. Infection of *Beauveria bassiana* and *Cordyceps javanica* on different immature stages of *Duponchelia fovealis* Zeller (Lepidoptera: Crambidae). **Crop Protection**, 138: 105347, 2020.

BENATTO, A. et al. Performance of *Chaetosiphon fragaefolii* (Hemiptera: Aphididae) in different strawberry cultivars. **Neotropical Entomology**, 48: 692–698, 2019.

BEZERRA, C. E. S. et al. Rearing *Chrysoperla externa* larvae on artificial diets. **Neotropical Entomology**, 46: 93-99, 2017.

CARVALHO M. M. P. et al. Is a diet of *Planococcus citri* nymphs and adults suitable for *Chrysoperla externa* for use in biological control? **Revista Brasileira de Entomologia**, 67: e20220010, 2023.

CARVALHO, C. F.; SOUZA, B. Métodos de criação e produção de crisopídeos. In: BUENO, V. H. P. (Ed.). **Controle biológico de pragas: produção massal e controle de qualidade**. Lavras,MG: UFLA, 2009. p. 77-115.

COSTA, M. B. et al. Development and reproduction of *Chrysoperla externa* (Neuroptera: Chrysopidae) fed with *Neotoxoptera formosana* (Hemiptera: Aphididae). **Revista Colombiana de Entomologia**, 38: 187-190, 2012.

DHANDAPANI, N. et al. Chrysopids. In: OMKAR, K. K. (Ed.). **Ecofriendly Pest management for food security**. London: Academic Press, 2016. p. 311-327.

DIAS, P. M. et al. Potencial de uso de *Chrysoperla externa* (Neuroptera: Chrysopidae) alimentada com *Diatraea saccharalis* (Lepidoptera: Crambidae) em sistemas agroecológicos. **Cadernos de Agroecologia**, 13: 10-10, 2018.

FERREIRA, J. A. et al. Seletividade de inseticidas usados na cultura da macieira a duas populações de *Chrysoperla externa* (Hagen, 1861) (Neuroptera: Chrysopidae). **Ciência Rural**, 36: 378-384, 2006.

FREITAS, C.; MORALES, A. C. Indicadores morfométricos em cabeças de espécies brasileiras de *Chrysoperla* (Neuroptera, Chrysopidae). **Revista Brasileira de Entomologia**, 53: 499-503, 2009.

FREITAS, S.; PENNY, N. D. The green lancewings (Neuroptera: Chrysopidae) of Brazilian agroecosystems. **Proceedings of the California Academy of Sciences**, 52: 245-395, 2001.

GONÇALVES, R. B. et al. *Annona* (Annonaceae) by-products derivatives: toxicity to the European pepper moth and histological assessment. **Crop Protection**, 155: 105937, 2022.

MAIA, A. H. N. et al. Statistical inference on associated fertility life table parameters using Jackknife technique: Computational aspects. **Journal of Economic Entomology**, 93: 511-518, 2000.

MEYER, J. S. et al. Uncertainty in population growth rates: Jackknife vs. Bootstrap techniques. **Ecology**, 67: 1156-1166, 1986.

MURATA, A. T.; BORTOLI, S. A. Estudo da capacidade de consumo do pulgão da couve por *Chrysoperla externa* e *Ceraeochysa cubana* (Neuroptera: Chrysopidae). **Revista Brasileira Agroecologia**, 4: 3034-3038, 2009.

PALOMARES-PÉREZ, M. et al. Life table of *Chrysoperla externa* (Neuroptera: Chrysopidae) reared on *Melanaphis sacchari* (Hemiptera: Aphididae). **Revista Colombiana de Entomologia**, 46: e6831, 2020.

PAPPAS, M. L.; BROUFAS, G. D.; KOVEOS, D. S. Chrysopid predators and their role in biological control. **Journal of Entomology**, 8: 301-326, 2011.

RIBEIRO, M. J.; CARVALHO, C. F. Aspectos biológicos de *Chrysoperla externa* (Hagen, 1861) (Neuroptera: Chrysopidae) em diferentes condições de acasalamento. **Revista Brasileira de Entomologia**, 35: 423-427, 1991.

RIBEIRO, A. L. P. et al. Development of *Chrysoperla externa* fed in the larval stage with eggs of *Bonagota cranaodes*. **Ciência Rural**, 41: 1571-1577, 2011.

TAUBER, M. J. et al. Commercialization of predators: recent lessons from green lacewings (Neuroptera: Chrysopidae: Chrysoperla). **American Entomologist**, 46: 26-38, 2000.

SOUTHWOOD, T. R. E. **Ecological methods, with particular reference to the study of insect populations**. London, UK: The English Language Book Society and Chapman-Hall, 1978. 524 p.

SOUZA, M. T. et al. First record of *Heliothrips haemorrhoidalis* (Thysanoptera: Thripidae) causing damage on greenhouse strawberries. **Florida Entomologist**, 102: 651-653, 2019.

SUJII, E. R. et al. Controle de artrópodes-praga com insetos predadores. In: FONTES, E. M. G.; VALADARES-INGLIS, M. S. (Eds.). **Controle biológico de pragas da agricultura**, Brasília, DF: Embrapa, 2020. p. 113-140.

ZAWADNEAK, M. A. C. et al. First Record of *Duponchelia fovealis* (Lepidoptera: Crambidae) in South America. **Idesia**, 34: 91-95, 2016.

ZAWADNEAK, M. A. C. et al. Biological parameters of *Duponchelia fovealis* (Lepidoptera: Crambidae) reared in the laboratory on two diets. **European Journal of Entomology**, 114: 291–294, 2017.