

The life history of *Euborellia annulipes* (Lucas) (Dermaptera: Anisolabididae) fed on larvae and pupae of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae)

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Abstract: *Euborellia annulipes* (Lucas) (Dermaptera: Anisolabididae) is reported as a potential predator of *Plutella xylostella* (L.) (Lepidoptera: Plutellidae). In this study, we aimed to investigate whether fourth instar larvae, 1 or 3-day-old pupae of *P. xylostella* are suitable food for the development and reproduction of *E. annulipes*. We evaluated the characteristics of the predation, development of each life stage, and reproduction of the predator, by comparing them with an artificial diet. The nymphs consumed larvae and pupae equally in the first instars, but, from the third to fifth, they consumed more larvae over pupae. Both males and females consumed more larvae over pupae as well. The shortest developmental period of nymphs was observed on larvae at the fourth instar. Males and females presented lower longevity fed on 3-day-old pupae. The highest longevity and survival rate of adults were observed on an artificial diet. Pupae of *P. xylostella* at any age provided the highest weight for nymphs (fourth and fifth instar) and adults. One-day-old pupae provided the highest fecundity (480 eggs/female); however, the egg hatching rate was higher when the predator fed on fourth instar larvae. The net reproductive rate was higher on 1-day-old pupae (292.8), but the intrinsic rate of increase (0.03 day^{-1}) and the finite rate of increase (1.034 day^{-1}) were lower, and both mean generation time (143.4 days) and doubling time (20.6 days) were higher on artificial diet. This study shows that fourth instar larvae, 1- and 3-day-old pupae of *P. xylostella* can be suitable food for the development and reproduction of *E. annulipes*.

Key words: Biological control, Brassicaceae, diamondback moth, entomophagy

1. Introduction

Brassicaceae constitute a group of plants with great economic importance and cropped in different regions of the world (Gonçalves et al., 2013). In Brazil, *Brassica* spp. represent the major share of vegetable production for familiar farmers because of their short period of development and the possibility of intercropping systems (Fernandez et al., 2015; Hendges et al., 2018). However, the main threat for brassica crop worldwide is the pest attack, especially *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), a cosmopolitan species known as the diamondback moth, considered the most aggressive insect pest. Regarding its high reproductive potential and faster development on different *Brassica* species and genotypes, the diamondback moth generates significant production costs (Saeed et al., 2010; Furlong et al., 2013). Damage caused by *P. xylostella* can lead to losses of up to 90% (Zalucki et al., 2012; Machekano et al., 2020).

Chemical control with synthetic pesticides is a predominant strategy in the management of the

diamondback moth because farmers can acquire these products easily, and their application is simple (Gong et al., 2013). However, the intensive use of chemicals can be harmful to the environment and humans (Nguyen et al., 2008; Regueiro et al., 2015), owing to the toxic action to non-target organisms, besides causing the evolution resistance in insect pest (Cheng et al., 2008). In this sense, the adoption of control strategies economic feasible and sustainable is fundamental for farmers, given that the search for healthy products by consumers has been increasing in recent years (Cullen et al., 2008).

Biological control is one of the alternatives to reduce or eliminate the use of synthetic pesticides, leading to an integrated production and more sustainable agriculture. Earwigs (Dermaptera) are voracious predators with high survival potential (Freitas et al., 2017; Logan et al., 2017), and some species are associated with different habitats and crops, such as cruciferous crops, with the potential to act efficiently upon their insect pests (Basedow, 1993;

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Frizzas et al., 2014; Ribeiro and Gontijo, 2017). Rana et al. (2019) reported the association of the ring-legged earwig, *Euborellia annulipes* (Lucas) (Dermaptera: Anisolabididae) – the species with the most extensive geographical distribution (Kočárek et al., 2015); with predation of *P. xylostella* in plantations of cauliflower in Pakistan. In addition, Nunes et al. (2018; 2019a) reported that young and adult stages of *E. annulipes* predate a large number of fourth-instar larvae and pupae of this pest. Pupae can have different nutritional values compared to larvae for predators, and their age may influence the development of consumers (Morales-Ramos et al., 2016; Li et al., 2019). We hypothesize that the age of *P. xylostella* pupae may have an influence on the development of the ringlegged earwig. So, we aimed to evaluate whether *P. xylostella* larvae or pupae are suitable food sources for the development and reproduction of *E. annulipes*.

2. Material and methods

2.1. Predator and prey rearing

The ring-legged earwig was obtained from a colony established in the Biological Control Unity of the Embrapa Algodão, Campina Grande, Paraíba, Brazil (Lemos et al., 2003) and reared in the Laboratory of Entomology of the Federal University of Paraíba, Areia, Paraíba, Brazil. The species was confirmed according to the body and leg colors cited by Kočárek (2011). The colonies were supplemented with field-collected individuals every 2–3 years. Diamondback moth larvae, pupae, and adults were obtained from a colony maintained under laboratory conditions after being collected in a commercial production farm of cabbage in Areia. No other species of *Plutella* was described in Brazil so far, then we considered the insect pest species as *P. xylostella* (Moreno and Vilorio, 2020). We used controlled conditions of 25 ± 2 °C, $70 \pm 10\%$ relative humidity, and L12:D12 h photoperiod to maintain both laboratory-cultured insects. These conditions are optimum for both predator and prey according to Lemos et al. (2003) and Vacari et al. (2013).

The predators were reared in containers (20 × 13 × 7 cm) closed with a perforated cap sealed with voile fabric for aeration, in a density of 40 nymphs. Adults were grouped in a density of 32 insects per container at a sex ratio of 3:1 (females:male). The interior of each container included a moistened absorbent paper W-shape folded (to offer refuge for nymphs and adults, and oviposition site for females) and an artificial diet based on brewer's yeast (22%), powdered milk (13%), wheat bran (26%), broiler chicken feed (35%), and Methylparaben (4%) (Silva et al., 2009). Diamondback moth larvae were reared on plastic conta201rs (36 × 25 × 12 cm) sealed with voile fabric (50 × 35 cm) and were maintained feeding on collard green (*Brassica oleracea* var. *acephala*) leaves. Pupae were

removed from the leaves and placed in flat bottom test tubes (8.5 cm height × 2.4 cm diameter) sealed with hydrophilic cotton. After emergence, adults were transferred into plastic cages (15 cm height × 6.5 cm diameter) sealed on the top with voile fabric containing hydrophilic cotton with food [honey (5%) and water (95%)] and collard green leaves as a substrate for oviposition inside.

2.2. Bioassays

In the present study, we tested three *P. xylostella*-based feeding treatments: fourth instar larvae, 1-, and 3-day-old pupae. Besides, as the predator is considered an omnivore, we compared the treatments with an artificial diet, the same used for rearing *E. annulipes* (Silva et al., 2009). To obtain pupae of known ages, late fourth instar larvae of *P. xylostella* were collected from the stock culture and observed once every 24 h to collect newly formed pupae, and some fresh pupae were retained to obtain 3-day-old pupae.

In due to encounter the amount of prey to provide ad libitum to the predator, some evaluations were performed previously by analyzing the predation rate according to each predator's stage, as reported by Nunes et al. (2018), where 10 nymphs at each instar, 10 males, and 10 females were submitted isolatedly to analysis in Petri dishes (9 cm diameter) with different numbers of prey. The number of preys consumed was registered after 24 h of exposure. After that, the evaluations of biological characteristics were analysed as follows:

Nymphal development: Twenty newly-hatched nymphs (24 h) were separated in Petri dishes (9 cm diameter) containing one moistened absorbent paper (3 cm²), one collard green leaf disk (3 cm diameter), and prey of each treatment provided ad libitum according to the predation rate obtained by the previous bioassay. We recorded daily the development time of each nymphal instar, of the entire nymphal stage, and the survival percentage.

Longevity, fecundity, and fertility: After adult emergence, the sex ratio of *E. annulipes* was recorded according to the equation: number of females/number of males + number of females. Males and females were carefully separated and paired at random in Petri dishes (9 cm diameter). After 24 h coupling, 10 females were transferred individually into new dishes to allow the evaluation of the periods of preoviposition, oviposition, and post-oviposition, the number of eggs per female, clutches (during females' lifespan) and eggs per clutch, the incubation period, and the egg hatching rate. Although the ring-legged earwig mates frequently or lays eggs without mating, it needs at least one union for the production of several clutches with feasible eggs (Klostermeyer et al., 1942; Rankin et al., 1997). No female remained unmated because one male of the same treatment was always added to the dish. Because of the need for a dark environment to

allow oviposition and maternal care (Lemos et al., 2003), the females were maintained in the dishes (as mentioned above) under dark conditions and remained with the eggs until hatching. We recorded the longevity of males and females, individually, but we estimated the survival rate of females.

Predator's weight: As nymphs and adults developed according to the food supplied, the weight was recorded. After eclosion, ecdysis of each nymphal stage and adult, and feeding over a 24 h period, the insects were carefully put into a plate and weighed in an analytical balance (BioScale FA2204).

2.3. Statistical analysis

All data were subjected to analysis of variance (ANOVA) followed by a Student-Newman-Keuls test ($p < 0.05$) using the PROC GLM. The survival rate of adults is presented as Kaplan–Meier curves and was analyzed by log-rank test using PROC LIFETEST (SAS Institute, 2015).

The biological data were used to construct an *E. annulipes* fertility life table suggested by Price (1984) and Krebs (1994). The net reproductive rate [$R_0 = \sum_{x=0}^y (lx)(mx)$], that is, the rate of population increased, considering females from one generation to another; finite rate of increase ($\lambda = \text{antilog}[(r_m) (0.4343)]$), defined as the number of times the population multiplies in a unit of time; mean generation time ($T = \sum x.lx.mx/R_0$); intrinsic rate of increase ($r_m = \ln(R_0)/T$); and population doubling time [$DT = \ln(2)/r_m$] were determined. According to the equations, x is the age of an individual in days, lx the specific survival, and mx the specific fertility.

The Jackknife method was used to estimate the mean and standard error of the fertility life table parameters (Maia et al., 2000). The mean values of the life table parameters were compared by Student's t -test. All analyzes were conducted using the SAS software (SAS Institute, 2015).

3. Results

The predation of *E. annulipes* on *P. xylostella* was significantly affected by the life stage of the prey ($F_{2,189} = 795.28$; $p < 0.0001$). Nymphs of first instars consumed the same quantity of either fourth instar larvae or pupae (~1 prey consumed). The same was observed for the second instar nymphs, who consume around 2 preys. However, the other nymphal instars, males, and females consumed more larvae over pupae at any age (Table 1).

The development of each instar of *E. annulipes* was affected by feeding with different phases of *P. xylostella* ($F_{3,76} = 8.39$; $p < 0.001$). Nymphs in the first instar showed the lowest developmental period when fed either on larvae or 3-day-old pupae (~8 days); the development of the second instar was higher on an artificial diet (10 days) compared to the other feeding treatments; the third instar nymphs presented a lower duration of the stage when they fed on fourth instar larvae (7 days) and higher on 1-day-old pupae (10 days); the fourth instar nymphs developed in a lower developmental period when they fed on fourth instar larvae and 3-day-old pupae (~10 days), but feeding on an artificial diet promoted the highest time to reach the next stage (12 days), and the fifth instar nymphs developed faster when fed on fourth instar larvae and 1-day-old pupae (~13 days) (Figure 1).

The shortest developmental period observed for the entire nymphal stage of *E. annulipes* was 45 days when nymphs were fed on fourth-instar larvae, and the highest was observed on both artificial diet and 1-day-old pupae (~56 days) ($F_{3,67} = 15.72$; $p < 0.0001$). The survival of nymphs fed on both fourth instar larvae and 3-day-old pupae was 90%, whereas on 1-day-old pupae was 75% and on an artificial diet was 85,0%. The sex ratio was 0.56, 0.73, 0.61, and 0.63 on fourth instar larvae, 1-day-old pupae, 3-day-old pupae, and artificial diet, respectively. The longevity of males ($F_{3,23} = 35.87$; $p < 0.001$) and females

Table 1. Mean predation rate (means \pm SE) of fourth instar larvae and pupae of *Plutella xylostella* by nymphs and adults of *Euborellia annulipes* during 24 h.

Predator's life stage	4th instar larvae	1-day-old pupae	3-day-old pupae
1st instar	0.5 \pm 0.16 a	0.8 \pm 0.33 a	0.7 \pm 0.21 a
2nd instar	2.5 \pm 0.27 a	0.7 \pm 0.15 a	1.1 \pm 0.18 a
3rd instar	7.3 \pm 0.45 a	1.9 \pm 0.18 b	2.5 \pm 0.17 b
4th instar	14.6 \pm 1.19 a	2.9 \pm 0.18 b	3.9 \pm 0.35 b
5th instar	24.5 \pm 0.93 a	7.2 \pm 0.61 b	7.4 \pm 0.73 b
Male	31.1 \pm 1.19 a	8.8 \pm 0.39 b	8.9 \pm 0.48 b
Female	50.8 \pm 1.87 a	11.0 \pm 1.21 b	12.3 \pm 0.99 b

Values followed by the same letter in the line are not significantly different from each other as analyzed by the Student-Newman-Keuls' test ($p < 0.05$).

($F_{3,35} = 28.44$; $p < 0.0001$) was significantly different among treatments, being the highest period observed on an artificial diet alone (Table 2). Females fed on an artificial diet survived at a significantly higher rate than those fed on *P. xylostella* life stages ($\chi^2 = 66.38$; $df = 3$, $p < 0.0001$) (Figure 2).

The weight of *E. annulipes* varied as a function of feeding treatments ($F_{3,377} = 34.47$; $p < 0.0001$). The nymphs from the first to the third instars presented similar weight in any treatment (Figures 3a–3c). On the other hand, either nymphs of the fourth or fifth instar (Figures 3d, 3e), males, and females (Figure 3f) weighed more when they fed on pupae. Artificial diet and fourth instar larvae of *P. xylostella* provided lower weight to fourth and fifth instar nymphs, as well as to males of *E. annulipes*. Females weighed lower when fed on an artificial diet (Figure 3f)

The preoviposition period of *E. annulipes* was lower when fed on 1-day-old pupae of *P. xylostella* (~15 days) and higher on an artificial diet ($F_{3,34} = 12.49$; $p < 0.0001$). The oviposition period was higher when the predator consumed either an artificial diet or 1-day-old pupae, being lower on 3-day-old pupae ($F_{3,34} = 4.19$; $p = 0.0126$). The postoviposition period also differed among treatments ($F_{3,34} = 68.94$; $p < 0.0001$), being higher when the predator fed on an artificial diet and lower when fed on 3-day-old pupae (Table 3).

Females laid more clutches when they fed on 1-day-old pupae of *P. xylostella* and artificial diet ($F_{3,34} = 6.29$; $p = 0.0016$) but laid more eggs per clutch fed on 1-day-old pupae ($F_{3,34} = 3.50$; $p = 0.026$). The total most of eggs laid per female were observed when the predator fed on 1-day-old pupae ($F_{3,34} = 7.24$; $p < 0.001$). The artificial diet provided

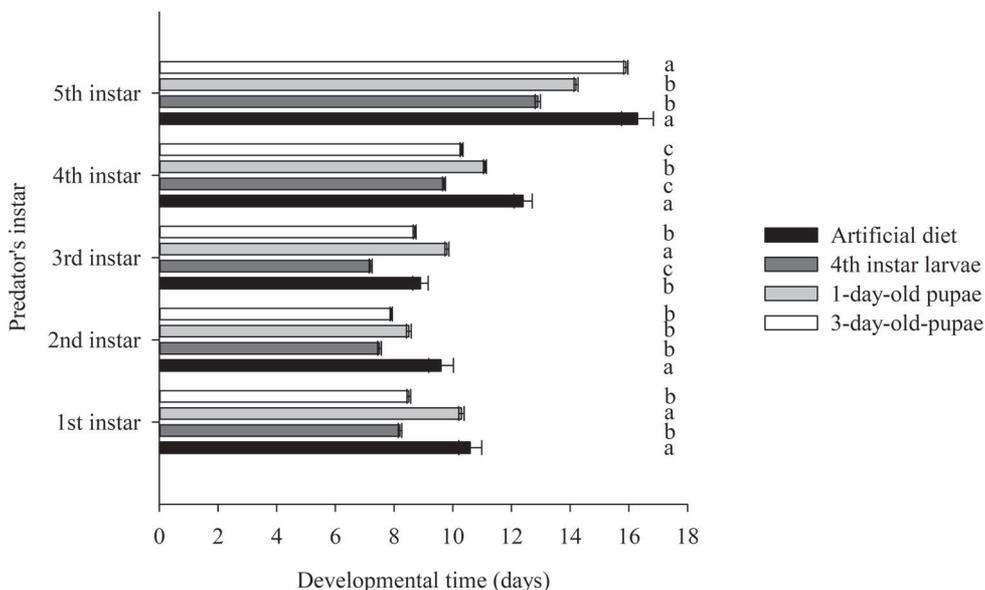


Figure 1. Developmental time (mean \pm SE) of the nymph stages of *Euborellia annulipes* fed on an artificial diet, fourth instar larvae, and pupae with different ages (days of development) of *Plutella xylostella*. Means followed by the same letter in the bars are not significantly different among treatments by the Student-Newmann-Keuls test ($p < 0.05$).

Table 2. Developmental period of the nymphal stage, longevity (means \pm SE), survival of nymphs and sex ratio of *Euborellia annulipes* fed on an artificial diet, fourth instar larvae, and pupae at different ages (days of development) of *Plutella xylostella*.

Treatments	Nymphal stage (days)	Survival (%)	Sex ratio	Longevity of males (days)	Longevity of females (days)
Artificial diet	55.6 \pm 2.15 a	85.0	0.63	190.4 \pm 6.15 a	187.1 \pm 6.11 a
4th instar larvae	45.4 \pm 0.12 c	90.0	0.56	128.3 \pm 4.89 b	115.6 \pm 9.99 b
1-day-old pupae	54.5 \pm 0.21 a	75.0	0.73	117.7 \pm 6.25 b	130.3 \pm 2.72 b
3-day-old pupae	50.6 \pm 0.11 b	90.0	0.61	116.1 \pm 4.34 b	109.6 \pm 5.13 b

Values followed by the same letter in columns are not significantly different among treatments as analyzed by the Student-Newman-Keuls test ($p < 0.05$).

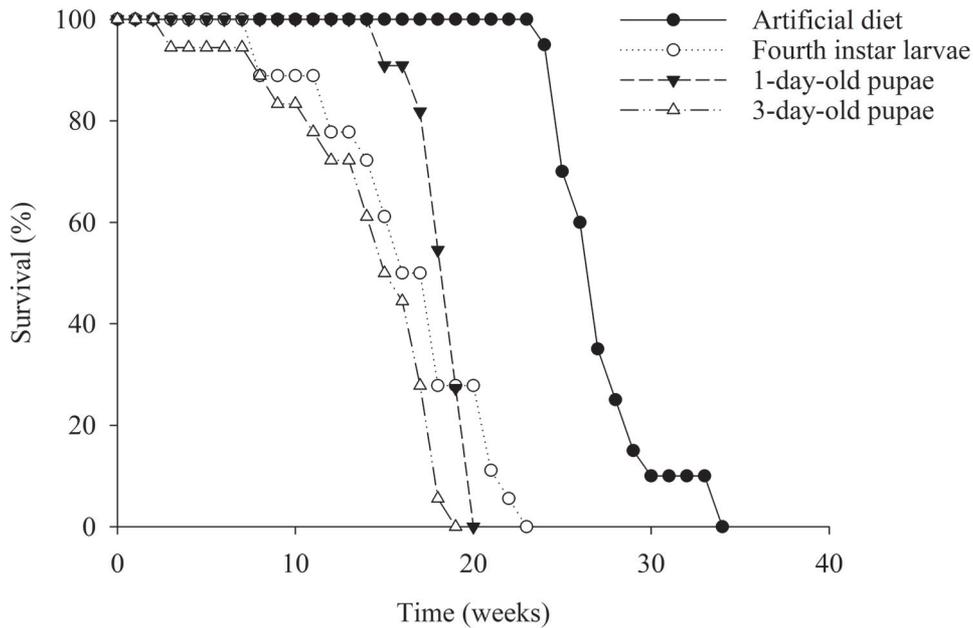


Figure 2. Survival of *Euborellia annulipes* adult females fed on an artificial diet, fourth instar larvae, and pupae of *Plutella xylostella* at different ages (days of development). Different letters indicate significant differences among treatments according to the log-rank test ($p < 0.05$).

the highest and both fourth instar larvae and 3-day-old pupae the lowest values of the incubation period of *E. annulipes* in this study ($F_{3,34} = 13.72$; $p < 0.0001$); however, the egg hatching rate did not differ among treatments, ranging from 78 to 93% ($F_{3,34} = 2.52$; $p = 0.075$) (Table 3).

The fertility life table for *E. annulipes* elucidated differences among the food provided. The mean value of R_0 was higher when the predator fed on 1-day-old pupae (292.8). However, both r_m (0.034 day^{-1}) and λ (1.034 day^{-1}) were lower, and either the mean generation time (143.4 days) or time required for the population to double in number (20.6 days) were higher on artificial diet (Table 4).

4. Discussion

In this study, we report the potential of fourth instar larvae and pupae of *P. xylostella* as a food source for *E. annulipes*, compared with an artificial diet. Using *P. xylostella* fourth instar larvae as food decreased the developmental time of the nymphal stage of *E. annulipes*, but decreased the longevity of females, which was higher when they fed on an artificial diet and the number of eggs per clutch. In addition, the fertility life table indicates the effects of artificial diet on the growth of the *E. annulipes* population.

Despite the number of preys consumed is in agreement with those observed by Nunes et al. (2018), we showed that pupae are consumed equally at different ages, either by nymphs from the third to fifth instars or by males and females. However, there were variations in the developmental period of each nymphal instar and in the

time to completion of the whole predator's life-cycle as a function of the food provided. *Euborellia annulipes* prefers larvae over pupae and increases predation according to densities of *P. xylostella* (Nunes et al., 2019a). This insect is reported as a predator of economically important insect pests consuming *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) larvae (Silva et al., 2009), and pupae of insects, such as the cotton boll weevil, *Anthonomus grandis* Boheman (Coleoptera: Curculionidae) (Ramalho 1994), and the fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) (Urbaneja et al., 2006). With the exception of parasitoids (Wang et al., 1999; Liu et al., 2015; Sarfraz et al., 2005), few predators of diamondback moth pupae are reported. The stink bug *Podisus nigrispinus* (Dallas) (Hemiptera: Pentatomidae) also consumes pupae (Vacari et al., 2013); however, conversely to our results, the ring-legged earwig presented shorter developmental period for the nymphal stage when feeding on larvae compared to pupae.

Earwigs are insects that have long been considered pests, but several types of research have been indicated them as beneficial agents of biocontrol in some agriculture plantations (Romeu-Dalmau et al., 2012; Kočárek et al., 2015; Dib et al., 2017; Logan et al., 2017); however, descriptions of their life history are scarce, especially compared with artificial diets. Earwigs are omnivorous predators, and, because of that, we compared them with an artificial diet (Kocarek et al., 2015). Information about *E. annulipes*' life stage feeding on an artificial diet were

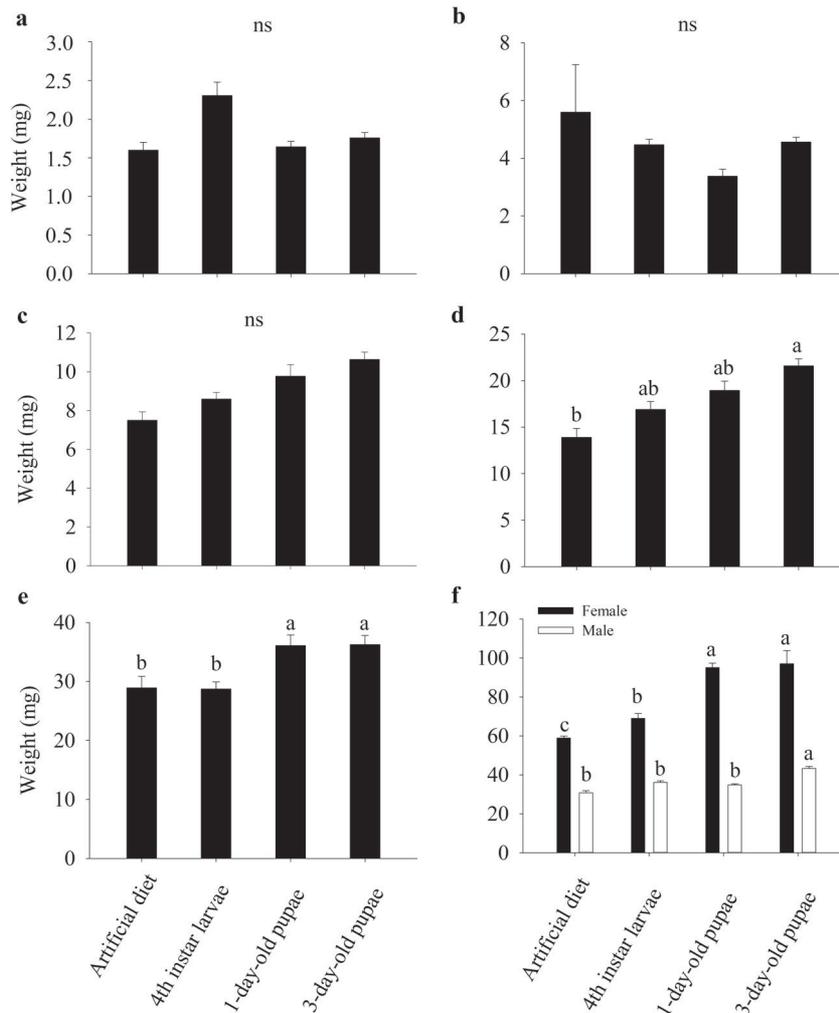


Figure 3. Weight (mean \pm SE) of the nymphs in (a) first, (b) second, (c) third, (d) fourth, and (e) fifth instars and of (f) adults of *Euborellia annulipes* fed on an artificial diet, fourth instar larvae, and pupae of *Plutella xylostella* with different ages (days of development). Different letters on bars indicate significant differences among treatments in each treatment (as analyzed by the Student-Newman-Keuls test, $p < 0.05$); ns = no significant differences among treatments.

well reported by Lemos et al. (2003) so far. Therefore, we present here a comparison and a detailed description of the development and reproduction of *E. annulipes* consuming one of the insect pests with higher economic relevance worldwide.

Larvae incite predation of *E. annulipes* due to their movement but, because of their defense responses and greater size compared to the first instars of the predator, they were probably consumed equally compared to pupae. The protection mechanism (silk fiber) that wraps pupae, which may prevent the access of the predator or discourage predation, and the greater integument stiffness of pupae may cost some time and energy consumption. In the case of this study, the age of *P. xylostella* pupae was a relevant factor that

has an impact on the length of the developmental periods of *E. annulipes* nymphs. The age of lepidopteran pupae can affect positively or negatively a natural enemy (Silva et al., 2015). Older pupae may contain fewer resources used for differentiation to form adult internal organs (Wang and Liu, 2002); however, they can be considered better food for a predator when compared to larvae, owing to their higher nutritional content (Morales-Ramos et al., 2015). Older pupae of *P. xylostella* provided a similar survival percentage for the nymphs, 1-day old pupae provided a higher fecundity, and we verified a greater weight of both fourth and fifth instar nymphs and females fed on pupae at any age.

Several factors can be determinant for biological and behavioral responses of *E. annulipes* naturally,

Table 3. Fecundity and fertility (means \pm SE) of *Euborellia annulipes* fed on an artificial diet, fourth instar larvae, and pupae of *Plutella xylostella* at different ages (days of development).

Parameters	Artificial diet	4th instar larvae	1-day-old pupae	3-day-old pupae
Pre-oviposition (days)	20.1 \pm 0.43 a	18.2 \pm 0.85 b	14.8 \pm 0.67 c	16.6 \pm 0.48 bc
Oviposition (days)	94.2 \pm 1.28 a	87.7 \pm 7.80 ab	102.9 \pm 3.06 a	67.8 \pm 10.8 b
Post-oviposition (days)	23.0 \pm 1.07 a	10.8 \pm 0.67 bc	12.4 \pm 0.65 b	9.0 \pm 0.53 c
Clutches (no.)	4.6 \pm 0.16 a	3.4 \pm 0.31 b	5.3 \pm 0.37 a	3.6 \pm 0.45 b
Eggs/clutch (no.)	74.4 \pm 2.67 ab	54.5 \pm 6.80 b	87.9 \pm 9.32 a	74.0 \pm 8.87 ab
Eggs/female (no.)	286.3 \pm 11.36 b	183.5 \pm 25.81 b	480.1 \pm 74.32 a	273.4 \pm 52.85 b
Incubation (days)	14.3 \pm 0.48 a	10.4 \pm 0.68 c	12.3 \pm 0.71 b	9.2 \pm 0.61 c
Egg hatching (%)	78.8 \pm 2.65 a	92.5 \pm 5.34 a	78.3 \pm 5.42 a	82.4 \pm 3.09 a

Values followed by the same letter in the line are not statistically different from each other as analyzed by the Student-Newman-Keuls test ($p < 0.05$).

Table 4. Life table parameters (means \pm SE) for *Euborellia annulipes* fed on an artificial diet, fourth instar larvae, and pupae of *Plutella xylostella* at different ages (days of development).

Parameters	Artificial diet	4th instar larvae	1-day-old pupae	3-day-old pupae
R_0 (offspring/generation)	122.9 \pm 8.37 b	99.9 \pm 12.86 b	292.8 \pm 28.97 a	149.8 \pm 37.50 b
r_m (day ⁻¹)	0.034 \pm 0.001 b	0.052 \pm 0.002 a	0.054 \pm 0.002 a	0.050 \pm 0.002 a
λ (day ⁻¹)	1.034 \pm 0.001 b	1.053 \pm 0.002 a	1.055 \pm 0.002 a	1.052 \pm 0.003 a
T (days)	143.4 \pm 4.81 a	89.1 \pm 3.34 b	105.1 \pm 3.49 b	99.7 \pm 3.85 b
DT (days)	20.6 \pm 0.86 a	13.4 \pm 0.60 b	12.8 \pm 0.54 b	13.7 \pm 0.64 b

Values followed by the same letter in the line are not significantly different by Student *t*-test ($p < 0.05$) Note that r_m is the intrinsic rate of increase, λ is finite rate of increase, T is mean generation time in days, and DT is doubling time in days.

such as population size, entomopathogens, presence of prey patches, other food sources, and temperature (Klostermeyer, 1942; Oliveira et al., 2011; Lemos et al., 2003; Moral et al., 2017; Nunes et al., 2019b). According to Marucci et al. (2019), the survival rate of earwigs decreases when the predator fed on an exclusive feeding, that is, omnivorous predators, need to have alternative food under environmental conditions, where they are not restricted to a single food source, because of the complexity of food webs. Herein, either larvae or pupae may be considered restricted food, and it is likely that a mixture of items, as the artificial diet provided, may be more beneficial for females of generalist predators because a broader range of nutrients is obtained, favoring biological aspects such as weight gain and reproduction (Toft and Wise, 1999; Bahar et al., 2013). Nevertheless, Pasini et al. (2007) reported a survival rate of 75% when *Doru luteipes* (Scudder) (Dermaptera: Forficulidae) fed exclusively on *S. frugiperda* eggs.

According to the ability to forage and aggressiveness, earwigs can complement their feeding with supplemental

sources, although is necessary to determine what selective forces drive the food choice of generalist predators (Denno and Fagan, 2003; Kočárek et al., 2015). It is probably that this is not a factor that would compromise the predation of the ringlegged earwig. As observed by Li and Zang (2020), the generalist predatory mites *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae) continue to be efficient predators even with the presence of supplementary food.

The oviposition period of *E. annulipes* was affected by the food provided, but the earwig's reproductive success may vary according to various aspects, such as rearing conditions, mating, and diet (Rankin et al., 1997; Kamimura, 2003; Lemos et al., 2003). Females can oviposit on average 45 eggs after 18 days and perform around 3.5 to 9 clutches during 180 days after emergence and mating (Klostermeyer, 1942; Rankin et al., 1995). In a biological control context, the time ovipositing has great importance to indicate more time for the predator's population stability in areas under the diamondback moth attack. Under the conditions of our study, *P. xylostella* fourth-instar larvae can be considered suitable food for egg production, but

1-day-old pupae seemed to have influenced better because the predator laid a remarkable number of eggs during their life span (Table 3). Using an artificial diet composed of different ingredients is such a good alternative under mass-rearing conditions because seems to be less expensive and workable. Herein, we observed that the food based on an insect is suitable for some biological aspects of the predator, which might be important to diamondback moth management.

Although being a wingless species, *E. annulipes* shows a high capacity for exploitation looking for food (foraging) and may have access to *P. xylostella* in plants by scaling surfaces (Klostermeyer, 1942; Abramson et al., 2007). Larvae and pupae of the diamondback moth can be found in different parts of host plants (Talekar and Shelton 1993). So, the contact of the leaves on the soil surface or even the stems of the plants would favor the access of the predator. A generalist predator that does not have flying capability can be advantageous because, in times of prey shortage, they will not migrate to other areas to forage and can persist in the absence of the target pest, feeding on alternative preys or alternative food sources (Symondson et al., 2002; Messelink et al., 2012).

The fertility life table showed that using *P. xylostella* 1-day-old pupae as prey resulted in a higher production of offspring per generation than that obtained when the artificial diet, 4th instar larvae of 3-day-old pupae, was used. This parameter is more relevant than generational duration for population increase (Menezes et al., 2014). Peluzio et al. (2018) observed that *Tenebrio molitor* L.

(Coleoptera: Tenebrionidae) pupae are more suitable to this parameter and, consequently, as food for *P. nigrispinus*. The stink bug consumes larvae or pupae of this pest, and the R_0 is not affected by the prey; however, pupae as prey improved its reproductive performance (Vacari et al., 2013). Artificial diet affected all the other *E. annulipes* life table parameters, and the values obtained for λ and r_m are in agreement with those observed by Lemos et al. (2003). According to Tsai (1998), the doubling time (DT) is a useful index of population growth under a given set of growing conditions.

The results of this study showed that *E. annulipes* can consume either fourth-instar larvae or pupae of *P. xylostella* at any age and complete its life cycle, i.e., the diamondback moth is a suitable food for the development and reproduction of the predator. Our findings provide a basis for further studies on integrated pest management of this pest.

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Conflicts of interest:

The authors declare no conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

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