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RESEARCH PAPER

Insecticide application effect on ground dwelling arthropods in edamame crops

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ABSTRACT

Ground-dwelling arthropods play many important roles in agroecosystems. This experiment was conducted to assess the effects of botanical and synthetic insecticides on soil arthropods in edamame crops. The study included six treatments: soursop leaf extract at concentrations of 1% and 2%, diflubenzuron at concentrations of 0.05% and 0.1%, a common synthetic insecticide (chlorantraniliprole 0.15%), and a control (untreated plants), each with three replications. Pitfall traps were used to sample soil arthropods. A total of 2222 soil arthropods were collected, consisting of 1443 (64.94%) predatory arthropods and 778 (35.06%) detritivorous arthropods. The dominant orders of predators and detritivores were Araneae (61.5%) and Coleoptera (40.2%), respectively. The highest numbers of predatory and detritivorous arthropods were found on edamame plants sprayed with soursop extract, while the lowest numbers were recorded on plants treated with the common synthetic insecticide chlorantraniliprole. These results indicate that chlorantraniliprole negatively impacts the presence of ground-dwelling arthropods in edamame agroecosystems. In contrast, the application of the botanical insecticide (soursop leaf extract) and the synthetic insect growth regulator (diflubenzuron) did not reduce the abundance or diversity of ground-dwelling arthropods in edamame fields.

Key words: Chlorantraniliprole, diflubenzuron, edamame field, soil arthropods, soursop extract

INTRODUCTION

Edamame, or vegetable soybean, is a relatively new type of soybean (Dong et al., 2014). It has been consumed for centuries in many Asian countries, including Indonesia, and its consumption has now expanded to other parts of the world (Djanta et al., 2020). Unlike grain-type soybean, which is primarily used as a source of protein in human foods and animal feeds, edamame beans are mainly consumed by humans as a vegetable. In Indonesia, edamame is mostly consumed as a side dish or snack, typically eating directly from pods. The pods are harvested before they fully ripen, at the green and immature stage (Williams, 2015; Moseley et al., 2020). Edamame is a nutritious food, rich in vitamins C (ascorbic acid) and E (tocopherol), dietary fiber, protein, and essential amino acids (Xu et al., 2016; Lovabyta et al., 2020).

Arthropod pests can infest edamame plants from the early vegetative stage, such as bean fly (*Ophiomya phaseoli*) (Diptera: Agromyzidae), to the reproductive stage, including pests like the soy pod borer (*Etiella zinckenella*) (Lepidoptera: Pyralidae) and the bean plataspid (*Megacopta cribraria*) (Heteroptera: Plataspidae) (Lord et al., 2021; Greene et al., 2021; Thrash et al., 2021). Insecticide application is the main strategy for managing vegetable soybean pests (Smith et al., 2020; Machado et al., 2022). However, excessive use of broad-spectrum synthetic insecticides can lead to adverse effects and environmental problems (Biondi et al., 2012; Hanif et al., 2020).

Alternative control strategies, such as the use of biorational insecticides, including synthetic insect growth regulators (IGRs) and botanically derived products, offer promising options for edamame pest management (Frewin et al., 2014; Marcombe et al., 2018). Due to their effectiveness and selectivity, IGRs provide innovative solutions for controlling arthropod pests (Joseph, 2017; Lau et al., 2018). In addition to IGRs, plants in the Annonaceae family, such as soursop, have been studied as potential sources of botanical insecticides (Moghadamtousi et al., 2015; Alves et al., 2016). These plant-derived insecticides are considered viable alternatives to replace broad-

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spectrum synthetic chemicals (Hikal et al., 2017). Several studies have tested plant extracts against a variety of arthropod pests: Annonaceae species against *Spodoptera frugiperda* (Alves et al., 2016), twenty plant extracts against the hemipteran *Bemisia tabaci* (Emilie et al., 2015), turmeric extracts against the termite *Reticulitermes flavipes* (Raje et al., 2015), and four plant extracts for management of the European red ant *Myrmica rubra* (Bernard et al., 2020).

Ground-dwelling (soil) arthropods are a major component of edamame plantations and play an important role in maintaining ecological stability in cropping systems (Elie et al., 2018; Mattson, 2012). Soil arthropods comprise many species, contributing significantly to biodiversity (Riggi & Bommarco, 2019; Wagner et al., 2021; Dunbar et al., 2016). Habitats with higher biodiversity tend to have more complex food webs, leading to greater resilience against pest outbreaks (Redlich et al., 2018). However, arthropod populations are sensitive to ecological disturbances in agricultural systems, such as insecticide use. Chemical pesticides can have toxic effects on non-target organisms, including soil arthropods.

Therefore, the objective of this study was to investigate the effects of botanical and synthetic insecticide applications on ground-dwelling arthropods in edamame crop.

MATERIALS AND METHODS

Research Site. The experimental research was conducted at the Agricultural Experimental Station, Lampung State Polytechnic, Rajabasa County, Bandar Lampung, Indonesia, from December 2020 to March 2021. The geographical coordinates of the site were 5º21'11" S -105º13'44" E, at an elevation of 112 m above sea level.

Plot Preparation and Plant Maintenance. The experimental area measured 450 m^2 (25 m × 18 m) and was divide into 18 plots for six treatments with three replications. The field was ploughed twice using a tractor until the soil was sufficiently loose for plot formation. It was then leveled and ridged mechanically, and shaped perpendicularly (Figure 1A). Fertilization was performed once before planting, using organic fertilizer (*Bokashi Plus*, produced by Lampung State Polytechnic) and synthetic fertilizer: 50 kg ha^{-1} [$CO(NH_2)_2$], 100 kg ha^{-1} SP-36, 100 kg ha^{-1} KCl) (Figure 1A).

Each plot measured 4 m × 3 m, with a 0.5 m spacing between plots. Edamame seeds (Ryokkoh variety) were first planted in seed trays with 72 cells for seedling development (Figure 1B). After germination, the seedlings were transplanted into the field at a spacing of 30 cm × 20 cm per row (Figure 1C). Edamame growth was maintained under optimal conditions through appropriate irrigation and regular weed removal (Figure 1D).

Treatments and Experimental Design. The experiment involved six treatments: T0 = Control (untreated plants); T1 = 1% soursop leaves extract; T2 = 2% soursop leaves extract; T3 = Diflubenzuron concentrations 0.05%; T4 = Diflubenzuron concentrations 0.1%; T5 = Chlorantraniliprole 0.15%. Soursop leaves extract, diflubenzuron, chlorantraniliprole were used as representatives of botanical insecticides, insect growth regulators (IGRs), and commonly recommended insecticides,

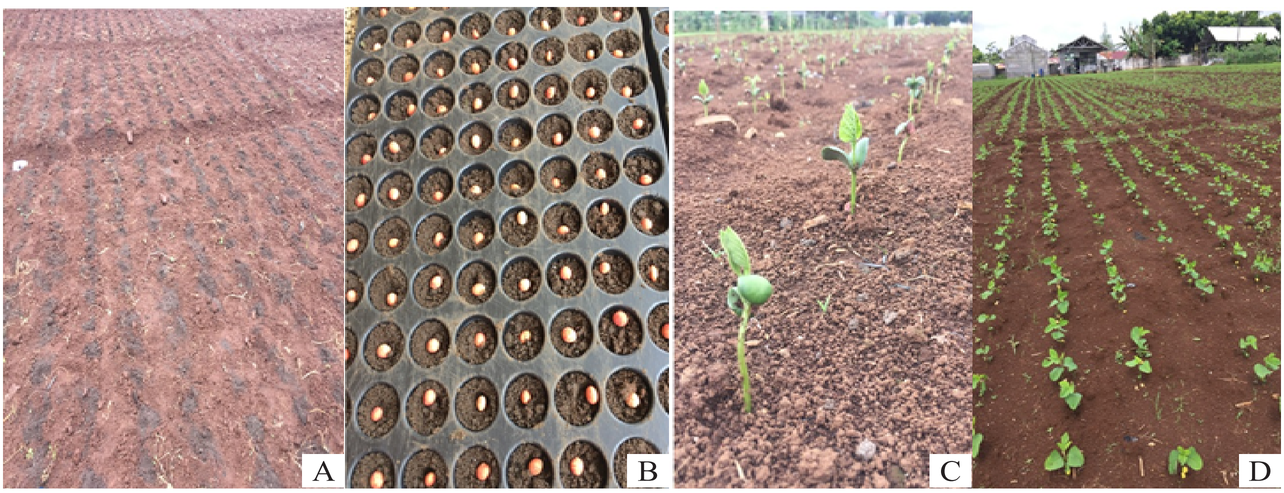

Figure 1. Experimental field for the edamame study. A. Plot area prepared for planting; B. Edamame seeds in germination trays; C. Transplanted edamame seedling in the plot area; D. Edamame plants on each plot.

respectively. All treatments were arranged in the field using a randomized complete block design (RCBD).

Botanical Insecticide Preparation. Insecticide preparation and arthropod identification were conducted in the Laboratory of Arthropod Pests, Department of Plant Protection, Faculty of Agriculture, University of Lampung, Indonesia. Fully grown soursop leaves were collected from insecticide-free areas around Bandar Lampung. The leaves were rinsed thoroughly and air-dried at room temperature for one week. Dried leaves were ground into a fine powder using a blender.

A total of 150 g of the powdered leaf sample was mixed with 1 liter of 98% ethanol and kept in the dark at 25 ^{o}C for 24 h. The mixture was shaken using a magnetic stirrer at 180 rpm to ensure thorough extraction. Afterward, the extract was filtered through Whatman No. 1 filter paper. The ethanol was then evaporated from the supernatant using a rotary evaporator (RV 10 D, IKA, USA) at 50 mmHg and 50 ^{o}C with a rotation speed of 100 rpm. The final product was a thick, paste-like crude extract, which was stored in airtight 100 mL bottles in a refrigerator at 4 ^{o}C until application.

Insecticide Application. Two concentrations of soursop extract (1% and 2%) were prepared by diluting 10 g and 20 g of crude extracts in 1000 mL of distilled water. Then, 0.1 mL of 0.1% Tween 80 was added to each solution as an emulsifier. Diflubenzuron (25% Dimilin 25 WP) was applied at 0.05% and 0.01% concentrations, respectively. Chlorantraniliprole was applied 0.15%, as commonly used in vegetable soybean pest management. Control plants were sprayed with water containing 0.1% Tween 80.

All insecticide treatments were applied using a lever-operated knapsack sprayer. The sprayer was calibrated before use to ensure application accuracy in liters per area. Each plot was sprayed according to the assigned treatment. Insecticide applications were conducted twice: once at the V3 (three-node) stage and again at the R3 (beginning pod) stage.

Arthropod Sampling. Ground-dwelling arthropods was collected using the pitfall trap method. The traps consisted of transparent disposable plastic cups (7 cm diameter, 9 cm depth). From the central rows of each crops, five plants were randomly selected. Near each selected plant, a pitfall trap was installed by digging a hole the same depth as the cup, the rim of the cup flush with the soil surface to prevent gaps. Each cup was filled halfway with 100 mL of water mixed with 1 mL of 96% ethanol.

To protect the traps from rain, a 15 cm-diameter mica plastic cover was mounted using three 12 cm bamboo sticks as supports. In each plot, traps were set up in the evening and left for 24 hours. Arthropod sampling was conducted three times: at the V3, R3, and R5 (beginning seed) stages. All captured arthropods were preserved in 76% ethanol in labeled glass vials and transported to the laboratory for identification.

Data Analysis. The number of genera and individuals per treatment were used to analyze arthropod abundance and diversity. The abundance data were analysed using analysis of variance (ANOVA), followed by the least significant difference (LSD) test at a 5% significance level to identify significant differences among treatments. The number of genera per feeding guild was recorded and presented in tabular form. Relative abundance by feeding type and dominant arthropod orders was presented graphically using Microsoft Excel (2019 version).

Arthropod diversity was calculated using the Shannon-Wiener Diversity Index (H′) and Shannon Evenness Index (J′), as described by Magurran (2004):
(i) Shannon-Wiener Diversity Index (H′):

$$H' = -\sum\left(\frac{n_i}{N}\right)\ln\left(\frac{n_i}{N}\right)$$

H' = Shannon-Wiener Diversity Index;
n_i = Number of individual of species i;
N = Total number of individuals.

(ii) Shannon Evenness Index (J′):

$$J' = \frac{H'}{\ln(S)}$$

J' = Shannon-Evennes Index;
H'= Shannon-Wiener Diversity Index;
S = Total number of species.

RESULTS AND DISCUSSION

Community Composition of Ground-Dwelling Arthropods. In this study, ground-dwelling (soil) arthropods were grouped into two functional categories based on their feeding characteristics, predators and detritivores. As soil-inhabiting organisms, these arthropods rely on the soil for all or part of their life cycles and are typically classified as non-target organisms.

From pitfall traps placed in the edamame field, a total of 2222 soil arthropodswere collected, consisting of 1443 (64.94%) predatory arthropods and 778

(35.06%) were detritivores. The pitfall trapping results showed that predators represented more than half of the total arthropods caught.

Predatory Soil Arthropods. As illustrated in Figure 2, the composition of predatory arthropods by taxonomic order was dominated by Araneae (spiders), accounting for 61.5% of the total, followed by Hymenoptera (13.5%) and Orthoptera (12.4%). Coleoptera and Dermaptera ranked fourth and fifth, with relative abundances of 9.1% and 2.7%, respectively. The remaining orders, Hemiptera and Mantodea, each contributed less than 1%.

This finding suggests that spiders (Araneae) were the dominant predatory group. Unlike insects, spiders have eight legs and chelicerae, which they use to inject venom into their prey. Most species are nocturnal and feed on a wide range of insects and arthropods. According to Adam et al. (2017), the most abundant orders in pitfall traps in corn fields included Acari (32.4%), Collembola (26.6%), and other such as Hymenoptera (12.9%), Coleoptera (11.1%), Diptera (7.6%), and Hemiptera (3.7%). Similarly, Ibrahim et al. (2012) highlighted Araneae the most important natural predators in wheat, cotton, and maize. Radermacher et al. (2020) emphasized spiders' role as key biocontrol agents in rice ecosystems, even at low herbivore densities.

Two common spider genera found in this study were *Oxyopes* sp. (lynx spider) and *Pardosa* sp. (thin-legged wolf spiders) (Figure 3), both widely distributed in various agricultural systems. Anggraini et al. (2021) also reported the presence of these genera in zinnia fields. Other predatory arthropods identified included: 1) *Camponotus* sp. (Hymenoptera: Formicidae)–social ants and generalist predators, also useful as bioindicators (Chandran et al., 2018); 2) *Paederus* sp. (Coleoptera: Staphylinidae); 3) *Harmonia* sp. (Coleoptera: Coccinellidae)–a predatory beetle widely used in biological control (Biranvand et al., 2019; Edde, 2021); 4) *Neoscapteriscus* sp. (Orthoptera: Gryllotalpidae.

Detritivorous Soil Arthropods. In addition to predatory arthropods, detritivores were also found in the pitfall traps during the study, as presented in Figure 4. As soil-inhabiting arthropods, detritivores rely on the soil for most of their life cycle. As the name implies, detritivores are organisms that obtain their nutrition by feeding on detritus—dead or decaying plant and animal material. These organisms play an important role in nutrient cycling by contributing to the breakdown of organic matter in ecosystems.

The data in Figure 4 show that the most dominant order of soil detritivorous arthropods was Coleoptera, with a relative abundance of 40.2%, followed by Entomobryomorpha (29.5%) and Blattodea (20.0%). The fourth and fifth most common orders were Polydesmida and Spirobolida, with relative abundances of 8.0% and 2.17%, respectively. These results indicate that the taxonomic diversity of detritivores was greater than that of predatory arthropods, as shown in Figure 2.

Unlike predatory arthropods, which mostly belong to spiders and insects, detritivores collected in the pitfall traps included springtails (Collembola: Entomobryomorpha), insects (Coleoptera and Blattodea), and millipedes (Polydesmida and Spirobolida). According to Louzada & Nichols (2012), detritivorous arthropods play an essential ecological

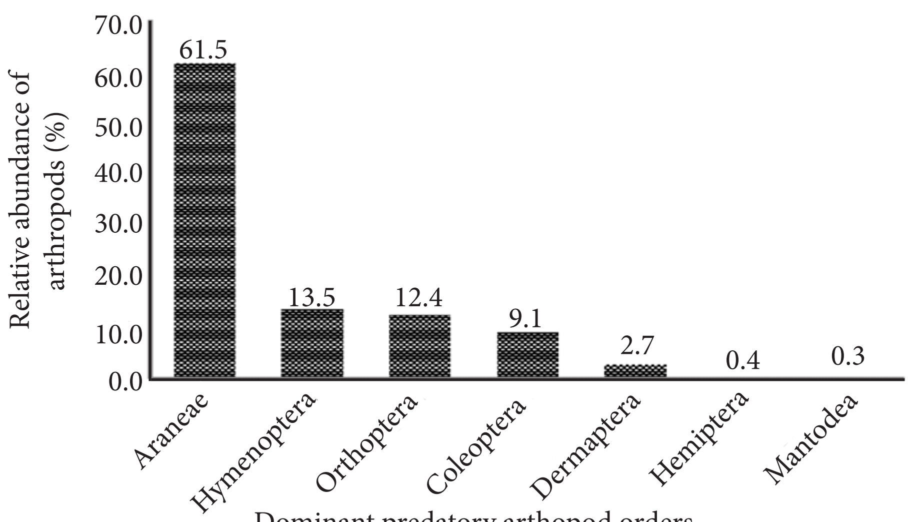

Figure 2. Dominant orders of predatory arthropod sampled using pitfall traps in the edamame field.

role by structuring soil habitats, breaking down organic material, and enhancing decomposition rates.

Figure 5 presents the common detritivorous arthropods found in the edamame field through pitfall sampling, including: *Isotoma* sp. (Entomobryomorpha: Isotomidae), *Cylisticus* sp. (Entomobryomorpha: Cylistidae), *Onthophagus* sp. (Coleoptera: Scarabaeidae), *Parcoblatta* sp. (Blattodea: Ectobiidae), *Harpaphe* sp. (Polydesmida: Xystodesmidae).

Springtails (Collembola) are important members of the phylum Arthropoda. They are wingless anthropods that primarily live as detritivores in decaying organic matter such as dead leaves. Entomobryomorpha is one of the three main order of Collembola, and the family Isotomidae is the largest within this order. According to Lafooraki et al. (2020), many members of the indigenous Isotomidae family in Iran were found in leaf litter, moss, and decaying wood.

Another important detritivore found during the study was the dung beetle, *Onthophagus* sp., a member of the wider scarab beetle family Scarabaeidae. The distribution of *Onthophagus* species is mainly influenced by habitat structure and the availability of animal manure. Widhiono et al. (2017) reported that *Onthophagus echinus* and *Onthophagus palatus* were the second and the third most abundant species in tropical forest ecosystem on the southern slope of Mount Slamet.

Effect of Insecticide Application on Predatory Arthropod Abundance

Predatory Soil Arthropod Abundance. In this study, three types of insecticides were tested for their effects on soil arthropods in edamame fields: botanical insecticides (soursop leaf extract), an insect growth

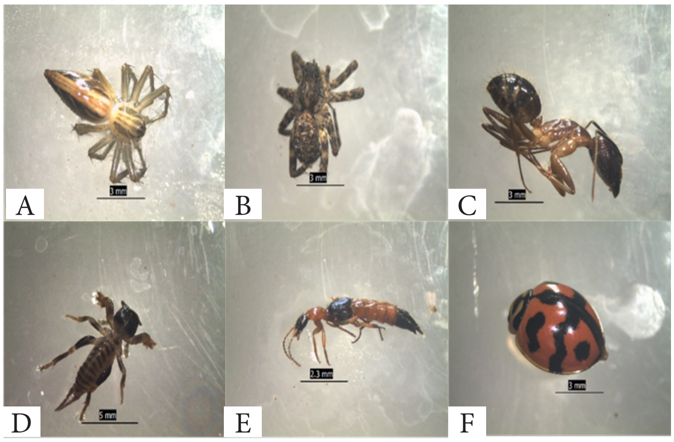

Figure 3. Dominant soil predatory arthropods found in the edamame field. A. *Oxyopes* sp. (Araneae: Oxyopidae); B. *Pardosa* sp. (Araneae: Lycosidae); C. *Camponotus* sp. (Hymenoptera: Formicidae); D. *Neoscapteriscus* sp. (Orthoptera: Gryllotalpidae); E. *Paederus* sp. (Coleoptera: Staphylinidae); F. *Harmonia* sp. (Coleoptera: Coccinellidae).

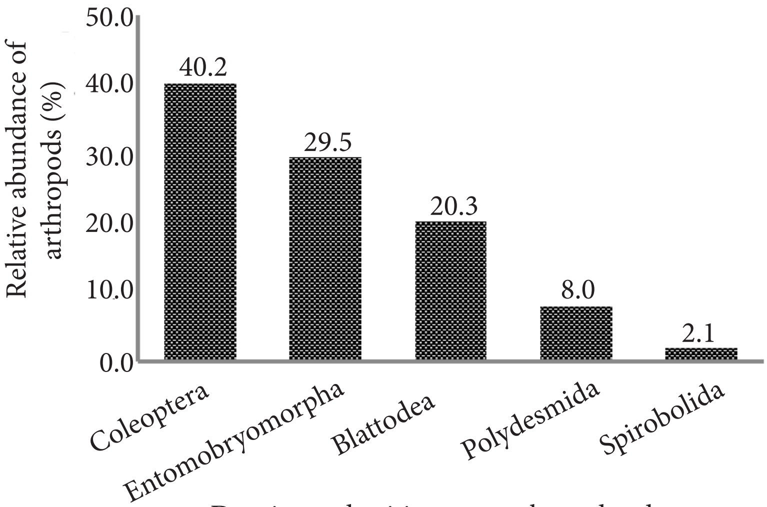

Figure 4. Dominant detritivorous arthropod orders sampled by pitfall trapping in the edamame field.

regulator (IGR, diflubenzuron), and a conventional synthetic insecticide (chlorantraniliprole). The data in Table 1 indicate that the application of these insecticides had a significant impact on the abundance (number of individuals) of predatory arthropods in the edamame agroecosystem. Overall, the results showed that the application of various insecticides at different concentrations significantly affected the mean number of predatory arthropods at the V3-stage ($F_{5,10}$ = 17.99; $P < 0.0001$), R3-stage ($F_{5,10}$ = 26.33; $P < 0.0001$), and R5-stage ($F_{5,10}$ = 18.14; $P < 0.0001$) (Table 1).

Additionally, the data showed that the number of predatory arthropods increased with edamame growth, from the V3 stage (three unfolded trifoliolate leaves) to the R5 stage (beginning seed). At the V3 stage, the lowest number of predatory arthropods (0.33 ± 0.11 individuals per 5 plants) was recorded in plots sprayed with the synthetic insecticide chlorantraniliprole 0.15% (T5). This number was significantly lower than in most other treatments, except for the control (T0), which had 3.67 ± 0.78 individuals per 5 plants. In contrast, the highest number of predatory arthropods at the V3 stage (19.67 ± 7.44 individuals per 5 plants) was found in plots treated with soursop leaves extract 1% (T1), and this was not significantly different from the numbers recorded for soursop extract 2% (T2), diflubenzuron concentrations 0.05% (T3), and diflubenzuron concentrations 1% (T4).

A slightly different trends was observed at the R3-stage, where the highest number of predatory

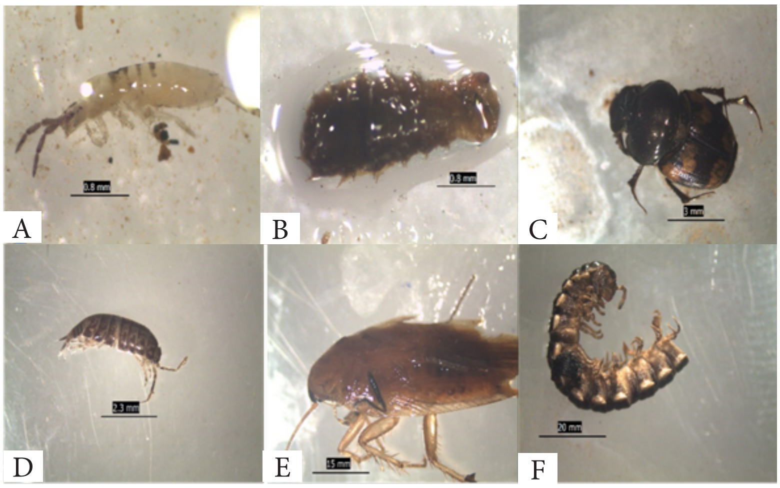

Figure 5. Dominant detritivorous arthropods found in the edamame fields. A–B. *Isotoma* sp. (Entomobryomorpha: Isotomidae); C. *Onthophagus* sp. (Coleoptera: Scarabaeidae); D. *Cylisticus* sp. (Entomobryomorpha: Cylistidae); E. *Parcoblatta* sp. (Blattodea: Ectobiidae); F. *Harpaphe* sp. (Polydesmida: Xystodesmidae).

Table 1. Effect of insecticide application on the abundance of predatory arthropods at three growth stages of the edamame field

Treatment	Number of arthropods / 5 plants		
	V3-stage	R3-stage	R5- stage
T0	3.67±0.78b	26.33±0.78d	18.67±10.11b
T1	19.67±7.44a	62.00±12.33a	45.33±13.44a
T2	15.67±8.44a	42.33±0.78c	40.67±6.78a
T3	18.00±2.33a	57.00±10.33ab	48.33±20.11a
T4	14.67±0.11a	44.33±7.11bc	22.67±23.11b
T5	0.33±0.11b	0.67±0.44e	0,77±0.19c
F Value	17.99	26.83	18.14
Pr > F	0.000	0.000	0.000
LSD	5.95	13.658	13.743

T0 = Control (untreated plant), T1 = 1% soursop leaves extract, T2 = 2% soursop leaves extract; T3 = diflubenzuron concentrations 0.05%, T4 = diflubenzuron concentrations 0.1%, T5 = Chlorantraniliprole 0.15%. Same letters after means within the same column are the sign for non - significance difference based on LSD test, with significance level 5%.

arthropods (62.00 ± 12.33 individuals per 5 plants) was found in plots treated with soursop extract 1% (T1). This was not significantly different from the value in the diflubenzuron 0.05% (T3) treatment (57.00 ± 10.33 individuals), but was significantly higher than in the soursop extract 2% (T2) and diflubenzuron 1% (T4) treatments. As with the V3 stage, the lowest numbers of predatory arthropods at the R3 and R5 stages (0.67 ± 0.44 and 0.77 ± 0.19 individuals per 5 plants, respectively) were found in plots treated with chlorantraniliprole (T5). Conversely, at the R5 stage, the highest number of predatory arthropods (48.33 ± 20.11 individuals per 5 plants) was observed in the diflubenzuron 0.05% (T3) treatment.

These results suggest that the use of common synthetic insecticides such as chlorantraniliprole negatively affects the abundance of predatory arthropods in edamame fields. Chlorantraniliprole, a broad-spectrum neurotoxic insecticide, can affect a wide variety of organisms, including beneficial predators. This finding is supported by Zaller & Brühl (2019), who reported that synthetic pesticides have harmful effects on non-target organisms in agroecosystems. Jaya et al. (2022) also reported that the continuous use of synthetic pesticides in shallot cultivation led to a decline in arthropod abundance. Additionally, Biondi et al. (2012) found that spinosyns, a family of widely used broad-spectrum insecticides, also have adverse effects on beneficial arthropods.

In contrast, Table 1 also shows that the application of botanical insecticides and synthetic IGRs did not significantly reduce the abundance of predatory arthropods. This indicates that selective insecticides and plant-based insecticides have less harmful effects on predatory arthropods compared to conventional synthetic insecticides. According Sánchez-Bayo (2012), selective insecticides such as IGRs and naturally derived compounds are less harmful to non-target organisms than broad-spectrum neurotoxins. Similar findings were reported by He et al. (2018), who found that IGRs had no significant effect on the coleopteran predator *Harmonia axyridis*. Furthermore, Hanif et al. (2020) reported that bioinsecticide application did not reduce the abundance of predatory arthropods in swamp paddy fields. Finally, Tembo et al. (2018) concluded that the application of plant-based pesticidal extracts had minimal effects on beneficial arthropods that play important roles in pest control.

Detritivorous Soil Arthropod Abundance. Unlike the results for predatory arthropods, the application of various insecticides had a significant effect on the mean number (abundance) of detritivorous arthropods only at the V3 stage ($F_{5,10}$ = 2.97; P < 0.047) and the R5-stage ($F_{5,10}$ = 3.44; P < 0.045) (Table 2). At the V3 stage, the highest number of detritivorous arthropods (8.67 ± 0.11 individuals per 5 plants) was recorded in plots treated with the botanical insecticide (soursop leaf extract 1%) (T1), and this number was significantly higher only compared to the control treatment (T0).

At the R5 stage, the highest number of detritivorous arthropods (19.67 ± 0.78 individuals per 5 plants) was also observed in the soursop extract 1% (T1), and this number was significantly higher only

Table 2. Effect of insecticide application on the abundance of detritivorous arthropods at three growth stages of the edamame field.

Treatment	Number of arthropods / 5 plants		
	V3-stage	R3-stage	R5- stage
T0	4,67±1,44b	14,00±0,33a	17,00±14,33a
T1	8,67±0,11a	26,00±7,00a	19,67±0,78a
T2	6,33±1,44ab	18,67±16,44a	18,67±1,44a
T3	5,67±0,44ab	20,00±17,33a	17,00±9,00a
T4	8,00±1,00a	25,67±52,11a	12,00±1,33ab
T5	5,67±0,78ab	23,00±2,33a	9,00±3,00b
F Value	2,97	1,21	3,44
Pr > F	0,047	0,369	0,045
LSD	3,007	13,138	7,058

T0 = Control (untreated plant), T1 = 1% soursop leaves extract, T2 = 2% soursop leaves extract; T3 = diflubenzuron concentrations 0.05%, T4 = diflubenzuron concentrations 0.1%, T5 = Chlorantraniliprole 0.15%. Same letters after means within the same column are the sign for non - significance difference based on LSD test, with significance level 5%.

than that recorded in plots treated with the synthetic insecticide chlorantraniliprole (T5). These results indicated that the application of soursop leaf extract (botanical insecticide) and diflubenzuron (synthetic IGR) did not reduce the number of detritivorous arthropods in the edamame field.

According to the data presented in Figure 4 and 5, the two most common detritivores in edamame field were dung beetle (*Onthophagus* sp., Coleoptera: Scarabaeidae) and springtails (*Isotoma* sp., Entomobryomorpha: Isotomidae). This finding was supported by the work Ponsankar et al. (2016), who reported that botanical insecticide had no harmful effects on non-target species.

Effect of Insecticide Application on Predatory Arthropod Diversity. During the study, 20 families of predatory arthropods were collected from the pitfall traps in the edamame field, consisting of 35 genera and 1443 individuals (Table 3). Furthermore, data in Table 3 revealed that the family Coccinellidae had the highest number of genera (6), followed by Formicidae with five (5) genera. The third rank included Lycosidae, Tetragnathidae, Thomisidae, Salticidae, Araneidae, and Mantidae, each with two (2) genera. The remaining families had only one (1) genus each (Table 3).

Another result presented in Table 3 indicated that the number of genera (used as a measure of predator diversity) did not correspond with the number of individuals (representing predator abundance). The family Coccinellidae had the highest number of genera (6), whereas the family Oxyopidae had the highest number of individuals (456). This finding implies that ladybird beetles (Coccinellidae) were the most diverse predatory arthropods, while lynx spiders (Oxyopidae) were the most abundant. The findings of Oxbrough & Ziesche (2013) also supported this, noting that spiders are among the most abundant groups of terrestrial predators.

Predatory Soil Arthropod Diversity. The diversity of arthropods in edamame fields treated with different insecticide applications was calculated using a taxon-based approach, specifically by analyzing the genera from the data in Table 3. Two diversity indices—Shannon-Wiener diversity index (H′) and evenness

Table 3. Number of genera and individuals of soil predatory arthropods in each family collected in the edamame field

No	Family name	Number of genera	Number of Individuals
1	Coccinellidae	6	48
2	Formicidae	5	195
3	Lycosidae	2	139
4	Tetragnathidae	2	42
5	Thomisidae	2	17
6	Salticidae	2	55
7	Araneidae	2	17
8	Mantidae	2	5
9	Reduviidae	1	1
10	Pentatomidae	1	5
11	Staphylinidae	1	74
12	Carabidae	1	9
13	Forficulidae	1	16
14	Anisolabididae	1	23
15	Gryllotalpidae	1	158
16	Tettigoniidae	1	21
17	Oxyopidae	1	456
18	Linyphiidae	1	107
19	Pisauridae	1	42
20	Clubionidae	1	13
	Total	35	1443

index (J′)—were used to assess ground-dwelling arthropod diversity. The results are presented in Table 4 (predatory arthropod diversity) and Table 5 (detritivorous arthropod diversity).

Results in Table 4 show that the lowest values of H′ and J′ across all sampling periods were recorded in edamame plots treated with the common synthetic insecticide chlorantraniliprole 0.15% (T5). Notably, at the V3 stage, both H′ and J′ values were zero, indicating the presence of only one species in that treatment. This suggests that the application of neurotoxic synthetic insecticides had a strong negative impact on the diversity of soil-dwelling predatory arthropods.

In contrast, the highest values of H′ and J′ for predatory arthropods at the V3 stage (2.02 and 0.56, respectively) were observed in plots treated with the synthetic IGR (diflubenzuron 0.05%) (T3). At the R3 stage, the highest values of H′ and J′ (2.76 and 0.76, respectively) were recorded in plots treated with the botanical insecticide (soursop leaf extract 1%) (T1). Similarly, at the R5 stage, the highest diversity (H′ = 2.17 and J′ = 0.60) was also found in the T1 treatment. These results indicate that the application of chlorantraniliprole had a severe impact on the presence and diversity of predatory arthropods, leading to the lowest diversity levels.

Karenina et al. (2019) found that the lowest diversity of predatory arthropods (spiders and predatory insects) occurred in rice fields sprayed with synthetic pesticides. In addition, Geiger et al. (2010) reported the negative effects of pesticide use on biodiversity across European farmlands. Further results in Table 4 suggest that the application of botanical insecticides (soursop leaf extract) and selective insecticides like IGR (diflubenzuron) did not negatively impact the diversity of predatory arthropods in the edamame agroecosystem. Tembo et al. (2018) also stated that treatments with plant extracts appeared to have minimal effects on beneficial arthropods.

Detritivorous Soil Arthropod Diversity. In general, the values of the Shannon-Wiener diversity index (H′) and evenness index (J′) for detritivorous arthropods (Table 5) were lower compared to those of predatory arthropods (Table 4) across all sampling periods. At the V3 stage, the highest H′ and J′ values for detritivorous

Tabel 4. Effect of insecticide application on the diversity (H’) and evenness (J’) values of predatory arthropods at different stages of edamame growth

Plant stage	Diversity indices	Insecticide application treatment					
		T0	T1	T2	T3	T4	T5
V3	H`	1.85	1.93	1.58	2.02	1.50	0.00
	J’	0.51	0.53	0.44	0.56	0.42	0.00
R3	H`	1.96	2.76	1.39	1.57	1.12	0.69
	J’	0.54	0.76	0.38	0.43	0.31	0.19
R5	H`	2.10	2.17	1.94	1.94	1.68	0.69
	J’	0.58	0.60	0.54	0.54	0.47	0.19

T0 = Control (untreated plant), T1 = 1% soursop leaves extract, T2 = 1% soursop leaves extract; T3 = diflubenzuron concentrations 0.05%, T4 = diflubenzuron concentrations 0.1%, T5 = chlorantraniliprole concentrations 0.15%.

Tabel 5. Effect of insecticide application on the diversity (H’) and evenness (J’) values of detritivorous arthropods at different stages of edamame growth

Plant stage	Diversity indices	Treatment					
		T0	T1	T2	T3	T4	T5
V3	H`	1.71	1.17	1.24	0.66	0.68	0.22
	E	0.82	0.56	0.60	0.32	0.33	0.11
R3	H`	1.67	0.90	1.17	1.26	0.78	1.55
	E	0.81	0.43	0.56	0.61	0.37	0.74
R5	H`	1.32	1.25	1.18	0.79	0.99	0.78
	E	0.63	0.60	0.57	0.38	0.48	0.37

arthropods—1.71 and 0.82, respectively—were recorded in edamame plants that were not sprayed with insecticides (T0). This pattern was consistent with the data collected at the R3 and R5 stages (Table 5). These results indicate that detritivorous arthropods are more sensitive to insecticide application than predatory arthropods.

According to Bitzer et al. (2005), insecticide application in transgenic Bt corn reduced the abundance and diversity of springtails (Collembola). Similarly, Hanif et al. (2020) reported that the use of bioinsecticides also reduced the species diversity of non-target arthropods.

CONCLUSION

All arthropods collected from the pitfall trap samples were classified by trophic level (herbivore or predator) and by order. A total of 2,222 soil arthropods were recorded, comprising 1,443 (64.94%) predatory arthropods and 778 (35.06%) detritivorous arthropods. The most dominant order among soil predatory arthropods was Araneae (spiders), accounting for 61.5% of the total, followed by Hymenoptera and Orthoptera with relative abundances of 13.5% and 12.4%, respectively. Meanwhile, the most dominant order among soil detritivorous arthropods was Coleoptera (40.2%), followed by Entomobryomorpha (29.5%) and Blattodea (20.0%). These results suggest that the use of insecticides—particularly conventional synthetic insecticides such as chlorantraniliprole—had a negative impact on the presence of predatory arthropods in edamame fields. In contrast, the application of botanical insecticides (soursop leaf extract) and synthetic insect growth regulators (diflubenzuron) did not adversely affect the abundance or diversity of either predatory or detritivorous arthropods in the edamame agroecosystem.

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AUTHORS' CONTRIBUTIONS

RH, OC, MK, P, & AK contributed to the design and implementation of the research; OC carried out the experiments; RH wrote the manuscript with input from all authors.

COMPETING INTEREST

The authors declare no conflict of interest.

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