

## ORIGINAL ARTICLE OPEN ACCESS

# Potential of the Predatory Mites *Gamasellodes lavafesii* (Mesostigmata: Ascidae) and *Cosmolaelaps mediocuspis* (Mesostigmata: Laelapidae) on Different Soil Pests/Parasites and Alternative Prey for Large-Scale Rearing

A. R. A. Barros<sup>1</sup>  | J. P. I. Martin<sup>2</sup> | G. J. Moraes<sup>1</sup> | M. M. Inomoto<sup>1</sup> | R. C. Castillo<sup>1,3</sup>

<sup>1</sup>Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Universidade de São Paulo (USP), Piracicaba, São Paulo, Brazil | <sup>2</sup>University of Western Ontario (UWO), London, Ontario, Canada | <sup>3</sup>CNPq Researcher, Brasília, Brazil

**Correspondence:** A. R. A. Barros (avyla\_@hotmail.com)

**Received:** 3 September 2025 | **Revised:** 18 December 2025 | **Accepted:** 22 December 2025

**Keywords:** biological control | Gamasina mites | predatory mites | soil pests

## ABSTRACT

Many species of Mesostigmata soil mites have potential as biological control agents of pests/parasites. This study evaluated the predation potential of two of these species, *Gamasellodes lavafesii* (Ascidae) and *Cosmolaelaps mediocuspis* (Laelapidae). The harmful species evaluated as prey were the root-knot nematode, *Meloidogyne javanica* (Heteroderidae), the gastrointestinal sheep-parasitic nematode, *Haemonchus contortus* (Trichostrongylidae), the bulb mite, *Rhizoglyphus columbianus* (Astigmata: Acaridae) and the sciarid fly, *Bradysia matogrossensis* (Diptera: Sciaridae). Additionally, five species were tested as potential alternative food sources for the mass rearing of predators: eggs of *Ephestia kuehniella* (Lepidoptera: Pyralidae), the mites *Glycyphagus destructor* (Astigmata: Glycyphagidae), *Thyreophagus cracentiseta* and *Tyrophagus putrescentiae* (Astigmata: Acaridae), and the free-living nematode *Rhabditella axei* (Rhabditidae). Daily predation rates (by female) between the predators did not differ when *M. javanica* was offered ( $\cong 240$ – $245$  second-stage juveniles). For *H. contortus*, *G. lavafesii* exhibited a higher daily predation rate ( $\cong 204$  third-stage juveniles), whereas *C. mediocuspis* showed higher daily consumption of *R. columbianus* ( $\cong 6.1$  larvae/nymphs) and *B. matogrossensis* ( $\cong 1.5$  larvae). The highest oviposition rate of *G. lavafesii* (3 eggs/female/day) was observed on *M. javanica*, while *C. mediocuspis* laid at most 0.6 eggs/female/day on all evaluated prey. For large-scale rearing, *R. axei* provided the best oviposition rate for *G. lavafesii* (8 eggs/female/day), whereas the highest rate for *C. mediocuspis* was obtained on *E. kuehniella* eggs (1.3 eggs/female/day). These findings will provide valuable insights for developing new biological agents for harmful organisms that spend part of their life cycle in the soil.

## 1 | Introduction

Predatory mites are among the most widely used biological control agents worldwide, especially those of the family Phytoseiidae (order Mesostigmata) (van Lenteren 2012; van Lenteren et al. 2018; Knapp et al. 2018). These inhabit predominantly aerial plant parts and have been intensively studied and used for pest control, including whiteflies (Hemiptera: Aleyrodidae),

thrips (Thysanoptera), and mites (McMurtry et al. 2013, 2015). Nearly 40 phytoseiid species have been commercialised in different countries for that purpose (van Lenteren 2012; van Lenteren et al. 2018; Knapp et al. 2018).

Although most species of Mesostigmata predatory mites are found in soil environments, predominating in the organic matter fraction and in the superficial centimetres of the

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Journal of Applied Entomology* published by Wiley-VCH GmbH.

mineral layer (Lindquist et al. 2009; Castilho et al. 2015), their application in the biological control of soil-dwelling pests remains relatively limited, despite their considerable potential for expansion. Only six species of edaphic Mesostigmata have been commercialised worldwide for pest control (van Lenteren 2012; van Lenteren et al. 2018; Knapp et al. 2018). *Gaeolaelaps aculeifer* (Canestrini), *Gaeolaelaps gillessie* Beaulieu, *Stratiolaelaps miles* (Berlese), *Stratiolaelaps scimitus* (Womersley) (Laelapidae), and *Macrocheles robustulus* (Berlese) (Macrochelidae) have been used mainly for the control of sciarid fly and shore fly larvae (Diptera: Sciaridae, Ephydriidae), as well as of thrips pupae, in addition to *Pergamasus quisquiliarum* (Canestrini & Canestrini) (Parasitidae), which has been used for symphylan (Myriapoda) control. In Brazil, *S.scimitus* is the only soil-predatory mite commercially available, used solely for the control of sciarid flies (Agrofit – Ministério da Agricultura, Pecuária e Abastecimento 2025).

Other soil Mesostigmata species demonstrated potential for controlling harmful organisms that live in the soil or spend at least part of their life cycle in this environment, including small insects (mainly sciarid flies), bulb mites, nematodes parasitic on plants, such as root-knot nematodes, *Meloidogyne* spp. (Nematoda: Heteroderidae), and also nematodes parasitic on animals, such as *Haemonchus contortus* (Rudolphi) (Nematoda: Trichostrongylidae) (Castilho et al. 2015; Moraes et al. 2015; Azevedo et al. 2015; Moreira and Moraes 2015). The sciarid flies, *Bradysia* spp. (Diptera: Sciaridae), known as fungus gnats, are pests mainly in seedling production, such as vegetables, sugarcane, and tobacco (Moraes et al. 2024). The bulb mites, *Rhizoglyphus* spp. (Astigmata: Acaridae), are pests of bulbs under storage and in the field (Palevsky et al. 2022). Root-knot nematodes are root parasites of many crops, such as soybean and vegetables (Jones et al. 2013; Phani et al. 2021). The gastrointestinal nematode *H. contortus*, commonly known as the Barber's Pole worm, parasitises the abomasum of sheep, where it feeds on blood from the stomach wall, often leading to anaemia and reduced productivity (Taylor et al. 2016). These organisms can cause significant economic and ecological impacts by reducing crop productivity and, in the case of animal parasitic nematodes, causing disease mainly in sheep.

The use of biological control with soil natural enemies is particularly desirable, as synthetic pesticides often fail to reach their targets in such a complex habitat. Edaphic predatory mites can be a promising alternative for managing soil-dwelling pests, as they share the same environment and can access prey at different depths according to their size and body morphology. This scenario points to the need for prospecting for additional soil-predatory mites that may be potentially beneficial for biological control.

Studies to understand the diversity of Mesostigmata predatory-soil mites have demonstrated their great abundance across Brazilian biomes, mainly of species in the families Ascidae, Laelapidae, and Rhodacaridae (Azevedo, Azevedo, et al. 2020; Barros et al. 2021; Castro et al. 2021; Barros 2025a). In one of the studies conducted in the Caatinga biome (Barros 2025a), characterised by high temperatures and low rainfall, the species *Gamasellodes lavafesii* Castro, Azevedo & Castilho (Ascidae)

and *Cosmolaelaps mediocuspis* (Karg) (Laelapidae) were found in high abundance in the field and showed excellent development in laboratory breeding.

The objective of this work was to evaluate the potential for predation and reproduction of common soil-dwelling predators from northeastern Brazil on selected harmful edaphic species, including small insects, mites, and nematodes, with a view to their possible practical use in the future. In addition, the study included a preliminary assessment of suitable small invertebrates for use as alternative prey in the prospective mass rearing of these predators, as the feasibility of application of biological control strategies with predatory mites depends on their large-scale production at competitive costs.

## 2 | Material and Methods

The study was carried out between June and September 2023, at the Acarology Laboratory of the Department of Entomology and Acarology of Escola Superior de Agricultura 'Luiz de Queiroz' (Esalq) of the University of São Paulo (USP), in Piracicaba, State of São Paulo, Brazil.

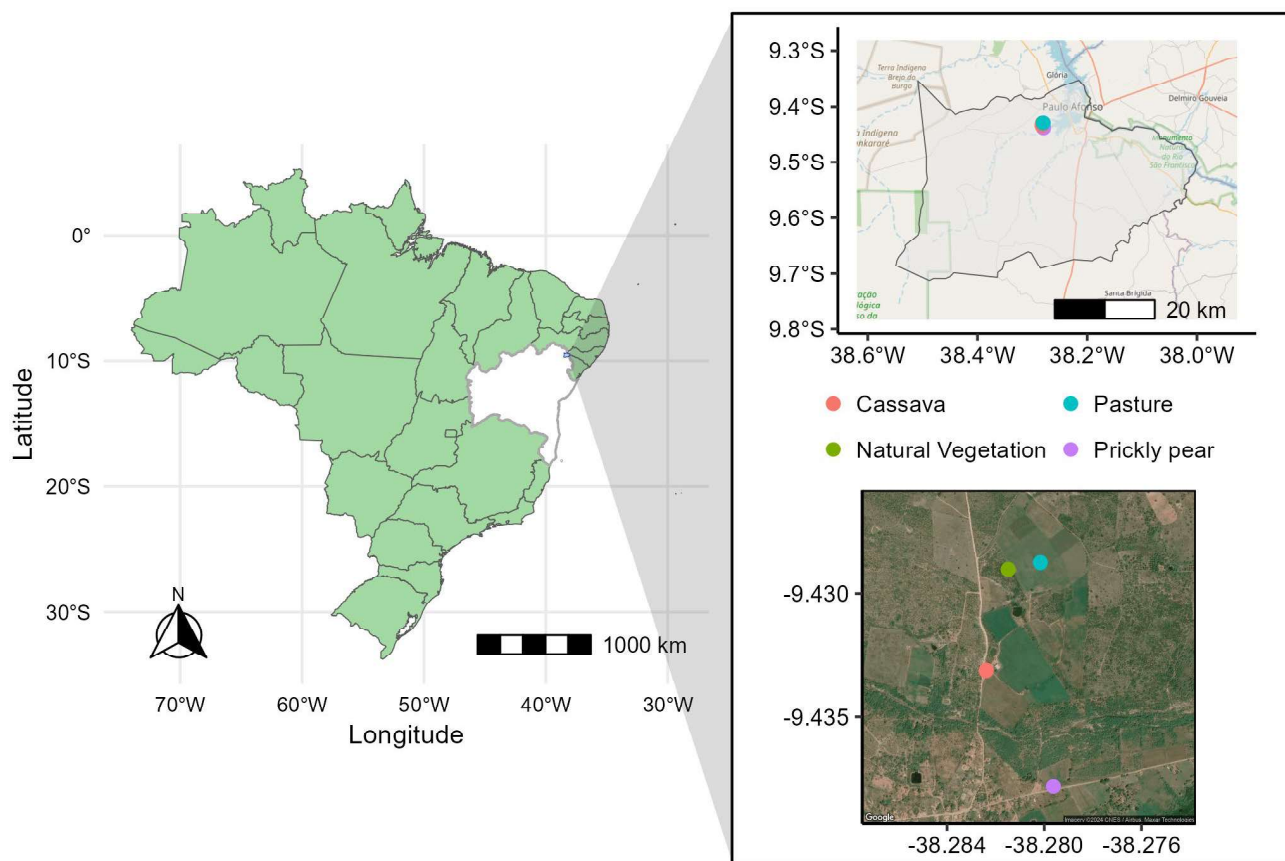
### 2.1 | Origin and Rearing of Predators

Soil samples were collected in November 2022 in areas of natural vegetation, cultivation of cassava [*Manihot esculenta* Crantz (Euphorbiaceae)], cultivation of prickly pear [*Opuntia cochenillifera* (L.) Mill.], and in a pasture consisting mostly of brachiaria grass [*Urochloa* (Poaceae)], in the municipality of Paulo Afonso, Bahia State, northeastern Brazil (Figure 1). The region's climate is classified as BSh by the Köppen-Geiger classification, characterised as semi-arid, typical of the Caatinga biome (Köppen 1948; Peel et al. 2007). In 2022, the average annual temperature for the collection region was around  $27^{\circ}\text{C} \pm 1^{\circ}\text{C}$ , and precipitation was 785 mm (Instituto de Controle do Espaço Aéreo (ICEA) 2025).

These were taken to a laboratory for the extraction of predatory mites for the establishment of colonies to be used in the trial. The soil samples were collected using metal cylinders (9×5 cm in external diameter and height) and maintained in modified Berlese-Tullgren funnels (Oliveira et al. 2001) for a few days to extract the mites alive in plastic containers (500 mL) containing a few pieces of wet filter paper.

A total of 15 mesostigmatid mite species were collected, from which laboratory colonies of eight species were successfully established. Among these, *C. mediocuspis* and *G. lavafesi* were selected, as they belonged to families that were more abundant at the collection sites and exhibited promising initial performance under laboratory conditions.

Each stock colony was maintained in a plastic container (500 mL), the bottom of which was lined with a mixture of plaster of Paris and activated charcoal (9:1). This base layer was covered with a 1–3 cm layer of vermiculite, which was kept humid by daily water additions. Both colonies were fed periodically with all stages of the free-living nematode *Rhabditella axei* Cobbold



**FIGURE 1** | Map of Brazil showing the geographic coordinates and collection sites of Gamasina mites (Mesostigmata) across different ecosystems in Paulo Afonso, Bahia, Brazil, November 2022. [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1111/jen.120057)]

(Nematoda: Rhabditidae) offered on pieces of rotting common bean (*Phaseolus vulgaris* L.) pods. The colonies were maintained in a climate-controlled room at  $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ ,  $90\% \pm 5\%$  RH, and in the dark.

## 2.2 | Origin and Breeding of Prey

The following organisms were evaluated as prey to assess their suitability for predation and oviposition by the predators: the sciarid fly, *Bradysia matogrossensis* (Lane) (Diptera: Sciaridae); the bulb mite, *Rhizoglyphus columbianus* Oudemans (Astigmata: Acaridae); the root-knot nematode, *Meloidogyne javanica* (Treub) (Nematoda: Heteroderidae); and the Barber's Pole worm, *H. contortus*.

Additionally, the following organisms were evaluated as alternative prey for predator mite mass rearing: *Ephestia kuehniella* (Zeller) (Lepidoptera: Pyralidae) – eggs are commonly used as hosts for parasitoid mass rearing; *Glycyphagus destructor* (Schrank) (Astigmata: Glycyphagidae), *Thyreophagus cracenticeta* Barbosa, O'Connor & Moraes and *Tyrophagus putrescentiae* (Schrank) (Astigmata: Acaridae)—mites of stored products such as cereals, grains, seeds, dried fruits and animal feed, commonly used as food for predatory mite mass rearing; and the free-living nematode *R. axei*—bacteriophagous nematode used as positive control, as it serves as the standard reference food for rearing mites in the laboratory.

A colony of *B. matogrossensis* was established from specimens collected in 2021 at a screen house of the Acarology Laboratory of Esalq/USP. The colony was maintained in the laboratory in 20L plastic cages equipped with openings in the lid and side walls to ensure proper ventilation. Each cage contained four rearing units (500 mL) filled with moss, organic potato slices, and crushed white beans to promote the oviposition of flies that prefer environments rich in organic matter.

A colony of *R. columbianus* was established from specimens collected in 2021 from garlic bulbs in Piracicaba, São Paulo, Brazil. This mite was reared in 500 mL plastic containers and fed twice a week with brewer's yeast.

The *M. javanica* isolate was obtained from soybean roots collected in Cambé, Paraná State, Brazil, and maintained in a greenhouse at Esalq/USP by alternating different host plants (soybean, green onion, and tomato). To recover nematodes from green onion roots, the roots were macerated in a common kitchen blender with a 1% sodium hypochlorite solution. The resulting suspension was sieved through 60-, 200-, and 500-mesh sieves (0.25-, 0.74-, and 0.025-mm apertures). The material retained in the 500-mesh sieves was collected, resulting in an aqueous suspension containing eggs and second-stage juveniles ( $J_2$ ) of *M. javanica* mixed with root debris. The motility of  $J_2$  was used to separate them from eggs and root debris by allowing them to migrate through a paper towel, in an adaptation of the Baermann funnel technique (Hooper 1986). To obtain the

desired concentration of  $J_2$  (500 $J_2$  per 30 $\mu$ L), the number of  $J_2$  per millimetre was estimated with a Peters counting slide under a light microscope (Leica DMLB, Wetzlar, Germany) at 100 $\times$  magnification. Thereafter, the aqueous suspension containing  $J_2$  was kept undisturbed in a cold room at 15°C for 24 h to allow  $J_2$  decantation. After this period, the excess water was carefully removed using a copper microsiphon.

The nematode *H. contortus* was obtained from sheep faeces collected at the experimental unit of the Animal Science Department of Esalq/USP. To obtain the third-stage juvenile ( $J_3$ ), the infective stage, collection bags were attached to infected sheep to gather faecal samples containing the nematodes. The collected faeces were stored in glass jars covered with perforated aluminium foil to allow ventilation. The faeces were moistened with a few drops of water to maintain internal humidity and then incubated for 10 days. Following incubation, nematodes were extracted using the coproculture technique. Water was added to each glass jar until it reached full capacity. The contents of each jar were then transferred individually into Petri dishes. Filtered water was subsequently added to the dishes, keeping the water level below the edge, allowing nematodes to migrate and be extracted via capillary action. After 24 h, the water from each Petri dish was collected using a 10 mL glass pipette and transferred to 50 mL Falcon tubes. The tubes were stored in a refrigerator until nematode decantation. The supernatant was removed with a pipette, concentrating the nematodes, which were then kept refrigerated for subsequent use in predation assays.

Eggs of *E. kuehniella*, produced according to Parra et al. (2023), were obtained from the Insect Biology Laboratory of Esalq/USP. Mites of the Astigmata group (*G. destructor*, *T. cracentiseta*, and *T. putrescentiae*) were sourced from breeding colonies maintained in the Acarology Laboratory of Esalq/USP. Each mite species was reared separately in 500 mL plastic containers and fed twice weekly with a 1:1 mixture of brewer's yeast and wheat bran.

A colony of the free-living nematode *R. axei* was maintained in a 500 mL plastic container, to which sections of common bean pods and a small volume of distilled water were added weekly, keeping the pods moist and in a state of decomposition.

### 2.3 | Experimental Procedure

The tests were carried out according to the methodology proposed by Castilho, Moraes, Silva, and Silva (2009). Each experimental unit consisted of an acrylic Petri dish (2 cm high  $\times$  3 cm in diameter), whose base was lined with a mixture of plaster of Paris and activated charcoal (9:1), kept permanently wet by daily additions of water, except for tests using nematodes as prey. In the latter case, the base of each Petri dish was covered with a 0.5 cm layer of agar, onto which a small piece of inert material was placed as a substrate for the predator's oviposition.

A gravid adult female of *C. mediocuspis* or *G. lavafesii*, taken randomly from the respective stock colony, was transferred to each experimental unit. For each treatment, prey type and respective numbers offered daily to each experimental unit were as follows: (1) *M. javanica*: 500  $J_2$ ; (2) *H. contortus*: 500  $J_3$ ; (3)

*B. matogrossensis*: six larvae (1st and 2nd instar); (4) *R. columbianus*: 15 larvae/protonymphs; (5) *E. kuehniella*: eggs *ad libitum*; (6) *G. destructor*: all stages *ad libitum*; (7) *T. cracentiseta*: all stages *ad libitum*; (8) *T. putrescentiae*: all stages *ad libitum*; (9) *R. axei*: all stages *ad libitum* (positive control); (10) no food (negative control). The number of prey was determined in preliminary tests to prevent food limitation for the predatory mites. Each experimental unit was sealed with a piece of transparent plastic wrap (Magipac) to prevent the mites and prey from escaping.

Thirty replicates were used per treatment. The experimental units were maintained at 25°C  $\pm$  1°C, 95%  $\pm$  5% RH, and in the dark.

When the prey was either *M. javanica* or *H. contortus*, the inoculum was offered in a concentration of 500 $J_2$  or  $J_3$ , respectively, in 30 $\mu$ L of distilled water. To enable the estimation of the number of nematodes consumed, each predatory mite was transferred to a new experimental unit at the end of each day. The agar of the old unit was rinsed with water over a plastic pot three to four times, and the nematodes were subsequently sucked from the aqueous medium using a 3 mL plastic pipette. In the experimental units containing *H. contortus*, a complementary procedure was necessary to kill the nematodes before counting. Due to the high motility of their nematodes, which hindered accurate counting, a drop of Lugol's iodine solution was added to the water used to rinse the agar from the old unit, facilitating nematode counting. The nematodes were counted using a counting slide (Peters' counting slide) under an optical phase-contrast microscope (Leica, DMLB) at 40 $\times$ .

The experimental units were examined daily for 11 consecutive days to determine: (a) the number of attacked prey (treatments 1–4) – determined by the difference between the initial number of prey and the number of surviving prey after 1 day of exposition to the predator in the experimental unit; (b) the number of eggs laid by the predator (all treatments); (c) the number of surviving predators (all treatments). The results of the first day were discarded to reduce the effect of previous feeding. Dead prey were replaced daily, and predator eggs were counted and discarded.

### 2.4 | Data Analysis

All analyses were performed in R Studio and R version 4.0.2 (R Studio Team 2019; R Core Team 2020). The packages used for the analyses were car, readxl, nortest, agricolae, dunn.test, dplyr, rstatix, pacman, FSA, and PMCMR. First, the data were analysed using the Shapiro–Wilk test, followed by the Levene test to verify the homogeneity of variances. Statistical comparisons were made by relating the different predators to the same prey, using the Mann–Whitney test ( $\alpha=0.05$ ), as well as comparisons of the different prey for each predator, using the Kruskal–Wallis test ( $\alpha=0.05$ ), followed by the Dunn test with Bonferroni correction to compare the means, the last two, only for oviposition. Comparisons of treatments 1–4 were analysed separately from treatments 5–9 due to differing experimental objectives. No statistical comparison of the predation across different prey was conducted due to differences in their biomasses.

### 3 | Results

#### 3.1 | Potential as Control Agents

All evaluated pests were attacked by *G. lavafesii* and *C. mediocuspis* (Table 1). The difference between the predation rates of *M. javanica* by the two predator species was not significant ( $U=424$ ;  $p>0.05$ ). The predation rate of *H. contortus* by *G. lavafesii* was significantly higher than by the other predator ( $U=54$ ;  $p<0.001$ ). Conversely, when the prey offered was *R. columbianus* ( $U=864$ ;  $p<0.001$ ) and *B. matogrossensis* ( $U=775$ ;  $p<0.001$ ), the predation rates by *C. mediocuspis* were significantly higher than by the other predator.

Regarding oviposition, both predator species oviposited when fed with all organisms offered separately as prey (Table 2). Significant differences in oviposition rates between predators were observed on all prey. *Gamasellodes lavafesii* had higher oviposition rates than *C. mediocuspis* when the prey offered were *M. javanica* ( $U=14$ ;  $p<0.001$ ) or *H. contortus* ( $U=1$ ;  $p<0.001$ ). *Cosmolaelaps mediocuspis* had the highest oviposition rate compared to *G. lavafesii* when the prey offered were *B. matogrossensis* ( $U=615$ ;  $p<0.05$ ) or *R. columbianus* ( $U=605$ ;  $p<0.05$ ), despite the low rates of both predators on these prey.

When comparing the effect of prey on the oviposition rates of each predator separately, significant differences were observed for both (*G. lavafesii*:  $X^2=184.5$ ;  $df=6$ ;  $p<0.001$ ; *C. mediocuspis*:  $X^2=45.62$ ;  $df=6$ ;  $p<0.001$ ). *Gamasellodes lavafesii* had the highest rate on *M. javanica*, followed by *H. contortus*, and very low and similar rates on the other prey. For *C. mediocuspis*, rates were low on all evaluated prey, with the highest on *R. columbianus*.

Survivorship was at least 73% for both predators across most prey (Table 3). The lowest survivorship rates of *G. lavafesii* were observed on *B. matogrossensis* and *R. columbianus* (56.6% and 60%, respectively), and of *C. mediocuspis* on *H. contortus* (73%).

**TABLE 1** | Daily number of prey (mean±SE) attacked by *Gamasellodes lavafesii* and *Cosmolaelaps mediocuspis*, in the laboratory at 25°C±1°C, 95%±5% RH, in the dark, for 10 days.

Prey	Predators	
	<i>Gamasellodes lavafesii</i>	<i>Cosmolaelaps mediocuspis</i>
<i>Meloidogyne javanica</i>	245.7±4.4 a	241.7±5.8 a
<i>Haemonchus contortus</i>	204.1±3.5 a	149.0±5.2 b
<i>Bradysia matogrossensis</i>	0.8±0.07 b	1.5±0.1 a
<i>Rhizoglyphus columbianus</i>	2.0±0.1 b	6.1±0.3 a

Note: Means followed by the same letter on the same line do not differ from each other by the Mann-Whitney U test ( $p>0.05$ ).

In the absence of food, survivorship of *C. mediocuspis* was about twice as high as that of *G. lavafesii*.

#### 3.2 | Potential as Alternative Prey

Both predators oviposited when fed on all prey evaluated as potential food sources for their mass rearing (Table 4). When comparing the oviposition rates of the two predators on each prey, *G. lavafesii* showed significantly higher rates, except when the prey was *E. kuehniella*, for which the opposite pattern was observed (*R. axei*:  $U=16$ ;  $p<0.001$ ; *T. cracentiseta*:  $U=129$ ;  $p<0.001$ ; *T. putrescentiae*:  $U=133$ ;  $p<0.001$ ; and *G. destructor*:

**TABLE 2** | Daily oviposition rates per female (mean±SE) of *Gamasellodes lavafesii* and *Cosmolaelaps mediocuspis* fed with different prey, in the laboratory at 25°C±1°C, 95%±5% RH, in the dark, for 10 days.

Prey	Predators	
	<i>Gamasellodes lavafesii</i>	<i>Cosmolaelaps mediocuspis</i>
<i>Meloidogyne javanica</i>	3.0±0.09 Aa	0.3±0.1 Bb
<i>Haemonchus contortus</i>	1.6±0.09 Ba	0.1±0.02 Cb
<i>Bradysia matogrossensis</i>	0.1±0.02 Cb	0.3±0.05 Ba
<i>Rhizoglyphus columbianus</i>	0.2±0.03 Cb	0.6±0.1Aa
No food (–)	0.0±0.0 Db	0.2±0.03 BCa

Note: Means followed by the same letter (lowercase) in the same row do not differ by the Mann-Whitney U test, and in the same column (uppercase) by the Kruskal-Wallis test, followed by the Dunn-Bonferroni test ( $p>0.05$ ); (–) negative control.

**TABLE 3** | Survivorship females (%) of *Gamasellodes lavafesii* and *Cosmolaelaps mediocuspis* fed with different prey, in the laboratory at 25°C±1°C, 95%±5% RH, in the dark, 10 days after the beginning of the evaluation.

Prey	Predators	
	<i>Gamasellodes lavafesii</i>	<i>Cosmolaelaps mediocuspis</i>
<i>Meloidogyne javanica</i>	86.6	86.6
<i>Haemonchus contortus</i>	86.6	73.0
<i>Bradysia matogrossensis</i>	56.6	83.0
<i>Rhizoglyphus columbianus</i>	60.0	83.3
No food (–)	40	80

Note: –, negative control.

**TABLE 4** | Daily oviposition rates per female (mean±SE) of *Gamasellodes lavafesii* and *Cosmolaelaps mediocuspis* fed with different prey ad libitum, in the laboratory at 25°C±1°C, 95%±5% RH, in the dark, for 10 days.

Prey	Predators	
	<i>Gamasellodes lavafesii</i>	<i>Cosmolaelaps mediocuspis</i>
<i>Ephestia kuehniella</i>	0.3±0.08 Ea	1.3±0.2 Ab
<i>Glycyphagus destructor</i>	1.1±0.1 Da	0.6±0.1 Bb
<i>Tyreophagus cracentiseta</i>	3.4±0.3 Ba	1.0±0.1 Ab
<i>Tyrophagus putrescentiae</i>	2.3±0.2 Ca	0.7±0.1 Bb
<i>Rhabditella axei</i> (+)	8.0±0.8 Aa	1.0±0.2 Ab

Note: Means followed by the same letter (lowercase) in the same row do not differ by the Mann–Whitney *U* test and in the same column (uppercase) by the Kruskal–Wallis test, followed by the Dunn–Bonferroni test ( $p > 0.05$ ); (+) positive control.

$U = 232$ ;  $p < 0.05$ ; *E. kuehniella*:  $U = 741$ ;  $p < 0.001$ ). In all cases, differences were substantial.

Different patterns were observed when comparing the effects of prey on oviposition by each predator. Significant differences were observed between all oviposition rates of *G. lavafesii* ( $X^2 = 139.38$ ;  $df = 5$ ;  $p < 0.001$ ). The rate was markedly highest on *R. axei*, followed by *T. cracentiseta*, *T. putrescentiae*, and *G. destructor*, with a negligible value on *E. kuehniella*. However, significant differences were observed only in some comparisons involving *C. mediocuspis* ( $X^2 = 133.98$ ;  $df = 4$ ;  $p < 0.001$ ). The rates were divided into two groups: the most promising group, consisting of *E. kuehniella*, *T. cracentiseta*, and *R. axei*, which showed similar values among themselves and significantly higher rates than those of *G. destructor* and *T. putrescentiae*, which were also similar to each other. However, on all prey species, rates of *C. mediocuspis* were low (at most 1.3 eggs per female per day).

Predator survivorship was at least 73.3% on all prey species, except for *G. lavafesii* on *G. destructor* (66.6%) (Table 5).

## 4 | Discussion

### 4.1 | Potential as Biocontrol Agents

The predation and oviposition rates of *G. lavafesii* on the nematodes *M. javanica* and *H. contortus* were rather promising. These results reinforce the potential of *Gamasellodes* species as nematode predators (Walter and Ikonen 1989; Moraes et al. 2015). The small size of these mites (250–350 µm) favours their movement through soil crevices, supposedly facilitating their encounter with edaphic nematodes and possibly making these some of their main food sources (Walter 2003; Moraes et al. 2015). This could explain the encouraging performance of *G. lavafesii* as a predator of *M. javanica* and *H. contortus*, given the natural co-occurrence

**TABLE 5** | Survivorship females (%) of *Gamasellodes lavafesii* and *Cosmolaelaps mediocuspis* fed with different prey ad libitum, in the laboratory at 25°C±1°C, 95%±5% RH, in the dark, 10 days after the beginning of the evaluation.

Prey	Predators	
	<i>Gamasellodes lavafesii</i>	<i>Cosmolaelaps mediocuspis</i>
<i>Ephestia kuehniella</i>	73.3	93.3
<i>Glycyphagus destructor</i>	66.6	76.3
<i>Tyreophagus cracentiseta</i>	80	90
<i>Tyrophagus putrescentiae</i>	83.3	80
<i>Rhabditella axei</i> (+)	90	90

Note: +, positive control.

of mites of this group with nematodes, at least during part of the latter's life cycle. According to Rueda-Ramírez, Palevsky, and Ruess (2023), the family Ascidae, to which *G. lavafesii* belongs, includes the largest number of mite species reported to feed on nematodes.

The present study is among the first referring to the suitability of *M. javanica* as a food source for predatory mites. Previous studies (Zhou et al. 2012; Xu et al. 2014; Yang et al. 2020; Prado 2023) have evaluated the effect of mesostigmatid mites as predators of a related species, *Meloidogyne incognita* (Kofoid & White). Prado (2023) estimated that each female of *Protogamasellopsis zaheri* Abo-Shnaf, Castilho & Moraes (Rhodacaridae) preyed on a daily average of about 320 J<sub>2</sub> of *M. incognita*, with an average daily oviposition rate of two eggs. Despite belonging to a different family, *P. zaheri* exhibits morphological similarities to *G. lavafesii*, including a slender body and a divided dorsal shield that confers greater flexibility. However, *P. zaheri* is larger, measuring about 550 µm in length compared with approximately 300 µm for *G. lavafesii*. This rhodacarid species has been studied precisely due to morphological traits that enable it to live under the soil surface, an environment where plant-parasitic nematodes generally occur, and its proven ability to prey on several nematode species, including those of the genus *Meloidogyne* (Castilho, Moraes, Silva, and Silva 2009; Rossini et al. 2022; Prado 2023).

*Cosmolaelaps mediocuspis* females also demonstrated significant predation on *M. javanica*. However, oviposition was very low, despite many species of this genus having been reported to be associated with nematodes (Moraes and Moraes 2015). Al Rehiyani and Fouly (2005) observed that *Cosmolaelaps simplex* Berlese could develop normally and complete its life cycle by feeding on egg masses of *M. javanica* in the laboratory, and reduced the population of the citrus nematode *Tylenchulus semipenetrans* Cobb under greenhouse conditions. In a study of another species of that same family (Laelapidae), Yang et al. (2020) observed that a female of *S. scimitus* preyed daily on an average of about 200 J<sub>2</sub> of *M. incognita* and had a daily oviposition rate of about 1.95 eggs. Taking into account this considerable difference

in oviposition rates between predatory mites, Rueda-Ramírez, Narberhaus, et al. (2023) demonstrated that the nutritional value of different species of nematodes offered as prey varied in quality.

The predation and oviposition rates of *G. lavafesii* on *H. contortus* were significantly higher than those of *C. mediocuspis*. Other studies with *H. contortus* have demonstrated the ability of *Lasioseius penicilliger* Berlese (Mesostigmata: Blattisociidae), *Macrocheles* sp., *Macrocheles merdarius* (Berlese), *Macrocheles robustulus* (Berlese), and *Holostaspella bifoliata* (Trägårdh) (Mesostigmata: Macrochelidae) to prey on this parasite (Aguilar-Marcelino et al. 2014; Grisez et al. 2023; Anjos et al. 2024; Bamière et al. 2025). However, these studies did not provide the exact number of prey consumed, which hampered comparison with the results of the present study.

The higher predation rate of *C. mediocuspis* on *B. matogrossensis* compared with *G. lavafesii* may be related to the sizes of these predators. *Cosmolaelaps mediocuspis*, being a more robust species of mite (about 550–560 µm in body length), appears capable of efficiently handling and subduing this prey, whereas *G. lavafesii* may experience difficulty due to the relatively large size of the *B. matogrossensis* larvae (about 300 µm in length). Duarte et al. (2021) reported a daily average predation of about 4.5 *Bradysia* aff. *ocellaris* larvae by *Cosmolaelaps brevistilis* (Karg), approximately three times more than the value reported in the present study, showing that the predation rate can vary markedly between *Cosmolaelaps* species. Regarding size, *C. brevistilis* is probably more robust (about 630–750 µm in body length) than *C. mediocuspis*. The laelapid *S. scimitus* has been successfully used in Brazil to control *B. matogrossensis* (Freire et al. 2007; Castilho, Moraes, Silva, Freire, and Eira 2009).

Similar to the results of the present study, Duarte et al. (2021) also reported a low daily oviposition rate (0.4 egg per female) for *C. brevistilis* when fed on larvae of *B. aff. ocellaris*. The reduced oviposition observed may be related to the predation of predator eggs by *Bradysia* larvae, as previously reported by Castilho, Moraes, Silva, and Silva (2009). However, further studies are needed to confirm this hypothesis.

The predation of *R. columbianus* was more effective for *C. mediocuspis*, although oviposition was low. It is possible that *R. columbianus* does not meet the nutritional or physiological requirements of *C. mediocuspis* for a significant oviposition. According to Moreira & Moraes et al. (2015), *Cosmolaelaps barbatus* Moreira, Klompen & Moraes and *Cosmolaelaps jaboticabalensis* Moreira, Klompen & Moraes were observed feeding and ovipositing on another bulb mite species, *Rhizoglyphus echinopus* (Fumouze & Robin). However, the authors did not report quantitative data on prey consumption and oviposition, but highlighted the potential of *Cosmolaelaps* species for the biological control of this pest. Lesna et al. (1995) reported that the laelapids *S. miles* and *G. aculeifer* were able to feed and reproduce when offered the bulb mite *Rhizoglyphus robini* Claparède as prey. In Europe, *G. aculeifer* is commercialised for the control of *Rhizoglyphus* species (Moreira and Moraes 2015).

Other species of Mesostigmata mites, from the families Ascidae, Blattisociidae, Macrochelidae, Parasitidae, and Rhodacaridae,

were tested for control of bulb mites (Palevsky et al. 2022). Wu et al. (2009) observed that an unidentified species of *Lasioseius* (Blattisociidae) reproduced when feeding on *R. echinopus*. In addition, Castilho, Moraes, Silva, and Silva (2009) demonstrated that *P. zaheri*, referred to as *Protogamasellopsis posnaniensis* Wisniewski & Hirschmann (Rhodacaridae), fed on *R. echinopus*, and was also capable of reproduction.

Of great interest was the high survivorship rate (at least 73%) of *C. mediocuspis* on all prey species. This is compatible with the also high survivorship observed even in the absence of food (80%), while suggesting no significant negative impact of any prey on the predator. Previous studies indicated that *Cosmolaelaps* species are generally longevous, even in the absence of food, standing fasting for up to 20 to 150 days (Moreira and Moraes 2015). These results are highly relevant from an applied perspective, as they demonstrate the ability of *C. mediocuspis* to survive in the absence of prey, suggesting a degree of resilience in biological control programmes and potentially reducing the need for frequent field releases.

The ability of *G. lavafesii* to survive in the absence of food was markedly lower than that of *C. mediocuspis*, with survivorship declining to approximately 40% after 11 days. This value was also considerably lower than when nematodes were available (up to about 86% on *M. javanica* or *H. contortus*). These contrasting results are consistent with evolutionary expectations, suggesting that species exhibiting greater specificity in their accepted food items may have a reduced capacity to withstand periods of food deprivation.

## 4.2 | Potential as Alternative Prey

The results of this study indicate that at least two of the organisms evaluated as alternative prey, *R. axei* and *T. cracentiseta*, appear particularly promising for the large-scale rearing of *G. lavafesii*. The markedly higher oviposition rate of *G. lavafesii* on *R. axei* offered *ad libitum* was expected, as this prey serves as the standard food source for maintaining the predator's stock colony. Moreover, this finding reinforces the concept of *Gamaselloides* as a predominantly nematophagous group.

However, the laboratory mass rearing of this nematode remains laborious, highlighting the need to develop more efficient strategies for its large-scale production. Studies have been conducted to optimise the large-scale rearing of other free-living nematode species, such as *Caenorhabditis elegans* Maupas and *Panagrolaimus* sp., although several challenges still remain (Stiernagle 2006; Ayub et al. 2013; Hibshman et al. 2021). In addition to their potential use in large-scale rearing, these free-living nematodes may also serve as an alternative food source for maintaining soil-dwelling predatory mites in the field, thereby enhancing their performance in controlling target pests (Azevedo, Moreira, et al. 2020).

Regarding Astigmata as a food source, the encouraging results obtained with *T. cracentiseta* as prey for *G. lavafesii* were consistent with previous evaluations of predatory mites under laboratory conditions. Various Astigmata species have been used in different studies as alternative prey for the mass rearing of

mesostigmatid mites from several families, often supporting adequate development and oviposition (Barbosa and Moraes 2015, 2016; Castilho et al. 2015; Moreira and Moraes 2015). Further research should assess the economic feasibility of these options, particularly the comparative production costs of each prey species.

For *C. mediocuspis*, intriguing results were obtained in this study, as none of the evaluated prey proved suitable for oviposition. This finding is particularly interesting given that the species reached high population levels in the stock colonies when fed on the free-living nematode *R. axei*. Duarte et al. (2021) reported a similar situation for *C. brevistilis* fed on *R. axei*, with the species reproducing readily in colony conditions but with females exhibiting low oviposition rates (about 0.95 egg/female/day) when kept individually in an experimental unit. A possible explanation may involve an aggregation factor influencing reproductive behaviour. Similar phenomena have been reported for species of Parasitidae. According Rueda-Ramírez et al. (2019), *Parasitus bituberosus* Karg could complete its life cycle and oviposit only when maintained in groups, suggesting that the higher oviposition rate observed in females kept with males may, at least in part, be related to the possibility of multiple inseminations.

However, Moreira et al. (2015) observed higher oviposition rates for *C. jaboticabalensis* (about 2.3 eggs/female/day) when fed on the free-living nematode *R. axei* (referred to as *Protorhabditis*). The variation in the consumption and oviposition observed among different *Cosmolaelaps* species when offered the same prey also extends to their reproductive mode (Moreira and Moraes 2015), which may, in turn, influence oviposition performance.

Reproduction by thelytoky has been observed in *Cosmolaelaps vacua* (Michael) and *C. jaboticabalensis* (Walter and Oliver 1989; Moreira et al. 2015), although males of the former have been reported in the literature (Bregotova 1977; Gwiazdowicz and Klemt 2004). Reproduction by arrhenotoky was observed in *Cosmolaelaps* nr. *weeversi* (Oudemans) (Walter and Kaplan 1990). Sexual reproduction has been reported in *Cosmolaelaps claviger* (Berlese) and *Cosmolaelaps paulista* Freire & Moraes (Afifi and van der Geest 1984; Freire and Moraes 2007). Furthermore, arrhenotoky was also observed in unmated females of *C. claviger*, indicating facultative parthenogenesis (Afifi and van der Geest 1984). Regarding *C. mediocuspis* of the present study, males were observed in stock colonies.

One of the best oviposition rates of *C. mediocuspis* was obtained when the predator was fed with *E. kuehniella*, much higher than when offered this prey to *G. lavafesii*. The nutritional characteristics of this prey were possibly compatible with the dietary needs of *C. mediocuspis*. However, the oviposition rate was much lower than that observed for *Cosmolaelaps keni* Hafez, Elbadry & Nasr (3.3 eggs/female/day) (Hassan et al. 2017) and for the laelapid *G. aculeifer* (2.0 eggs/female/day) (Navarro-Campos et al. 2016) when offered the same prey. The use of *E. kuehniella* eggs for raising predatory mites in the laboratory could be a promising approach, as they have high nutritional value (Li et al. 2024) and a well-established mass-rearing protocol. Moreover, *E. kuehniella* eggs are commonly used for the mass production of several parasitoid species (Parra et al. 2021).

Since this prey was the one that provided the best oviposition performance for *C. mediocuspis*, further studies are needed to evaluate whether it can serve as a suitable alternative food source, including studies with females isolated or grouped with other colony specimens, mainly males. Such investigations could contribute valuable insights into the development of more efficient mass-rearing systems and enhance the use of these predatory mites in biological control programmes.

## 5 | Conclusions

The results of this study are expected to provide valuable insights for identifying potential biological control agents of soil-dwelling pests among the groups investigated. In particular, the prospects for the biological management of harmful nematodes appear promising, underscoring the need for targeted field studies focusing on periodic releases or on the conservation of predatory species already present in the local environment.

The observed differences in prey preferences between *G. lavafesii* and *C. mediocuspis* may be associated with the distinct ecological niches these species occupy. However, the specific biological traits underlying these differences remain unclear and may be related to particular nutritional requirements. The hypotheses warrant further investigation.

Furthermore, given that these prey occupy different niches, the two predator species could be used in a complementary manner to control diverse pests. However, no studies have yet evaluated the risk of intraguild predation between them, highlighting the need for future research on their interactions in biological control programmes.

The predatory mites *G. lavafesii* and *C. mediocuspis* were collected in the Caatinga Brazilian biome, a semi-arid region characterised by high temperatures and low rainfall, according to the Köppen-Geiger classification. Prospecting for predatory mites in areas with these characteristics can be very interesting, given the current global warming scenario, as they may have developed adaptations that enable them to survive high temperatures and prolonged dry periods. These findings highlight the importance of further research to better understand the ecology, distribution, and functional roles of these organisms in the field.

### Author Contributions

**A. R. A. Barros:** resources, conceptualization, investigation, funding acquisition, writing – original draft, methodology, validation, visualization, writing – review and editing, data curation, formal analysis. **J. P. I. Martin:** investigation. **G. J. Moraes:** validation, visualization, writing – review and editing, supervision. **M. M. Inomoto:** methodology, writing – review and editing. **R. C. Castilho:** resources, writing – review and editing, validation, supervision, visualization, project administration.

### Acknowledgements

To FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) for the scholarship provided to the first author (Process: 2019/27793-7). This work was supported by the São Paulo Research Foundation (FAPESP) and was part of the BIOTA-FAPESP program (2017/12004-1).

## Conflicts of Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Ávyla Régia de Albuquerque Barros reports financial support was provided by The São Paulo Research Foundation (Fundação de Amparo a Pesquisa do Estado de São Paulo, FAPESP. Process: 2019/27793-7)].

## Data Availability Statement

The data that support the findings of this study are openly available in Zenodo at <https://doi.org/10.5281/zenodo.17037116> (Barros 2025b).

## References

- Afifi, A. M., and L. P. S. van der Geest. 1984. "Notes on the Development and Biology of the Predaceous Soil Mite *Cosmolaelaps claviger* (Berlese 1883) (Gamasida: Laelapidae)." In *Acarology VI. Vol I*, edited by D. Griffiths and C. Bowman, 585–590. Ellis Horwood Limited Publishers.
- Agrofit - Ministério da Agricultura, Pecuária e Abastecimento. 2025. [https://agrofit.agricultura.gov.br/agrofit\\_cons/principal\\_agrofit\\_cons](https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons).
- Aguilar-Marcelino, L., M. T. Quintero-Martínez, P. M. de Gives, et al. 2014. "Evaluation of Predation of the Mite *Lastoseius penicilliger* (Aracnida: Mesostigmata) on *Haemonchus contortus* and Bacteria-Feeding Nematodes." *Journal of Helminthology* 88: 20–23. <https://doi.org/10.1017/S0022149X12000624>.
- Al Rehiyani, S. M., and A. H. Fouly. 2005. "*Cosmolaelaps simplex* (Berlese), a Polyphagous Predatory Mite Feeding on Root-Knot Nematode *Meloidogyne javanica* and Citrus Nematode *Tylenchulus semipenetrans*." *Pakistan Journal of Biological Sciences* 8: 168–174. <https://doi.org/10.3923/pjbs.2005.168.174>.
- Anjos, K. A., F. C. Duarte, L. M. Katiki, R. Giglioti, B. G. Santos, and M. C. Mendes. 2024. "In Vitro Evaluation of the Potential of Mites of the Family Macrochelidae (Acari: Mesostigmata) as Macrobiological Agents Against the Nematode *Haemonchus contortus* (Strongylida: Trichostrongylidae)." *Veterinary Parasitology* 328: 110191. <https://doi.org/10.1016/j.vetpar.2024.110191>.
- Ayub, F., L. Seychelles, O. Strauch, M. Wittke, and R.-U. Ehlers. 2013. "Monoxenic Liquid Culture With *Escherichia coli* of the Free-Living Nematode *Panagrolaimus* sp. (Strain NFS 24-5), a Potential Live Food Candidate for Marine Fish and Shrimp Larvae." *Applied Microbiology and Biotechnology* 97: 8049–8055.
- Azevedo, E. B., L. H. Azevedo, G. F. Moreira, et al. 2020. "Diversity of Soil Gamasina Mites (Acari: Mesostigmata: Gamasina) in an Area of Natural Vegetation and Cultivated Areas of the Cerrado Biome in Northern Brazil." *Diversity* 12: 331. <https://doi.org/10.3390/d12090331>.
- Azevedo, L. H., R. M. Emberson, F. C. N. Esteca, and G. J. Moraes. 2015. "Macrochelid Mites (Mesostigmata: Macrochelidae) as Biological Control Agents." In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*. Progress in Biological Control, edited by D. Carrillo, G. J. Moraes, and J. E. Peña, vol. 19, 103–132. Springer. [https://doi.org/10.1007/978-3-319-15042-0\\_4](https://doi.org/10.1007/978-3-319-15042-0_4).
- Azevedo, L. H., M. F. P. Moreira, G. G. Pereira, et al. 2020. "Combined Releases of Soil Predatory Mites and Provisioning of Free-Living Nematodes for the Biological Control of Root-Knot Nematodes on 'Micro Tom Tomato'." *Biological Control* 146: 104280.
- Bamière, A., J. Petermann, D. Morel, P. Jacquiet, and C. Grisez. 2025. "The Mite *Macrocheles robustulus* (Mesostigmata, Macrochelidae) a New Promising Natural Enemy of *Haemonchus contortus* (Strongylida, Trichostrongylidae)." *Parasites and Vectors* 18: 351. <https://doi.org/10.1186/s13071-025-06990-x>.
- Barbosa, M. F. C., and G. J. Moraes. 2015. "Evaluation of Astigmatid Mites as Factitious Food for Rearing Four Predaceous Phytoseiid Mites (Acari: Astigmatina; Phytoseiidae)." *Biological Control* 91: 22–26. <https://doi.org/10.1016/j.biocontrol.2015.06.010>.
- Barbosa, M. F. C., and G. J. Moraes. 2016. "Potential of Astigmatid Mites (Acari: Astigmatina) as Prey for Rearing Edaphic Predatory Mites of the Families Laelapidae and Rhodacaridae (Acari: Mesostigmata)." *Experimental and Applied Acarology* 69: 289–296. <https://doi.org/10.1007/s10493-016-0043-4>.
- Barros, A. R. A. 2025a. "Diversity and Predatory Potential of Gamasina Soil Mites (Mesostigmata) From the Caatinga Biome and Construction of Databases for Ologamasidae and Rhodacaridae (Mesostigmata: Rhodacaroidea)." Doctorate Thesis. Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba, Brazil, p. 188.
- Barros, A. R. A. 2025b. "Potential of the Predatory Mites *Gamasellodes lavafesii* (Mesostigmata: Ascidae) and *Cosmolaelaps mediocuspis* (Mesostigmata: Laelapidae) on Different Soil Pests/Parasites and Alternative Prey for Large-Scale Rearing." Zenodo (Version 1.0). <https://doi.org/10.5281/zenodo.17037116>.
- Barros, A. R. A., E. B. Azevedo, E. S. Silva, R. C. Castilho, and G. J. Moraes. 2021. "Diversity of Edaphic Gamasina Mites (Acari: Mesostigmata) in Different Ecosystems of the Caatinga Biome in Northeast Brazil." *Systematic and Applied Acarology* 26: 1301–1313. <https://doi.org/10.11158/saa.26.7.10>.
- Bregetova, N. G. 1977. "Laelaptidae." In *Key to the Soil-Inhabiting Mites. Mesostigmata*, edited by M. S. Ghilyarov and N. G. Bregetova, 169–226. Nauka.
- Castilho, R. C., G. J. Moraes, E. S. Silva, R. A. Freire, and F. C. Eira. 2009. "The Predatory Mite *Stratiolaelaps scimitus* as a Control Agent of the Fungus Gnat *Bradysia matogrossensis* in Commercial Production of the Mushroom *Agaricus bisporus*." *International Journal of Pest Management* 55: 181–185. <https://doi.org/10.1080/09670870902725783>.
- Castilho, R. C., G. J. Moraes, E. S. Silva, and L. O. Silva. 2009. "Predation Potential and Biology of *Protogamasellopsis posnaniensis* Wisniewski & Hirschmann (Acari: Rhodacaridae)." *Biological Control* 48: 164–167. <https://doi.org/10.1016/j.biocontrol.2008.10.004>.
- Castilho, R. C., R. Venancio, and J. P. Z. Narita. 2015. "Mesostigmata as Biological Control Agents, With Emphasis on Rhodacaroidea and Parasitoidea." In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*. Progress in Biological Control, vol 19., edited by D. Carrillo, G. J. Moraes, and J. E. Peña, 1–31. Springer. [https://doi.org/10.1007/978-3-319-15042-0\\_1](https://doi.org/10.1007/978-3-319-15042-0_1).
- Castro, M. C., E. B. Azevedo, E. P. J. Britto, et al. 2021. "Gamasina Mite Communities (Acari: Mesostigmata) in Grain Production Systems of the Southwestern Brazilian Amazon." *Systematic and Applied Acarology* 26: 1–14. <https://doi.org/10.11158/saa.26.1.1>.
- Duarte, A. F., J. L. P. Duarte, L. R. Silva, P. C. Gobbi, and U. S. Cunha. 2021. "Evaluation of *Cosmolaelaps brevistilis* and *Stratiolaelaps scimitus* (Mesostigmata: Laelapidae) as Natural Enemy of *Bradysia* Aff. *ocellaris* (Diptera: Sciaridae)." *Systematic and Applied Acarology* 26: 1293–1300. <https://doi.org/10.11158/saa.26.7.9>.
- Freire, R. A. P., and G. J. Moraes. 2007. "Description of a New Species of *Cosmolaelaps* Berlese (Acari: Laelapidae, Hypoaspidae) From Brazil and Its Biological Cycle." *International Journal of Acarology* 33: 353–358. <https://doi.org/10.1080/01647950708683697>.
- Freire, R. A. P., G. J. Moraes, E. S. Silva, A. C. Vaz, and R. C. Castilho. 2007. "Biological Control of *Bradysia matogrossensis* (Diptera: Sciaridae) in Mushroom Cultivation With Predatory Mites." *Experimental and Applied Acarology* 42: 87–93. <https://doi.org/10.1007/s10493-007-9075-0>.
- Grisez, C., W. Perrin, M. Begou, P. Jay-Robert, and P. Jacquiet. 2023. "An Initial Investigation of the Predatory Activity of the Phoretic Mites of Dung Beetles, *Macrocheles* sp. (Mesostigmata: Macrochelidae), on the Gastrointestinal Nematode of Sheep *Haemonchus contortus* (Strongylida: Trichostrongylidae)." *Biological Control* 185: 105301. <https://doi.org/10.1016/j.biocontrol.2023.105301>.

- Gwiazdowicz, D. J., and J. Klemt. 2004. "Mesostigmatic Mites (Acari, Gamasida) in Selected Microhabitats of the Biebrza National Park (NE Poland)." *Biology Letters* 41: 11–19.
- Hassan, M. F., F. M. Momen, A. K. Nasr, A. H. Mabrouk, and M. M. Ramadan. 2017. "Development and Reproduction of Three Predatory Mites (Acari: Laelapidae and Rhodacaridae) on Eggs of *Ephestia kuehniella* (Lepidoptera: Pyralidae)." *Acta Phytopathologica et Entomologica Hungarica* 52: 97–106. <https://doi.org/10.1556/038.52.2017.008>.
- Hibshman, J. D., A. K. Webster, and L. R. Baugh. 2021. "Liquid-Culture Protocols for Synchronous Starvation, Growth, Dauer Formation, and Dietary Restriction of *Caenorhabditis elegans*." *STAR Protocols* 2: 100276. <https://doi.org/10.1016/j.xpro.2020.100276>.
- Hooper, D. J. 1986. "Extraction of Nematodes From Plant Material." In *Laboratory Methods for Work With Plant and Soil Nematodes*, edited by J. F. Southey, 51–58. Her Majesty's Stationery Office.
- Instituto de Controle do Espaço Aéreo (ICEA). 2025. <https://pesquisa.icea.decea.mil.br/>.
- Jones, J. T., A. Haegeman, E. G. J. Danchin, et al. 2013. "Top 10 Plant-Parasitic Nematodes in Molecular Plant Pathology." *Molecular Plant Pathology* 14: 946–961. <https://doi.org/10.1111/mpp.12057>.
- Knapp, M., Y. van Houten, E. Ball, and T. Groot. 2018. "Use of Predatory Mites in Commercial Biocontrol: Current Status and Future Prospects." *Acarologia* 58: 72–82. <https://doi.org/10.24349/acarologia/20184275>.
- Köppen, W. 1948. *Climatologia: Con un Estudio de los Climats de la Tierra*, 479. Fondo de Cultura Económica.
- Lesna, I., M. W. Sabelis, H. R. Bolland, and C. G. M. Conijn. 1995. "Candidate Natural Enemies for Control of *Rhizoglyphus robini* Claparède (Acari: Astigmata) in Lily Bulbs: Exploration in the Field and Pre-Selection in the Laboratory." *Experimental and Applied Acarology* 19: 655–669. <https://doi.org/10.1007/BF00145254>.
- Li, G., P.-T. Chen, M.-L. Chen, et al. 2024. "Effect of *Ephestia kuehniella* Eggs on Development and Transcriptome of the Ladybird Beetle *Propylea japonica*." *Insects* 15: 407. <https://doi.org/10.3390/insects15060407>.
- Lindquist, E. E., G. W. Krantz, and D. E. Walter. 2009. "Order Mesostigmata." In *A Manual of Acarology*, edited by G. W. Krantz and D. E. Walter, 3rd ed., 124–232. Texas Tech University Press.
- McMurtry, J. A., G. J. Moraes, and N. F. Sourassou. 2013. "Revision of the Lifestyles of Phytoseiid Mites (Acari: Phytoseiidae) and Implications for Biological Control Strategies." *Systematic and Applied Acarology* 18: 297–320. <https://doi.org/10.11158/saa.18.4.1>.
- McMurtry, J. A., N. F. Sourassou, and P. R. Demite. 2015. "The Phytoseiidae (Acari: Mesostigmata) as Biological Control Agents." In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*. Progress in Biological Control, edited by D. Carrillo, G. J. Moraes, and J. E. Peña, vol. 19, 133–150. Springer. [https://doi.org/10.1007/978-3-319-15042-0\\_5](https://doi.org/10.1007/978-3-319-15042-0_5).
- Moraes, G. J., R. C. Castilho, and C. H. W. Flechtmann. 2024. *Manual de Acarologia: Acarologia Básica e Ácaros de Plantas no Brasil*. 2ª. Edição ed, 485. Fealq. <https://doi.org/10.37856/9786589722588.fealq.2024.485>.
- Moraes, G. J., R. Venancio, V. L. V. Santos, and A. D. Paschoal. 2015. "Potential of Ascidae, Blattisociidae and Melicharidae (Acari: Mesostigmata) as Biological Control Agents of Pest Organisms." In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*. Progress in Biological Control, 19, edited by D. Carrillo, G. J. Moraes, and J. E. Peña, 33–76. Springer. [https://doi.org/10.1007/978-3-319-15042-0\\_2](https://doi.org/10.1007/978-3-319-15042-0_2).
- Moreira, G. F., and G. J. Moraes. 2015. "The Potential of Free-Living Laelapid Mites (Mesostigmata: Laelapidae) as Biological Control Agents." In *Prospects for Biological Control of Plant Feeding Mites and Other Harmful Organisms*. Progress in Biological Control, 19., edited by
- D. Carrillo, G. J. Moraes, and J. E. Peña, 77–102. Springer. [https://doi.org/10.1007/978-3-319-15042-0\\_2](https://doi.org/10.1007/978-3-319-15042-0_2).
- Moreira, G. F., M. R. Morais, A. C. Busoli, and G. J. Moraes. 2015. "Life Cycle of *Cosmolaelaps jaboticabalensis* (Acari: Mesostigmata: Laelapidae) on *Frankliniella occidentalis* (Thysanoptera: Thripidae) and Two Factitious Food Sources." *Experimental and Applied Acarology* 65: 219–226. <https://doi.org/10.1007/s10493-014-9870-3>.
- Navarro-Campos, C., F. L. Wäckers, and A. Pekas. 2016. "Impact of Factitious Foods and Prey on the Oviposition of the Predatory Mites *Gaeolaelaps aculeifer* and *Stratiolaelaps scimitus* (Acari: Laelapidae)." *Experimental and Applied Acarology* 70: 69–78. <https://doi.org/10.1007/s10493-016-0061-2>.
- Oliveira, A. R., G. J. Moraes, C. G. B. Demétrio, and E. A. B. de Nardo. 2001. *Efeito do Vírus da Poliedrose Nuclear de Anticarsia gemmatilis Sobre Oribatida Edáficos (Arachnida: Acari) em um Campo de Soja*, 32. Embrapa Meio Ambiente.
- Palevsky, E., J. Konopická, D. Rueda-Ramírez, and R. Zemek. 2022. "A Review of Prospective Biocontrol Agents and Sustainable Soil Practices for Bulb Mite (Acari: Acaridae) Management." *Agronomy* 12: 1491. <https://doi.org/10.3390/agronomy12071491>.
- Parra, J. R. P., A. S. Pinto, D. E. Nava, R. C. Oliveira, and A. J. F. Diniz. 2021. *Controle Biológico Com Parasitoides e Predadores na Agricultura Brasileira*, 592. Fealq.
- Parra, J. R. P., T. A. Takahashi, L. D. Geremias, and A. Coelho Junior. 2023. *Criação de Ephestia kuehniella em Pequena Escala Para Produção de Trichogramma*, 47. Esalq.
- Peel, M. C., B. L. Finlayson, and T. A. McMahon. 2007. "Updated World Map of the Köppen-Geiger Climate Classification." *Hydrology and Earth System Sciences* 11: 1633–1644. <https://doi.org/10.5194/hess-11-1633-2007>.
- Phani, V., M. R. Khan, and T. K. Dutta. 2021. "Plant-Parasitic Nematodes as a Potential Threat to Protected Agriculture: Current Status and Management Options." *Crop Protection* 144: 105573. <https://doi.org/10.1016/j.cropro.2021.105573>.
- Prado, T. J. 2023. "Potencial do Ácaro Predador *Protogamasellopsis zaheri* (Rhodacaridae) no Controle do Fitonematoide *Meloidogyne incognita* (Meloidogynidae)." Doctorate Thesis. Universidade Estadual Paulista, Jaboticabal, p. 78.
- R Core Team. 2020. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>.
- R Studio Team. 2019. *R Studio: Integrated Development for R*. RStudio, Inc. <http://www.rstudio.com/>.
- Rossini, L. A. C. J., T. J. Prado, R. J. Ferreira, P. L. M. Soares, G. J. Moraes, and R. C. Castilho. 2022. "Suitability of the Soybean Cyst Nematode as Prey to *Protogamasellopsis zaheri* (Acari: Mesostigmata: Rhodacaridae)." *Biological Control* 170: 104905. <https://doi.org/10.1016/j.biocontrol.2022.104905>.
- Rueda-Ramírez, D., A. Narberhaus, E. Palevsky, J. Hallmann, and L. Ruess. 2023. "Bottom-Up Effects of Nematode Prey on Soil Predatory Mites (Acari: Mesostigmata)." *Soil Biology and Biochemistry* 185: 109143. <https://doi.org/10.1016/j.soilbio.2023.109143>.
- Rueda-Ramírez, D., E. Palevsky, and L. Ruess. 2023. "Soil Nematodes as a Means of Conservation of Soil Predatory Mites for Biocontrol." *Agronomy* 13: 1–27. <https://doi.org/10.3390/agronomy13010032>.
- Rueda-Ramírez, D., D. Rios-Malaver, A. Varela-Ramírez, and G. J. Moraes. 2019. "Biology and Predation Capacity of *Parasitus bituberousus* (Acari: Mesostigmata: Parasitidae) on *Frankliniella occidentalis* (Thysanoptera: Thripidae) and Free-Living Nematodes as Complementary Diet." *Pest Management Science* 75: 1819–1830. <https://doi.org/10.1002/ps.5326>.
- Stiernagle, T. 2006. "Maintenance of *C. elegans*." In *WormBook*. C. elegans Research Community, WormBook. <http://www.wormbook.org>. <https://doi.org/10.1895/wormbook.1.101.1>.

- Taylor, M. A., R. L. Coop, and R. L. Wall. 2016. *Veterinary Parasitology*. Fourth ed, 1006. Wiley Blackwell. <https://doi.org/10.1002/9781119073680>.
- van Lenteren, J. C. 2012. "The State of Commercial Augmentative Biological Control: Plenty of Natural Enemies, but a Frustrating Lack of Uptake." *BioControl* 57: 1–20. <https://doi.org/10.1007/s10526-011-9395-1>.
- van Lenteren, J. C., K. Bolckmans, J. Köhl, W. J. Ravensberg, and A. Urbaneja. 2018. "Biological Control Using Invertebrates and Microorganisms: Plenty of New Opportunities." *BioControl* 63: 39–59. <https://doi.org/10.1007/s10526-017-9801-4>.
- Walter, D. E. 2003. "The Genus *Gamasellodes* (Acari: Mesostigmata: Ascidae): New Australian and North American Species." *Systematic and Acarology Acarology Special Publications* 15: 1–10. <https://doi.org/10.11158/saasp.15.1.1>.
- Walter, D. E., and E. K. Ikonen. 1989. "Species, Guilds and Functional Groups: Taxonomy and Behaviour in Nematophagous Arthropods." *Journal of Nematology* 21: 315–327.
- Walter, D. E., and D. T. Kaplan. 1990. "A Guild of Thelytokous Mites (Acari: Mesostigmata) Associated With Citrus Roots in Florida." *Environmental Entomology* 39: 1338–1343.
- Walter, D. E., and J. H. Oliver. 1989. "*Geolaelaps oreithyiae*, n. sp. (Acari: Laelapidae), a Thelytokous Predator of Arthropods and Nematodes, and a Discussion of Clonal Reproduction in the Mesostigmata." *Acarologia* 30: 293–303.
- Wu, Z.-Y., X.-H. Zhang, J. Luo, and Q.-H. Fan. 2009. "Effects of Five Preys on Growth and Reproduction of *Lasioseius* sp." *Journal of Fujian Agriculture and Forestry University (Natural Science Edition)* 38: 581–584.
- Xu, C.-L., Y.-L. Chen, X.-N. Xu, et al. 2014. "Evaluation of *Blattisocius dolichus* (Acari: Blattisociidae) for Biocontrol of Root-Knot Nematode, *Meloidogyne incognita* (Tylenchida: Heteroderidae)." *BioControl* 59: 617–624. <https://doi.org/10.1007/s10526-014-9581-z>.
- Yang, S.-H., D. Wang, C. Chen, C.-L. Xu, and H. Xie. 2020. "Evaluation of *Stratiolaelaps scimitus* (Acari: Laelapidae) for Controlling the Root-Knot Nematode, *Meloidogyne incognita* (Tylenchida: Heteroderidae)." *Scientific Reports* 10: 5645. <https://doi.org/10.1038/s41598-020-62643-2>.
- Zhou, W.-Q., C.-L. Xu, X.-N. Xu, et al. 2012. "The Predatory Mite *Neoseiulus barkeri* (Acari: Phytoseiidae), a New Biocontrol Approach for Plant-Parasitic Nematode, and Associated Development and Reproduction." *Chinese Journal of Biological Control* 4: 484–489. <https://doi.org/10.3969/j.issn.2095-039X.2012.04.007>.