

Soil-dwelling arthropod assemblages in maize sprayed with entomopathogenic fungi from South Sumatra, Indonesia

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Abstract. Herlinda S, Nasir MY, Suwandi S, Anggraini E, Irsan C, Sari JMP, Rindiani DE. 2025. Soil-dwelling arthropod assemblages in maize sprayed with entomopathogenic fungi from South Sumatra, Indonesia. *Biodiversitas* 26: 3387-3396. This study examined effects of entomopathogenic fungi on abundance and species diversity of soil-dwelling arthropods associated with maize. The fungal species applied were *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*. Pitfall traps and Berlese funnels were employed to collect arthropods soil-dwelling on the ground surface and within/below the soil, respectively. The identified arthropod guilds included predatory, herbivorous, and detritivore arthropods, with predatory arthropods being the most abundant. The arthropods were categorized into classes of Insecta, Collembola, Arachnida, and Diplopoda. The arthropods found from the ground surface and below the soil were 25 and 8 species, respectively. The total abundance (achieving 300 individuals/20 traps) of predatory arthropods did not differ significantly ($P>0.05$) across all treatments. The species diversity of below-ground predatory arthropods exhibited a significant decrease ($P<0.05$) after treatment with *P. citrinum* (H' from 0.71 to 0.39). The detritivore arthropod abundance from ground surface increased significantly ($P<0.05$) after being treated with *B. bassiana* (695 individuals/20 traps) compared to *M. anisopliae* (588 individuals/20 traps) and *P. citrinum* (569 individuals/20 traps) treatments. Therefore, *M. anisopliae* and *P. citrinum* could alter ground-surface arthropod assemblages. However, *B. bassiana* application may be integrated with soil-dwelling predatory arthropods for Integrated Pest Management (IPM) and for environmental safety.

Keywords: *Beauveria bassiana*, Berlese funnel, *Metarhizium anisopliae*, *Penicillium citrinum*, pitfall trap

INTRODUCTION

Maize (*Zea mays* L.) is attacked by several insect pest species that may disrupt. For example, *Helicoverpa armigera* (Hübner, 1808) (Lepidoptera: Noctuidae) bores corn cobs, causing the cob prices decreasing significantly (da Silva et al. 2020). (da Silva et al. 2020). The fall armyworm, *Spodoptera frugiperda* (J.E.Smith, 1797) (Lepidoptera: Noctuidae) which can damage corn seedlings and growing points, causing 100% damage (Herlinda et al. 2022). The Asian corn borer, *Ostrinia furnacalis* (Guenée, 1854) (Lepidoptera: Crambidae), bores into corn stalks and causes corn death (Alviar et al. 2021). These pests are generally controlled with synthetic insecticides (da Silva et al. 2020; Alviar et al. 2021). They have generally developed resistance to the synthetic insecticides (Lv et al. 2020). Spraying insecticides also kills non-target arthropods (Ricupero et al. 2020). A better alternative pest control compared to synthetic insecticides is to apply biological control using natural enemies, such as entomopathogenic fungi.

Entomopathogenic fungi demonstrated to be lethal to *H. armigera* larvae are *Nomuraea rileyi* and *Isaria tenuipes* (Vega-Aquino et al. 2010). *Beauveria bassiana* and *Metarhizium anisopliae* are proficient in killing *S. frugiperda* larvae (Sari et al. 2023). *Purpureocillium* sp. can kill *O.*

furnacalis larvae (Chen et al. 2024). Research indicated that entomopathogenic fungi can be combined with the release of egg parasitoids to control the insect pest, *Duponchelia fovealis* (Zeller, 1847) (Lepidoptera: Crambidae) (Araujo et al. 2020). Moreover, the fungi do not decrease the emergence rate of parasitoid adults from their host eggs (Putri et al. 2024). Field studies have shown that entomopathogenic fungi do not diminish the population of arboreal predatory arthropods in paddy fields (Hanif et al. 2020), however, the fungi can reduce the population of rice pests (Herlinda et al. 2020c).

Previous studies indicated the presence of entomopathogenic fungi in both lowland and highland regions of South Sumatra, with some fungi isolated from soil (Safitri et al. 2018) and others from fungal infected insects (Herlinda et al. 2020b) and plant tissues (Herlinda et al. 2021). The fungi from South Sumatra have also been shown to act as entomopathogens, for example, *Penicillium citrinum* and topical application of fungi results in a mortality rate of 98.67% in *Spodoptera litura* (Fabricius, 1775) larvae (Herlinda et al. 2020a). Whereas as an endophytic entomopathogenic fungus, *B. bassiana* induces a mortality rate of 51.33% in *S. frugiperda* larvae in corn (Sari et al. 2022). The endophytic entomopathogenic fungi are isolated from the plants, this means that the fungi can inhabit the

plant tissues both intracellularly and intercellularly (de Lira et al. 2020; Herlinda et al. 2021). The endophytic entomopathogenic fungi establish a mutually beneficial symbiotic relationship with their host plants and enhance the host plant growth and protection against insect pests (Kinyungu et al. 2023).

Entomopathogenic fungi applied to the leaf surfaces generate residues that may be transferred to the soil (Gava et al. 2021) to facilitate exposure to non-target arthropods, such as soil-dwelling arthropod assemblages. *B. bassiana* has adversely effect on non-target arthropods (araneid, lycosid, salticids, and carabid beetles) under field conditions (Goettel et al. 2021). *B. bassiana* and *Metarhizium brunneum* cause mortality of *Solenopsis invicta* (Buren, 1972) achieving more than 50% (Rojas et al. 2018). *Beauveria bassiana* can contaminate the genus *Formica* (Novgorodova 2021). The effects of spraying entomopathogenic fungi on the abundance and species diversity of soil-dwelling arthropods remain inadequately studied. The study of soil-dwelling arthropods is essential due to the predominance of predatory arthropods and detritivore arthropods within this group. Soil-dwelling arthropods in paddy fields are predominantly predatory arthropods, comprising over 88%, with the remainder consisting of detritivore and herbivorous arthropods (Karenina et al. 2020). Predatory arthropods serve as predators of insect pests, while detritivore arthropods function as decomposers and alternative prey for these predatory arthropods (Karenina et al. 2019). This study aimed to analyze the effects of applying entomopathogenic fungi from South Sumatra on the abundance and species diversity of soil-dwelling arthropods associated with maize plants.

MATERIALS AND METHODS

Study area and field preparation

This study was conducted from March to September 2024 in the maize fields located in the test farm of Faculty of Agriculture, Universitas Sriwijaya (3°13'15"S 104°38'49"E), Indralaya, Ogan Ilir District of South Sumatra Province, Indonesia. The field experiment was set up in a Latin-square design with four treatments and four replications. The treatments were maize plots treated with three fungal species and control (untreated fungal treatment). The fungal species used were *B. bassiana*, *M. anisopliae*, and *P. citrinum*. The fungi were identified molecularly and deposited in Genbank. The isolates of each fungus were *B. bassiana* JgSPK isolate (acc. no. MZ356494), *M. anisopliae* CaTpPga isolate (acc. no. MZ242073), and *P. citrinum* JaTpOi (2) isolate (acc. no. MZ359812) (Herlinda et al. 2021). The experimental plot measured 12 m × 12 m and was subdivided into 16 sub-plots (9 m² per subplot), with each subplot containing 60 maize plants at a spacing of 50 cm × 30 cm. The variety of maize seed used were Bonanza' (yellow) sweet corn. Before being planted, the seeds were surface sterilized according to the method of Russo et al. (2020). The plants were mechanically weeded weekly without the application of herbicides and received water

daily using a pump. Manure was applied at a rate of 1 ton per hectare.

Preparation and application of entomopathogenic fungi

The fungal isolates were recultured on Glucose-Yeast extract Agar (GYA) medium. The GYA medium was composed of 1 L of distilled water, 20 g of agar, 10 g of sucrose, 5 g of cricket powder, and 4 g of yeast (Azish et al. 2021). The GYA medium was boiled to ensure complete dissolution and subsequently sterilized via autoclaving at 121°C for 20 minutes. Then, each isolate was grown on GYA medium. The fungal culture was incubated for 14 day at 82±1% of relative humidity and room temperature (27±1°C). Fungal suspension with concentration of 1×10¹⁰ conidia.mL⁻¹ was sprayed on maize leaf surface with dosage of 0.5 L per sub-plot (9 m²) and for the control sprayed with 0.5 L of sterilized tap water. The fungal suspension was sprayed on the leaves from 7 am to 8 am when the maize stomata were opened (de Oliveira et al. 2025). The fungal spraying was conducted when the maize was on susceptible stages, 21, 35, and 49 days old after planting and this experiment was replicated four times.

Sampling of soil-dwelling arthropods using pitfall traps

Arthropods dwelling surface soil were collected using pitfall traps. Two pitfall traps were positioned in a sub-plot, with a spacing of 1.5 m between them at the center. The pitfall traps were constructed using 220 mL transparent plastic cups with a height of 120 mm and an opening diameter of 50 mm, as described in the modified technique of Bertoia et al. (2023). The pitfall trap contained approximately 60 mm of water mixed with 0.5 mL of liquid soap to inhibit the escape of soil-dwelling arthropods. Pitfall traps were deployed in a sub-plot and inspected 24 hours post-installation in the cornfield. Pitfall traps were installed at 14, 21, 28, 35, 42, 49, 56, 63, 70, and 77 days post-planting of corn. All collected arthropods were cleaned and separated from debris. The arthropods were labeled and preserved in glass vials containing 30 mL of 96% ethanol. The specimens were examined with an Olympus Zoom Stereo Microscope SZ51, and arthropod images were obtained using an Optilab Advance Plus Sony IMX577. Arthropods were identified to the genus or species level based on morphological characteristics at the Laboratory of Entomology, Department of Plant Protection, Faculty of Agriculture, Universitas Sriwijaya. Spiders were identified using Whyte and Anderson (2017), while insects were identified using Soto-Adames et al. (2008) and Heinrichs et al. (2017) conducted by our team, an insect taxonomist, Dr. Chandra Irsan. Mites were identified using Ihsan et al. (2021) and clarified by an acarologist from Brawijaya University, Prof. Retno Dyah Puspitarini.

Samplings of soil-dwelling arthropods using Berlese funnel

Arthropods dwelling within the soil were collected utilizing Berlese funnels. A soil core sample with a diameter of 5 cm was collected and extended to a depth of 20 cm for Berlese funnel extraction in each sub-plot (Junod et al. 2023). Soil cores were collected on a weekly basis from specific locations. Soil samples were collected on

days 14, 21, 28, 35, 42, 49, 56, 63, 70, and 77 days after planting of maize. The soil cores were stored in sealed plastic bags and then placed in a Berlese extractor within one hour of collection. The extractor comprised a wooden frame that housed funnels with a diameter of 15 cm. The entrance of the funnel tube was equipped with a 1 cm nylon mesh screen, onto which the soil core was positioned. A 25 W light bulb functioned as the heat source, located centrally 15 cm above each funnel, and remained illuminated during the two-day extraction period. A glass container (diameter 50 mm, height 84 mm) containing water and liquid soap was placed at the funnel's base to collect arthropod specimens. All arthropod specimens were meticulously cleaned and separated from debris. The specimens were examined with an Olympus Zoom Stereo Microscope SZ51, and arthropod images were obtained using an Outilab Advance Plus Sony IMX577. All arthropods were identified based on morphological characteristics to the genus or species level. The spiders were identified using Whyte and Anderson (2017), while insects were identified using Soto-Adames et al. (2008) and Heinrichs et al. (2017). The mites were identified using Ihsan et al. (2021).

Data analysis

The data on species composition and abundance of soil-dwelling arthropods were classified into guilds: predatory, parasitoid, herbivorous, and detritivore arthropods. Analysis of Variance (ANOVA) was employed to analyze the differences in arthropod data across treatments with four replications. The Tukey's Honestly Significant Difference (HSD) test was employed to evaluate significant differences among the treatments at $P = 0.05$. The data were computed utilizing the open-source software platform R Studio. The measurement of species diversity was conducted using the Shannon-Wiener index (H'), dominance (D), and evenness (E) (Magurran 2004).

RESULTS AND DISCUSSION

Soil-dwelling arthropod species

A total of 25 species of soil-dwelling arthropods were collected using pitfall traps in maize sprayed with *B. bassiana*, *M. anisopliae*, *P. citrinum*, and control. The species number of arthropods from maize sprayed with *M. anisopliae* was 24, but the species number from other treatments and control was 25 (Table 1). The arthropod species were sampled using pitfall traps that were operational on the ground surface. The identified arthropod guilds comprised predatory, herbivorous, and detritivore arthropods. The predatory arthropods were the most numerous species, but no parasitoid guild was found. The identified arthropods were categorized into class of Insecta, Collembola, Arachnida, and Diplopoda. The identified Insecta comprised five orders and seven families, while Collembola had an order and a family. Two orders and three families of Arachnida were identified. The Diplopoda comprised only two orders and two families. The identified arthropod guilds included predatory, herbivorous, and detritivore arthropods, with predatory arthropods being the

most prevalent among them. No parasitoid guilds were found in the experiment. The identified predatory arthropod species were *Chlaenius* sp., *Melanolestes picipes* (Herrich-Schaeffer, 1848), *Camponatus americanus* (Buckley, 1866), *Tegenaria domestica* (Clerck, 1757), *Microlinyphia pusilla* (Sundevall, 1830), *Pardosa amentata* (Clerck, 1757), *Monomorium floricola* (Jerdon, 1851), *Labidura riparia* (Pallas, 1773), *Odontoponera denticulata* (F. Smith, 1858), *Solenopsis invicta* (Buren, 1972), *Trochosa ruricola* (De Geer, 1778), *Pardosa hortensis* (Thorell, 1872), and two unknown species from family of Cunaxidae and Laelapidae (Figure 1). The herbivorous arthropod species collected included *Tetrix subulata* (Linnaeus, 1758), *Phyllopalpus pulchellus* (Uhler, 1864), *Dianemobius fascipes* (Walker, 1869), *Velarifictorus micado* (Saussure, 1877), and *Tetrix undulata* (Sowerby, 1806) (Figure 2). The identified detritivore arthropods were an oribatid mite or Oribatida (unknown species), *Entomobrya atrocincta* (Schött, 1896), *Orchesella cincta* (C. Linnaeus, 1758), *Entomobrya nivalis* (C. Linnaeus, 1758), *Asiomorpha coarctata* (De Saussure, 1860), and *Trigoniulus coralinus* (Eydoux & Souleyet, 1842) (Figure 3).

A total of eight of soil-dwelling arthropod species were collected using Berlese funnels in maize treated with *B. bassiana*, *M. anisopliae*, *P. citrinum*, and the control group (Table 2). The arthropod species collected via Berlese funnels typically exhibit activity both on the surface and within the soil substrate. The identified arthropod guilds comprised predatory, herbivorous, and detritivore arthropods but no parasitoid guild was found. The most abundant species was the predatory arthropods. Classes of Insecta and Arachnida were identified from the Berlese funnels. The identified Insecta comprised three orders and three families and Collembola comprised an order and a family. The Arachnida gathered from the funnels comprised two orders and two families. The identified arthropod guilds included predatory, herbivorous, and detritivore arthropods. The parasitoid was not detected in the funnels. The predominant guild identified was also the predatory arthropods. The collected predatory arthropod species were *L. riparia*, *S. invicta*, *M. pusilla*, and *Anoplolepis gracilipes* (Smith, 1857) (Figure 4). The identified herbivorous arthropod species was only *Ahasverus advena* (Walt, 1832) (Figure 5). The detritivore arthropods found were an oribatid mite or Oribatida (unknown species), *Entomobrya atrocincta* (Schött, 1896) and *Entomobrya nivalis* (C. Linnaeus, 1758) (Figure 6).

Abundance and species diversity of soil-dwelling arthropods

A total abundance of soil-dwelling predatory arthropods collected from pitfall traps did not significantly differ among all treatments ($P > 0.05$) (Table 3). However, the abundance of some predatory arthropod species (*T. ruricola*, *M. pusilla*, *T. domestica*, *C. americanus*, *A. gracilipes*, unknown species Cunaxidae) treated with the entomopathogenic fungi was significantly different from control ($P > 0.05$) (Table 1). The abundance of *C. americanus* was highest in maize treated with *M. anisopliae* and was not significantly different from the *M. anisopliae* treatment, but was significantly different from *P. citrinum*

treatment and control (untreated fungal maize). *Tegenaria domestica* and *A. gracilipes* decreased significantly on the fungal treated maize ($P < 0.05$). However, *T. ruricola* and Cunaxidae (unknown species) increased significantly on the fungal treated maize ($P < 0.05$). Consequently, fungi did not reduce the abundance of soil-dwelling predatory arthropods. The total abundance of herbivorous insects collected from pitfall traps did not differ significantly across all treatments ($P > 0.05$) (Table 3). Nevertheless, herbivorous insect, *T. undulata* decreased significantly in the control ($P < 0.05$) but did not differ significantly from maize treated with *B. bassiana* (Table 1). Total abundance of detritivore arthropods increased significantly on the fungal-treated maize ($P < 0.05$) (Table 3) and detritivore abundance increased were *E. atrocincta*, *E. nivalis*, *O. cincta*, and *A. coarctata* (Table 1).

The total abundance of soil-dwelling predatory arthropods collected from Berlese funnels did not differ significantly

among all treatments ($P > 0.05$) (Table 4). However, the abundance of predatory insect, *S. invicta* treated with *P. citrinum* decreases significantly ($P < 0.05$) (Table 2). The fungus application had no effect on the abundance of other species of predatory arthropods ($P > 0.05$). Thus, fungi only affected the abundance of a species (*S. invicta*) of soil-dwelling predatory arthropods and tended not to reduce the abundance of the other predatory arthropods. The total abundance of herbivorous arthropods collected from Berlese funnels did not differ significantly among the treatments ($P > 0.05$) (Table 4). The total abundance of detritivore arthropods collected from Berlese funnels increased significantly after treatment with entomopathogenic fungi ($P < 0.05$) (Table 4). The prevalence of detritivore arthropod, *E. nivalis* increased significantly after treated with *M. anisopliae* and *P. citrinum* (Table 2).

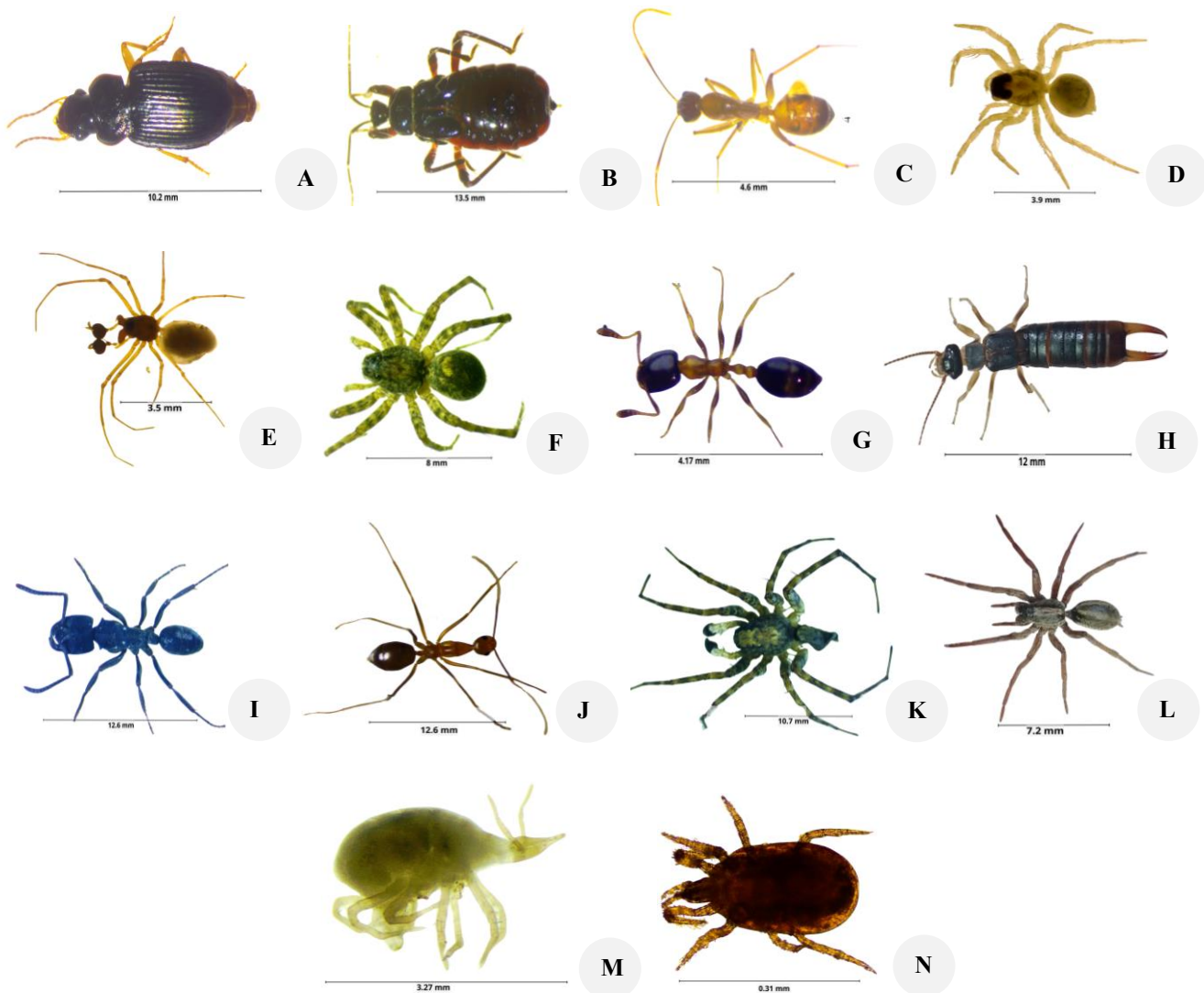


Figure 1. Species of soil-dwelling predatory arthropods collected using pitfall traps in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: A. *Chlaenius* sp., B. *Melanolestas picipes*, C. *Camponatus americanus*, D. *Tegenaria domestica*, E. *Microlinyphia pusilla*, F. *Pardosa amentata*, G. *Monomorium floricola*, H. *Labidura riparia*, I. *Odontoponera denticulata*, J. *Solenopsis invicta*, K. *Trochosa ruricola*, L. *Pardosa hortensis*, M. Cunaxidae (unknown species), N. Laelapidae (unknown species)

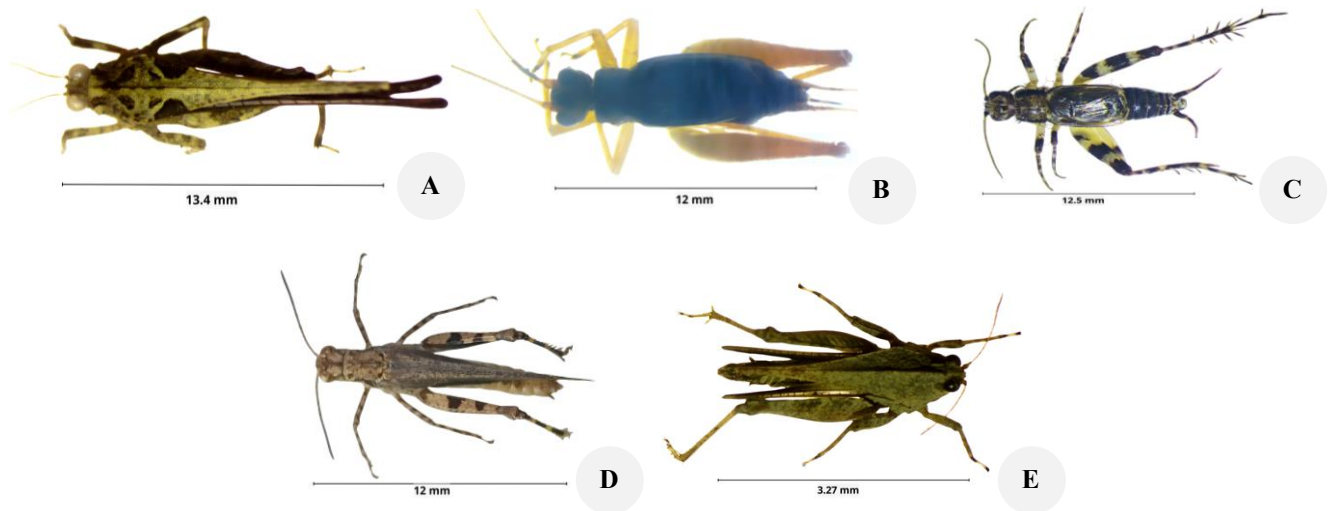


Figure 2. Species of soil-dwelling herbivorous arthropods collected using pitfall traps in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: A. *Tetrax subulata*, B. *Phyllopalpus pulchellus*, C. *Dianemobius fascipes*, D. *Velarifictorus micado*, and E. *Tetrax undulata*

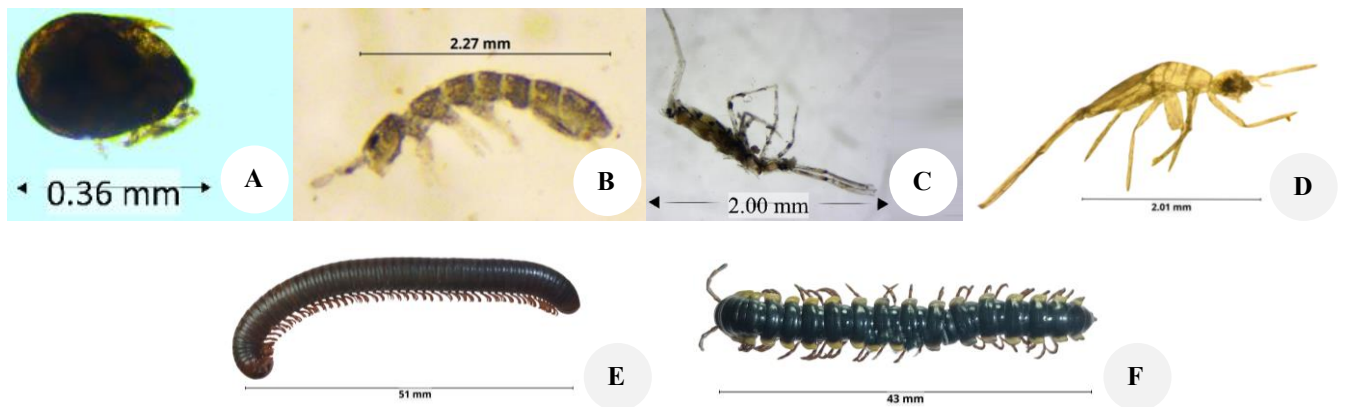


Figure 3. Species of soil-dwelling detritivore arthropods collected using pitfall traps in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: A. Oribatida (unknown species), B. *Entomobrya atrocincta*, C. *Orchesella cincta*, D. *Entomobrya nivalis*, E. *Asiomorpha coarctata*, and F. *Trigoniuulus coralinus*



Figure 4. Species of soil-dwelling predatory arthropods collected using Berlese funnels in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: A. *Labidura riparia*, B. *Solenopsis invicta*, C. *Microlynphia pusilla*, D. *Anoplolepis gracilipes*

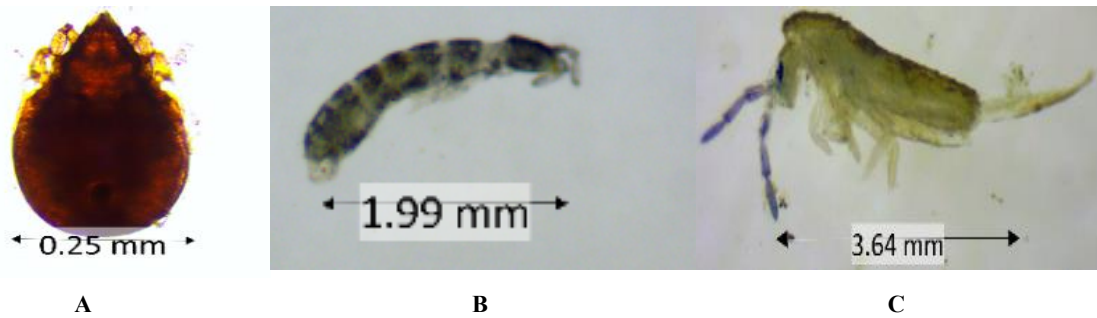


Figure 6. Species of soil-dwelling detritivore arthropods collected using Berlese funnels in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: A. Oribatida (unknown species), B. *Entomobrya atrocincta*, C. *Entomobrya nivalis*



Figure 5. Species of soil-dwelling herbivorous arthropods collected using Berlese funnels in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*: *Ahasverus advena*

Species diversity and evenness of soil-dwelling predatory arthropods collected from pitfall traps were not affected by fungal applications ($P > 0.05$) but their species dominance was affected by fungal application (Table 3). There were no significant differences in the species diversity of herbivorous arthropods collected from pitfall traps across all treatments ($P > 0.05$). Species diversity, evenness, and dominance of detritivore arthropods collected from pitfall traps was not significantly different among all treatments ($P > 0.05$). However, abundance of detritivore arthropods increased significantly after treatment with entomopathogenic fungi ($P < 0.05$).

The species diversity of soil-dwelling predatory arthropods collected from Berlese funnels exhibited a significant decrease after treatment with *P. citrinum* ($P < 0.05$), and species dominance was also observed in maize treated with the fungus of *B. bassiana* (Table 4). The predatory arthropod community was primarily represented by the ant species, *A. gracilipes*. The species diversity of herbivorous collected from Berlese funnels did not exhibit significant differences across all treatments ($P > 0.05$), but detritivore arthropod abundance increased significantly after treatment with entomopathogenic fungi ($P < 0.05$). This indicated that the entomopathogenic fungi did not cause any harm to below-ground herbivorous and detritivore arthropods. However, *P. citrinum* could decrease species diversity of

predatory arthropods within the soil. This indicated that *P. citrinum* could harm soil-dwelling predators.

Discussion

Entomopathogenic fungi sprayed to the leaf surfaces generate residues that can be absorbed into the soil and effect the abundance and species diversity of soil-dwelling arthropods. A total of 25 species of soil-dwelling arthropods were collected from the soil surface in maize treated with *B. bassiana*, *M. anisopliae*, *P. citrinum*, and a control. This collection included 14 species of predatory arthropods, 5 species of herbivorous arthropods, and 6 species of detritivore arthropods. The species number of arthropods within the soil was only found to be 8 species, namely 4 species of predatory arthropods, 1 species of herbivorous arthropods, and 3 species of detritivore arthropods. Predatory arthropod species were the most abundant in the soil. The predominant arthropod species identified on the soil surface and within the soil were predatory arthropods. These predatory arthropods significantly contributed to ecosystem services. Predatory arthropods, including *P. amentata*, may prey on fruit flies and detritivore arthropods (Toft et al. 2024).

The number of herbivorous arthropod species observed on the soil surface (5 species) exceeded that found within the soil (1 species). They were *T. subulata*, *P. pulchellus*, *D. fascipes*, *V. micado*, *T. undulata*, and *A. advena*. *Ahasverus advena* is a pest commonly identified in corn grain products within warehouses (de Sousa et al. 2020). *Tetrix subulata* and *T. undulata* are common groundhoppers found on surface soil of crops, such as rice and they are polyphagous herbivores (Herlinda et al. 2019). In this research, *T. undulata* was significantly suppressed by *B. bassiana*, but other herbivore abundance was not affected by the fungal applications. The prepupae and pupae of lepidopteran found within the soil, including *S. frugiperda*, were eliminated by *B. bassiana* and *M. brunneum* (Garrido-Jurado et al. 2020). *Penicillium citrinum* has the potential to induce mortality in insect pests, such as *S. litura* (Sharma and Kulkarni 2024).

Table 1. Species composition and abundance of soil-dwelling arthropods collected using pitfall traps in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*

Class/Order/Family	Species composition	Guilds	Arthropod abundance (individual/20 traps)				P-value
			Bb	Ma	Pc	Co	
Arachnida/Araneae/Lycosidae	<i>Pardosa amentata</i> (Clerck, 1757)	PR	15.25	13.75	12.50	14.75	0.56 ^{ns}
Arachnida/Araneae/Lycosidae	<i>Pardosa hortensis</i> (Thorell, 1872)	PR	4.75	4.50	6.50	5.00	0.57 ^{ns}
Arachnida/Araneae/Lycosidae	<i>Trochosa ruricola</i> (De Geer, 1778)	PR	15.50 ^a	16.50 ^a	7.50 ^b	7.75 ^b	0.03 [*]
Arachnida/Araneae/Linyphiidae	<i>Microlinyphia pusilla</i> (Sundevall, 1830)	PR	0.00 ^b	1.00 ^a	0.00 ^b	0.00 ^b	0.02 [*]
Arachnida/Araneae/Agelenidae	<i>Tegenaria domestica</i> (Clerck, 1757)	PR	43.25 ^{ab}	26.00 ^b	22.75 ^c	66.00 ^a	0.01 [*]
Insecta/Coleoptera/Carabidae	<i>Chlaenius</i> sp.	PR	1.75	1.50	1.50	1.25	0.99 ^{ns}
Insecta/Dermaptera/Labiduridae	<i>Labidura riparia</i> (Pallas, 1773)	PR	14.75	6.50	6.00	4.75	0.19 ^{ns}
Insecta/Hemiptera/Reduviidae	<i>Melanolestas picipes</i> (Herrich-Schaeffer, 1848)	PR	5.25	4.25	4.00	5.75	0.81 ^{ns}
Insecta/Hymenoptera/Formicidae	<i>Camponatus americanus</i> (Buckley, 1866)	PR	96.50 ^a	97.25 ^a	56.75 ^b	49.50 ^b	0.01 [*]
Insecta/Hymenoptera/Formicidae	<i>Monomorium floricola</i> (Jerdon, 1851)	PR	13.00	12.50	11.75	16.50	0.37 ^{ns}
Insecta/Hymenoptera/Formicidae	<i>Anoplolepis gracilipes</i> (Smith, 1857)	PR	31.50 ^b	37.25 ^b	52.25 ^a	69.00 ^a	3.73x10 ⁻³ [*]
Insecta/Hymenoptera/Formicidae	<i>Odontoponera denticulata</i> (F.Smith, 1858)	PR	25.00	21.50	16.75	23.25	0.33 ^{ns}
Arachnida/Acariformes/Laelapidae	Unknown species	PR	17.25	15.50	23.25	22.50	0.43 ^{ns}
Arachnida/Acariformes/Cunaxidae	Unknown species	PR	15.75 ^a	14.75 ^a	8.50 ^{ab}	4.50 ^b	0.04 [*]
Insecta/Orthoptera/Gryllidae	<i>Velarifictorus micado</i> (Saussure, 1877)	HA	17.25	23.25	22.25	20.25	0.84 ^{ns}
Insecta/Orthoptera/Tetrigidae	<i>Tetrix undulata</i> (Sowerby, 1806)	HA	4.50 ^b	13.75 ^a	11.75 ^a	8.25 ^{ab}	0.05 [*]
Insecta/Orthoptera/Tetrigidae	<i>Tetrix subulata</i> (Linnaeus, 1758)	HA	2.75	1.50	1.00	1.75	0.62 ^{ns}
Insecta/Orthoptera/Trigoniidae	<i>Dianemobius fascipes</i> (Walker, 1869)	HA	60.75	57.50	59.75	68.25	0.56 ^{ns}
Insecta/Orthoptera/Trigoniidae	<i>Phyllopalpus pulchellus</i> (Uhler, 1864)	HA	4.50	5.50	2.25	2.75	0.24 ^{ns}
Arachnida/Acariformes/Oribatida	Unknown species	DA	33.25	72.00	37.25	42.50	0.27 ^{ns}
Collembola/Entomobryomorpha/Entomobryidae	<i>Entomobrya atrocincta</i> (Schött, 1896)	DA	222.25 ^b	152.25 ^b	153.75 ^{ab}	180.50 ^{ab}	0.01 [*]
Collembola/Entomobryomorpha/Entomobryidae	<i>Entomobrya nivalis</i> (C.Linnaeus, 1758)	DA	299.75 ^a	257.25 ^b	248.00 ^b	251.25 ^b	0.02 [*]
Collembola/Entomobryomorpha/Entomobryidae	<i>Orchesella cincta</i> (C.Linnaeus, 1758)	DA	64.50 ^a	47.75 ^{ab}	64.75 ^a	40.75 ^b	0.04 [*]
Diplopoda/Polydesmida/Paradoxomatidae	<i>Asiomorpha coarctata</i> (De Saussure, 1860)	DA	14.75 ^{ab}	13.25 ^{ab}	22.00 ^a	12.25 ^b	0.01 [*]
Diplopoda/Spirobolida/Trigoniulidae	<i>Trigoniulus coralinus</i> (Eydoux & Souleyet, 1842)	DA	60.25	45.75	43.25	53.50	0.27 ^{ns}

Note: PR: Predatory arthropods, HA: Herbivorous Arthropods, DA: Detritivore Arthropods, Bb: Sprayed with *Beauveria bassiana*, Ma: Sprayed with *Metarhizium anisopliae*, Pc: Sprayed with *Penicillium citrinum*, Co: Control (untreated). *: Significantly different, ^{ns}: Not significantly different, data labeled by the different letters in the same row were significantly different ($P<0.05$) according to HSD Tukey's test

Table 2. Species composition and abundance of soil-dwelling arthropods collected using Berlese funnels in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*

Class/Order/Family	Species composition	Guilds	Arthropod abundance (individual/10 funnels)				P-value
			Bb	Ma	Pc	Co	
Arachnida/Araneae/Linyphiidae	<i>Microlinyphia pusilla</i>	PR	1.25	0.75	0.00	0.75	0.41 ^{ns}
Insecta/Dermaptera/Labiduridae	<i>Labidura riparia</i>	PR	1.00	0.75	0.25	0.50	0.53 ^{ns}
Insecta/Hymenoptera/Formicidae	<i>Anoplolepis gracilipes</i>	PR	14.50	16.00	15.75	14.25	0.97 ^{ns}
Insecta/Hymenoptera/Formicidae	<i>Solenopsis invicta</i>	PR	8.25 ^a	7.50 ^a	0.25 ^b	2.00 ^b	0.02 [*]
Insecta/Coleoptera/Silvanidae	<i>Ahasverus advena</i>	HA	0.25	2.00	0.75	1.75	0.73 ^{ns}
Arachnida/Acariformes/Oribatida	Unknown species	DA	23.00 ^a	22.75 ^a	13.00 ^b	15.50 ^b	0.05 [*]
Collembola/Entomobryomorpha/Entomobryidae	<i>Entomobrya atrocincta</i>	DA	23.75	24.25	21.00	21.00	0.61 ^{ns}
Collembola/Entomobryomorpha/Entomobryidae	<i>Entomobrya nivalis</i>	DA	25.50 ^{ab}	30.25 ^a	29.75 ^a	21.25 ^b	0.04 [*]

Note: PR: Predatory arthropods, HA: Herbivorous Arthropods, DA: Detritivore Arthropods, Bb: Sprayed with *Beauveria bassiana*, Ma: Sprayed with *Metarhizium anisopliae*, Pc: Sprayed with *Penicillium citrinum*, Co: Control (untreated). *: Significantly different, ^{ns}: Not significantly different, data labeled by the different letters in the same row were significantly different ($P<0.05$) according to HSD Tukey's test

Table 3. Community characteristics of soil-dwelling arthropods collected using pitfall traps in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*

Community characteristics	Guilds	Bb	Ma	Pc	Co	P-value
Abundance (individuals/20 traps)	Predatory arthropods	300	273	230	291	0.42 ^{ns}
Biodiversity index (H')	Predatory arthropods	2.27	2.12	1.98	2.16	0.19 ^{ns}
Evenness index (E)	Predatory arthropods	1.22	1.25	1.33	1.22	0.24 ^{ns}
Dominance index (D)	Predatory arthropods	0.32 ^a	0.36 ^a	0.25 ^a	0.17 ^b	0.01 [*]
Abundance (individuals/20 traps)	Herbivorous arthropods	90	102	97	101	0.15 ^{ns}
Biodiversity index (H')	Herbivorous arthropods	0.68	0.83	0.71	0.69	0.49 ^{ns}
Evenness index (E)	Herbivorous arthropods	2.38	1.94	2.26	2.32	0.53 ^{ns}
Dominance index (D)	Herbivorous arthropods	0.68	0.57	0.62	0.67	0.42 ^{ns}
Abundance (individuals/20 traps)	Detritivore arthropods	695 ^a	588 ^b	569 ^b	581 ^b	7.50 x 10 ^{-3*}
Biodiversity index (H')	Detritivore arthropods	1.39	1.37	1.36	1.32	0.26 ^{ns}
Evenness index (E)	Detritivore arthropods	1.29	1.30	1.32	1.35	0.22 ^{ns}
Dominance index (D)	Detritivore arthropods	0.43	0.44	0.44	0.44	1.00 ^{ns}

Note: Bb: Sprayed with *Beauveria bassiana*, Ma: Sprayed with *Metarhizium anisopliae*, Pc: Sprayed with *Penicillium citrinum*, Co: Control (untreated), *: Significantly different, ^{ns}: Not significantly different, data labeled by the different letters in the same row were significantly different ($P < 0.05$) according to HSD Tukey's test

Table 4. Community characteristics of soil-dwelling arthropods collected using Berlese funnels in maize sprayed with *Beauveria bassiana*, *Metarhizium anisopliae*, and *Penicillium citrinum*

Community characteristics	Guilds	Bb	Ma	Pc	Co	P-value
Abundance (individuals/10 funnels)	Predatory arthropods	25	25	16	18	0.60 ^{ns}
Biodiversity index (H')	Predatory arthropods	0.96 ^a	0.86 ^{ab}	0.39 ^c	0.71 ^b	4.19 x 10 ^{-3*}
Evenness index (E)	Predatory arthropods	1.44	1.62	3.59	1.96	0.29 ^{ns}
Dominance index (D)	Predatory arthropods	0.58 ^c	0.64 ^{bc}	0.97 ^a	0.81 ^{ab}	0.01 [*]
Abundance (individuals/10 funnels)	Herbivorous arthropods	0	2	1	2	0.65 ^{ns}
Biodiversity index (H')	Herbivorous arthropods	0.00	0.00	0.00	0.00	0.45 ^{ns}
Evenness index (E)	Herbivorous arthropods	-	-	-	-	-
Dominance index (D)	Herbivorous arthropods	1.00	1.00	1.00	1.00	0.45 ^{ns}
Abundance (individuals/10 funnels)	Detritivore arthropods	72 ^{ab}	77 ^a	64 ^{bc}	58 ^c	0.02 [*]
Biodiversity index (H')	Detritivore arthropods	0.73	0.73	0.72	0.72	0.45 ^{ns}
Evenness index (E)	Detritivore arthropods	1.50	1.50	1.52	1.53	0.40 ^{ns}
Dominance index (D)	Detritivore arthropods	0.35	0.39	0.47	0.37	0.09 ^{ns}

Note: Bb: Sprayed with *Beauveria bassiana*, Ma: Sprayed with *Metarhizium anisopliae*, Pc: Sprayed with *Penicillium citrinum*, Co: Control (untreated), *: Significantly different, ^{ns}: Not significantly different, data labeled by the different letters in the same row were significantly different ($P < 0.05$) according to HSD Tukey's test

The number of detritivore arthropod species found on the soil's surface (6 species) exceeds that found in the soil (3 species). Springtails (Collembola) were the most common detritivore arthropods found in this research. Although Collembola were fewer in species number, only five species were found on the surface and within the soil compared to predatory and herbivorous insects, but their abundance was the highest. In this study, the Collembola abundance (*E. atrocincta* and *E. nivalis*) from ground surface decreased significantly after being treated with *M. anisopliae* and *P. citrinum*. However, *B. bassiana* did not reduce Collembola abundance or species diversity. This indicated that *B. bassiana* did not harm the detritivore arthropods inhabiting the surface and within the soil. Therefore, the *B. bassiana* application could be recommended for maize pest control and for environmental safety. Collembola is an indicator of soil health and play crucial roles in nutrient cycling (Mutymbai et al. 2024). Soil arthropod species ($\varnothing > 2$ mm) serve as important biological indicators of specific soil disturbances (Nahmani et al. 2006). Collembola serve a significant function in food chains and webs as alternative prey for predatory arthropods

(Baulechner et al. 2022). Soil macrofauna, including termites, serve dual roles as components of the food web and as ecosystem engineers, as they alter both the organic and inorganic composition of the soil (Brussaard et al. 2007). Other detritivore arthropod found in this research was an oribatid mite (Oribatida). The oribatid mite abundance within the soil was significantly suppressed by *P. citrinum* application, however the mite abundance increased at the plots applied with *B. bassiana* and *M. anisopliae*. The oribatid mite is vulnerable and sensitive to exogenous disturbances in soil, therefore, the mite is regarded as suitable bioindicators to assess soil disturbances (Amani et al. 2020). This indicates that *P. citrinum* could not harm the oribatid mite communities, however *B. bassiana* and *M. anisopliae* may still preserve the oribatid mite communities. The oribatid mite may significantly influence soil carbon cycling dynamics (Wickings and Grandy 2011).

The species diversity of soil surface dwelling predatory arthropods was not affected by fungal applications but the species diversity of the below-ground predatory arthropods decreased after treatment with *P. citrinum*. Previous

research found that *B. bassiana* has adversely effect on spiders (araneid, lycosid, salticids) and carabid beetles (Goettel et al. 2021). However, in the present research, the application of *B. bassiana* had no effect on the abundance of predatory arthropods residing on the soil surface. *B. bassiana* and predatory arthropods could be two biological control agents used to manage insect pests of maize. When the predators, *Dalotia coriaria* (Kraatz, 1856) and *Stratiolaelaps scimitus* (Womersley, 1956) and the fungi (*M. anisopliae* and *B. bassiana*) were combined, they can increase mortality of western flower thrips achieving >90% (Saito and Brownbridge 2016).

The application of *P. citrinum* resulted in a reduction of species diversity among predatory arthropods in the soil. However, there is no evidence that *P. citrinum* can eliminate predatory arthropods. *Penicillium citrinum* may enhance the species diversity of detritivore arthropods. The application of *P. citrinum* did not demonstrate a consistent impact that could adversely affect the species diversity of soil-dwelling arthropods; however, its application must be careful concerning its negative effect on the predatory arthropods. The lowest species diversity and evenness occurred in maize treated with *P. citrinum*. This suggests that *P. citrinum* may adversely affect on predatory species diversity within the soil ecosystem. Mortality caused by indirect exposure to *B. bassiana* and *M. brunneum* to the red imported fire ant, *S. invicta* achieve more than 50% (Rojas et al. 2018). *Beauveria bassiana* conidia-contaminated aphids and sporulating cadavers are potentially dangerous entities to the genus *Formica* (Novgorodova 2021). However, Argentine ants (*Linepithema humile* (Mayr, 1868)), an invasive alien species can prevent fungal spore germination (*Aspergillus nomius* and *Fusarium solani*) due to the ant anal secretion to prevent spread of the pathogenic fungi (Kesäniemi et al. 2019). The application of entomopathogenic fungi did not influence on the abundance of predatory and herbivorous arthropods within the soil. The species diversity of detritivore arthropods increased following the application of entomopathogenic fungi. A significant decline in the species diversity of soil-dwelling predatory arthropods was observed after treatment with *P. citrinum*. The species diversity of herbivorous and detritivore arthropods in the soil was not affected by the application of entomopathogenic fungi. This suggests that entomopathogenic fungus did not adversely affect herbivorous and detritivore arthropods present in the soil.

In conclusion, the application of entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae* did not alter soil-dwelling predatory arthropod assemblages. However, a reduction in species diversity among the below-ground predatory arthropods occurs following the application of *Penicillium citrinum*. *Metarhizium anisopliae* and *P. citrinum* decrease significantly the detritivore arthropod abundance from ground surface. *P. citrinum* alter species diversity of below-ground predatory arthropods. Consequently, applying *P. citrinum* in the soil must be careful concerning its negative effect on the predatory arthropods. *Beauveria bassiana* can decrease the ground surface herbivorous insect but did not adversely effect on other soil-dwelling arthropods, and it can be utilized for

biological control in ecosystems rich in detritivore and predatory arthropods. Therefore, *B. bassiana* and predatory arthropods can be two biological control agents used to manage insect pest of maize. *B. bassiana* application may be integrated with soil-dwelling predatory arthropods for Integrated Pest Management (IPM) and for environmental safety.

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