



Doru luteipes (Dermaptera: Forficulidae) and *Orius insidiosus* (Hemiptera: Anthocoridae) as Nocturnal and Diurnal Predators of Thrips

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Abstract

Thrips (Thysanoptera, Thripidae) are pests of several crops and their chemical control is mainly hindered by their thigmotactic habits, which in turn allows the use of biological control agents with similar habits. *Orius* (Hemiptera: Anthocoridae) are effective control agents for thrips and are commercialized in many countries. Habitat overlap exists between *Doru luteipes* (Scudder) (Dermaptera: Forficulidae) and thrips, making *D. luteipes* a potential predator in the control of these insects. Our goals were to confirm the predatory ability of *D. luteipes* when exposed to thrips, *Caliothrips phaseoli* (Hood), and to evaluate the interaction between *D. luteipes* and *Orius insidiosus* Say for the control of thrips using behavioral and feeding preference tests. The ability of *D. luteipes* and *O. insidiosus* to prey on thrips at all stages was tested by predation bioassays; adults of *D. luteipes* consumed 210.9 ± 23.2 thrips per day, while adults of *O. insidiosus* consumed 32.4 ± 3.6 thrips per day. Intraguild predation was absent, and the predatory behavior feeding of the two predatory species was not altered in the presence of the other predator. In addition, these predators forage at different times—*O. insidiosus* during the day and *D. luteipes* at night, indicating that both predators do not interact negatively, allowing the use of both in a biological pest control program for thrips.

Keywords Predation · Behavior · Biological control · Earwig · Minute pirate bug · Thysanoptera

Introduction

Thrips (Thysanoptera: Thripidae) are insects present in various crops and are key pests in ornamental plants and vegetables grown in protected and open environments (Stuart et al. 2011; Souza and Marucci 2021). A thrips infestation in ornamental plants causes economic losses due to direct damage characterized by the presence of light striae in the floral structures (Morse and Hoddle 2006; Mouden et al. 2017; Rogge and Meyhöfer 2021) preventing the commercialization of the affected plants.

Adults and larvae occupy the same ecological niche and use similar food sources (Kirk 1997; Mouden et al. 2017; Rogge and Meyhöfer 2021) which can include feeding on pollen (Kirk 1984; Bhuyain and Lim 2019). The spatial distribution of the thrips within the plant may differ (Mo et al. 2008), but adults and larvae prefer to inhabit protected sites as well as flowers, buds, or closed plant structures (Mound 2005). The highly thigmotactic behavior may hinder the detection of infestations in plants as well as the successful control through the application of insecticides on host plants (Stuart et al. 2011). In addition, pupation can occur in the soil, allowing the escape of part of the population when the shoots of the plants are sprayed (Otieno et al. 2017). Adults have high mobility and reproductive capacity and are reportedly tolerant to insecticides (Morse and Hoddle 2006). Thus, biological control through the use of predators and entomopathogens has become a high-priority strategy.

Orius spp. (Hemiptera: Anthocoridae) are reported to be effective predators of thrips in crops in the field and in protected environments (Souza and Marucci 2021). They occupy the same habitat as thrips, remaining hidden in

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closed plant structures, and can prey on both adults and nymphs (Silveira et al. 2004; Blaeser et al. 2004; Arnó et al. 2008; Mouden et al. 2017). They prey on several pests such as aphids, red spider mites, whiteflies, and the eggs of Lepidoptera (Arnó et al. 2008; Tuan et al. 2016; Salehi et al. 2016; Helgadóttir et al. 2017; Aragón-Sánchez et al. 2018), and are known to feed on plant resources such as pollen, nectar, and sap (Salas-Aguilar and Ehler 1977; Clercq et al. 2014; Zhao et al. 2017). The pollen-feeding habit allows for their survival and multiplication in alternative plants in the absence of preferential prey (Sánchez et al. 2000; Silveira et al. 2004; Mendoza et al. 2020), allowing the exploitation of the ecosystem and survival of the *Orius* spp. in the area (Tuan et al. 2016). *Orius insidiosus* (Say) are diurnal predators (Wang et al. 2013) that are quick to locate food and are commercialized in several countries in the Americas, including Brazil (Souza and Marucci 2021).

Earwigs (Dermaptera) are cryptic predators that stay hidden during the day and become active at night (Lamb and Wellington 1975; Sueldo et al. 2010; Haas 2018); thus, as a foraging strategy, they occupy a space free from competition at night by diurnal predators. Because they exhibit thigmotactic behavior, they stay protected in close contact with plant surfaces, preferring dark and humid areas (Jarvis et al. 2005), similar to that of the thrips species. Similar to *Orius*, dermapterans are omnivorous and the consumption of maize pollen increases the survival of nymphs and the fecundity and fertility of females (Marucci et al. 2019). This habit allows for their survival in the area (Romero Sueldo and Virla 2009; Haas 2018), in addition to exploring various prey at different stages of their development such as eggs and larvae/nymphs from the orders Lepidoptera, Hemiptera, Coleoptera, and Diptera (Costa et al. 2007). However, no information about their behavior with Thysanoptera is available even though they occupy the same niche.

According to Figueiredo et al. (2006), *Doru luteipes* (Scudder) (Dermaptera: Forficulidae) and *O. insidiosus* are present in the same habitat, feeding on eggs and larvae of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in maize crops. However, the foraging periods of both species differ, indicating that they are possibly not competitors but instead interact in a complementary way to controlling small arthropods in field.

One of the prerequisites for selection of a biocontrol that suppresses a pest population is the occupation of the same niche as the prey, and in this case both the prey (thrips) and the predators (*Doru* and *Orius*) are protected in closed structures of the plants from which they also obtain pollen to meet their nutritional needs. Therefore, an investigation is needed into whether *D. luteipes* is a potential thrips predator that can be used in combination with the traditionally commercial predator *O. insidiosus*. We first demonstrated that the earwig *D. luteipes* have

good ability to prey on the American bean thrips *Caliothrips phaseoli* (Hood) (Thysanoptera: Thripidae). Then, we addressed the following questions: (i) Does the concomitant occurrence of *D. luteipes* and *O. insidiosus* in a hypothetical shared space affect their behavior? (ii) Does the omnivorous habit of *D. luteipes* and *O. insidiosus* affect the predator preference for thrips?

Bioassays were conducted to evaluate the predatory ability, foraging behavior, and preference between traditional food sources and thrips for the predatory species *D. luteipes* and *O. insidiosus*.

Materials and methods

Insect collection and maintenance

Caliothrips phaseoli

Caliothrips phaseoli specimens were used as standard experimental species in the bioassays because of the species ease of multiplication and maintenance. Rearing was performed in an air-conditioned room (27 ± 2 °C, $70 \pm 10\%$ RH, and 12 h photophase) on jack bean plants *Canavalia ensiformes* L. (Fabaceae) grown in 250-mL plastic containers filled with a 3:1 soil and manure ratio. On average, three plants were placed in $30 \times 30 \times 60$ cm acrylic cages, containing openings on the top and sides (15 cm in diameter) and sealed with voile fabric to facilitate gas exchange. The plants were irrigated daily and replaced periodically when damaged by the thrips. Dry leaves containing the pseudopupae of the thrips were kept inside the cage until adult emergence, with their removal thereafter.

Orius insidiosus

Adult *O. insidiosus* were stored in 15-cm-wide Petri dishes sealed with polyethylene film and kept in an air-conditioned room (25 ± 2 °C, $70 \pm 10\%$ RH and 12 h of photophase). Nonviable eggs of *Ephesthia kuehniella* (Zeller) (Lepidoptera: Pyralidae) were used as the food source, *Bidens pilosa* L. (Asteraceae) inflorescences were used as substrate for oviposition and shelter for the nymphs, and a moistened cotton ball was used to maintain the turgidity of the inflorescence. Inflorescences containing *O. insidiosus* eggs were placed in 15-cm-wide Petri dishes sealed with polyethylene film. To prevent egg and nymph mortality due to desiccation, cotton moistened with distilled water was added to the Petri dish. The dishes were checked twice a week for the addition of food and to moisten the cotton.

Doru luteipes

Newly hatched *D. luteipes* nymphs originating from the laboratory rearing were separated into 15 × 10 cm glass containers and kept in an air-conditioned room (27 ± 2 °C, 70 ± 10% RH and 14 h of photophase) until the nymph stage was complete. After emergence, 25 individuals of known age were separated into glass containers. Each rearing unit consisted of moistened cotton, plastic straws for oviposition which contained moistened cotton on one end, fan-folded paper for shelter, and an artificial diet provided within a 50-mL plastic container. The containers were sealed with voile fabric secured by elastic bands, and the diet consisted of 35% cat food, 27% wheat bran, 23% beer yeast, 14% milk powder, 0.5% Nipagin, and 0.5% sorbic acid, which were blended to create a homogeneous powder (Cruz 2009). Green peach aphids *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) were added to the rearing containers in *Nicandra physaloides* (L.) (Solanaceae) leaves once per week as extra prey for the earwigs. The straws containing the eggs were removed weekly and kept in a separate container with diet for the females until the hatching of the nymphs, at which point they were transferred to containers containing fan-folded paper for shelter, moistened cotton, and an artificial diet; the females were released back into the same container with the adults.

Bioassays

All bioassays were performed in an air-conditioned room at 25 ± 2 °C, 70 ± 10% RH, and 12 h of photophase.

Predation of *Caliothrips phaseoli* by *Orius insidiosus* or *Doru luteipes* in 24 h

Newly hatched nymphs of first-, third-, and fifth-instar *O. insidiosus* and newly emerged adults fasted for 24 h while isolated in Petri dishes (diameter of 4 cm) containing moistened cotton and sealed with polyethylene film. First- to fourth-instar nymphs and adults of *D. luteipes* within 48 h of emergence were placed into Petri dishes (diameter of 9 cm) under the same conditions described above. After the fasting period, a jack bean leaf was added to each of the first, third, and fifth instars and adult *O. insidiosus* Petri dishes, each of which contained 30, 35, 40, and 45 adults and larvae of thrips for feeding, respectively. A single jack bean leaf was also added into each of the first to the fourth instar and adult earwig Petri dishes containing 100, 150, 200, 250, and 300 adults and larvae of thrips, respectively. The number of thrips was counted using a dissecting binocular microscope (10–20×) (Opton TIM-10B). After 24 h of exposure to different thrips densities, the number of preys consumed was

determined by counting the remaining thrips in the Petri dishes. It was not possible to separate the amount needed for only one stage of development from the thrips, so all stages were used. The tests were conducted in a completely randomized design with 20 replicates for each stage of the predator.

Predation of *Caliothrips phaseoli* by *Orius insidiosus* or *Doru luteipes* day and night

This bioassay followed the same procedure as the previous one; however, only adults (most voracious) were used, and two predation periods were tested: 7:00 AM to 7:00 PM (day) and 7:00 PM to 7:00 AM (night).

After 24 h of fasting, a jack bean leaf was added into each Petri dish that contained a known number of preys near to 45 and 300 larvae and adults of *C. phaseoli* for the *O. insidiosus* and *D. luteipes*, respectively. After 12 h of exposure, the number of preys consumed was determined based on the number of thrips remaining on the Petri dish. The tests were conducted in a completely randomized design, with 20 replicates for each predator.

Predatory behavior of *Orius insidiosus* and *Doru luteipes* exposed to *Caliothrips phaseoli*

We only used adult predators to study predatory behavior because of their voracious nature. Petri dishes (diameter of 9 cm) were set up for *O. insidiosus* and *D. luteipes*, respectively, containing a thin layer of water-agar and a jack bean leaf covering the entire space to prevent the insects from hiding during the observations. A jack bean leaf infested with *C. phaseoli* adults and larvae was placed in contact with the leaf on the agar, and the Petri dish was then sealed with polyethylene film. After 24 h of infestation, the insect behavior was observed for 15 min using EthoLog 2.2 software.

The following combinations were evaluated: (i) adult *D. luteipes* + 40 *C. phaseoli*, (ii) adult *O. insidiosus* + 40 *C. phaseoli*, (iii) adult *D. luteipes* + adult *O. insidiosus* + 80 *C. phaseoli*, and (iv) adult *D. luteipes* + adult *O. insidiosus*.

The behavior of *D. luteipes* as a nocturnal predator was measured after a fasting of 48 h (Naranjo-Guevara et al. 2017), but to *O. insidiosus* as a diurnal predator there was no fasting. Two observers evaluated the categories where both predators were present. The following categories were evaluated: stopped (did not move), foraging (whether *D. luteipes* touches the substrate with the antennae and the palps, and whether *O. insidiosus* touches the substrate with the antennae and their mouthparts was directed forward), feeding (prey consumption), cleaning (cleaning of mouthparts and antennae), walking (predator moves randomly without the foraging behaviors), intraguild predation (one predator feeds on another), and attempt of intraguild predation (one predator

attacks the other but mortality does not occur). The time obtained in each category was transformed into seconds and then into a percentage. A completely randomized experimental design was used with 10 replicates for each combination.

Food preference of the predators *Orius insidiosus* and *Doru luteipes*

In order to determine the food preference among various food sources, adults of *D. luteipes* and *O. insidiosus* were previously starved for 48 h and 24 h respectively the choice of food offered was based on the diets used in the laboratory and natural food sources for both predators:

Orius insidiosus: (i) *Ephestia kuehniella* eggs, (ii) hairy beggartick (*B. pilosa*) pollen, (iii) jack bean leaf infested with *C. phaseoli*, and (iv) *N. physaloides* leaf infested with *M. persicae* second and third instars.

Doru luteipes: (i) artificial diet, (ii) maize pollen tasseling (VT) to full flowering (R1) stage, (iii) *S. frugiperda* eggs, and (iv) jack bean leaf infested with *C. phaseoli*.

The amount of each diet supplied to the predators at the observed times was determined based on the preliminary tests. The hairy beggartick pollen were obtained from the inflorescence of plants harvested in the field and were dried for 24 h. The maize pollen grain was collected from the tassel in the field, which was covered with a paper bag and plucked. In the laboratory, the tassel was dried for 24 h, homogenized and sieved to obtain the pollen which was later stored in microtubes and frozen.

The four diets were used in a chance of choice test in Petri dishes with 9 and 15 cm in diameter for *O. insidiosus* and *D. luteipes*, respectively. Each diet was placed in an equidistant corner and the predator was released in the center. In an air-conditioned room, each predator was observed for the first 15 min, and the chosen food and the feeding time were determined. The bioassay was replicated 15 times, and one individual of *D. luteipes* or *O. insidiosus* was used in each replicate.

Statistical analysis

All analyses were performed using the program R (R Core Team 2017) using MASS (Ripley et al. 2013), Multcomp (Hothorn et al. 2008), and hnp (Moral et al. 2017) packages. All data were tested by the Shapiro–Wilk and Bartlett tests ($P < 0.05$) to ascertain normality and homoscedasticity, respectively. Time-related data were transformed into seconds and subsequently into percentages for statistical analysis. The number of thrips consumed by each stage of development of the predators in 24 h and the data referring to the number of thrips consumed by the adults of the

predators for 12 h did not follow the presuppositions of normality and homoscedasticity. The generalized linear model (GLM) was used with error distribution of Poisson family with log link function, and Tukey's post hoc tests ($P < 0.05$) were performed for multiple comparison. The time spent by predators in each category of the behavior test was converted into a percentage and was subjected to analysis of variance (ANOVA), with the means compared by the Tukey test at 5% significance. The categories of each predator were compared to each other, and with the same category as the other predator. The analysis used to compare the feeding time of predators in each diet did not follow the presuppositions of normality and homoscedasticity; thus, a non-parametric GLM test was performed using the error distribution of the Binomial family; however, there was an overdispersion of the data so the Quasibinomial family distribution using the logit link function was utilized and later, Tukey's post hoc tests ($P < 0.05$) were performed for multiple comparison.

Results

Predation of *Caliothrips phaseoli* by *Orius insidiosus* or *Doru luteipes* in 24 h

The first and second instar *O. insidiosus* had the lowest predation rate of 16.58 ± 1.9 larvae in 24 h compared to the other instars of the predator (Fig. 1(A)). No significant difference was observed between the total *C. phaseoli* consumed by the third/fourth (23.53 ± 2.5) and fifth instars (22.5 ± 3.6); these numbers were higher than those for the first/second instar, but the number of larvae and adults consumed was different, showing that the consumption of adults increases as the predator moves on to the subsequent instar. Adult *O. insidiosus* consumed 32.42 ± 3.6 *C. phaseoli* in 24 h, with 25.68 ± 3.5 larvae and 6.74 ± 0.8 adults; numbers that were higher than the other instars (GLM, $X^2 = 85.338$, $df = 3$, $P < 0.001$).

Thrips consumption by *D. luteipes* gradually increased from one instar to the next, except for the third and fourth instars, which were similar (Fig. 1(B)) (GLM, $X^2 = 2479.3$, $df = 4$, $P < 0.001$). In the first instar, *D. luteipes* consumed 47.5 ± 3.9 thrips in 24 h, a higher number than that consumed by the adult *O. insidiosus*. The total adult intake of 210.9 ± 23.2 was approximately two times greater than the total intake of the fourth instar of 99.5 ± 15.8 and approximately six times greater than the total intake of adult *O. insidiosus* of 32.42 ± 3.6 .

Predation of *Caliothrips phaseoli* by *Orius insidiosus* or *Doru luteipes* day and night

The consumption of *C. phaseoli* in 12 h showed that predators have different foraging times. *Orius insidiosus* is more active during the day (Table 1), as a significant difference

Fig. 1 Average consumption (\pm standard error) of *Caliothrips phaseoli* by *Orius insidiosus* nymphs and adults (A) and by different instars and *Doru luteipes* adult (B) in 24 h. Values above the column correspond to the total consumption. Means with by the same letter do not differ (contrast after GLM, $P < 0.05$)

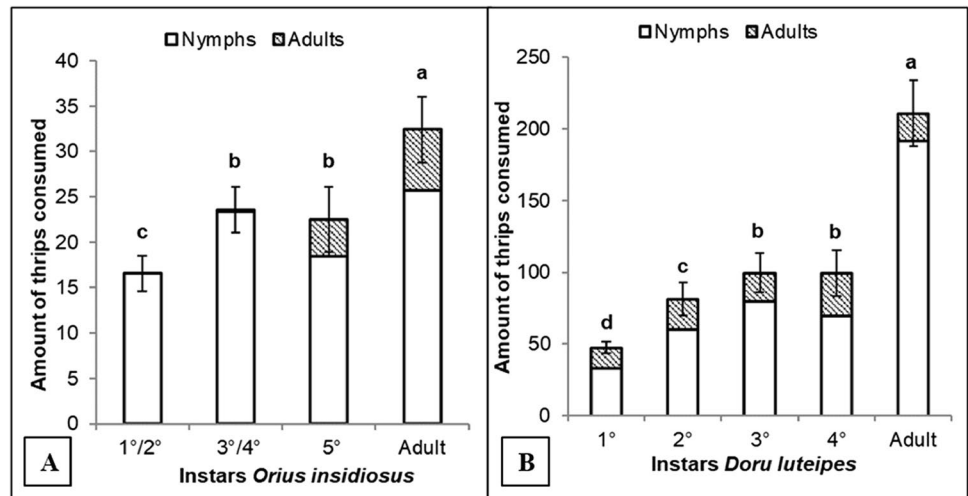


Table 1 Average consumption (\pm standard error) of *Caliothrips phaseoli* by *Doru luteipes* and *Orius insidiosus* during 12 h/day and 12 h/night

Treatment	Larvae	Adults
<i>Orius insidiosus</i>		
24 h	25.7 \pm 3.6A	6.7 \pm 0.8A
12 h/day	22.7 \pm 3.6A	2.8 \pm 1.2B
12 h/night	14.6 \pm 2.2B	2.8 \pm 0.6B
<i>Doru luteipes</i>		
24 h	191.7 \pm 2.9A	19.3 \pm 4.7B
12 h/day	43.9 \pm 8.5C	44.8 \pm 7.6A
12 h/night	125.3 \pm 20.6B	6.1 \pm 1C

Means followed by the same letter in the column for each predator do not differ (contrast after GLM, $P < 0.05$)

existed between the number of thrips consumed during the day and night (GLM, $X^2 = 26.601$, $df = 1$, $P < 0.001$). In contrast, *D. luteipes* consumed more prey during the night (GLM, $X^2 = 166.03$, $df = 1$, $P < 0.001$) (Table 1).

Predatory behavior of *Orius insidiosus* and *Doru luteipes* exposed to *Caliothrips phaseoli*

No intraguild predation was observed; i.e., the survival rates of *D. luteipes* and *O. insidiosus* when confined together in the presence or absence of *C. phaseoli* were 100%. However, when the other predator of different species is on the plate, some behavioral changes occurred for both species.

When the behavior of predators only in the presence of *C. phaseoli* was compared, both *O. insidiosus* and *D. luteipes* spent more time feeding on the prey than in any other category (Fig. 2). For *O. insidiosus*, the feeding category differed from the other categories (ANOVA, $F = 4.59$; $df = 4$; $P = 0.0034$). *O. insidiosus* forages by moving its head and when it finds the prey, it captures and feeds on it

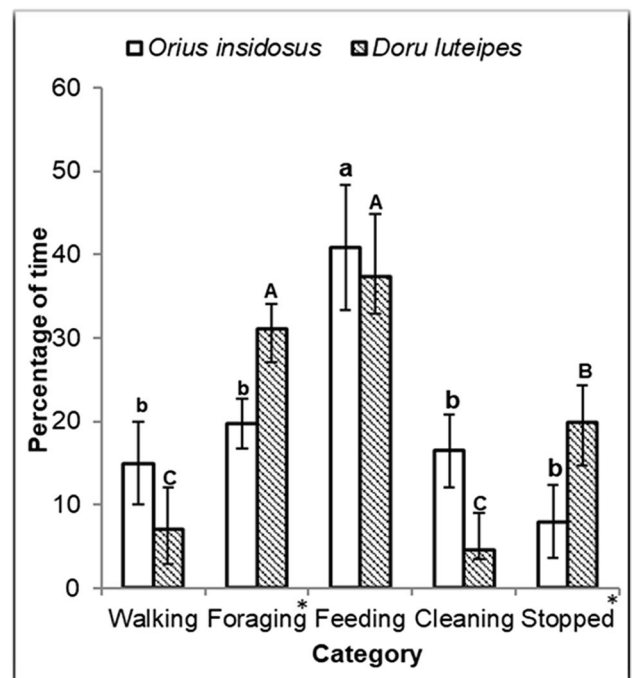


Fig. 2 Predatory behavior of *Orius insidiosus* and *Doru luteipes* exposed to *Caliothrips phaseoli*. Means with the same uppercase or lowercase letter do not differ by Tukey’s test $P \leq 0.05$. *Significant difference within the category

for approximately 7 min. *Doru luteipes* on the other hand showed no difference between the feeding and foraging categories. A difference was observed between the Stopped category and the Walking and Cleaning categories (ANOVA, $F = 15.37$; $df = 4$; $P < 0.0001$). Thus, *D. luteipes* spent most of the time searching for or feeding on prey and *Orius insidiosus* spent most of the time feeding.

Doru luteipes spent more time locating and catching food than *O. insidiosus* (ANOVA, $F=4.67$; $df=1$; $P=0.045$), in addition to remaining stopped for a longer period of time (ANOVA, $F=4.61$; $df=1$; $P=0.045$) (Fig. 2). When the prey was found, the predator fed for approximately 10 s. In the presence of *D. luteipes*, *O. insidiosus* does not present difference between the Walking and Feeding categories (ANOVA, $F=4.07$; $df=4$; $P=0.0067$). In the absence of *D. luteipes*, a difference was observed between the feeding and the other categories (Fig. 3(A)).

When comparing the behavior of *O. insidiosus* in the presence and absence of *D. luteipes*, only the Foraging category showed a significant difference (ANOVA, $F=12.03$; $df=1$; $P=0.0027$); that is, in the presence of another predator, *O. insidiosus* spends less time searching for food (Fig. 3(A)). The behavior of the predator *D. luteipes* in both the presence and absence of *O. insidiosus* was similar (ANOVA, $F=5.27$; $df=4$; $P=0.0014$) (Fig. 3(B)). Only in the Cleaning category was a significant difference observed (ANOVA, $F=6.45$; $df=1$; $P=0.0205$), showing that in the presence of another predator, *D. luteipes* spends more time cleaning its mouthparts and antennas.

Food preference of predators *Orius insidiosus* and *Doru luteipes*

Orius insidiosus preferred to feed longer on hairy beggartick pollen and on natural host nymphs and adults than on the other diets (GLM, $X^2=18.571$, $df=4$, $P=0.001$), which did not differ significantly from each other (Fig. 4(A)).

No significant difference was observed between the maize pollen, diet, and *C. phaseoli*, although *D. luteipes* spent more time feeding on the maize pollen grain (GLM, $X^2=9.686$, $df=4$, $P=0.0461$). *Doru luteipes* spends less time feeding on *S. frugiperda* eggs, a common prey in maize

crops, than on pollen reflecting the omnivorous habit of this predator (Fig. 4(B)).

Discussion

Our findings showed that both omnivorous predators have the ability of consuming thrips and suggests a possible increase in the efficiency of *C. phaseoli* pest control since *O. insidiosus* forages during the day and *D. luteipes* forages mostly at night.

Caliothrips phaseoli consumption rate by *O. insidiosus* gradually increased over the course of the instars until the predator reached the fourth instar and then stabilized in the fifth instar. This same result was found by Mendes and Bueno (2001), where an increase in consumption of *C. phaseoli* adults occurred throughout the instars, except for the fourth and fifth instars, in which the number of thrips consumed remained the same. Calixto et al. (2013) found that adult *O. insidiosus*, without starving, consume 20 *Frankliniella occidentalis* (Pergante) (Thysanoptera: Thripidae) larvae and adults per day. This amount was lower than that obtained in this study; 32 *C. phaseoli* larvae and adults were consumed by *O. insidiosus* after 24 h of fasting.

The predation rate in 12 h showed that *O. insidiosus* is more active during the day; this finding is in agreement with that from Wang et al. (2013), who found that low light intensity directly affects the locomotor capacity of adults and nymphs of *Orius sauteri* (Poppius) (Hemiptera:Anthocoridae), decreasing their locomotion speed and thus their food foraging ability.

Caliothrips phaseoli predation rate by *D. luteipes* increased gradually between the instars, except for the third and fourth instars, which did not differ. Nymphs of first instar consume an average of 4.6 eggs of *Helicoverpa*

Fig. 3 Predatory behavior of *Orius insidiosus* over *Caliothrips phaseoli* in the presence and absence of *Doru luteipes* (A) and *Doru luteipes* predatory behavior over *Caliothrips phaseoli* in the presence and absence of *Orius insidiosus* (B). Means with by the same uppercase or lowercase letter do not differ by Tukey's test $P \leq 0.05$. *Significant difference within the category

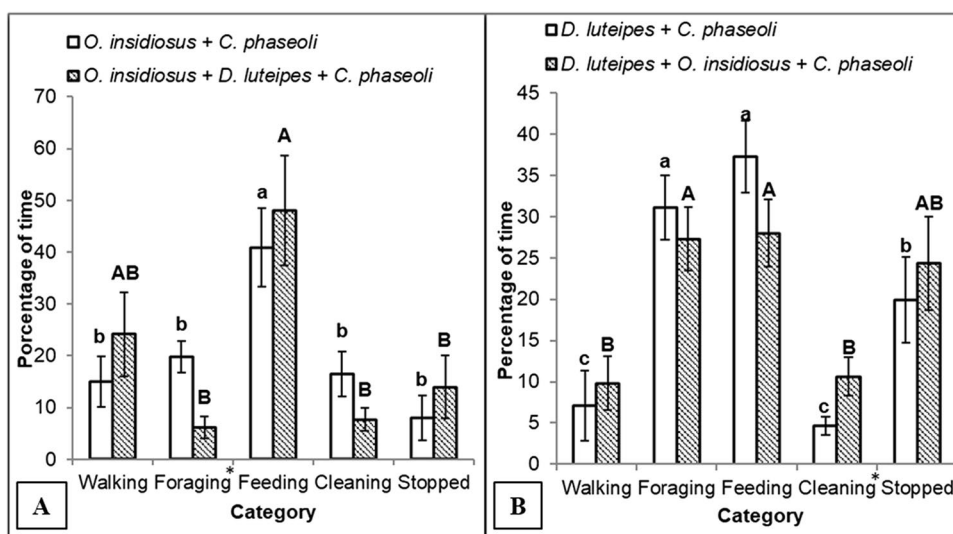
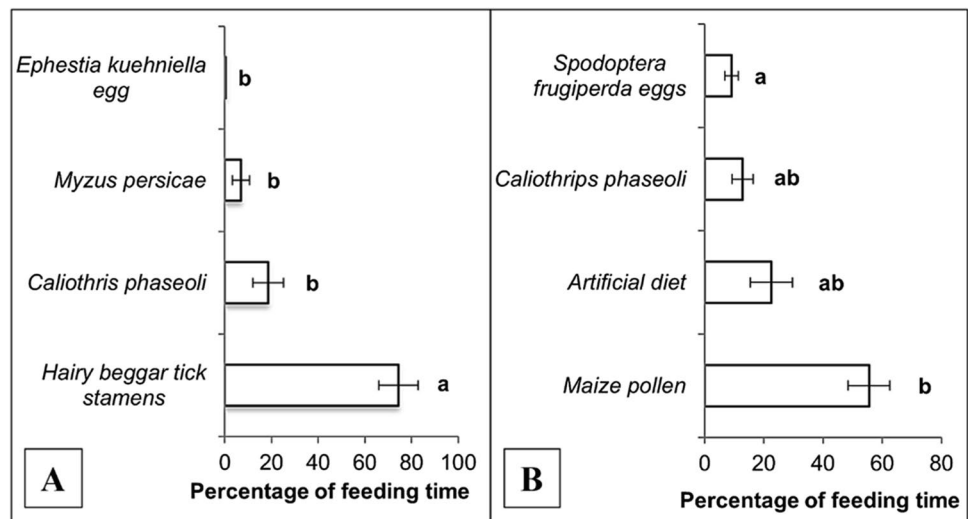


Fig. 4 Percentage of feeding time of *Orius insidiosus* (A) and *Doru luteipes* (B) exposed to different diets. Means followed by same letter do not differ (contrast after GLM, $P < 0.05$)



zea (Boddie) (Lepidoptera: Noctuidae) per day, a value that doubles from one instar to the next, reaching 45.3 eggs in the fourth instar (Cruz et al. 1995). When fed *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), nymphs of first instar consumed approximately 18 eggs, a value that gradually increased, with the instars consuming 399 eggs in the fourth instar (Pedroso et al. 2010). The data shows that this predator, regardless of prey, is very voracious. Alvarenga et al. (1995) found an average daily consumption by *D. luteipes* of 3.1 *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), which increased between the instars, reaching 33.2 aphids in the fourth instar and 64 in the adults. Although no studies have been conducted with insects of the order Dermaptera feeding on thrips, the daily amount consumed by the adult was approximately 210 thrips. This number is higher than that found in studies with aphids and other small arthropods, showing the predatory potential of this dermapteran.

The predation rate during the day and night shows that *D. luteipes* has a habit of feeding mostly at night. This behavior is already known as characteristic of the order Dermaptera, which includes generalist insects of nocturnal habit (Lamb and Wellington 1975; Naranjo-Guevara et al. 2017). We must take into account that most predators forage during the day, which creates a competition-free space, possibly providing a foraging strategy that allows the coexistence of nocturnal and diurnal predators in the same habitat.

From this perspective, these predators do not seem to compete in the same niche and potentially can be used together in a biological control program. This finding is confirmed by the observations of their behavior and the absence of intraguild predation in the various combinations (in the presence and absence of *C. phaseoli*).

D. luteipes probably spent more time searching for food than *O. insidiosus* because this predator randomly forages prey on the leaf surface, moving the head from side to side,

as well as moving its antennae and mouthparts. In the time spent for *Orius* to feed on one prey, *D. luteipes* is capable of feeding on several prey, explaining the greater time spent searching for food compared to *O. insidiosus*. Similar results were found by Isenhour and Yeargan (1981) regarding the foraging behavior of *O. insidiosus* on *Sericothrips variabilis* (Beach) (Thysanoptera: Thripidae). These authors observed that the predator moves its head to find the prey and feeds on it for approximately nine minutes.

Members of the Dermaptera order are known to live hidden in a dark, damp shelter and in close contact with surfaces (Alvarenga et al. 1995; Jarvis et al. 2005; Haas 2018). Thus, once satiated, *D. luteipes* finds a place to shelter and display its positive thigmotropism, explaining why it remains immobile for longer periods than *O. insidiosus*.

When *D. luteipes* was close, *O. insidiosus* spent less time in the search for food. Possibly, this behavior suggests that *O. insidiosus* moves away from *D. luteipes*, the larger-sized predator, which confers an advantage over *O. insidiosus*. Studies have shown that predator size is an important factor for predation (Lucas et al. 1998, 2000; Michaud and Grant 2003); however, in this study, no evidence was observed of intraguild predation. We hypothesize that *O. insidiosus* releases a defense substance that deters other predators as well as other Hemiptera, which would support the behavior of *D. luteipes*, as individuals of this species spend more time cleaning their antennae and mouthparts in the presence of *O. insidiosus*. No intraguild predation was observed between *D. luteipes* and *O. insidiosus*, and although *D. luteipes* attempted to attack *O. insidiosus*, the action was not completed.

Both predators, *O. insidiosus* and *D. luteipes*, when exposed to different food sources, preferred to feed on the plant resources and maize pollen grain for *Doru* and hairy beggarticks pollen for *Orius*. The effect of omnivory on the

predator–prey interactions is complex. The presence of the plant as a food source on the one hand can reduce predation by omnivory (Coll and Guershon 2002). However, the food provided by the plant can enable the omnivore to remain in the area when prey is scarce (Pimm and Lawton 1978; Haas 2018). While many *Orius* species show a preference for thrips (Arnó et al. 2008; Xu and Enkegaard 2009), the nutritional value of prey derived from plant materials, such as pollen and sap, is highly variable.

The importance of pollen in the diet of both predators has already been proven. Kiman and Yeargan (1985) tested the effects of different diets on the biology, longevity, and fecundity of *O. insidiosus* and proved that hairy beggartick pollen alone or when combined with arthropods is important for predator development. Similar results were observed when *D. luteipes* was fed a diet containing maize pollen grain, which resulted in a shorter nymph development time, higher survival rate, and higher fertility (Marucci et al. 2019). In addition, we hypothesize that pollen may be an attractant for the arrival of the predator in the environment prior to the pest insect infestation, which is important in the case of insects with a cryptic habit (Coll and Guershon 2002; Mendoza et al. 2020).

However, according to Schuldiner-Harpaz et al. (2016), plants providing a dietary supplement to omnivorous predators can influence biological control in two ways: by increasing the predator populations or reducing the prey consumption. Thus, it is necessary to understand the possible interactions among the food sources to enhance the use of *D. luteipes* and *O. insidiosus* as biological control agent against thrips pests.

The food preference data are preliminary, aiming to guide future studies as predators were already known to locate their prey through plant volatiles induced by herbivory, which may enhance prey searching. (Naranjo-Guevara et al. 2017) found that *D. luteipes* uses nocturnal herbivore-induced plant volatiles in searching for prey, allowing them to efficiently locate their prey in the dark when visual cues are absent. *Orius laevigatus* predator was attracted to plants with higher infestation rates due the high release of volatiles by the plant, regardless of prey nutritional quality (Venzon et al. 2002). Thus, future studies should address the role of plant volatiles to guide choice of these omnivorous predators. Understanding this food preference is relevant to determine the real contribution of each predator to thrips control.

In conclusion, our results show that *D. luteipes* prey on *C. phaseoli* nymphs and adults at all stages of development. Secondly, *D. luteipes* and *O. insidiosus* probably do not compete for predation of thrips. Also, no intraguild predation was observed and both predators feed longer on maize and hairy beggartick pollen, respectively, in relation to their preferred prey.

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Author Contribution R.C. Marucci and L.P. Silva conceived the research. L.P. Silva conducted the experiments. L.P. Silva and R.C. Marucci contributed the material. L.P. Silva and I. L. Souza analyzed the data and conducted the statistical analyses. L.P. Silva, R.C. Marucci, I. L. Souza, and M. Guzman-Martinez wrote the manuscript. All authors read and approved the manuscript.

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Declarations

Conflict of Interest The authors declare no competing interests.

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