THE EFFECT OF INSECTICIDE APPLICATION ON ARTHROPOD COMMUNITIES IN SUGARCANE PLANTATIONS

Pengaruh Aplikasi Insektisida terhadap Komunitas Artropoda pada Pertanaman Tebu

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ABSTRAK

Penelitian ini bertujuan untuk mengevaluasi pengaruh aplikasi insektisida biologis (*Bacillus thuringiensis* dan *Bacillus siamensis*) dan insektisida kimia (Carbofuran dan Chlorantraniliprole) terhadap keanekaragaman, kelimpahan, dan struktur komunitas artropoda pada pertanaman tebu (*Saccharum officinarum* L.). Studi dilakukan dengan membandingkan kekayaan spesies, indeks keanekaragaman (Shannon-Wiener, Simpson, Evenness), serta komposisi fungsional artropoda di lahan yang diberi perlakuan insektisida biologis, kimia, dan kontrol tanpa perlakuan. Hasil menunjukkan bahwa insektisida biologis secara signifikan mempertahankan dan bahkan meningkatkan kekayaan spesies (65-67 spesies) dan kelimpahan individu (945-996 individu) dibandingkan insektisida kimia (44-47 spesies; 514-783 individu). Indeks keanekaragaman Shannon-Wiener tertinggi juga ditemukan pada perlakuan biologis, menandakan komunitas artropoda yang lebih seimbang dan stabil. Analisis NMDS mengungkapkan bahwa aplikasi insektisida kimia menyebabkan perubahan signifikan dalam struktur komunitas artropoda, sedangkan insektisida biologis mempertahankan kemiripan komposisi dengan kontrol. Komposisi fungsional menunjukkan bahwa insektisida biologis mendukung keberadaan dekomposer dan musuh alami (predator dan parasitoid), sementara insektisida kimia menurunkan proporsi dekomposer dan meningkatkan herbivora spesifik seperti *leafminer*. Temuan ini menegaskan bahwa insektisida berbasis mikroorganisme lebih ramah lingkungan dan efektif dalam menjaga keseimbangan ekosistem agroekosistem tebu. Oleh karena itu, integrasi insektisida biologis dalam pengelolaan hama terpadu sangat dianjurkan untuk mendukung pertanian tebu yang berkelanjutan dan ramah lingkungan.

Kata kunci*: Bacillus siamensis*, indeks Shannon-Wiener, insektisida sintetik, musuh alami.

ABSTRACT

This study aimed to evaluate the effects of biological insecticides (Bacillus thuringiensis and Bacillus siamensis) and chemical insecticides (Carbofuran and Chlorantraniliprole) on the diversity, abundance, and community structure of arthropods in sugarcane (Saccharum officinarum L.) plantations. The research compared species richness, diversity indices (Shannon-Wiener, Simpson, Evenness), and functional composition of arthropods across plots treated with biological insecticides, chemical insecticides, and untreated controls. Results showed that biological insecticides significantly maintained or enhanced species richness (65–67 species) and individual abundance (945–996 individuals) compared to chemical insecticides (44–47 species; 514–783 individuals). The highest Shannon-Wiener diversity indices were observed in biological treatments, indicating a more balanced and stable arthropod community. Non-metric multidimensional scaling (NMDS) analysis revealed that chemical insecticides caused significant shifts in arthropod community structure, whereas biological insecticides preserved community composition similar to the control. Functional group analysis indicated that biological insecticides supported decomposers and natural enemies (predators and parasitoids), while chemical insecticides reduced decomposer proportions and increased specific herbivores such as leafminers. These findings suggest that microbial-based insecticides are more environmentally friendly and effective in maintaining ecological balance within sugarcane agroecosystems. Therefore, integrating biological insecticides into integrated pest management strategies is recommended to promote sustainable and eco-friendly sugarcane cultivation.

Keywords: Bacillus siamensis, natural enemy, Shannon-Wiener index, synthetic insecticide

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of Indonesia's strategic commodities, playing a significant role in the agricultural sector and the national sugar industry. Sugarcane production not only contributes to food security and the economy but also employs millions of farmers and industry workers (Perwitasari *et al.,* 2021; Viegas *et al.* 2024). However, sugarcane productivity is often hindered by pest infestations that can cause substantial quantitative and qualitative losses (Mehdi *et al*., 2025). Major pests in Indonesian sugarcane plantations include *Chilo sacchariphagus*, *Scirpophaga nivella*, *Lepidiota stigma*, *Valanga nigricornis*, *Locusta migratoria*, and *Aulacapis tegalensis* (Sarjan *et al*., 2021; Subiyakto *et al*., 2023). Therefore, pest management is a crucial aspect of sugarcane cultivation to ensure optimal harvest yields (Sulaiman *et al*., 2023).

Pest control in sugarcane has traditionally relied heavily on the use of synthetic insecticides as the primary method. Chemical insecticides such as Chlorantraniliprole, Spinosad, Carbofuran, Lambda-cyhalothrin, Tebufenozide, Flubendiamide, and ß-cyfluthrin are widely used due to their effectiveness in rapidly and broadly suppressing pest populations (Paudel *et al*., 2021; Li *et al.,* 2024). However, intensive use of chemical insecticides has led to various environmental and health issues, including pest resistance, environmental pollution, and negative impacts on non-target organisms, particularly natural enemies of pests (Gong *et al*., 2023; Wan *et al*., 2025). This situation necessitates the development of more environmentally friendly and sustainable pest management strategies.

Arthropod diversity within sugarcane agroecosystems plays an important role in maintaining ecological balance and supporting natural plant protection. Arthropods consist not only of pests but also include natural enemies such as predators and parasitoids that function as biological control agents (Altieri, 1999). The presence of a diverse and balanced arthropod community can enhance ecosystem stability, reduce dependence on chemical pesticides, and support sustainable crop production (van der Werf and Bianchi, 2022). Therefore, understanding how insecticide applications affect arthropod communities is essential for designing more sustainable agricultural practices.

Previous studies have shown that biological insecticides, such as those based on *Bacillus thuringiensis* and *Bacillus siamensis*, have the potential to effectively control pests with lower impacts on non-target arthropod diversity compared to chemical insecticides (Lacey *et al*., 2015; Tartanus *et al*., 2021). However, comprehensive studies examining the effects of various insecticide types on arthropod community structure in sugarcane plantations remain limited. Therefore, this study aims to evaluate the impact of biological and chemical insecticide applications on the diversity and composition of arthropod communities in sugarcane plantations. The results are expected to provide scientific information supporting the development of environmentally friendly and sustainable integrated pest management strategies in the sugarcane agricultural sector.

MATERIAL AND METHODS

Time and Location

This study was conducted from July 2024 to October 2024. The research site was located in the sugarcane plantation area of Gunung Batin Udik, Terusan Nunyai, Central Lampung Regency, Lampung.

Land Preparation and Sugarcane Planting

The experimental plot measured 50 m × 15 m, arranged in a monoculture planting pattern (10 rows of plants) with a spacing of 1.5 m between rows. The length of the observed plant rows was 6.67 m, consisting of 10–13 sample plants. One plot consisted of 5 sample rows located at rows 3, 4, 6, 7, and 8. Distance between plots 3 meters. Sample plants were selected following a diagonal pattern (Figure 1). There were five insecticide application treatments: 1) *Bacillus siamensis* APE35 (a collection by Asmoro and Munif, 2020), 2) *Bacillus thuringiensis* SC var. Kurstaki strain ABTS-351, 3) Carbofuran 3GR, 4) Chlorantraniliprole 50SC, and 5) control. Each treatment was replicated three times.

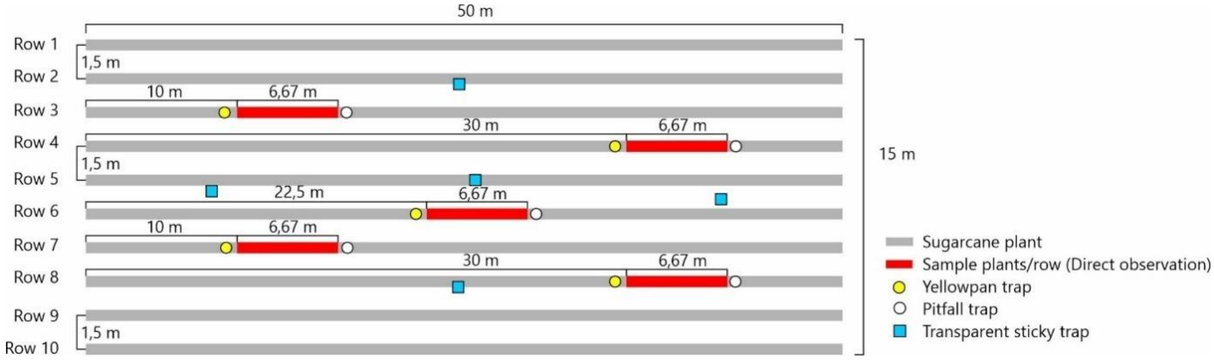

Figure 1. Trial plot size, determination of sample plants/plant rows, and trap placement

Insecticide Application

Insecticide applications were carried out according to the treatment plots. Carbofuran 3GR was applied at a dose of 5 g per plant, Chlorantraniliprole 50SC at a concentration of 5 ml/l, *Bacillus thuringiensis* SC at 5 ml/l, and *Bacillus siamensis* APE35 (cell density 4 × 10^8) at a concentration of 10%. Applications were performed when the sugarcane was one month old after planting. Spraying of Chlorantraniliprole, *B. thuringiensis*, and *B. siamensis* insecticides was conducted using a semi-automatic knapsack sprayer with a spray volume of 300–400 l/ha. In contrast, Carbofuran 3GR was applied by broadcasting it onto the soil around the sugarcane plants.

Observation of Arthropod Abundance and Diversity

Arthropod abundance and diversity observations were conducted three times: one day before insecticide application, one month after application, and two months after application. Observations employed four methods: direct observation, pitfall traps, yellow pan traps, and transparent sticky traps. Trap placement was carried out according to Figure 1.

Direct observation was used to monitor arthropods present on the plant canopy and surrounding areas. This observation was performed on sample plants. The pitfall trap method was employed to assess arthropod abundance on the soil surface. The traps were made from plastic cups (10 cm in height and 9 cm in diameter). Each cup was filled with detergent solution up to one-third of its volume, and a zinc sheet (30 cm × 15 cm) shaped like a roof was placed above to prevent rainwater from entering the trap. Traps were set for 24 hours. Captured arthropods were transferred into plastic containers containing 96% ethanol.

Yellow pan traps were used to capture flying arthropods or insects attracted to bright colours. These traps consisted of yellow plastic dishes or containers (15 cm diameter and 5.5 cm height) filled with detergent solution up to approximately one-third of the container volume. Traps were deployed for 24 hours.

Transparent sticky traps were made from transparent mica plastic shaped into rectangles (20 cm × 10 cm). Both sides were curved to meet each other, forming a tube-like shape. The outer surface of the mica was coated with a special adhesive. Traps were installed on bamboo stakes (height: 1.5 m) at 5–10 cm above the plants. The traps were left in place for 7 days.

Specimen Sorting and Identification

All collected specimens were brought to the laboratory for sorting and stored in containers filled with 96% ethanol. Arthropod specimens were identified to the lowest possible taxonomic level using relevant taxonomic literature (Shaw and Huddleston, 1991; Goulet and Huber, 1993).

Data Analysis

Identified arthropods were tabulated into a database using pivot tables. Arthropod specimens were grouped based on their ecological roles, namely: phytophagous, parasitoid, predator, and decomposer. Arthropod diversity in each observation plot was analyzed using alpha diversity indices such as the Shannon-Wiener index (H’) and Simpson’s index (1/D), which are calculated using the following formulas:

$$H' = -\sum_{i=1}^{s} P_i\ (\ln P_i)$$

H' = Shannon-Wiener diversity index
P_i = proportion of the i^{th} species in the community
s = number of morphospecies

The Shannon-Wiener index values typically range from 1.5 to 3.5. Higher H′ values indicate greater species diversity and ecosystem stability at a given site. The criteria for interpreting Shannon-Wiener index values are as follows:

$H' \geq 3$ = high species diversity
$1 < H' < 3$ = moderate species diversity
$H' \leq 1$ = low species diversity

$$D = 1/\sum_{i=1}^{s} P_i^2$$

D = Simpson diversity index
s = number of morphospecies
P_i = proportion of the i^{th} species in the community

The Simpson diversity index assesses the complexity of a community and species diversity within a population. Its values range from 0 to 1, with values closer to 1 indicating a more complex community and higher species diversity.

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

E = Evenness index
H' = Shannon-Wiener index
S = number of species found
ln = natural logarithm

The Evenness index indicates the degree of species distribution uniformity within a habitat. Higher E values indicate a more evenly distributed community. The index ranges from 0 to 1, with the following interpretation criteria:

$E \leq 0{,}3$ = low evenness
$0{,}3 < E < 0{,}6$ = moderate evenness
$E \geq 0{,}6$ = high evenness

The effect of insecticide treatment factors influencing arthropod community grouping in sugarcane plantations was visualized using Non-metric Multidimensional Scaling (NMDS). Differences in arthropod community structure were measured using the Bray-Curtis dissimilarity index. Analyses were performed using the R statistical software, employing the ggplot2 package for boxplot visualization and the vegan package for NMDS analysis.

RESULTS AND DISCUSSIONS

Arthropod Species Richness and Individual Abundance

The observation results revealed significant differences in species richness and individual abundance among the insecticide treatments: Carbofuran (Cf), Chlorantraniliprole (Ch), *B. siamensis* APE35 (Bs), *B. thuringiensis* (Bt), and the control (Co). Overall, treatments using biological agents (Bs and Bt) exhibited higher species richness and individual density compared to chemical pesticides (Cf and Ch) and the control group.

The highest arthropod species richness was observed in the Bs and Bt treatments, reaching 67 and 65 species, respectively. This result indicated that the use of these natural insecticides can maintain or even enhance the diversity of arthropod taxa. In contrast, synthetic pesticides such as Carbofuran and Chlorantraniliprole resulted in fewer species (47 and 44 species), suggesting a decline in taxa likely due to the impact of chemical insecticides on non-target organisms.

The highest overall individual abundance was found in the Bt (996 individuals) and Bs (945 individuals) treatments, indicating that biological insecticides not only maintain species diversity but also support large and stable arthropod populations. Conversely, Chlorantraniliprole and the control had lower individual abundances (514 and 616 individuals), while Carbofuran was intermediate (783 individuals).

Table 1. Effect of insecticide application on arthropods species richness and abundance in sugarcane plantation

Order	Family	[a]Role	Species richness					Individual abundance				
			[b]Cf	Ch	Bs	Bt	Co	Cf[a]	Ch	Bs	Bt	Co
Araneae	Oxyopidae	Pre	1	1	1	1	1	8	1	3	7	6
Blattodea	Blattellidae	Dec	1	1	1	-	-	1	1	1	-	-
Coleoptera	Aderidae	Hrb	3	4	4	4	3	4	20	14	11	12
	Anobiidae	Dec	1	1	-	1	-	2	3	-	1	-
	Anthicidae	Dec	1	-	1	-	2	1	-	2	-	3
	Anthribidae	Dec	-	-	-	-	1	-	-	-	-	1
	Bostrichidae	Dec	-	-	-	-	1	-	-	-	-	1
	Carabidae	Pre	1	-	3	1	-	3	-	12	4	-
	Chrysomelidae	Hrb	3	2	1	1	2	10	3	8	3	3
	Ciidae	Dec	-	1	1	-	-	-	1	1	-	-
	Coccinelidae	Pre	3	3	1	3	3	3	5	1	6	5
	Corylophidae	Dec	1	1	1	2	1	14	4	44	26	18
	Elateridae	Hrb	-	-	-	2	-	-	-	-	2	-
	Endomychidae	Dec	1	1	1	-	-	1	3	2	-	-
	Eucnemidae	Dec	1	1	1	1	1	1	1	4	1	1
	Histeridae	Dec	1	1	1	1	1	3	10	2	4	2
	Laemophloeidae	Pre	1	-	-	2	1	2	-	-	3	1
	Latridiidae	Dec	-	-	-	-	1	-	-	-	-	1
	Nitidulidae	Dec	2	1	2	2	2	4	2	3	4	2
	Phalacridae	Dec	-	1	-	-	-	-	4	-	-	-
	Ptiliidae	Dec	-	1	1	-	1	-	3	2	-	2
	Silvanidae	Dec	-	-	1	-	-	-	-	5	-	-
	Staphylinidae	Pre	4	5	7	10	7	27	33	17	19	12
	Tenebrionidae	Dec	1	-	-	1	-	1	-	-	1	-
Diptera	Chironomidae	Dec	-	-	2	-	-	-	-	3	-	-
	Chloropidae	Dec	1	1	2	2	1	111	80	73	125	145
	Culicidae	Dec	1	-	-	1	1	3	-	-	1	1
	Muscidae	Dec	1	1	1	1	1	27	21	11	23	13
	Phoridae	Pre	-	1	1	1	-	-	1	3	1	-
	Piophilidae	Dec	1	1	2	1	1	10	16	4	1	8
	Sciaridae	Dec	-	1	-	1	1	-	4	-	6	2
	Tachinidae	Par	-	1	-	1	-	-	1	-	2	-
	Tipulidae	Dec	1	1	1	1	1	2	3	1	2	3
Hemiptera	Aphididae	Hrb	-	-	1	-	1	-	-	1	-	1
	Cicadellidae	Hrb	1	1	1	1	1	8	11	1	3	2
	Miridae	Hrb	1	-	1	1	1	2	-	2	1	1
	Pentatomidae	Hrb	-	-	-	1	-	-	-	-	1	-
Hymenoptera	Braconidae	Par	1	-	3	3	3	4	-	2	5	4
	Ceraphronidae	Par	-	1	-	1	-	-	1	-	1	-
	Diapriidae	Par	1	-	2	1	1	2	-	3	9	3
	Eucolidae	Par	1	1	-	-	-	3	1	-	-	-
	Eulophidae	Par	1	-	1	-	1	1	-	4	-	4
	Evaniidae	Par	-	-	1	1	1	-	-	2	2	2
	Formicidae	Pre	5	4	6	4	5	456	198	599	632	281
	Ichneumonidae	Par	-	-	1	1	1	-	-	1	1	1
	Mymaridae	Par	1	1	2	1	2	5	5	11	6	8
	Platigastridae	Par	1	1	3	2	3	5	3	58	7	14
	Scelionidae	Par	1	1	3	3	1	16	19	17	35	30
	Trichogrammatidae	Par	-	-	2	1	1	-	-	2	1	3
Lepidoptera	Amatidae	Hrb	-	1	-	-	-	-	1	-	-	-
	Crambidae	Hrb	-	-	1	1	-	-	-	2	3	-
Thysanoptera	Thripidae	Hrb	2	1	2	2	2	43	55	24	36	20
Total			47	44	67	65	58	783	514	945	996	616

[a]Pre: predator, Par: parasitoid, Hrb: herbivore, Dec: decomposer.

[b]Cf: Carbofuran, Ch: Chlorantraniliprole, Bs: *Bacillus siamensis* APE35, Bt: *Bacillus thuringiensis,* Co: Control

The family Chloropidae (order Diptera) exhibited very high individual abundance across all treatments, especially in the control (145 individuals) and Bt (125 individuals). This high abundance may indicate the important role of these small flies in the sugarcane ecosystem, both as decomposers and as part of the food chain. The family Staphylinidae (order Coleoptera) also showed high abundance, particularly in the Bs and Bt treatments, indicating the role of these predators in controlling pest populations. The very high abundance of Formicidae (ants) in biological treatments further supports their role as effective biological control agents.

These data indicate that the use of biological insecticides such as *B. siamensis* and *B. thuringiensis* is more favorable to the diversity and abundance of non-target arthropods compared to chemical insecticides like Carbofuran and Chlorantraniliprole. The presence of a rich and abundant arthropod community, especially natural predators such as Staphylinidae beetles and Formicidae ants, is crucial for maintaining ecosystem balance.

Arthropod Diversity Indices

The Shannon-Wiener index measures diversity by considering both species richness and the evenness of individual distribution. The results showed that arthropod communities in the Bt (2.497) and Bs (2.394) treatments had the highest diversity indices, indicating that these communities are not only species-rich but also have relatively even individual distributions. The lowest value was 2.201 in the control group (Co), indicating the lowest diversity among the treatment groups (Figure 2A).

The Simpson index, which assesses the probability that two randomly selected individuals belong to the same species, showed the highest values in Bt (0.849) and Cf (0.808), indicating high species dominance in Bt and Cf. However, the high Simpson value for Bt can also be interpreted as a stable community where several dominant species play important ecological roles. The lowest values in Bs (0.732) and Co (0.730) suggest more balanced communities without excessive dominance by certain species (Figure 2B).

Evenness values, which measure the uniformity of individual distribution among species, were highest in Bt (0.486) and Bs (0.446), indicating a more even distribution of individuals among species within these communities. The lowest values in the control (0.333) and Chlorantraniliprole (0.338) indicate a less even distribution, likely due to certain species' dominance (Figure 2C).

These results indicate that treatments with biological insecticides such as *B.thuringiensis* and *B. siamensis* significantly support higher arthropod diversity compared to chemical pesticides like Carbofuran and Chlorantraniliprole. The higher species richness observed in biological treatments suggests that the use of these biocontrol agents is not only effective in pest management but also more environmentally friendly to non-target organisms, thereby preserving vital ecosystem functions such as natural biological control and organic matter decomposition (Lacey *et al.,* 2015).

The greater individual abundance in biological treatments also indicates that arthropod communities can maintain stable and sustainable populations, which is important for maintaining ecosystem balance and preventing secondary pest outbreaks. Conversely, chemical pesticides tend to suppress overall arthropod populations, which can disrupt ecological functions and reduce ecosystem resilience to disturbances (Arfan *et al.,* 2018; Kariyanna *et al.*, 2024).

The higher Shannon-Wiener index in biological treatments indicates communities that are not only species-rich but also have an even distribution of individuals, which is an indicator of healthy and stable communities. The high Simpson index value in Bt suggests dominance by certain species that may act as key predators or parasitoids, which are important in natural pest control. The high evenness values in biological treatments further reinforce the conclusion that individual distribution among species is more balanced, reducing the risk of excessive dominance by one or a few species that could cause ecosystem imbalance. Overall, these data support the use of biological insecticides as a sustainable and environmentally friendly pest management strategy that is not only effective in controlling pests but also maintains arthropod diversity and ecosystem functions in sugarcane plantations (Rahmawasiah *et al.,* 2022; Valeria *et al.,* 2022).

High arthropod diversity, as reflected by indices such as Shannon-Wiener, Simpson, and evenness, has a significant positive effect on crop protection within agroecosystems. This is due to several interrelated ecological mechanisms. First, high diversity enhances ecosystem stability and resilience to disturbances, including pest outbreaks. Diverse arthropod communities typically perform various ecological functions, such as predation, parasitism, and herbivore consumption, which collectively can effectively regulate pest populations (Wyckhuys *et al.*, 2025). With many species acting as natural enemies, the risk of pest population outbreaks is minimized due to functional redundancy if one natural enemy species decline, others can assume its role (Snyder 2019).

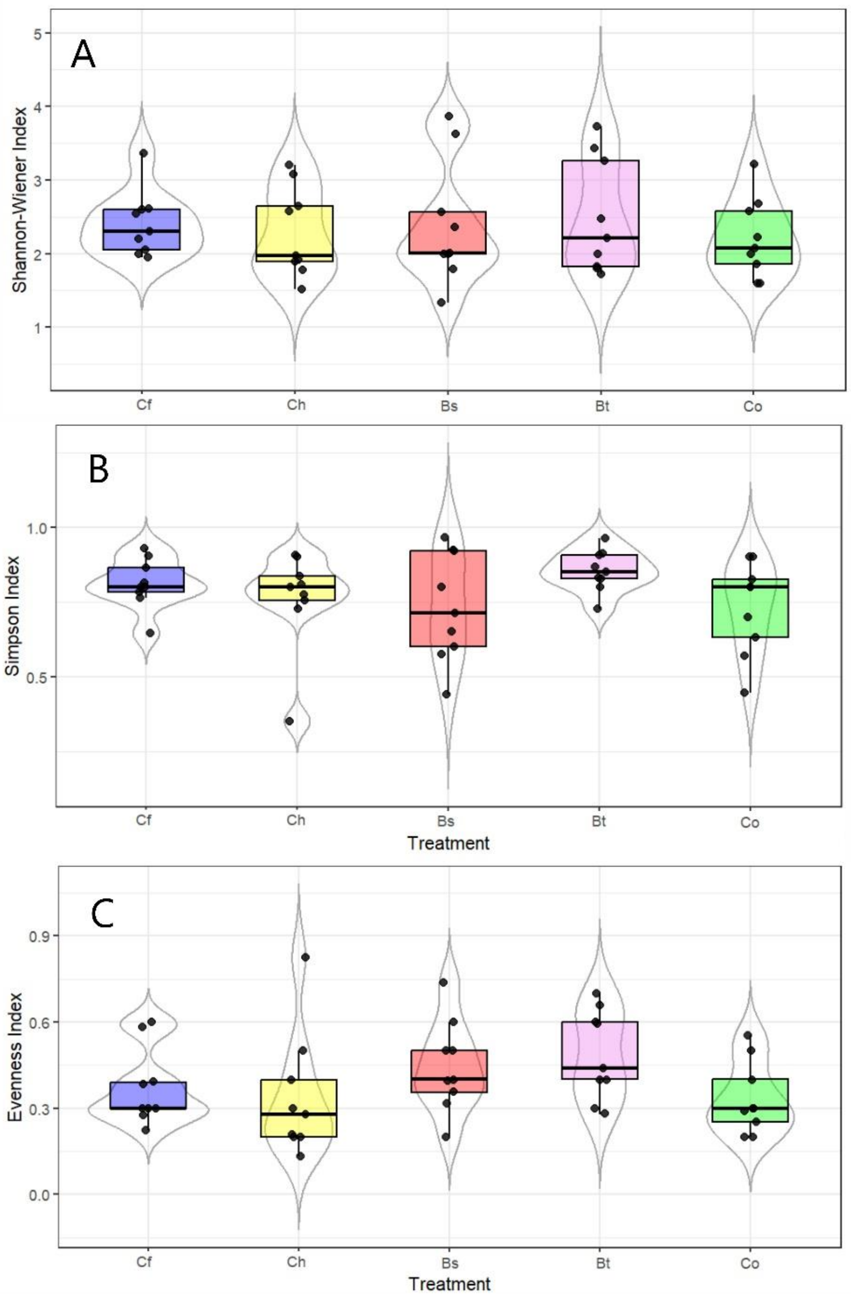

Figure 2. Diversity analysis, A. Shannon index, B. Simpson index, C. Evenness index) of arthropod communities under different insecticide treatments in sugarcane fields. Box plot showing mean values (horizontal line), population density distribution (grey line) and raw data (dots)

Second, high diversity supports complex interspecific interactions that strengthen biological control. For example, different predators and parasitoids can target various pest life stages or different pest species, making control more comprehensive and effective (Letourneau *et al.*, 2011). Additionally, this diversity can reduce the likelihood of dominance by certain pests that could cause massive crop damage. Third, diverse arthropod communities also contribute to other ecosystem functions that support plant health, such as pollination and organic matter decomposition, which enhance soil fertility (Altieri, 1999). These functions indirectly strengthen plant resistance to biotic and abiotic stresses.

In summary, high diversity index values indicate rich and balanced arthropod communities that serve as effective and sustainable natural pest control systems. Therefore, maintaining and enhancing arthropod diversity is an important strategy in integrated pest management and sustainable agriculture.

Arthropod Community Structure

Non-metric Multidimensional Scaling (NMDS) analysis in this graph illustrates the differences in arthropod community structure in sugarcane fields treated with various insecticide treatments (Figure 3). Each colour cluster represents a group of samples from one treatment, with the distance between clusters reflecting the degree of difference in species composition. It can be seen that the Carbofuran (Cf) group formed the most widely separated cluster from the other groups, indicating that the application of this chemical pesticide caused significant changes in arthropod community composition compared to the control and biological treatments.

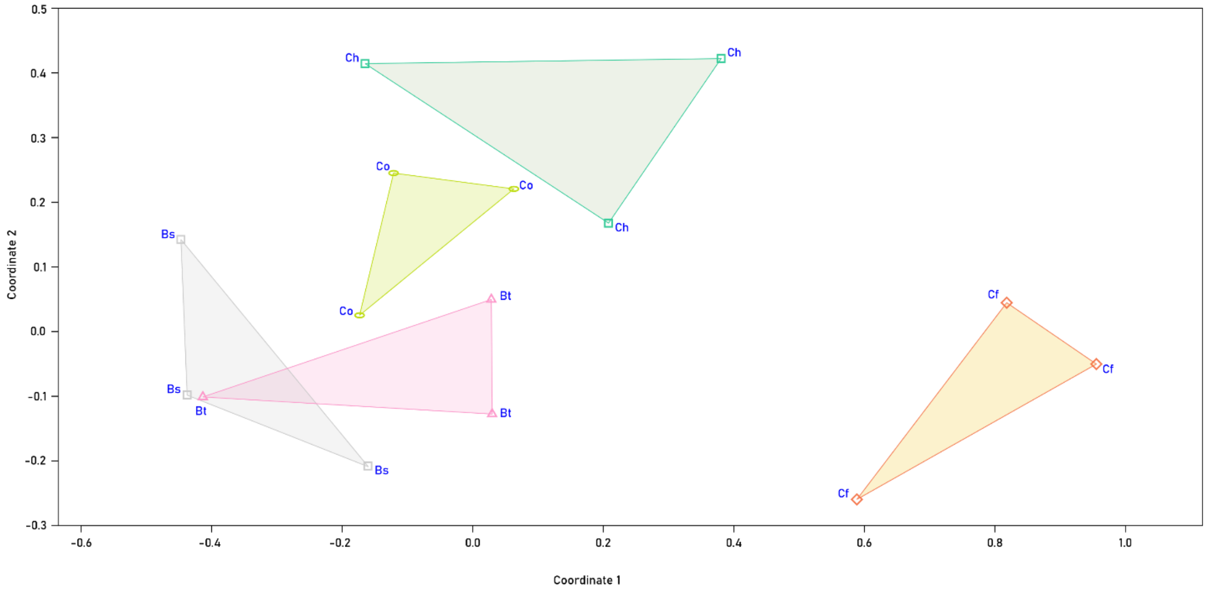

Figure 3. Non-metric Multidimensional Scaling (NMDS) of arthropod communities associated with sugarcane crops under different insecticide treatments. Each plot symbol represents an arthropod identified from each treatment of *B. siamensis* APE35 (Bs), *B. thuringienis* (Bt), Cf (Carbofuran), Chlorantaniliprole (Ch), and control (Co), based on Bray-Curtis dissimilarity

The Chlorantraniliprole (Ch) group also formed its cluster, which was quite separate, although not as far as Carbofuran. This indicates that Chlorantraniliprole had a different but still significant impact on community structure. In contrast, biological groups such as *B. siamensis* APE35 (Bs), *B. thuringiensis* (Bt), and control (Co) tended to cluster more tightly and closely together, indicating a similarity in arthropod composition under these treatments.

This phenomenon is consistent with the agricultural ecology literature, which states that synthetic chemical pesticides often disrupt soil biodiversity and non-target insects more drastically than biological agents or no treatment at all (Oguh *et al.* 2020; Quandahor *et al.* 2024). Chemical pesticides can reduce populations of natural predators and parasitoids, thus destroying the balance of the soil microfauna ecosystem and increasing the risk of secondary pest outbreaks.

In contrast, the use of entomopathogenic bacteria such as Bacillus spp. has been shown to maintain or even increase the diversity of non-target organisms due to their specific mechanism of action against target pests as well as their eco-friendly nature (Mnif and Ghribi 2015; Gunstone *et al.* 2021; Schmidt-Jeffris 2023). Therefore, the results of this NMDS support the recommendation of using biobased insecticides as an integrated pest management strategy to maintain arthropod community stability while minimizing negative impacts on sugarcane agroecosystems.

Functional Role Composition of Arthropods in Sugarcane Crops

The data presented illustrates changes in the composition of the ecological roles of arthropods in sugarcane fields due to various insecticide treatments, both biological and chemical. The roles of arthropods are classified into three main groups: decomposers (detritivore, fungivore, scavenger), herbivores (leafminer, chewing, sucking), and natural enemies (parasitoids and predators) (Figure 4). This analysis is important because the presence and proportion of each group contribute directly to the balance of agroforestry ecosystems and pest biological control.

In the decomposer group, it was seen that the percentage of scavengers dominated in all treatments with the highest values in *B. thuringiensis* (44.39%) and *B. siamensis* (43.83%). In comparison, the use of chemical pesticides such as Carbofuran significantly reduced the proportion of scavengers to 16.04%. This result shows that chemical pesticides tend to disrupt the function of natural decomposers that play an important role in the soil nutrient cycle through the process of decomposing organic matter (Meena *et al.,* 2020; Pearsons and Tooker 2021; Mitra *et al.,* 2024). Disrupted decomposer function can have a negative impact on long-term soil fertility.

In the herbivore category, leafminers showed the highest percentage, especially in the Carbofuran treatment at 34.91%, higher than the control (29.65%) and other biological treatments such as *B. thuringiensis* (19.75%). This increase in leafminers could be a side effect of the use of chemical insecticides that suppress natural predators or parasitoids, resulting in a disturbance of ecological balance by synthetic pesticides (Leroy *et al.,* 2020). Meanwhile, chewing and sucking herbivores were relatively low in all treatments but slightly higher in Chlorantraniliprole for sucking insects.

The natural enemy group is crucial as a biological control agent for sugarcane pests. The data showed that parasitoids had the highest percentage in *B. siamensis* at 17.39%, while predators also peaked in Chlorantraniliprole at 15.72%. The use of biological insecticides appeared to maintain or even increase the presence of natural enemies compared to chemical pesticides such as Carbofuran, which only produced parasitoids at 11.95% and predators at 15.41%. This is consistent with previous findings that microorganism-based products tend to be environmentally friendly for natural enemies, thus supporting sustainable biological control mechanisms in agroecosystems (Hutapea *et al.* 2019; Heviyanti *et al.* 2025). The application of aldicarb insecticide in potato crops was able to provide the best pest control and yield, but overall showed the lowest biodiversity in nontarget organisms, including predatory Heteroptera. On the other hand, *B. thuringiensis* applications were able to produce moderately good to excellent pest control effectiveness and yields, and allowed good survival of predatory Heteroptera and other nontarget organisms (Lacey *et al*. 2003).

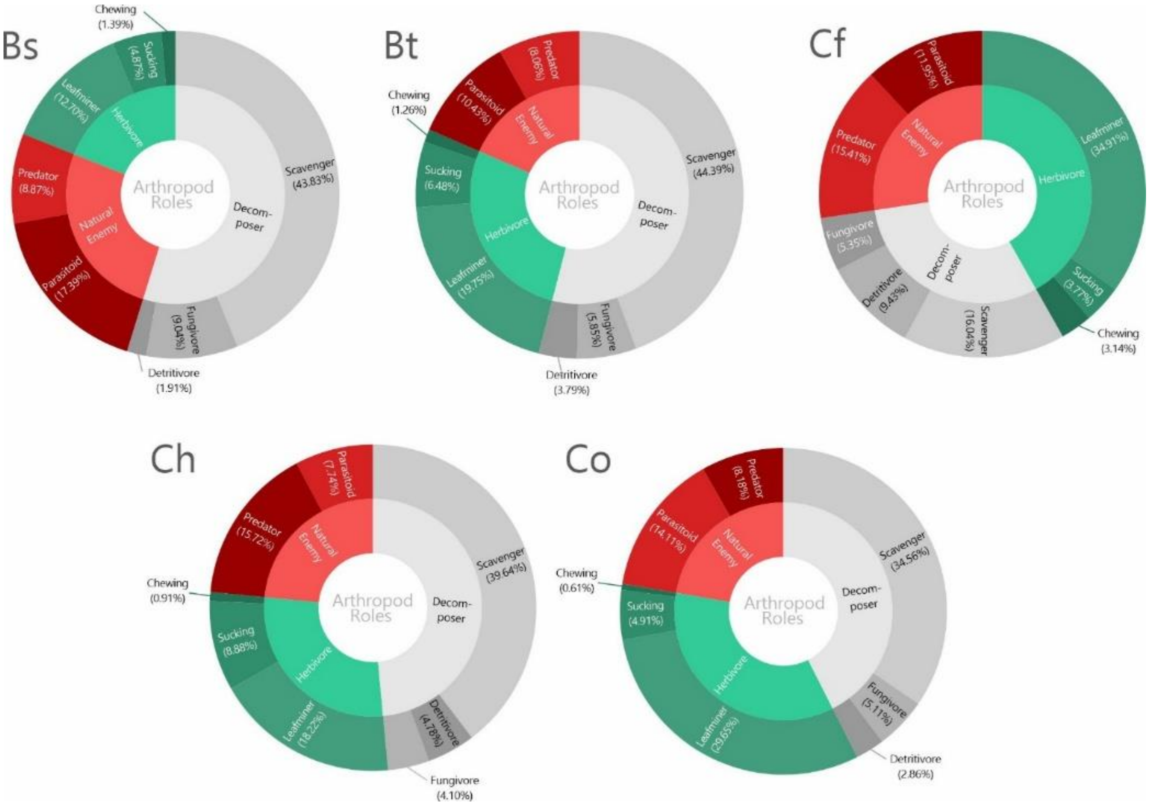

Figure 4. Relative abundance and functional group richness of sugarcane-associated arthropod communities under different insecticide treatments. Bs: *B. siamensis*, Bt: *B. thuringiensis*, Cf: Carbofuran, Ch: Chlorantraniliprole, dan Co: Control.

Overall, these data indicate that the application of microorganism-based insecticides (*B. siamensis* and *B. thuringiensis*) has a positive impact on the balance of functional arthropod communities compared to synthetic chemical pesticides such as Carbofuran and Chlorantraniliprole, which tend to damage the community structure through a decrease in decomposers and a potential increase in specific herbivores due to natural enemy interference.

CONCLUSION

Biological insecticides *B. thuringiensis* and *B. siamensis* significantly maintained arthropod diversity with species richness of 65–67 and individual abundance of 945–996, which were substantially higher than those observed in chemical insecticides Carbofuran (47 species, 783 individual) and Chlorantraniliprole (44 species, 514 individual) treatments. Biological treatments supported the presence of natural enemies such as predators and parasitoids, as well as decomposers. In contrast, chemical insecticides reduced ecological functions and increased specific herbivore populations, such as leafminers up to 34.91% in the Carbofuran treatment. Community structure analysis revealed that chemical insecticides caused significant shifts in arthropod composition, while biological insecticides maintained community stability. Therefore, the use of biological insecticides is strongly recommended in integrated pest management strategies to promote sustainable and environmentally friendly sugarcane cultivation.

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