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ORIGINAL RESEARCH ARTICLE

Life History and Predatory Behavior of *Euborellia annulata* (Dermaptera: Anisolabididae) on Papaya Mealybug (*Paracoccus marginatus*)

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ABSTRACT

This paper reports the life history of *Euborellia annulata* (Fabricius) and its predatory behavior against the papaya mealybug, *Paracoccus marginatus* Williams and Granara de Willink, under laboratory conditions (25 ± 2°C and 70 ± 5% RH). Ten second generation adult pairs of *E. annulata* were allowed to mate, oviposit, and complete their development while feeding exclusively on *P. marginatus*. The set-up was arranged in a Completely Randomized Design (CRD) with three biological replicates. Results indicate that mating to oviposition occurred after a short pre-oviposition period of 5.46 days, while egg incubation was completed within approximately 6-8 days. *E. annulata* underwent four nymphal instars before reaching adulthood. The first instar lasted 7.20 days, while the second instar lasted 5.73 days. The third instar required 8.07 days before transitioning to the fourth and final nymphal stage. The fourth instar exhibited the longest developmental duration of 9.20 days. The adults were characterized by a smooth, glossy black exoskeleton. Sexual dimorphism was evident through differences in cercal morphology. Predation involved prey assessment and repeated attempts at attack before successful capture and consumption. An individual earwig required approximately 30–40 minutes to consume a single mealybug nymph. This, however, suggests relatively high prey-handling costs which might be associated with overcoming the waxy defenses of *P. marginatus*. Although the predator readily accepted and consumed the mealybug, the prolonged handlingtime may constrain its maximum predation rate under high pest densities. In addition, because observations were conducted under controlled laboratory conditions using simplified rearing arenas, further studies are needed to evaluate its functional response, habitat overlap with arboreal pests, and field-level efficacy within integrated pest management programs.

Keywords: *Biological control, earwig, insect pest management, insect predator, predator-prey interaction*

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INTRODUCTION

The earwig *Euborellia annulata* (Dermaptera: Anisolabididae) is a generalist predator commonly found in tropical and subtropical regions (Gonzales et al., 1995; Pattuinan et al., 2014; CABI, 2019). It is known for its adaptability and predatory potential, serving as a biological control agent against the Asian Corn Borer (Adnan and Taufik, 2010). Aside from the Asian Corn Borer, *E. annulata* also preys on various soil-inhabiting organisms, such as the pupal stages of armyworms and cutworms (CABI, 2019). Recently, it has been identified as an important predator of the invasive fall armyworm that attacks corn crops (Asmanizar et al., 2023). This predator is commonly found in hills and corn fields actively seeking potential prey (Gonzales et al., 1995). It uses its distinctive, strong, forceps-like cerci to grasp and hold prey before feeding on it (Yulanda et al., 2024). These forceps are also used by earwigs in defense against potential predators and other insect enemies (Sahayaraj et al., 2023).

Papaya mealybug (*Paracoccus marginatus*) is a destructive pest in many agricultural regions, known for infesting a wide range of economically important crops, including papaya, citrus, and various ornamental plants (Sakthivel et al., 2012; Seni and Chongtham, 2013; Krishnan et al., 2016). Its feeding habits not only cause direct damage by sucking plant sap but also lead to the development of sooty mold through the excretion of honeydew, which further impacts plant health and marketable yield (Mani et al., 2012; Kansiime et al., 2023). Traditional chemical control methods for managing papaya mealybug infestations often have adverse environmental consequences and can lead to the development of resistance (Tanwar et al., 2010; Sakthivel et al., 2012). This underscores the need for effective biological control strategies, where natural biological control agents could offer an environmentally friendly and sustainable solution.

Optimal foraging principles often govern prey selection by generalist predators. This principle suggests that predators tend to maximize energetic gain while minimizing prey-handling costs and predation risk. Soft-bodied hemipterans, such as mealybugs, therefore serve as nutritionally accessible prey due to their sedentary behavior and reduced capacity to escape. However, their waxy secretions and protective coverings may increase handling difficulty and reduce feeding efficiency. In contrast, lepidopteran larvae, which are commonly reported prey of *Euborellia annulata*, are generally more mobile and defensive but may provide greater nutritional reward. These contrasting prey characteristics suggest that predation by *E. annulata* may involve behavioral and energetic trade-offs associated with prey profitability, handling efficiency, and prey-stage suitability. Understanding how this predator responds to wax-covered hemipteran prey may therefore provide essential ecological information into its adaptive feeding behavior and its potential utility as a biological control agent under varying prey conditions.

Despite the potential of *E. annulata* in integrated pest management (Asmanizar et al., 2023), its potential as a biological control agent against the papaya mealybug (*Paracoccus marginatus*) remains poorly understood. Additionally, most earwig studies focus heavily on other pests, such as planthoppers, aphids, and beetles (Marbun et al., 2006; Jiang and Kajimura, 2020). This limits understanding of *E. annulata's* effectiveness against other important pests. Further, there is limited information on how alternative prey, such as *P. marginatus*, affects the biology of the predator. Therefore, investigating the life-history traits of *E. annulata* is critical to optimizing its use as a biological control agent (Punzalan and Morallo-Rejesus, 2004; Nonci, 2016). Studying the predatory behavior of *E. annulata* towards prey insects also provides important information on its feeding behavior and predation efficiency (Zhong et al., 2016). Importantly, assessing its biology and predatory behaviour provides relevant information about how this biological control agent could perform under field conditions, thereby optimizing its subsequent deployment and integration into IPM packages.

Therefore, this study evaluated the life-history traits and predatory behavior of *E. annulata* when fed on the papaya mealybug, *P. marginatus*. This particularly emphasizes prey-handling behavior, prey-stage preference, and predatory responses of *E. annulata* toward sedentar, d wax-protected hemipteran prey.

MATERIALS AND METHODS

Stock population of the *Euborellia annulata* were collected from corn and eggplant fields at DOrSU Marfori Demonstration Farm, Brgy. Don Enrique Lopez, City of Mati, Davao Oriental, Philippines (Figure 1). Collected adults were carefully handled and transported to the Crop Protection Laboratory of DOrSU Marfori Campus, where they were maintained as the initial stock population. Meanwhile, *Paracoccus marginatus* individuals were collected from heavily infested papaya fruits at the same location and mass-cultured in the laboratory. The colony was maintained on fresh, green, and mature papaya fruits, which were replaced at seven-day intervals to ensure a continuous food supply. Mealybugs were periodically transferred to newly prepared fruits during rearing.

The rearing of *Euborellia annulata* was done in improvised arenas made of transparent polypropylene containers (15 cm diameter × 10 cm height) filled with a 2:1 mixture of soil and sand, overlaid with coco coir. Field-collected adult earwigs were paired (one male and one female) and placed in individual containers to allow mating and oviposition. Egg clusters laid within 24 hours were retained for observation. Upon hatching, nymphs were provided with the cultured *P. marginatus* as food. The cultures were maintained under controlled laboratory conditions at 25 ± 2°C, 70 ± 5% relative humidity, and a 12:12 h light: dark photoperiod.

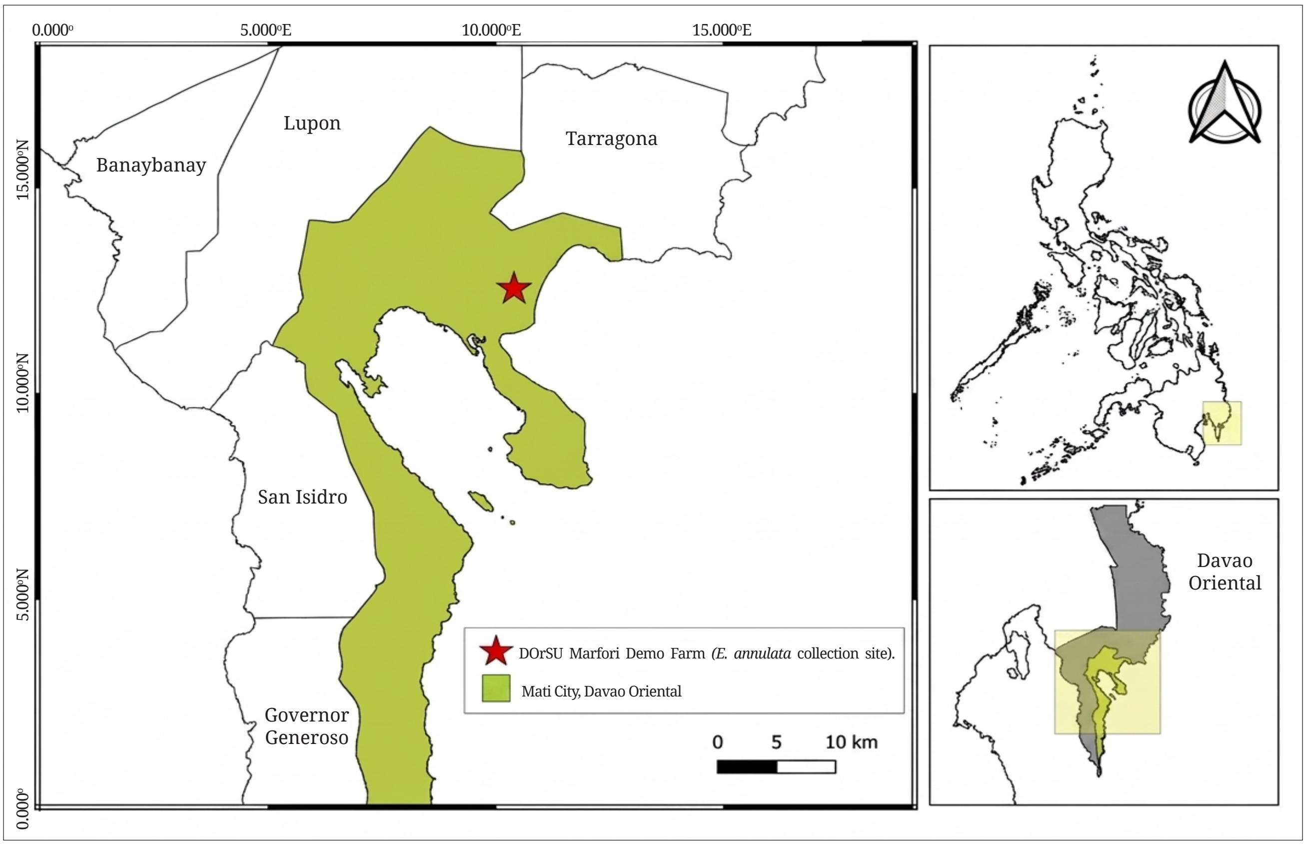

Figure 1. Location where the *Euborellia annulata* stock population were collected within the Davao Oriental State University Marfori Demonstration Farm a t Mati City, Davao Oriental, Philippines. The map with the red star indicate collection site.

For the life history observations of *Euborellia annulata,* ten second generation adult pairs were maintained in the same transparent polypropylene containers as described above, lined with moistened cotton and corrugated cardboard as shelter. This set-up was replicated 3 times. Observations were conducted daily to record the pre-oviposition period. 30 eggs were tagged for the determination of the incubation period. Following hatching, the female adults were separated from the newly hatched neonates, and 10 randomly selected nymphs were monitored through successive instars until adulthood. This set-up was replicated three times with a total of 30 individuals for the life history observation. The duration of each developmental stage and the total nymphal development period were recorded following standard procedures as described in a previous study (Navasero and Navasero, 2010).

The feeding preference assay was conducted using a choice test in an improvised arena (transparent polypropylene containers) containing a moistened cotton wick to maintain humidity. Different developmental stages of *Paracoccus marginatus* were simultaneously positioned at equal distances from the center of the arena. A single *E. annulata* adult individual pre-starved for 24 hours was released at the center of the arena. Observations were conducted for 2 hours to determine the first prey stage attacked and consumed. Each session was performed with three replicates.

RESULTS

Life history, morphology, and life cycle of *Euborellia annulata* Fed with *Paracoccus marginatus*

The adult female takes about 4-8 days after mating, with an average of 5.46 days, before successfully ovipositing the first batch of eggs (Table 1). The newly laid eggs are rounded, creamy white, and smooth. The female earwig positioned itself near where the eggs were laid and was observed to have repeated contact with the eggs. As they neared hatching, the eggs' colour changed from creamy white to creamy brown. Egg hatching occurs 6–8 days after oviposition by the mother. *Euborellia annulata* in this experiment undergoes four nymphal stages before reaching adulthood. The four stages can generally be differentiated by their size. However, male and female *E. annulata* are difficult to distinguish in the early instars. Their colors were also quite similar. They just turned bigger and darker as they approached the late stages. The first and second instars had relatively shorter developmental periods, whereas the third instar persisted slightly longer. The fourth instar exhibited the longest developmental duration among the nymphal stages before adult emergence. The complete life cycle of *E. annulata,* from egg to adult, is illustrated in Figure 2, while the corresponding developmental durations are presented in Table 1.

Table 1. Developmental period (in days) of *Euborellia annulata* fed with papaya mealybug *Paracoccus marginatus.*

Stages	*N*	Range (days)	Development[a] (days)
Pre-Oviposition	30	4-8	5.46±1.38
Egg Incubation	30	6-8	6.60±0.86
1st Instar	30	5-8	7.20±1.05
2nd nstar	30	5-7	5.73±0.74
3rd Instar	30	7-9	8.07±0.83
4th Instar	30	8-10	9.20±0.76
Total development	30	35-50	42.46±1.63

N = Total number of individuals observed *Euborellia annulata* in each developmental period.

[a]Mean developmental period ± standard deviation.

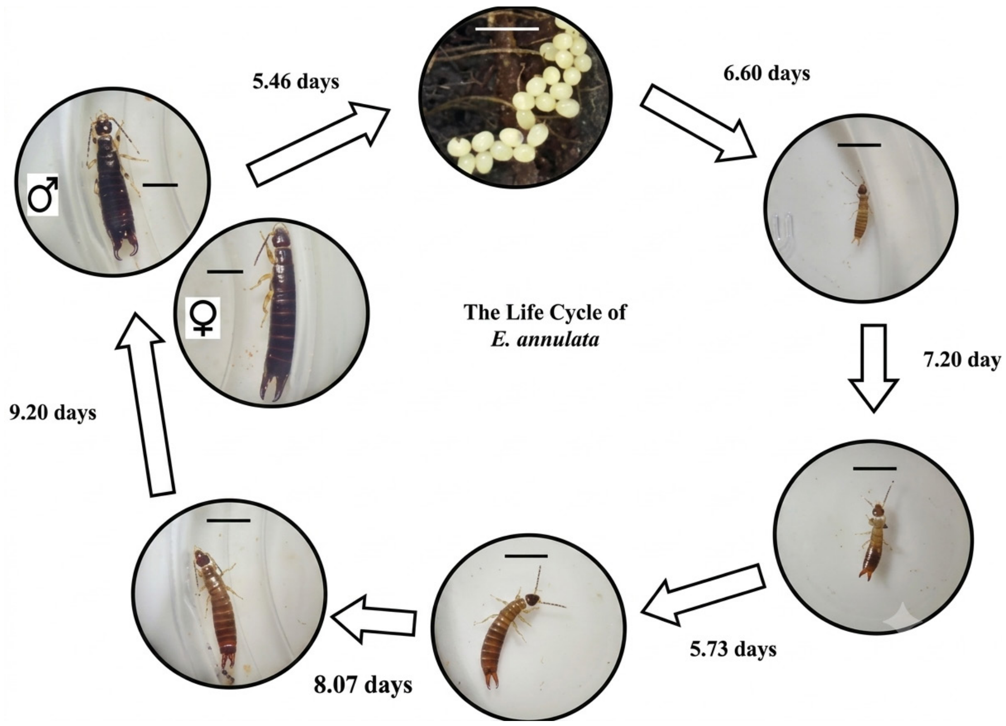

Figure 2. The lifecycle of *Euborellia annulata* from eggs to adult fed with papaya mealybug *Paracoccus marginatus*. It shows the developmental duration of every stage of *E. annulata* and their corresponding measurements. Scale bars = 3.00 mm.

Adults of *E. annulata* are black with a smooth and glossy exoskeleton (Figure 3A-3B). The body is flattened dorsoventrally and elongated. It is a medium-sized insect species, with females larger than males. Legs are long, slender, and pale yellow to creamy white, with conspicuous dark-brown markings on the femur and tibia. Antennae are segmented, black, long, filiform, and dark brown, but the last 2–3 flagellomeres are pale yellow in color. The abdomen is elongated and tapers slightly towards the end where the cerci are attached. Adults exhibited sexual dimorphism, primarily evident in the structure, shape, and size of their cerci. Females exhibit straighter, less pronounced, and smaller-sized cerci (Figure 3C), while males possess slightly inward-curved and larger cerci with sharp tips (Figure 3D).

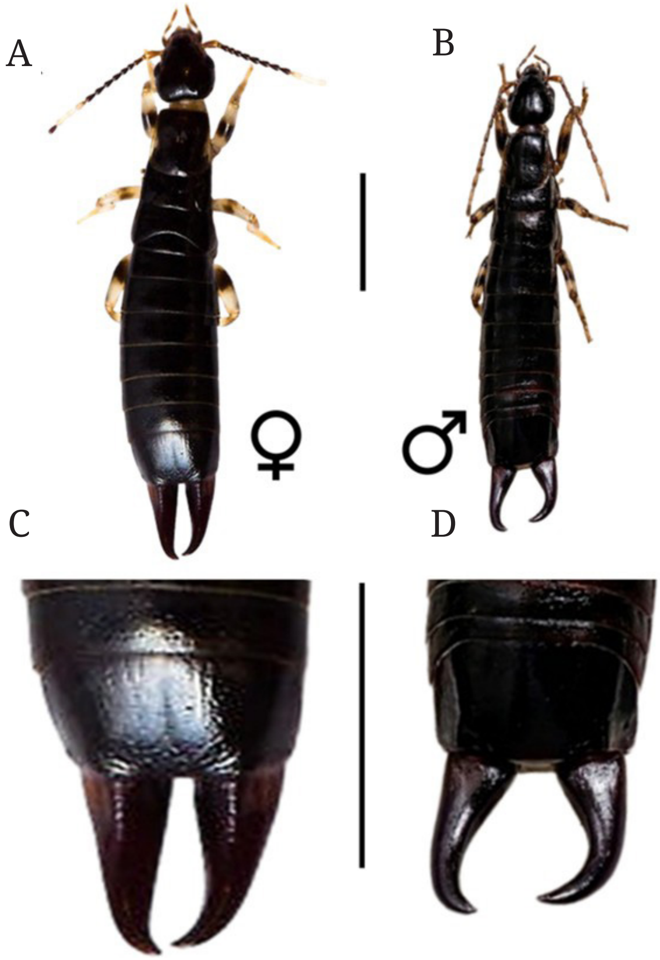

Figure 3. Morphological structure and sexual dimorphism of the *Euborellia annulata* adults fed with papaya mealybug *Paracoccus marginatus.* This shows the habitus of the female adult (A), male adult (B), and the structures of the female (C) and male (D) cerci. Scale bars = 3.00 mm.

Predatory behavior of *Euborellia annulata* towards *Paracoccus marginatus*

For the predatory behavior of *E. annulata,* the adult stage was used because it is the most efficient in terms of consumption and predation rates, as evidenced by previous studies (Punzalan and Morallo-Rejesus, 2004; Yulanda et al., 2024). In this experiment, *Euborellia annulata* was observed to prefer younger instars of *Paracoccus marginatus.* Upon encountering the prey, the *E. annulata* approached cautiously and examined it with its antennae and cerci. *E. annulata* attempted several initial contacts to assess the prey's suitability, often grasping it with its mandibles after a few exploratory touches. *E. annulata* typically makes 1 to 3 attempts to secure prey before commencing the attack. Once captured, *E. annulata* takes a brief period until the beginning of actual feeding, generally lasting a few seconds to a few minutes depending on the mealybug's level of initial resistance and subsequent defensive attempts. When resistance is overcome, *E. annulata* uses its mandibles to puncture the mealybug's exoskeleton, consuming the soft internal tissues while occasionally readjusting its hold with its cerci. The feeding duration of the *E. annulata* against the nymph of *P. marginatus* was observed to be 30–40 minutes. After feeding, grooming behavior was observed, during which *E. annulata* cleaned its cerci and mandibles.

DISCUSSION

This experiment aims to describe the life-history traits and evaluate the predatory behaviour of *E. annulata* fed the papaya mealybug, *P. marginatus*, with an emphasis on prey-handling behavior, prey-stage preference, and adaptive predatory responses of *E. annulata.* As to the life history of *E. annulata,* significant changes in the coloration were noted as the eggs were about to hatch. This is likely due to the physiological and biochemical changes in the embryo as it matures. Similar observations have been reported in an earlier study (Nonci, 2005), supporting the present observations. Meanwhile, it was also noted that the mother earwig appears to guard and groom her eggs until hatching, as evidenced by repeated contact with them. Egg grooming is a common maternal care behaviour in earwigs, primarily used to remove fungal inoculum that may compromise successful hatching of eggs (Diehl and Meunier, 2018). It is also performed by the mother to protect the eggs against desiccation by applying cuticular secretions to the eggshells (Boos et al., 2014). The same behaviour in female mother earwigs was also observed in several previous life history studies of earwigs (Situmorang and Gabriel, 1988; Nonci, 2005; Navasero and Navasero, 2010). However, it is also important to note that the maternal care observed in earwigs is likely an individual behavior rather than an evolutionary strategy, as argued by previous studies (Butnariu et al., 2013; Van Meyel et al., 2022). Thus, this particular behavior of egg grooming does not necessarily hold across all earwig lineages.

On the other hand, there were four nymphal stages observed for *E. annulata* in this experiment. This was generally consistent with previous life history studies (Situmorang and Gabriel, 1988; Nonci, 2005; Navasero and Navasero, 2010). The shortest period of development was notably recorded on the 2nd instar, while the longest was observed on the 4th nymphal instar. The extended developmental period of the final nymphal instar may reflect physiological and structural preparation for adult functions such as predation, mating, and reproduction (Meunier, 2024). The present finding is consistent with the findings of Situmorang and Gabriel (1988), who recorded the longest developmental period in the 4th nymphal instar of *E. annulata*. However, it is also important to note that in the present study, individuals for life-history observation were relocated from relatively natural conditions to artificial arenas. This shift between different environmental conditions may induce physiological and behavioral changes in *E. annulata*. Although in this study this method was intended to facilitate continuous observation, accurate monitoring, and recovery of eggs and nymphs throughout the life cycle, the potential influence of substrate differences on development, reproduction, maternal care, and predatory behavior cannot be entirely excluded.

As to the predatory behavior observation, the adult *E. annulata* was selected because mature individuals generally exhibit higher prey consumption rates and greater handling efficiency than immature instars due to their larger body size, fully developed mandibles, and stronger cerci (Marbun et al., 2006). Previous studies likewise identified adult earwigs as the most voracious developmental stage and therefore the most suitable for augmentative biological control and mass-rearing programs (Punzalan and Morallo-Rejesus, 2004; Zhong et al., 2016; Yulanda et al., 2024). In the present findings, *E. annulata* exhibited a clear preference for smaller mealybug instars, which are likely more profitable prey due to their thinner wax layers, reduced defensive capabilities, and lower energetic costs associated with capture and consumption. Similar prey-stage preferences have been documented in other predatory insects, in which predators selectively exploit prey that maximize energetic returns while minimizing handling costs (Zhong et al., 2016; Jiang and Kajimura, 2020; Miller-ter Kuile et al., 2022). Although *E. annulata* successfully attacked and consumed *P. marginatus*, the observed predation process required approximately 30–40 minutes to complete a single feeding event. This prolonged handling time observed in this study is likely attributable to the defensive characteristics of *P. marginatus*. Mealybugs are protected by waxy secretions that act as physical barriers against predators and other environmental stressors (Powell, 2023; Ulusoy et al., 2022; Yadav et al., 2024). These wax coatings can reduce prey accessibility, interfere with mouthpart penetration, and increase the time and energy required for successful consumption (Gunawardana et al., 2024; Galindo and Silva-Torres, 2025). Similar studies have demonstrated that prey defensive traits can significantly influence predator performance by increasing handling costs and reducing overall feeding efficiency (Hoback and Higley, 2000; Hoback and Smith, 2006). This result has important implications when interpreted within predators' functional response framework (Holling, 1965). Handling time (Th) is a principal factor limiting the maximum number of prey that a predator can consume over time (Holling, 1966; Juliano, 2020). Under a Type II functional response, the relatively longer handling time of *E. annulata* in the present experiment may reduce its maximum theoretical predation rate against *P. marginatus*. It may cause feeding saturation at relatively lower prey densities. In addition, while *E. annulata* has accepted *P. marginatus* as prey, as shown in the present study; the extended time required to process each mealybug indicates that its predatory capacity may become constrained if mealybug populations increase. This may limit the ability of *E. annulata* to effectively and rapidly suppress higher infestation rates under field conditions. From a biological control perspective, these findings suggest that *P. marginatus* may be an acceptable, though not necessarily optimal, prey resource for *E. annulata*. While the sedentary nature of *P. marginatus* may facilitate prey detection and encounters, the energy costs of overcoming wax-based defenses appear to reduce prey profitability. Therefore, despite the demonstrated predatory capability of *E. annulata* in the present study, the relatively long handling time means that its contribution to *P. marginatus* suppression may be density-dependent and potentially limited during severe outbreaks. Under field conditions, where *P. marginatus* populations can increase rapidly, predator feeding saturation may occur before meaningful population regulation is achieved. Under this pretext, *E. annulata* may function more effectively as a supplementary biological control agent that contributes to early-stage suppression or maintenance of low pest densities, rather than as a stand-alone regulator of high-density *P. marginatus* populations.

Moreover, although *E. annulata* was observed as a predator in the present study, its effectiveness under broader field conditions may vary due to ecological complexities. From an ecological perspective, predator efficiency generally depends on several factors, including habitat structure, cropping systems, environmental conditions, availability of refugia, and prey dynamics (Bischoff et al., 2024). For example, fluctuations in environmental conditions, such as temperature, greatly affect predator community composition, altering anticipated biological control potential (Laubmeier et al., 2023). This climatic instability may significantly affect the efficiency of *E. annulata* against *P. marginatus* when implemented under field conditions. Further, the observed preference of *E. annulata* for younger instars of *P. marginatus* in the present study indicates that the predator may be more efficient when mealybug populations are in early developmental stages. It therefore underscores the critical importance of timely predator establishment in the field, a point that must be addressed in future work. Additionally, the apparent spatial separation between *E. annulata* and *P. marginatus* under natural field conditions may affect the practical utility of the predator as a biological control agent against the mealybug. *E. annulata* is generally regarded as a geophilic and litter-associated predator, whereas *P. marginatus* is primarily an arboreal phytophagous pest colonizing leaves, stems, petioles, and fruits within the plant canopy. This spatial mismatch suggests that *E. annulata* may not function as an efficient stand-alone predator of canopy-dwelling mealybug populations under all field conditions. Instead, its predatory capabilities may be more relevant within the lower plant strata or during early infestation phases, when mealybug dispersal stages, fallen individuals, or lower-canopy populations become accessible to ground-associated predators.

From an IPM perspective, the evidence from the present study should be treated as suggestive rather than conclusive. Its potential incorporation into IPM programs may be implemented only after intensive optimisation and multiple verifications. Optimization could be achieved by integrating with other pest management approaches, such as cultural practices, mechanical control, habitat management, and the judicious use of selective, narrow-spectrumm insecticides thatminimisee non-target effects on beneficial arthropods. Factors such as *E. annulata's* susceptibility to broad-spectrum pesticides, the instability of the prey population, the availability of alternative refugia, and potential intraguild interactions with other natural enemies, including parasitoids and other predators, should be carefully examined. Additionally, agroclimatic factors such as temperature fluctuations, rainfall, relative humidity, and habitat disturbance may influence its reproduction and predation efficiency. Therefore, the successful integration of *E. annulata* into IPM systems requires careful, meticulous synchronization with other control strategies and intensive field validation of its efficacy across different agroecosystems.

CONCLUSION

This paper demonstrated the complete life cycle of *E. annulata*, which is approximately 42 days when fed with *P. marginatus*. Its predatory and feeding behavior indicates its potential as a biological control agent against papaya mealybug infestations. However, the results of the present study are purely descriptive and must be interpreted with caution. Additional experimental work is therefore needed with a larger sample size to allow for statistical inference. Research on the preferences of male and female *E. annulata* and on whether using other life stages could improve its predatory efficiency is also warranted. Moreover, it is recognized that there are difficulties and challenges in rearing using live food. Therefore, exploring other alternative feeds for mass production is recommended. Field-based evaluations are also necessary to validate its predation efficiency under natural conditions and assess its compatibility with other pest management strategies. Thus, future studies should explore biological preferences, alternative mass-rearing techniques, functional response, larger sample sizes, and long-term population dynamics and ecological interactions to optimize its application in integrated pest management systems.

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AUTHOR CONTRIBUTIONS

The author performed the conceptualized, conducted experiment, analysis, writing, and revision for this paper.

DECLARATIONS

Informed consent statement

The study does not involve human participants or the collection and experimentation of endangered or protected species. All experimental procedures were carried out solely for scientific purposes.

Conflict of interest

The author declares no conflict of interest associated with this publication.

AI Declaration

During the preparation of this article, the author used ChatGPT exclusively for language improvement and to enhance the manuscript's readability and clarity. All scientific content, including the study design, procedures, analysis, and conclusions, was developed and verified solely by the author himself. The author assumes full responsibility for the accuracy and integrity of this publication.

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