Biological Aspects and Predation of *Pygidicrana v-nigrum* against the Mediterranean Fly *Ceratitis capitata*

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ABSTRACT

Fruit flies are pests of great agricultural concern, as they cause serious damage to the global fruit production. However, there are potential entomophagous organisms that can reduce the population of pest species such as *Ceratitis capitata*. Among the voracious and entomophagous Dermaptera predators, the species *Pygidicrana v-nigrum* displays a strong predatory potential to improve the agricultural handling by assisting the reduction of agrochemical use. This study aims to evaluate the biological development and quantification of *P. v-nigrum* consumption and predation of *C. capitata* during the fruit fly's immature stages. Larvae from the 3rd instar and pupae of the Mediterranean fruit fly were used, where biological parameters were analyzed, including the duration and nymphal viability, adult insect size (length), sex ratio, survival of adults and egg production, and the ethology of predation behavior. It was found that the *P. v-nigrum* nymphs from the 1st to 3rd instar did not feed on the pupal stage *C. capitata*. When ingesting the *C. capitata* larvae, the Dermaptera reached the end of the nymph period, on average, after 228 days. The lowest nymphal viability of *P. v-nigrum* was 85.0% and occurred in its 1st instar when fed with larvae. The food provided did not influence the size of this regardless of sex; however, predation on *C. capitata* larvae resulted in a higher proportion of females. Furthermore, the survival of the female *P. v-nigrum* was longer than the male, regardless of the food consumed. There were a high number of deposited eggs from *P. v-nigrum* when feeding on pupae. The predatory consumption of *P. v-nigrum* increased when fed with *C. capitata* larvae and pupae,

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regardless of the nymphal or adult phases. It can be concluded, from the results, that the biological development of the *P. v-nigrum* is not affected when fed with the larval and pupal stages of *C. capitata*.

Keywords: Fruticulture, Dermapterous, biological control

1. INTRODUCTION

The Dermaptera are terrestrial insects with nocturnal habits and about 1800 species are distributed in the tropical and subtropical regions [1], including several species with predatory habits. Furthermore, studies have investigated the behavior and the biological development of the genera *Euborellia* and *Doru*, with the predation of numerous agricultural pests such as Coleoptera, Lepidoptera, and Hemiptera [2, 3, 4, 5, 6, 7], and Lepidoptera [8, 9], in the egg stages and young forms, respectively. These are commonly known in Brazil as “tesourinhas” (“earwig”), because they have two tweezer-like structures at the end of the thorax.

Moreover, the tephritids are considered the main pests of global fruticulture, and the direct damage from these pests has affect production, including costs related to monitoring and control, or eradication; while indirect damages are caused by the restriction imposed by certain importing countries [10]. The pests *Ceratitis* spp. and *Anastrepha* spp. are of major importance for agricultural research. Among the species, we highlight *Ceratitis capitata* Wiedemann (Diptera: Tephritidae), commonly known as the Mediterranean fruit fly, found in Brazil.

Pygidicrana v-nigrum Audinet-Serville, is one of the most prominent species of the family Pygidicranidae, whose dermapterous insects seek shelter in jackfruit and banana trees. A previous study fed this dermapterous insect with eggs from *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) and found that the average nymphal period for these *P. v-nigrum* were 237 days, with nine instars, showing improved development [11]. Thus, it is necessary to study the biology and ethology of this dermapterous species [12] and its effect on important pests such as *C. capitata*. The knowledge of the biological aspects of this dermapterous insect regarding its feeding is essential due to the influence on its biological cycle, as it is present in different environments, it also plays an important role in the predation of arthropod pests. The following research aimed to analyze the development of biological characteristics and the ability of *P. v-nigrum* predation when fed with immature stage *C. capitata*.

2. MATERIAL AND METHODS

The research was carried out in the Laboratory of Entomology (LEN), Campus II of the Federal University of Paraíba (UFPB), Areia, Paraíba State, Brazil. The experiments were performed at 25 ± 2 °C, 70.0 ± 10.0% relative humidity (RH), and a 12 h photophase.

2.1 Rearing of *Pygidicrana v-nigrum* and the Mediterranean fruit fly *Ceratitis capitata*

The nymphs and adults were kept in transparent plastic containers (6.0×8.0 cm) with moistened absorbent paper and fed on an artificial diet consisting of the following ingredients: milk powder (130 g), beer yeast (220 g), wheat bran (260 g), and nipagin (40 g), and an initial ration of chicken meat (350 g). The eggs were laid and fixed anywhere in the container by the female, who protects them until hatching into nymphs. The feed and absorbent paper were both exchanged weekly. Alcohol (70%) was applied to the lid of the container to inhibit the emergence of microorganisms.

The Mediterranean fruit flies were grown in the Laboratory of Entomology in the conditions already stated above. Their larvae were fed an artificial diet composed of beer yeast (120 g), raw carrot (600 g), and nipagin (5 g). The adults were kept in cages (50 × 50 × 60 cm) and fed daily with a solution of 10.0% honey in distilled water, provided in cotton placed on the cage during the adult stage.

2.2 Biological Development of Earwig *Pygidicrana v-nigrum* fed on *Ceratitis capitata*

The bioassays were organized by a completely randomized design (CRD) with two food treatments with 20 *P. v-nigrum* nymphs for each treatment and one individual nymph per replicate. The food (prey) used was 3rd instar larvae and pupae of *C. capitata* (<24 h old), which were unviable at low temperatures, leading to the death of *P. v-nigrum*. These were supplied in enough quantity for the development of the earwigs, as defined in the preliminary tests. To evaluate the biological characteristics, the following parameters were assessed: nymphal duration and viability, adult insect size (length), sex ratio, adult survival, and egg production per posture.

2.3 Predation Capacity of Earwig on *Ceratitis capitata*

We used 190 specimens of earwig, 110 of which were fed on 3rd instar larvae and the remaining 80 were fed on pupae of *C. capitata*. The nymphs and adults of the predator were individualized in Petri dishes (9.0 × 1.5 cm) and fed with 3rd instar larvae or pupae of *C. capitata*. The food was supplied in a quantity higher than that consumed by the predator daily at each instar or stage, so that the number of 3rd instar larvae and pupae consumed could be counted and the predation capacity per day of consumption could be determined. This number of 3rd instar larvae and supplied pupae was observed daily in preliminary trials.

2.4 Statistical Analysis

The experiments were carried out using a CRD. For the research into the biological aspects of the predator, the food consisted of larvae or pupae of the Mediterranean fruit fly, with 20 replicates for each food treatment. The sex ratio was calculated by dividing the number of females with the total number of individuals (females + males) according to [13]; the adult survival probability was analyzed using a non-parametric test and estimated using the

Kaplan-Meier survival test (Log-Rank test), using the MedCalc® software; and the means of the analysis of variance of the other characteristics were compared by the F-test at the 5.0% probability level. Data were analyzed by the Assistat 7.7 program [14]. The predation capacity research involved the use of the 3rd instar larvae or pupae of the Mediterranean fruit fly, with 15 repetitions for each different food treatment. The predator's consumption was measured using regression analysis.

3. RESULTS AND DISCUSSION

Biological Development of *P. v-nigrum* fed with *C. capitata*

There were nine instars during the nymphal period of *P. v-nigrum*, although some individuals only went through seven or eight stages regardless of the food (Table 1). This behavior was related to the adequacy of food, which can result in the lengthening or reduction of the number of instars, as the development of insects is affected by biotic and/or abiotic factors. It has been found in another study that the species *Tagalina papua* Bormans (Dermaptera: Pygidicranidae), belonging to the same family as *P. v-nigrum,* survived six instars [12].

Table 1. Average duration (days) and viability (%) of the stages of *Pygidicrana v-nigrum* fed with larvae and pupae of *Ceratitis capitata*

Duration (days)									
Food	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Larvae	21.46	22.40	24.40	27.06a	25.60a	26.40a	34.40a	35.27a	38.50a
Pupae	-	-	-	22.66b	23.20a	28.06a	32.93a	40.33a	31.50a
CV (%)				22.13	21.32	24.85	20.72	28.64	8.72
Viability (%)									
Larvae	85.0	88.2	93.3	100.0	100.0	100.0	100.0	100.0	100.0
Pupae	-	-	-	95.0	94.7	100.0	100.0	100.0	100.0

Means followed by the same letter in the column do not differ statistically.

Table 1 shows that 1^{st} to 3^{rd} instar nymphs of the predator did not consume pupae, but instead only consumed the larvae of this tephritid. The lack of consumption by early nymphs is due to the fragility of their oral apparatus in contrast to the stiffness of the integument of the pupa, making it impossible to break it down for ingestion. For an insect to feed, several characteristics of the food should be analyzed, among these are the color, shape, size (length), temperature, sound, texture, and hardness [15]. In the 4^{th} instar there was a statistically significant difference. Nymphs that consumed pupae had a shorter instar period (22.66 days on average). This reduction of *P. v-nigrum* instar may have occurred due to ingestion of the previous food (standard diet), as it provided the necessary nutrients for proper development.

The mean nymphal viability of the dermapterous species varied from 85.0% to 100.0% for those fed with larvae and between 94.7% and 100.0% for those fed with pupae, inferring a high viability of *P. v-nigrum* regardless of the food consumed. The failure of the nymphs (in the 1^{st}, 2^{nd}, and 3^{rd} instars) regarding the consumption of pupae. The natural alternative for this predator would be to search for prey with a soft tegument; in addition, the Dermaptera order are omnivores are omnivores, so other alternatives are available. The results of this research confirm that the prey is a suitable nutritional source for *P. v-nigrum* development.

There was no statistically significant difference between the sizes of the predators, in its adult stage, regardless of whether it was fed with pupae or larvae of the *C. capitata* (Table 2). The females reached a size-range of 3.0 to 4.2 cm and 3.3 to 4.2 cm when fed with larvae and pupae, respectively; whereas males were in the size-range of 3.2 to 3.9 cm for both food treatments. The result of *P. v-nigrum* individuals larger than 4.0 cm exceeds what has already been reported in the literature for the order Dermaptera. Working with species *T. papua*, found a length of 2.9 to 3.6 cm [12]. The *P. v-nigrum* sex ratio, regardless of the food, is within the expected and suitable values for laboratory breeding, with the ratio of one male per one female (1:1) being enough for reproductive success.

Table 2. Average size (length) and sex ratio of *Pygidicrana v-nigrum* when fed with larvae and pupae of *Ceratitis capitata*

Food	Size		Sex Ratio
	Female (cm)	Male (cm)	
Larvae	3.48a	3.47a	0.60
Pupae	3.73a	3.61a	0.46
CV (%)	9.81	7.21	

Means followed by the same letter in the column do not differ statistically rom each other by F test (P = 0.05).

The survival time of the *P. v-nigrum* when feeding on *C. capitata* was longer for adult females than for male insects (Fig. 1). In female insects, at 50 days, approximately 70.0% of the individuals were alive; at 80 days, there were only 40.0% of the initial amount; and after reaching 115 days, only 20.0% of the original adult females were left. At the end of their longevity, *P. v-nigrum* females averaged 160 and 163 days when consuming *C. capitata* larvae and pupae, respectively. Regarding male survival, it was found that at 50 days, approximately 70.0% of the individuals were alive; at 80 days, there was only 40.0% of the initial amount; and at 115 days, only 20.0% were alive.

The males showed a change in survival behavior at around 60 days between feeding with pupae and larvae. The latter prolonged the survival, but this variation in survival behavior was still exceptionally low. A similar longevity found for the *P. v-nigrum* species was also found in the literature for the species *Doru luteipes* Scudder (Dermaptera: Forficulidae), and *Euborellia peregrina* Mjöberg, *Euborellia annulipes* (Dermaptera: Anisolabididae), when consuming insect-pests.

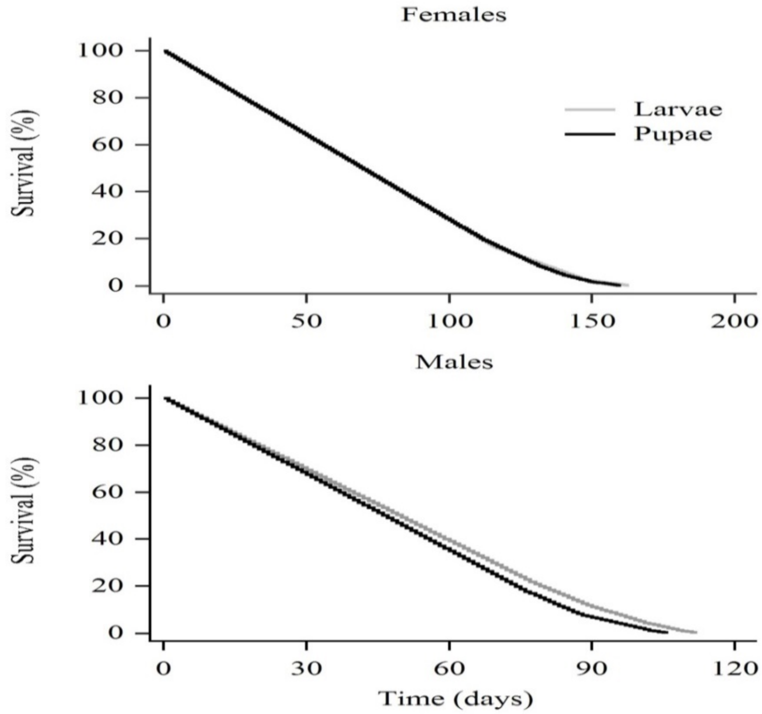

Figure 1. Average probability of adult survival for *Pygidicrana v-nigrum* **fed with larvae and pupae of** *Ceratitis capitata*

As for the number of deposited eggs for species *P. v-nigrum* fed with larvae and pupae of the Mediterranean fruit fly *C. capitata*, there was statistically significant difference (Table 3). Females fed with larvae produced, on average, 49.25 eggs whereas those that ingested pupae produced, on average, 101.75 eggs. Egg production is related to the accumulation of energy and nutrients and the quantity and quality of the food ingested, which explains the reproductive behavior of the insect.

The production of eggs or progeny involves energy and nutrient accumulation, which is also affected by both biotic and abiotic factors [16].

Table 3. Average number of eggs per posture of *Pygidicrana v-nigrum* fed with different stages of *Ceratitis capitata*

Food	Number of eggs per posture
Larvae	49.25b
Pupae	101.75a
CV (%)	44.23

Means significantly differed from each other as determined by the F test (P = 0.05).

The occurrence of a gradual oviposition of *P. v-nigrum* females was observed for days, during which time they were fed with pupae between 4 to 11 days, and with larvae, between 4 to 5 days. There was maternal care of the *P. v-nigrum* female during the oviposition, where it licked the eggs and always remained above or beside the egg. It is understood that by licking them, the mother releases secretions that simultaneously humidify and also protects the eggs from harmful microorganisms [12].

Another observed characteristic was that if disturbances occurred at any point during the incubation time, the *P. v-nigrum* might consume all of its eggs [9]. The authors infer that behavior possibly occurred due to the handling of cleaning, humidification, and exchange of the food in the breeding containers. Furthermore, when working with *D. luteipes*, a decrease in viability was observed when the male was left in contact with the female after intercourse, which also attributed to the male-caused disturbance which led to the female's consumption of her eggs.

Predation of *P. v-nigrum* on *C. capitata*

The predator consumption increased over time when fed with the larvae and pupae of *C. capitata* (Fig. 2). Early instar (1^{st}, 2^{nd} and 3^{rd}) *P. v-nigrum* consumed only larvae, as they were not successful with the pupae food. Furthermore, at 35 days the 4^{th} and 5^{th} instar nymphs had consumed more larvae than pupae. The 6^{th} instar nymphs consumed more pupae at the end of their stage. The predation of the 7th and 9th instar *P. v-nigrum* was higher for larvae, but the difference was not statistically significant. The 8th instar nymphs had similar predatory behavior. Regarding male and female adult consumption, there was higher larvae consumption in *P. v-nigrum* females than in males. The consumption of larvae by males was slightly higher than their consumption of pupae, although this was not statistically significant.

The behavior of this dermapterous species in the present study makes it a possible potentiator for the consumption of the pupae and 3rd instar larvae stages of this global pest. Its increasing consumption, regardless of the stage of development, shows its voracity in the constant search to meet its nutritional needs. In addition to this, it consumed more than necessary, that is, there was accumulation of reserves to aid in its nymphal development, ecdysis and reproductive processes.

During the experiment, the daily consumption behavior of the predator was inconsistent, reaching peaks of high daily food consumption interspersed with days where little or no food was consumed due to its food satiation. The same behavior of consumption was found by [17], with the species *E. annulipes,* when fed with eggs and caterpillars of the species *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae).

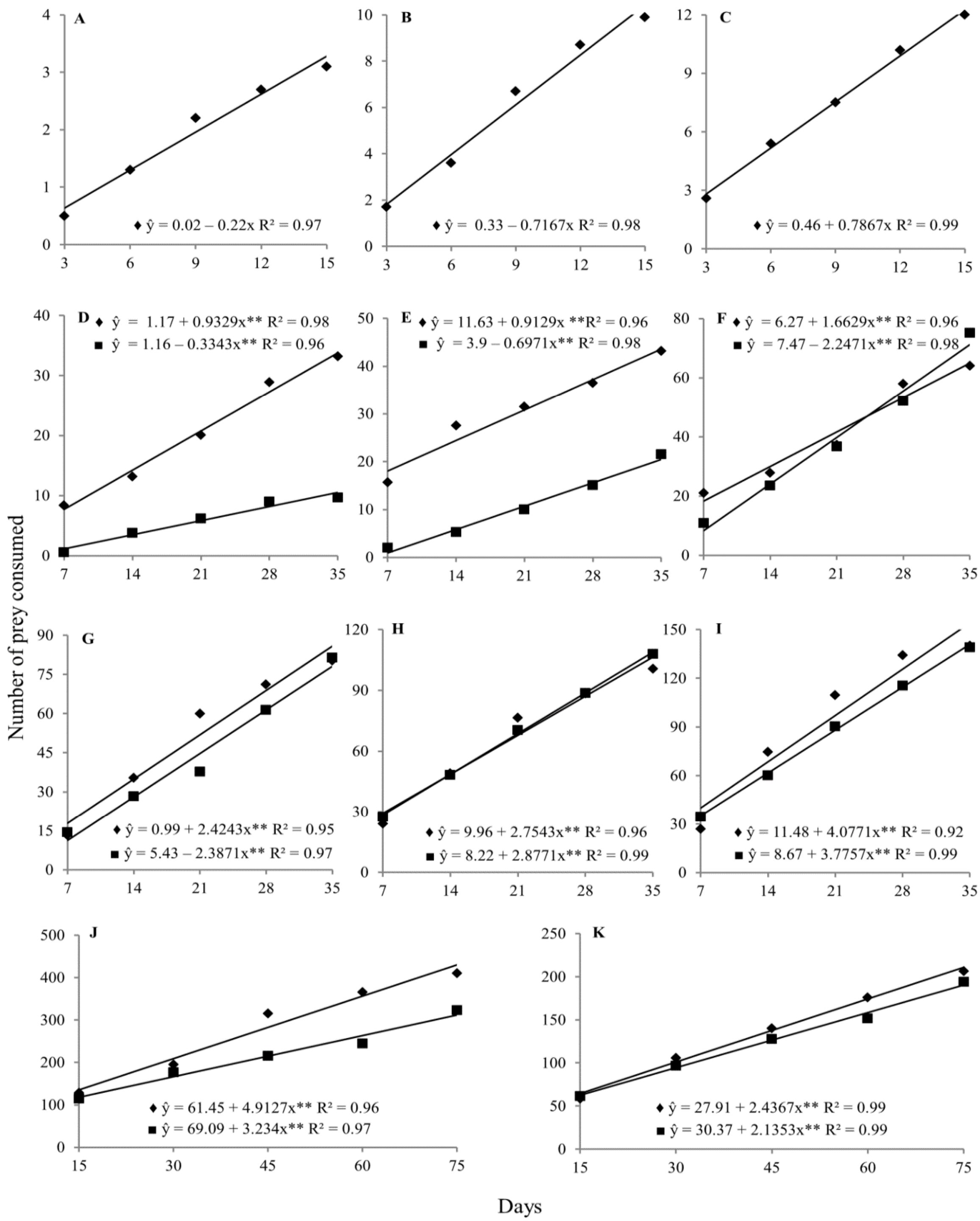

Figure 2. Predatory consumption of nymphs in their 1st (A), 2nd (B), 3rd (C), 4th (D), 5th (E), 6th (F), 7th (G), 8th (H), 9th (I) instars, and of female (J) and male (K) adults of *Pygidicrana v-nigrum* **when fed with the larvae and pupae of** *Ceratitis capitata*. **(♦) corresponds to the 3rd instar larvae of** *C. capitata* **and (■) to the pupae food.**

Pygidicrana v-nigrum consumption of larvae and pupae of the *Ceratitis capitata* throughout the juvenile stage was similar to the adult stage of the predator *P. v-nigrum* (Fig. 2) with the exception of the 1st to 3rd instars, where there was no consumption of pupae (Fig. 2A, B, & C). There was predominantly more in larvae consumption than pupae consumption, both in the juvenile and adult stages (Fig. 2). However, there was only a higher consumption of pupae than larvae in the 6th and 8th instar (Fig. 2F, & H), but this only occurred in the interval between 20 and 25 days after their ecdyses. Larger larvae consumption may be of nutritional benefit to the predator which has the need for increased consumption to meet its requirements. Physical characteristics, such as hardness, shape, and surface pilosity, in addition to the allelochemicals and nutritional elements, influence the consumption and digestion of food [16].

4. CONCLUSIONS

The 1st, 2nd and 3rd instar nymphs of the predator *Pygidicrana v-nigrum* did not consume the pupae of the prey *Ceratitis capitata*. The dermapterous species *P. v-nigrum* had successfully developed regardless of the growth phase of the supplied *C. capitata*. Further studies on species *P. v-nigrum* are required to determine its potential as a *C. capitata* regulator and its use in biological control programs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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