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Research Article

Comparative Analysis of Insect Diversity in *Allium cepa* var. *aggregatum*, *Solanum lycopersicum*, and *Capsicum annuum* Agroecosystems in Parhaboan District, Northern Tapanuli, and Juhar District, Karo, North Sumatra, Indonesia

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Abstract: This study compared insect diversity in *Allium cepa* var. *aggregatum* G. Don, *Solanum lycopersicum* L., and *Capsicum annuum* L. agroecosystems Parhaboan District, North Tapanuli, and Juhar District, Karo, North Sumatra, Indonesia, aiming to assess species composition, abundance, and ecological roles. Using pitfall, yellow sticky, and blue ball traps, hand picking, and direct observation, we identified pest and beneficial insects. In *A. cepa* var. *aggregatum* fields, *Spodoptera litura* (Fabricius) and *Liriomyza chinensis* (Kato) were dominant pests, with *L. chinensis* populations peaking during specific crop growth stages, highlighting the impact of crop phenology and pesticide use. *S. lycopersicum* plantations showed moderate diversity, dominated by *Bactrocera* spp. and Formicidae, with blue ball traps capturing high densities of *Bactrocera* spp., suggesting strong visual attraction. *C. annuum* crops had abundant natural enemies, including *Paratrechina longicornis* (Latreille) and *Scelio* spp., alongside pests like *S. litura* and *Aphis* spp., demonstrating a complex ecological balance. Despite moderate diversity, high evenness of natural enemies indicated a stable predator community. Intercropping *C. annuum* with *A. cepa* var. *aggregatum* or *S. lycopersicum* revealed varied insect compositions. A critical imbalance between herbivores and natural enemies was observed across all agroecosystems, emphasizing the need for integrated pest management (IPM). This research highlights the importance of insect diversity for sustainable agriculture in North Sumatra, advocating for habitat diversification, biological control, and strategic pesticide use. Future studies should examine seasonal dynamics, crop-specific variations, and long-term agricultural impacts to refine IPM and promote biodiversity conservation.

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1. Introduction

Insect diversity within agricultural ecosystems plays a pivotal role in maintaining ecological balance and ensuring sustainable crop production. Agroecosystems, particularly those dedicated to horticultural crops, are complex environments where interactions between plants, insects, and other organisms significantly influence productivity and resilience. Understanding the composition and dynamics of insect communities within these systems is crucial for developing effective pest management strategies and conserving biodiversity (Landis et al., 2000).

Horticulture, an intensive cultivation technique, encompasses a broad spectrum of practices, from seed propagation and pest and disease management to efficient produce distribution (Ilsan et al., 2016). Defined as the art and science of cultivating vegetables, fruits, and ornamental plants (Pangemanan, 2023), horticulture plays a pivotal role in global agriculture. The Encyclopaedia Britannica further categorises horticultural plants into olericulture (vegetable cultivation), fruticulture (fruit cultivation), floriculture (ornamental plant cultivation), and biopharmacy (medicinal plant cultivation) (Rasiska et al., 2024; Syngé et al., 2024). Indonesia and Malaysia, endowed with substantial horticultural potential, recognise this sub-sector as a critical component of agricultural development, contributing significantly to both economic and food security. In regions such as North Sumatra, Banda Yogyakarta, and West Java, farmers leverage abundant natural resources, integrating horticultural crops into local livelihoods and regional economies. Vegetable crops, including chillies, tomatoes, potatoes, carrots, cabbages, mustard greens, and long beans, present substantial market opportunities, driving economic activity (Borror and DeLong, 2005).

In Indonesia, horticultural crops such as shallots (*Allium cepa* var. *aggregatum* G. Don), tomatoes (*Solanum lycopersicum* L.), and chilli peppers (*Capsicum annuum* L.) are economically vital, contributing significantly to local and national food security. These crops, however, are susceptible to a wide range of insect pests, leading to substantial yield losses and increased reliance on chemical pesticides (Dent, 2000). The indiscriminate use of pesticides not only poses risks to human health and environmental integrity but also disrupts natural enemy populations, leading to pest resurgence and secondary pest outbreaks (Altieri, 1994). Therefore, there is a growing need to adopt integrated pest management (IPM) strategies that promote biodiversity and minimize reliance on chemical interventions (Direktorat Jenderal Hortikultura, 2022).

Prior research has illuminated the complex interactions between insects and horticultural crops. For example, Supartha and Yogi (2012) investigated *Liriomyza sativae* or *L. huidobrensis*, pests that afflict a range of crops, including potatoes, celery, red beans, cabbage, lettuce, spinach, carrots, and soybeans. Apriliyanto and Setiawan (2019) documented Coleoptera and Hemiptera pests on aubergine and red chilli plants. Additionally, Paruntu et al. (2016) identified various pests on tomato plants, including *Liriomyza* spp., *Helicoverpa amigera*, *Myzus persicae*, *Thrips tabaci*, *Valanga* spp., *Chrysodeixis chalcites*, and *Bactrocera* spp. Furthermore, studies have also identified various insects that are beneficial to horticultural agriculture like bees, butterflies, beetles, and grasshoppers (Meilin and Nasamsir, 2016). Building upon these investigations, the Indonesian Collaborative Research team initiated a study on "Insect Diversity in Horticultural Agricultural Lands Supporting Food Security in Indonesia and Malaysia."

Allium cepa var. *aggregatum*, a staple ingredient in Indonesian cuisine, are vulnerable to pests such as *S. litura* and *L. chinensis*, which can cause significant damage to foliage and bulbs, respectively (Kalshoven, 1981). *Solanum lycopersicum*, another essential crop, are attacked by various pests, including fruit flies (*Bactrocera* spp.) and whiteflies, impacting fruit quality and yield (Waterhouse, 1993). *Capsicum annuum*, widely cultivated for their culinary and economic value, are susceptible to aphids, thrips, and fruit borers, among others, which can severely reduce fruit production (Asian Vegetable Research and Development Center, 1990).

The ecological complexity of agroecosystems can be enhanced through intercropping, a practice that involves growing two or more crops in close proximity. Intercropping can increase biodiversity, enhance natural enemy populations, and reduce pest pressure (Altieri, 1994). Understanding the insect diversity within intercropping systems involving *A. cepa* var. *aggregatum*, *S. lycopersicum*, and *C.*

annuum is essential for optimizing crop production and minimizing pest-related losses (Shepard et al., 1987; Susilo and Swibawa, 2001; Spencer, 2012).

North Sumatra, Indonesia, with its diverse agroecological zones, provides an ideal setting for studying insect diversity within horticultural agroecosystems. Parhaboan District, North Tapanuli, and Juhar District, Karo, are regions where *A. cepa* var. *aggregatum*, *S. lycopersicum*, and *C. annuum* are extensively cultivated. This study aims to conduct a comparative analysis of insect diversity within these agroecosystems, focusing on the composition, abundance, and ecological roles of insect species. By elucidating the interactions between insects and these crops, this research seeks to provide valuable insights for developing sustainable pest management strategies and enhancing the ecological resilience of horticultural agroecosystems in the region. Specifically, this study aims to: (1) determine the species composition and diversity of insects present in horticultural crops in North Sumatra; and (2) identify the ecological roles and functions of these insects within horticultural systems. This research is particularly pertinent to the broader objective of understanding insect diversity in horticultural lands supporting food security in Indonesia and Malaysia.

2. Materials and Methods

2.1. Study sites and experimental design

This research investigated insect diversity within three common horticultural agroecosystems: shallot (*Allium cepa* var. *aggregatum*), tomato (*Solanum lycopersicum*), and chilli (*Capsicum annuum*). Two distinct geographical locations in North Sumatra, Indonesia, were selected to represent variations in agroecological conditions: Juhar District, Karo Regency (3.023862°N, 98.279225°E), and Parhaboan Village, Pagaran District, North Tapanuli Regency (1°20'–2°41'N, 98°05'–99°16'E).

A stratified random sampling design was implemented within each location. Three cultivated fields, each dedicated to one of the target crops (shallot, tomato, or chilli), were selected. Each field served as an independent experimental unit. Within each field, five observation plots, each measuring 10 m × 10 m, were established. Plots were positioned at a minimum distance of 1 m from each other and 1 m from the field edge to minimise edge effects. A consistent 1 m spacing was maintained between adjacent planting beds within each plot. The planting density for each crop followed a standard, loose planting distance of 40 cm × 25 cm. The total area of each field was 20 m × 20 m (Figure 1).

2.2. Insect sampling methods

To comprehensively assess insect diversity, three distinct trapping methods were employed. Standard entomological Sweep Nets (SNs), with a 38 cm diameter and 60 cm bag depth, were utilised to capture aerial and foliage-dwelling insects. Within each plot, 25 standardized Sweep Nets (SNs) sweeps were performed along predetermined transects, ensuring coverage of all plant strata. Sampling was conducted during peak insect activity periods, specifically 09:00–11:00 and 15:00–17:00 hours, to maximise capture rates. Captured insects were immediately transferred to labelled containers filled with 70% ethanol for preservation. Blue Ball Traps (BBTs), with a 10 cm diameter, were employed to attract and capture flower-visiting insects, particularly pollinators. Five BBTs, coated with a non-drying entomological adhesive (Tangle-Trap, Pherocon), were strategically placed within each plot, suspended at canopy height. These traps were deployed for a 24-hour period, after which captured insects were carefully removed and preserved in 70% ethanol. Yellow Sticky Traps (YSTs), with dimensions of 15 cm × 20 cm, coated with a non-drying entomological adhesive (Catchmaster Yellow Glue Boards), were used to capture small, flying insects, including aphids (Aphididae), whiteflies (Aleyrodidae), and thrips (Thripidae) (Figure 1). Five YSTs were vertically positioned within each plot, placed at plant canopy height. These traps were exposed for a 48-hour period, and captured insects were subsequently removed and preserved in 70% ethanol.

2.3. Environmental data collection

To investigate the influence of environmental factors on insect diversity, several parameters were measured. Physical parameters, including temperature (°C) and relative humidity (%), were measured using a digital thermo-hygrometer (Hanna Instruments HI9565). Soil pH was determined using a portable soil pH meter (Hanna Instruments HI981030). Rainfall (mm) data were obtained from

the nearest meteorological station (National Meteorology, Climatology, and Geophysics Agency of Indonesia, BMKG). Light intensity (lux) was measured using a digital lux meter (Lutron LX-101), and wind speed (m/s) was measured using a handheld anemometer (Extech AN300). Chemical parameters, specifically soil nutrient levels (nitrogen, phosphorus, potassium), were determined through soil samples taken from each plot and analysed by a certified soil testing laboratory (Soil Research Institute, Bogor, Indonesia), following standard procedures (Soil Survey Staff, 2014). Data on fertiliser and pesticide application practices, including type, frequency, and quantity, were obtained through structured interviews with farmers and verified through direct field observations.

2.4. Insect identification and functional categorization

Captured insects were identified to the lowest practical taxonomic level, either species or genera, using relevant taxonomic keys and expert consultation with entomologists from the Museum Zoologicum Bogoriense, Indonesia. Insects were then categorise based on their ecological function within the horticultural system. Pests were defined as insects known to cause direct or indirect damage to the target crops, based on published literature and local farmer knowledge. Predators were defined as insects that prey on other insects, including pests, identified by their morphological features and known predatory behaviour. Parasitoids were defined as insects that develop within or on another insect host, ultimately killing the host, identified by their life history and host associations.

2.5. Data analysis

Insect diversity and community structure across the shallot, tomato, and chilli agroecosystems were evaluated using quantitative ecological indices. Species richness (S) was determined by the total number of distinct insect species recorded within each experimental plot. To assess the complexity of the insect communities, the following diversity indices were calculated:

Shannon-Wiener Diversity Index (H'): was used as a measure of species diversity that considers both species richness and evenness, calculated as: This was used to measure species diversity by accounting for both richness and the relative abundance (evenness) of species. It was calculated as:

$$H' = - \sum_{i=1}^S p_i \ln p_i \quad (1)$$

where p_i is the proportion of individuals belonging to the *species*.

Simpson's Diversity Index (D): This served as a measure of dominance, reflecting the probability that two individuals randomly selected from a sample belong to the same species. It was calculated as:

$$D = 1 - \sum_{i=1}^S p_i^2 \quad (2)$$

Pielou's Evenness Index (J'): This measured the relative distribution of individuals among the species present, calculated as:

$$J' = H' / \ln S. \quad (3)$$

Temporal dynamics of insect populations were analyzed by tracking mean abundance across various crop growth stages, specifically from 7 to 70 days after planting (DAP). Functional group composition was assessed by categorizing identified species into pests, predators, or parasitoids to evaluate the ecological balance within each system. All quantitative data processing and index calculations were performed to provide a comparative overview of insect community stability and the impact of agricultural practices across the study sites.

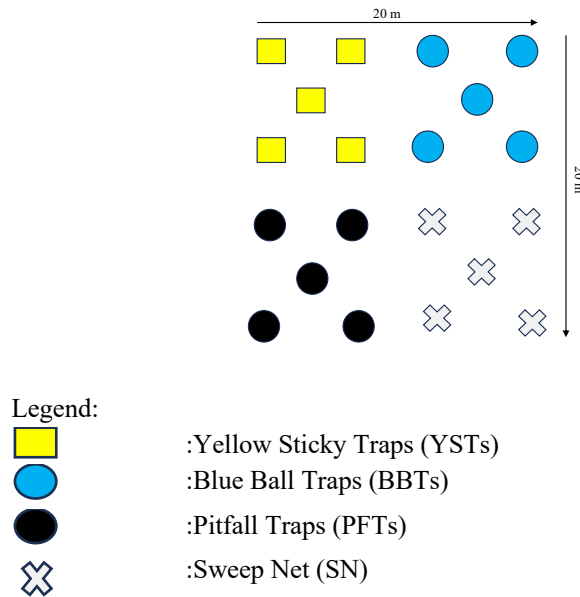


Figure 1. Layout of the experimental plots showing the distribution of insect sampling techniques: Yellow Sticky Traps (YSTs), Blue Ball Traps (BBTs), Pitfall Traps (PFTs), and Sweep Nets (SNs) sampling regions.

3. Results

3.1. Insect composition captured on shallots (*Allium cepa* var. *aggregatum*)

The investigation of insect diversity within *A. cepa* var. *aggregatum* crops in Parhaboan Village revealed the presence of insects belonging to five orders, nine families, and nine distinct species. These species encompassed both pest and beneficial insects associated with shallot cultivation. As presented in Table 1, a total of 176.6 individual insects were recorded, representing the following species: *Micraspis crocea* (Mulsant), *Conoderus posticus* (Eschscholtz), *Liriomyza chinensis* (Kato), *Empoasca fabae* (Harris), *Mictis longicornis* Westwood, *Spodoptera litura* (Fabricius), *Agrotis ipsilon* (Hufnagel), *Valanga nigricornis* (Burm), and *Mantis religiosa* (Linnaeus). Notably, *S. litura* was the most abundant species, with a mean of 75.2 individuals, while *M. longicornis* exhibited the lowest abundance, with a mean of 4.6 individuals. The functional roles of these insects varied, with *S. litura* and *L. chinensis* identified as key pest species affecting *A. cepa* var. *aggregatum* crops. The presence of other insects, such as *M. crocea* and *M. religiosa*, indicates the presence of predatory insects within the *Allium cepa* var. *aggregatum* agroecosystem, suggesting a degree of natural biological control.

Table 1. Mean abundance of insect species on *Allium cepa* var. *aggregatum* foliage, by order, family, and species, in North Sumatra, Indonesia

Order	Family	Species	Mean Abundance
Coleoptera	Coccinellidae	<i>Micraspis crocea</i> (Mulsant)	9.5
	Elateridae	<i>Conoderus posticus</i> (Eschscholtz)	7.8
Diptera	Agromyzidae	<i>Liriomyza chinensis</i> (Kato)	35.5
Hemiptera	Cicadellidae	<i>Empoasca fabae</i> (Harris)	17.4
	Coreidae	<i>Mictis longicornis</i> Westwood	4.6
Lepidoptera	Noctuidae	<i>Spodoptera litura</i> (Fabricius)	75.2
	Noctuidae	<i>Agrotis ipsilon</i> (Hufnagel)	12.4
Orthoptera	Acrididae	<i>Valanga nigricornis</i> (Burm)	7.8
	Mantidae	<i>Mantis religiosa</i> (Linnaeus)	6.4
Total			176.6

3.2. Temporal dynamics of insect species abundance on *Allium cepa* var. *aggregatum*

The temporal dynamics of insect populations on *A. cepa* var. *aggregatum* plants across different growth stages, ranging from 7 to 70 Days After Planting (DAP), are illustrated in Table 2. At 7 DAP, the initial insect population was recorded as 21.4 individuals, which gradually increased, peaking at 29.7 individuals at 40 DAP. Subsequently, a decline in insect populations was observed, with 20.9 individuals at 50 DAP and 19.3 individuals at 70 DAP. These fluctuations in insect populations are consistent with the principles of population dynamics, wherein insect numbers are influenced by factors such as birth rates, mortality, immigration, and emigration, as highlighted by (Apriyani et al., 2021). Furthermore, Schowalter (2016) noted that pest species composition can vary over time due to changes in cultivation practices, natural enemy effectiveness, insecticide use, commodity values, economic damage thresholds, and planted varieties. The observed population trends, with *S. litura* and *L. chinensis* being the most prevalent species, followed by *E. fabae*, *A. ipsilon*, *M. crocea*, *C. posticus*, *V. nigricornis*, *M. religiosa*, and *M. longicornis*, reflect these dynamic interactions.

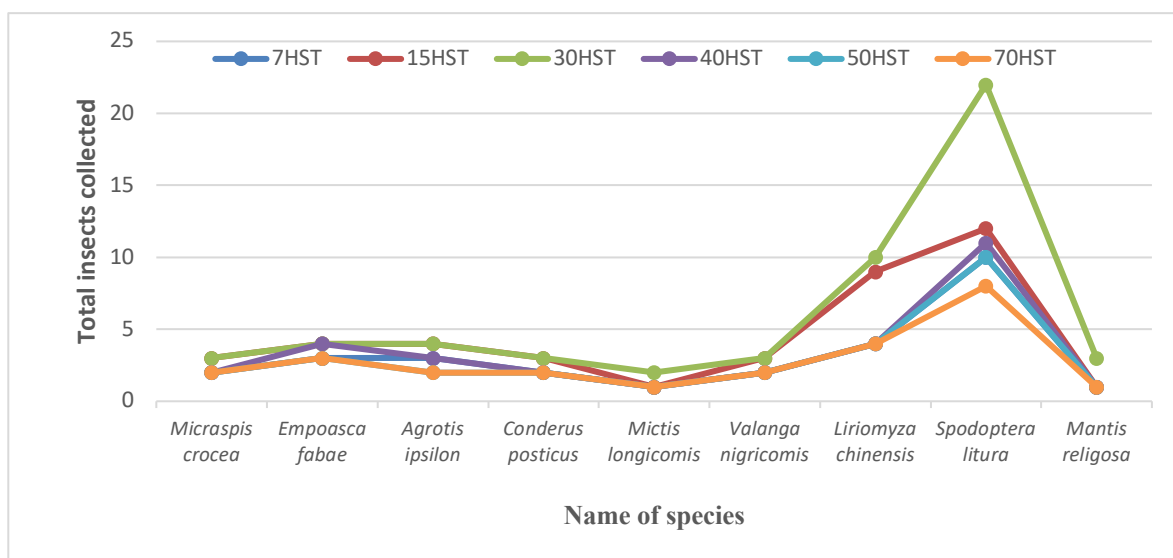
Table 2. Temporal dynamics of insect species abundance on *Allium cepa* var. *aggregatum* foliage, from 7 to 70 days after planting (DAP), in North Sumatra, Indonesia

Species	Mean Insect Abundance (DAP)						Total
	7	15	30	40	50	70	
<i>Micraspis crocea</i> (Mulsant)	0.9	1.8	3.1	1.9	0.9	0.9	9.5
<i>Conoderus posticus</i> (Eschscholtz)	0.7	1.4	2.4	1.7	0.8	0.8	7.8
<i>Liriomyza chinensis</i> (Kato)	4.2	8.4	10.0	4.3	4.2	4.4	35.5
<i>Empoasca fabae</i> (Harris)	1.9	3.3	4.4	3.8	2.0	2.0	17.4
<i>Mictis longicornis</i> Westwood	0.6	0.8	1.3	0.7	0.6	0.6	4.6
<i>Spodoptera litura</i> (Fabricius)	10.2	12.4	22.4	12.0	10.0	8.2	75.2
<i>Agrotis ipsilon</i> (Hufnagel)	1.5	2.6	3.8	2.7	0.9	0.9	12.4
<i>Valanga nigricornis</i> (Burm)	0.6	1.4	2.5	1.7	0.8	0.8	7.8
<i>Mantis religiosa</i> (Linnaeus)	0.8	1.2	2.1	0.9	0.7	0.7	6.4
Total	21.4	33.3	52.0	29.7	20.9	19.3	176.6

Table 3. Intensity of *Spodoptera litura* damage to *Allium cepa* var. *aggregatum* Foliage (%) at various days after planting (DAP)

Observations	Attack Intensity (%) per Plot					Total (%)	Mean (%)
	A	B	C	D	E		
7 DAP	4.28	6.75	4.27	6.28	8.42	30.00	6.00
15 DAP	8.45	14.48	6.45	4.19	12.64	46.21	9.24
30 DAP	12.74	12.65	4.37	14.55	6.45	50.76	10.15
40 DAP	14.76	16.82	8.63	10.46	12.38	63.05	12.61
50 DAP	8.48	12.69	6.45	10.47	10.54	48.63	9.73
70 DAP	8.56	10.54	8.63	6.26	8.69	42.68	8.54
Total	-	-	-	-	-	281.33	56.27
Mean	-	-	-	-	-	46.89	9.38

The temporal variations in damage intensity emphasize the importance of implementing timely and targeted pest management strategies. Monitoring *S. litura* populations and damage levels at different growth stages of *A. cepa* var. *aggregatum* can help in determining the optimal timing for interventions. Integrated pest management approaches, including biological control, cultural practices, and judicious use of insecticides, should be considered to minimize the impact of *S. litura* and *L. chinensis* on crop yield and quality.

Figure 2. Temporal dynamics of pest attacks on *Allium cepa* var. *aggregatum* agroecosystems.

3.3. Taxonomic distribution, functional roles and variances of traps used by insects

Table 4 presents the taxonomic distribution, functional roles (herbivores, predators, and parasitoids), and relative abundance of insect species identified in *Solanum lycopersicum* (tomato) agroecosystems across two districts in North Sumatra, Indonesia.

Table 4. Taxonomic distribution, functional roles (herbivore, predator, parasitoid), and relative abundance of insect species identified in *Solanum lycopersicum* (tomato) agroecosystems across two districts in North Sumatra, Indonesia

Order	Family	Species	Functional Role
Hymenoptera	Formicidae	<i>Dolichoderus thoracicus</i> (Smith)	Predator
		<i>Anoplolepis gracilipes</i> (Smith)	Predator
	Braconidae	<i>Stenobracon nicevillei</i> (Bingham)	Parasitoid
Orthoptera	Gryllidae	<i>Gryllus pennsylvanicus</i> Burmeister	Herbivore
	Pyrgomorphoidae	<i>Atractomorpha crenulata</i> Fabricius	Herbivore
	Tettigoniidae	<i>Conocephalus longipennis</i> (Haan)	Herbivore
Coleoptera	Labiduridae	<i>Labidura riparia</i> (Pallas)	Predator
	Coccinellidae	<i>Epilachna admirabilis</i> Crotch	Herbivore
		<i>Menochilus sexmaculatus</i> (Fabricius)	Predator
	Carabidae	<i>Pheropsophus occipitalis</i> (Macleay)	Predator
Odonata	Coenagrionidae	<i>Agrocnemis pygmaea</i> (Rambur)	Predator
	Libellulidae	<i>Diplacodes trivialis</i> (Rambur)	Predator
		<i>Orthetrum sabina</i> (Drury)	Predator
Hemiptera	Alydidae	<i>Leptocoris acuta</i> (Thunberg)	Herbivore
	Reduviidae	<i>Zelus</i> spp.	Predator
	Pseudococcidae	<i>Pseudococcus</i> spp.	Herbivore
Lepidoptera	Crambidae	<i>Diaphania indica</i> Saunders	Herbivore
Diptera	Tephritidae	<i>Bactrocera</i> spp.	Herbivore
Hemiptera	Aleyrodidae	<i>Bemisia tabaci</i> (Gennadius)	Herbivore

Table 5. Comparative summary of insect species diversity and abundance as sampled by three trapping techniques across *Allium cepa* var. *aggregatum*, *Solanum lycopersicum*, and *Capsicum annuum* agroecosystems in Parhaboan and Juhar Districts, North Sumatra

Species	Pitfall Traps (PFTs)	Yellow Sticky Traps (YSTs)	Blue Ball Traps (BPTs)
<i>Stenobracon nicevillei</i> (Bingham)	45	-	-
<i>Anoplolepis gracilipes</i> (Smith)	100	-	-
<i>Stenobracon nicevillei</i> (Bingham)	-	-	14
<i>Gryllus pennsylvanicus</i> Burmeister	9	-	-
<i>Atractomorpha crenulate</i> Fabricius	-	-	25
<i>Conocephalus longipennis</i> (Haan)	-	-	19
<i>Labidura riparia</i> (Pallas)	16	-	-
<i>Paederus littoralis</i> Gravenhorst	12	-	-
<i>Epilachna admirabilis</i> Crotch	-	6	-
<i>Menochilus sexmaculatus</i> (Fabricius)	-	8	-
<i>Pheropsophus occipitalis</i> (Macleay)	10	2	-
<i>Agrocnemis pygmaea</i> (Rambur)	6	3	2
<i>Diplacodes trivialis</i> (Rambur)	2	1	1
<i>Orthetrum sabina</i> (Drury)	5	2	14
<i>Leptocoris acuta</i> (Thunberg)	-	4	18
<i>Zelus</i> spp.	-	-	12
<i>Pseudococcus</i> spp.	-	-	75
<i>Diaphania indica</i> Saunders	-	-	19
<i>Bactrocera</i> spp.	-	168	-
<i>Bemisia tabaci</i> (Gennadius)	-	-	42
Total	265	194	241

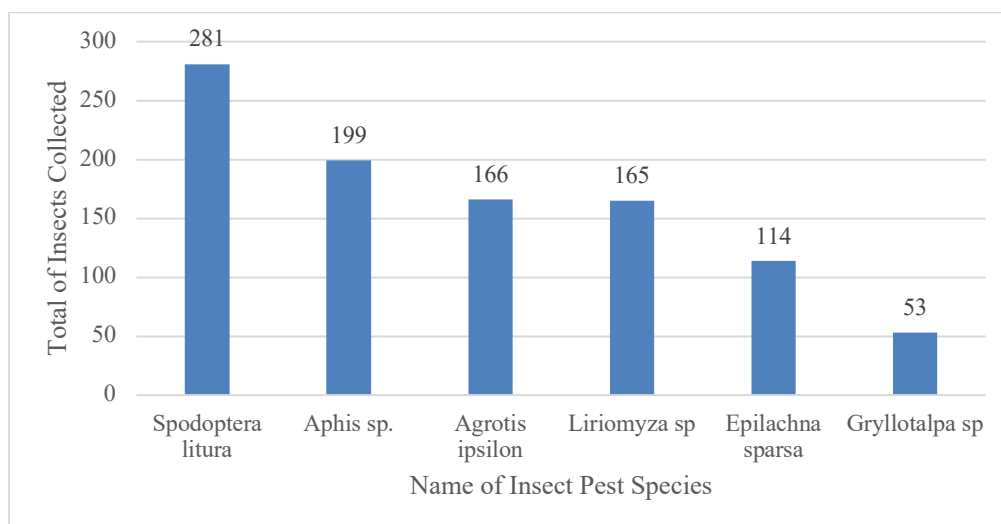
Table 6. Composition and abundance of predator insect species collected using traps in *Capsicum annuum* agroecosystems, differentiated by ecological function, order, and species, in Parhaboan District, Northern Tapanuli, and Juhar District, Karo, North Sumatra, Indonesia

Ecological Function	Order-Species	Total in Parhaboan	Total in Juhar
Predator	Odonata		
	<i>Agriocnemis pygmaea</i> (Rambur)	7	5
	<i>Agriocnemis femina</i> (Rambur)	4	2
	<i>Orthetrum sabina</i> (Rambur)	15	10
	<i>Pantala flavescens</i> (Fabricius)	3	1
Predator	Diptera		
	<i>Amblypsylopus</i> spp.	62	50
	<i>Coenosia</i> spp.	9	6
	<i>Culicoides</i> spp.	15	12
	<i>Eristalinus</i> spp.	3	2
	<i>Ischiodon scutellaris</i>	12	10
	<i>Neurigona</i> spp.	29	24
	<i>Sciapus</i> spp.	65	56
Predator	Hemiptera		
	<i>Cyrtorhinus lividipennis</i> Reuter	10	8
	<i>Deraeocoris</i> spp.	2	3
	<i>Triatoma</i> spp.	1	2
	<i>Anoplolepis gracilipes</i> (Smith)	247	235
	<i>Campsomeris</i> spp.	2	1
	<i>Dolichoderus thoracicus</i> (Smith)	28	22
Predator	<i>Formica</i> spp.	4	3
	Hymenoptera		
	<i>Odontoponera denticulata</i> (Smith)	9	6
	<i>Paratrechina longicornis</i> (Latreille)	549	463
	<i>Technomyrmex</i> spp.	3	2
	<i>Vespa analis</i> Fabricius	6	4
Predator	<i>Scelio</i> spp.	189	108

Table 6. Composition and abundance of predator insect species collected using traps in *Capsicum annuum* agroecosystems, differentiated by ecological function, order, and species, in Parhaboan District, Northern Tapanuli, and Juhar District, Karo, North Sumatra, Indonesia (continued)

Ecological Function	Order-Species	Total in Parhaboan	Total in Juhar
Predator	Orthoptera		
	<i>Conocephalus longipennis</i> (Haan)	26	22
	<i>Conocephalus</i> spp.	1	3
	<i>Metioche vittaticolis</i> (Stål)	21	25
Predator	Coleoptera		
	<i>Chilocorus nigrinus</i> (Fabricius)	24	26
	<i>Chlaenius</i> spp.	8	6
	<i>Cicindella</i> spp.	2	3
	<i>Coccinella repanda</i> Thunberg	1	4
	<i>Coccinella transversalis</i> Fabricius	30	35
	<i>Coleosoma octomaculatum</i> (Bösenberg and Strand)	2	1
	<i>Harmonia axyridi</i> Pallas	1	2
	<i>Menochilus sexmaculatus</i> (Fabricius)	10	14
	<i>Lathrobium</i> spp.	2	3
	<i>Paederus fuscipes</i> Curtis	15	12
	<i>Pterostichus</i> spp.	2	3
	<i>Verania lineata</i> Thunberg	9	6
Total		1.428	1.200

The composition of insect pests identified on *C. annuum* plants is visually represented in Figure 3. The most abundant pest species recorded was *S. litura*, followed by aphids (*Aphis* spp.) and *Perkinsinella* spp. The least abundant pest species observed was *Cicadulina* spp. The relative abundance of these key pest species provides insights into the primary challenges for *C. annuum* cultivation in the study areas. Further analysis will explore the potential impact of intercropping systems on the population dynamics of these pests.

Figure 3. Dominant insect pests infesting *Capsicum annuum* plants.

The diversity of natural enemy insects associated with *C. annuum* plants at both study sites, Parhaboan Village and Juhar Village, exhibited moderate Shannon-Wiener diversity indices (H'). Specifically, H' values ranged from 2.37 to 2.79 in Parhaboan and 2.45 to 2.94 in Juhar (Table 7). In contrast, the evenness of species distribution was high at both locations, with values between 0.60 and 0.85 in Parhaboan and 0.64 and 0.90 in Juhar (Table 7), indicating a relatively balanced community of predator species.

Table 7. Diversity indices (Simpson's Index, D, and Shannon-Wiener Index, H') for insect communities in *Capsicum annuum* agroecosystems at Parhaboan, Northern Tapanuli, and Juhar, Karo, North Sumatra, Indonesia

Sampling	Calculation Index in Parhaboan, Northern Tapanuli		Calculation Index in Juhar, Karo	
	D	H'	D	H'
First	0.60	2.45	0.72	2.65
Second	0.74	2.67	0.83	2.87
Third	0.85	2.79	0.90	2.94
Fourth	0.76	2.68	0.87	2.73
Fifth	0.72	2.56	0.72	2.62
Sixth	0.68	2.37	0.64	2.45

3.4. Diversity indices calculation

The findings from both sampling methods provide a comparative overview of the insect diversity associated with these two intercropping systems, highlighting the different insect taxa present and their ecological functions. Further analysis and discussion of the specific insect communities identified, their abundance, and potential interactions within each intercropping system will be presented in subsequent sections.

Table 8. Insect diversity in *Capsicum annuum* - *Allium cepa* var. *aggregatum* intercropping systems, collected by hand picking, including order, family, species, life stage (phase), and ecological function

Order	Family	Species	Life Stage (Phase)	Total Observation				Total	Function
				1	2	3			
Coleoptera	Coccinellidae	<i>Menochilus sexmaculatus</i> (Fabricius)	Imago	28	28	36	17	109	Entomophagous
Coleoptera	Chrysomelidae	<i>Coelophora partita</i> Mulsant	Imago	16	16	21	14	118	Phytophagous
Coleoptera	Chrysomelidae	<i>Aulacophora lewisii</i> Baly	Imago	7	7	8	4	26	Phytophagous
Hymenoptera	Aphididae	<i>Aphis gossypii</i> Glover	Nymph-Imago	685	685	753	794	2917	Phytophagous
Lepidoptera	Noctuidae	<i>Spodoptera litura</i> (Fabricius)	Larva	247	247	368	382	1244	Phytophagous
Orthoptera	Acrididae	<i>Valanga nigricornis</i> (Burmeister)	Imago	12	12	18	22	64	Phytophagous

Direct observation of actively flying or rapidly moving insects in the *C. annuum* and *A. cepa* var. *aggregatum* intercropping system identified a specific set of actively flying or rapidly moving insect taxa (Table 9).

Table 9. Insect diversity in *Capsicum annuum* vs. direct observation

Order	Family	Species	Stage	Total Observation			Total	Status
				1	2	3		
Hymenoptera	Apidae	<i>Apis cerana</i> Fabricius	Imago	4	6	5	15	Phytophagous
Hymenoptera	Formicidae	<i>Dolichoderus thoracicus</i> (Smith)	Imago	6	9	8	23	Entomophagous
Lepidoptera	Noctuidae	<i>Spodoptera litura</i> (Fabricius)	Imago	197	284	312	793	Phytophagous
Odonata	Libellulidae	<i>Orthetrum sabina</i> (Drury)	Imago	5	7	9	21	Phytophagous
Mantodea	Mantidae	<i>Mantis religiosa</i> (Linnaeus)	Imago	12	19	15	46	Phytophagous

Direct visual identification in the intercropping system of *C. annuum* and *S. lycopersicum* revealed the presence of insects from six orders, ten families, and thirteen species, encompassing both phytophagous and entomophagous functional roles (Table 10).

Table 10. The presence of insects on *Capsicum annuum* and *Solanum lycopersicum* plants using direct observation methods

Order	Family	Species	Plantation		Functional Role
			<i>C. annuum</i>	<i>S. lycopersicum</i>	
Coleoptera	Chrysomelidae	<i>Aulacophora</i> spp.	√	√	Phytophagous
	Coccinellidae	<i>Chilocorus</i> spp.	√	~	Entomophagous
		<i>Epilachna</i> spp.	√	√	Phytophagous
	Staphylinidae	<i>Paederus</i> spp.	√	~	Entomophagous
Diptera	Tephritidae	<i>Bactrocera</i> spp.	√	√	Phytophagous
Hymenoptera	Formicidae	<i>Dolichoderus thoracicus</i> (Smith)	~	√	Entomophagous
		<i>Anoplolepis gracilipes</i> (Smith)	~	√	Entomophagous
Hemiptera	Cicadellidae	<i>Empoasca</i> spp.	√	~	Phytophagous
	Coreidae	<i>Mictis longicornis</i> Westwood	√	~	Phytophagous
	Pentatomidae	<i>Euschistus</i> spp.	√	~	Phytophagous
		<i>Nezara viridula</i> (Linnaeus)	√	√	Phytophagous
Lepidoptera	Noctuidae	<i>Spodoptera litura</i> (F.)	√	√	Phytophagous
Orthoptera	Acrididae	<i>Valanga</i> spp.	~	√	Phytophagous

Footnote: (√) : Recorded; (~) : Not recorded.

4. Discussion

4.1. Insect composition captured on shallots (*Allium cepa* var. *aggregatum*)

The high abundance of *S. litura* suggests a significant pest pressure on *A. cepa* var. *aggregatum* crops in the studied area. This polyphagous pest is known for its voracious feeding habits and can cause substantial yield losses (Fathipour et al., 2018). The presence of *L. chinensis*, further exacerbates the pest pressure, as its larval feeding creates tunnels within leaf tissues, reducing photosynthetic efficiency and overall plant health (Farahdiba et al., 2023).

The presence of predatory insects, such as *M. crocea* and *M. religiosa*, is a positive indicator of natural pest regulation. *M. crocea* is a known predator of aphids and other small insects, while *M. religiosa* is a generalist predator that can contribute to the control of various pests (Triplehorn and Johnson, 2005). The relatively low abundance of these predators compared to *S. litura* suggests that natural biological control may not be sufficient to suppress pest populations effectively. This imbalance highlights the need for integrated pest management strategies that incorporate both biological and cultural control methods (Nusyirwan, 2013).

The use of yellow sticky traps (YSTs), designed to attract insects based on colour cues, resulted in the capture of *E. fabae*, *M. crocea*, and *A. ipsilon*. This phenomenon can be attributed to the passive trapping of insects carried by wind currents, as described by Arofah et al. (2013) who emphasized the close relationship between insect life and environmental factors, including food availability, habitat, and biotic and physical conditions. The effectiveness of yellow sticky traps in capturing these species suggests that they are attracted to yellow wavelengths, possibly due to their association with flowering plants or new plant growth (Prokopy and Owens, 1983; Weintraub and Murcia, 2010).

The relatively low abundance of *M. longicornis* may be attributed to its specific ecological requirements or its limited host range. This coreid bug is known to feed on a variety of plants, but its population dynamics may be influenced by factors such as host plant availability, natural enemies, and environmental conditions (Mitchell, 2000).

The overall insect community composition in *A. cepa* var. *aggregatum* crops reflects a complex interplay of pest and beneficial species, highlighting the need for a holistic approach to pest management that considers the ecological interactions within the agroecosystem (Ahmad et al., 2007).

4.2. Temporal dynamics of insect species abundance on *Allium cepa* var. *aggregatum*

The observed variations in insect population densities across different sampling periods are consistent with findings by (Jannah et al., 2021) who reported that unpredictable weather conditions can significantly impact insect diversity. Insect population fluctuations on *A. cepa* var. *aggregatum* plants can also be attributed to the dynamic movement of insect pests between plants, as noted by (Peni, 2022). Optimal temperature ranges for insect growth, between 20 °C and 29 °C, as well as food availability, play critical roles in these population dynamics. Silitonga (2005) further indicated that the temperature range of 15 °C to 33 °C is conducive to insect pest development. The observed surge in insect populations at 40 DAP, reaching 29.7 individuals, is likely due to the increased availability of food resources. Sista et al. (2016) suggested that increased plant height and leaf number, coupled with inappropriate insecticide applications, can contribute to insect population explosions.

The gradual increase in insect numbers from 7 to 40 DAP likely reflects the establishment and growth of pest populations as the *A. cepa* var. *aggregatum* plants matured, providing more food and habitat resources. The subsequent decline in insect numbers after 40 DAP could be attributed to several factors, including the depletion of food resources, increased natural enemy activity, or changes in plant physiology that make them less attractive to pests. Additionally, farmers may have applied insecticides during this later stage of plant growth, which could have reduced insect populations.

The high abundance of *S. litura* throughout the growth period suggests that it is a persistent and significant pest of *A. cepa* var. *aggregatum* in the study area. This pest is known for its polyphagous nature and high reproductive rate, which can lead to rapid population increases (Fathipour et al., 2018). The presence of *L. chinensis* as another dominant pest indicates that leafminers also pose a significant threat to *A. cepa* var. *aggregatum* production.

The presence of predatory insects like *M. crocea* and *M. religiosa* throughout the growth period suggests that natural biological control is occurring in the agroecosystem. However, the relatively low abundance of these predators compared to the pest species indicates that natural control may not be sufficient to regulate pest populations effectively (Eschscholtz, 1822).

The temporal dynamics of pest attacks on *A. cepa* var. *aggregatum* agroecosystems are presented in Figure 2. Pest populations fluctuated markedly throughout the observation period, with conspicuous peaks coinciding with the mid to late vegetative growth stages of the crop. Intensified pest infestations significantly curtailed plant productivity, posing risks of substantial yield losses and, in severe cases, total crop failure. Such losses are primarily attributed to the reduction of photosynthetic capacity due to extensive foliar damage, which impairs carbohydrate synthesis and translocation towards bulb development. One of the most damaging pest species, *L. chinensis*, initiated infestations through oviposition within the plant stems, as evidenced by initial symptoms such as discrete white punctures on the leaf epidermis (Zahro, 2015; Barita et al., 2018; Manueke et al., 2018).

As larval development progressed, the larvae extensively mined the mesophyll layer, commencing from the apical region and progressing towards the bulb. This feeding activity led to the characteristic desiccation of leaf tissues, with affected leaves displaying a conspicuous brownish-white and scorched phenotype. In cases of severe infestation, the foliage of entire plants exhibited complete

necrosis, resulting in the cessation of photosynthesis and subsequent bulb formation failure, particularly within high-density cultivation areas (Mahardhika et al., 2019).

The significant percentage of foliar damage recorded in *A. cepa* var. *aggregatum* agroecosystems, can be largely ascribed to the improper application of chemical pesticides by farmers (Mehrkhou et al., 2012; Sanjaya and Dibiyantoro, 2012). This is corroborated by the findings of Apriyani et al. (2021), which highlighted widespread deviations from recommended pesticide dosages and spraying intervals. The farmer interviews conducted in Parhaboan Village further substantiated these observations. Farmers typically commenced pesticide application at 14 days after planting (DAP) and continued at frequencies ranging from two to four applications per week. Alarming, most farmers applied dosages exceeding the recommended rates by one to three-fold, under the misconception that higher doses ensured more effective pest suppression (Mazid et al., 2011).

Chemical pest control predominantly involved the application of the insecticide Vayego 200 SC, containing the active ingredient Tetraniliprole (200 g/L), formulated as a brownish-white suspension concentrate. This insecticide exhibited both systemic and contact-stomach poison action modes and was applied twice during each planting season. Concurrently, fungicides such as Antracol 70WP and Trivia 73WP were employed to manage fungal pathogens. These fungicides were prepared as protective contact formulations, with Antracol 70WP presenting as a cream-coloured suspension powder, and Trivia 73 WP as a grey-coloured suspension powder. However, the excessive reliance on chemical pesticides raises serious concerns regarding the ecological stability of the agroecosystem (Arfan et al., 2019; Daryanto et al., 2019).

Over application of chemical pesticides, while temporarily suppressing pest populations, has been linked to a cascade of detrimental ecological consequences. Firstly, pest resurgence, pesticide resistance, and the suppression of natural enemies were observed, particularly in intensively managed *A. cepa* var. *aggregatum* plots (Susniahti and Sumeno, 2005). The reduction in populations of natural enemies, such as parasitoids and predatory insects, facilitated secondary pest outbreaks, thereby exacerbating pest-related damages. Secondly, pesticide-induced phytotoxicity was evident through alterations in plant physiology, including the reduction of stomatal aperture and the concomitant increase in stomatal density (Jaya et al., 2022). These changes are known to negatively affect plant water relations and gas exchange, further compromising plant growth and yield potential.

Insect composition and diversity in tomato (*Solanum lycopersicum*) agroecosystem A comprehensive survey of insect communities within *S. lycopersicum* agroecosystems in Parhaboan District and Juhar District revealed a rich diversity of 19 species across 8 insect orders and 16 families (Table 4), highlighting the ecological complexity of these cropping systems.

Orthoptera, Coleoptera, and Hemiptera were the most species-rich orders. The prevalence of phytophagous Orthoptera, including *G. pennsylvanicus* Burmeister, *Atractomorpha crenulata* Fabricius, and *Conocephalus longipennis* (Haan) were prevalent (Suin, 2000), contributed to significant herbivory, particularly during early fruiting stages, with notable defoliation observed in Parhaboan District (Krebs, 2014). The Coleoptera assemblage comprised both the herbivorous pest *Epilachna admirabilis* Fabricius, and predatory species like *Menochilus sexmaculatus* (Fabricius) and *Pheropsophus occipitalis* (Macleay). The higher abundance of these beneficial coleopterans in Juhar District may be linked to reduced pesticide use and greater floral diversity (Mahardhika et al., 2019). Hemiptera included the herbivores *Leptocorisa acuta* (Thunberg) and *Pseudococcus* spp., causing sap-feeding damage, and the predatory *Zelus* spp., potentially contributing to pest suppression, particularly under moderate pesticide regimes (Apriyani et al., 2021).

Within Hymenoptera, the predatory ants *Dolichoderus thoracicus* (Smith) and *Anoplolepis gracilipes* (Smith) were dominant, exhibiting both pest suppression and potential facilitation of hemipteran pests. The parasitoids *Stenobracon nicevillei* (Bingham) (Mazid et al., 2011) was present but in low abundance, possibly due to insecticide use (Daryanto et al., 2019). Predatory Odonata, including *Agriocnemis pygmaea* (Rambur), *Diplacodes trivialis* (Rambur), and *Orthetrum sabina* (Drury), were also recorded, with their larval stages linked to nearby aquatic habitats. Significant phytophagous pests included Diptera (*Bactrocera* spp.) causing fruit damage, and Lepidoptera (*Diaphania indica* Saunders) targeting flowering and fruiting structures.

A total of 700 individual insects were recorded in *Solanum lycopersicum* agroecosystems using Pitfall Traps (PFTs), Yellow Sticky Traps (YSTs), and Blue Ball Traps (BBTs), demonstrating the

effectiveness of multi-trap approaches in sampling insect biodiversity across different ecological guilds (Table 5).

4.3. Taxonomic distribution, functional roles and variances of traps used by insects

PFTs were most efficient for ground-dwelling insects, dominated by *Anoplolepis gracilipes* (Smith), a known predatory ant with dual ecological roles as both pest suppressant and potential mutualist with *Pseudococcus* spp. (Sanjaya and Dibiyantoro, 2012; Daryanto et al., 2019). The presence of *Stenobracon nicevillei* (Bingham), a parasitoid, and other predators such as and other predators such as *Labidura riparia* (Pallas) and *Paederus littoralis* Gravenhorst, further emphasizes the utility of PFTs in capturing beneficial ground arthropods.

BBTs recorded a rich assemblage of canopy-level insects, including foliage feeders like *Diaphania indica* Saunders and *Atractomorpha crenulata* Fabricius, and pests such as *Pseudococcus* spp. and *Bemisia tabaci* (Gennadius). Although predators like *Orthetrum sabina* (Drury) and *Zelus* spp. were captured, their relatively low abundance suggests inadequate natural enemy populations for meaningful biological control (Johnson et al., 2005). YSTs were highly specific for *Bactrocera* spp., a major pest of both *S. lycopersicum* and *C. annuum*, confirming their value in monitoring tephritid fruit flies (Arfan et al., 2019).

The variation in capture efficacy across trap types (Dharmadi, 1999; Mahardhika et al., 2019; Sani et al., 2020) highlights their complementary roles in ecological monitoring. PFTs effectively sampled ground-active predators and parasitoids, BBTs covered canopy-level herbivores and aerial predators, while YSTs targeted flying sap-feeders and Dipteran pests.

The Shannon-Wiener index ($H' = 2.369$) indicated moderate insect diversity, a typical pattern in monoculture systems (Odum and Bayers, 1993). This level of diversity aligns with earlier reports suggesting that monocultures support fewer species than polycultures due to reduced habitat heterogeneity (Yaherwandi, 2009; Danti et al., 2018). Such simplified systems are prone to pest outbreaks, driven by continuous host plant availability (Nurindah, 2006). The dominance of *Bactrocera* spp. during the fruiting stage supports this, reaffirming their economic significance in horticultural crop systems (Prastowo, 2017).

The high representation of herbivores relative to predators suggests an ecological imbalance likely exacerbated by pesticide use, which can suppress beneficial arthropods (Apriyani et al., 2021; Jaya et al., 2022). Environmental factors such as temperature, rainfall, light, and vegetation structure (Moraes and Silveira, 2018), as well as management practices (Denux and Zagatti, 2010), also modulate insect diversity and abundance. The prevalence of ants (Formicidae), known for both mutualistic interactions and predatory behavior (Philpott and Armbrrecht, 2006; Aguiar et al., 2013), further reflects the complexity of insect roles in these systems.

Composition of Insects Captured on Chilli Plants (*Capsicum annuum*) Trapping efforts within *Capsicum annuum* agroecosystems revealed a diverse community of predatory insects, with variations in species composition and abundance observed across the study sites (Table 6). The most numerically dominant predator was *Paratrechina longicornis* (Latreille) (Hymenoptera: Formicidae), with a total of 1012 individuals captured across both Parhaboan and Juhar. The next most abundant predator was *Scelio* spp. (Hymenoptera: Scelionidae), with a total of 297 individuals.

The high abundance of *P. longicornis*, commonly known as the longhorn crazy ant, is likely associated with its polygynous and polydomous colonial structure, leading to large population sizes (Wetterer, 2008). Its broad dietary range, including honeydew, isopods, and mites (Shahabuddin et al., 2013) and its frequent occurrence in human-modified environments (Untung, 2006; Vanderhaegen et al., 2019; Tneup et al., 2022), likely contributed to its prevalence, particularly given the proximity of the sampling locations to residential areas.

Scelio spp., the second most abundant predator, are known parasitoids of grasshopper eggs (Qodir et al., 2017) and also parasitize eggs of Hemiptera (Peverieri et al., 2018). The relatively high numbers of *Scelio* spp. likely reflect the presence of a substantial grasshopper population in the vicinity of the research sites. The proximity of the *C. annuum* plantations to uncultivated land, which often serves as breeding grounds for grasshoppers (Pollard et al., 1995), could explain this observation.

The trapped predator community also included various other taxa across the orders Odonata, Diptera, Hemiptera, Hymenoptera, Orthoptera, and Coleoptera, each contributing to the overall

predatory potential within the *C. annuum* agroecosystems (Table 6). The specific abundance of each predatory species varied between the two study locations, suggesting potential differences in local environmental factors or prey availability.

4.4. Diversity indices calculation

The observed moderate diversity of natural enemies in the *C. annuum* agroecosystems is likely linked to the limited surrounding plant diversity. The proximity of the study sites to residential areas, village roads, and adjacent watermelon plantations resulted in a relatively homogenous plant community, which can negatively impact natural enemy abundance and diversity (Kurniawati, 2015). This aligns with findings that polyculture systems, with their greater habitat and resource heterogeneity, typically support higher insect abundance and diversity compared to monocultures (Kurniawati, 2015). Furthermore, previous studies have reported relatively low natural enemy diversity in *C. annuum* monocultures, often dominated by few species or even a single family (Hendrival et al., 2016; Kaur and Sangha, 2016; Souza et al., 2018).

While Coccinellidae are commonly found in *C. annuum* plantations (Hendrival et al., 2016; Efendi, 2016), their abundance in this study was relatively low. This could be attributed to the limited aphid populations observed, as aphids are a primary food source for many Coccinellidae species. This observation supports the findings of Efendi (2016) and Widodo et al. (2017), who emphasized the dependence of Coccinellidae diversity and abundance on aphid availability.

Despite the moderate species diversity, the high evenness of natural enemy distribution (Table 7) suggests a lack of dominant predator species. This indicates that the prevailing environmental conditions, such as temperature and humidity, were likely conducive to the survival and reproduction of a variety of natural enemies, contributing to a relatively stable and balanced predator community within the *C. annuum* agroecosystems.

Variations in natural enemy distribution can be influenced by the presence of other plant species alongside *C. annuum*, as well as the availability of prey or hosts (Shahabuddin et al., 2013). Diverse plant communities can affect the distribution of herbivorous insects, which serve as food for natural enemies (Saeed et al., 2015; Gazali and Raihandito, 2025). Consequently, herbivore populations may not be solely concentrated on *C. annuum* but dispersed among other plant species in the vicinity. This is consistent with research highlighting the influence of herbivore presence on natural enemy populations (Inayat et al., 2011; Abraham et al., 2019) and the role of host plant availability in determining herbivore distribution (Kurniawati, 2015). Therefore, the surrounding vegetation and the presence of alternative hosts likely played a significant role in shaping the observed natural enemy community within the *C. annuum* agroecosystems.

Insect Diversity in Intercropping Plants This study assessed insect diversity in *Capsicum annuum* intercropped with *Allium cepa* var. *aggregatum*, and *C. annuum* intercropped with *Solanum lycopersicum* in two distinct agroecological zones of North Sumatra, Indonesia. Insect sampling, conducted through hand-picking and direct visual observation, provided insights into the insect communities associated with these intercropping systems (Tables 8 and 10).

Hand-picking in the *C. annuum* – *A. cepa* var. *aggregatum* intercropping system yielded a specific assemblage of insect taxa, detailing their order, family, species, life stage, and ecological roles (Table 8). This method captured both herbivorous and predatory insects present on the plants.

Direct visual observation in the *C. annuum* and *S. lycopersicum* intercropping system identified a distinct set of actively moving insect taxa, categorized by order, family, and species, along with their functional roles and presence on each crop (Table 10). This method focused on more mobile insect species within the agroecosystem.

The hand-picking method effectively captured less mobile insect life stages and species present on the plants. Among the phytophagous insects collected, aphids (*Aphis gossypii* Glover) were the most abundant, observed primarily in nymph and adult stages. Their high numbers and increasing trend throughout the observation period suggest a rapid population growth and potentially limited natural control within the intercropping system. Other phytophagous species identified through hand-picking included beetle larvae and adults, moth larvae, and grasshopper adults.

In contrast to the high numbers of phytophagous insects, the abundance of entomophagous insects, represented by predatory beetles, was notably lower. This disparity suggests that natural

predation may not have been a significant factor in regulating the populations of the observed phytophagous insects within this specific intercropping system during the study period. The relatively small numbers of predators did not correlate with the high densities of prey, which could indicate an imbalance influenced by environmental conditions, agricultural practices, or the structural complexity of the intercropping system.

The direct observation method allowed for the detection of mobile insect species, including a *A. cerana*, *S. litura*, and the predatory imago of *O. sabina*, as well as a stationary *M. religiosa* suggests a potential for biological control within the system, dependent on the availability of suitable prey. However, the feeding habits of these polyphagous predators indicate that prey selectivity may occur. Reed et al. (2010) highlighted the importance of considering insect behavior when choosing sampling techniques for ecological studies.

Analysis of insect diversity within the *C. annuum* intercropping system, considering the different plant species present, revealed a higher incidence of pest infestations on *C. annuum* compared to *A. cepa* var. *aggregatum* (Nelly et al., 2015). *Capsicum annuum* demonstrated susceptibility to a wide range of insect pests across its developmental stages. The intercropping strategy did not prevent pest attacks on *C. annuum*; furthermore, pests associated with *A. cepa* var. *aggregatum* exhibited a preference for *C. annuum*. The chemical composition of *C. annuum* plants may play a role in attracting insect pests (Pagare et al., 2015). This implies that the specific chemical signals from *C. annuum* might override any potential pest-deterrent effects of the intercropping system, concentrating pest pressure on this crop. Further investigation into the specific plant metabolites and their impact on pest behavior is warranted.

During the vegetative growth phase of both *C. annuum* and *S. lycopersicum* plants, active feeding or pronounced pest-like behavior was not observed. This aligns with previous findings indicating increased insect activity during the flowering stages of these crops (Departemen Pertanian, 2014). The flowering stage of tomatoes, for instance, attracts a diverse insect community, including parasitoids, pollinators, and predators, utilizing the plant as a foraging resource (Departemen Pertanian, 2014).

Solanum lycopersicum plants appeared to be frequently visited by insects, particularly during the reproductive period with abundant flowers. The presence of fruit flies, *Bactrocera* spp. (Diptera: Tephritidae), known to initiate fruit attacks early in development, exemplifies this. The preference of fruit flies for *S. lycopersicum* is well-documented, as they are polyphagous and can infest various horticultural crops, including *S. lycopersicum* and aubergines (Denux and Zagatti, 2010). This suggests that the inclusion of *S. lycopersicum* in the intercropping system might serve as an attractant and potential breeding ground for *Bactrocera* spp., potentially influencing pest pressure on neighboring *C. annuum* plants. Further research is necessary to understand the interspecific interactions and pest dynamics within this intercropping system.

Conclusion

This study revealed a critical imbalance between herbivorous pests and their natural enemies across *Allium cepa* var. *aggregatum*, *Solanum lycopersicum*, and *Capsicum annuum* agroecosystems in North Sumatra. Intensive pesticide use in *A. cepa* var. *aggregatum* led to reduced insect diversity and elevated pest pressure from *Spodoptera litura* and *Liriomyza chinensis*. *S. lycopersicum* monocultures showed a dominance of *Bactrocera* sp., while *C. annuum*, despite the presence of some natural enemies like *Paratrechina longicornis* and *Scelio* spp., still faced pest challenges. These findings underscore the urgent need for integrated pest management (IPM) strategies, including habitat diversification and biological control, to enhance ecological resilience and promote sustainable agricultural practices in the region. Future research should focus on detailed analyses of seasonal insect dynamics, crop-specific variations, and the long-term impacts of agricultural practices to refine IPM strategies for biodiversity conservation and food security.

Ethical Statement

Ethical approval is not required for this study because the pears used in the study were collected free of charge and were not protected pears.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Artificial Intelligence Declaration

The authors declare that no generative artificial intelligence tools were used at any stage of the preparation of this manuscript, including the writing, editing, or refinement of the text, or the creation of any images, figures, graphics, tables, or related titles.

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Author Contributions

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Abdul Hafiz Ab. Majid : Conducting laboratory analyses; result and discussion of manuscript.

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