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Biopesticides and Refugia Implementation Increasing the Population and Diversity of Natural Enemies in Rice Fields based on Ecology

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ABSTRACT

The diversity of natural enemies of insects is influenced by the availability of microhabitats and food sources, which can be increased through the use of refugia. Intensive use of pesticides in conventional agricultural systems has resulted in a decline in the diversity of natural enemies that play an important role in biological control of pests. This study aims to identify the types, roles, and populations of natural enemies of pests and determine the level of natural enemy diversity including the species diversity index, species evenness, species richness, and dominance in rice fields using integrated and conventional farming systems. Data collection methods were carried out through a combination of direct observation, insect nets, yellow traps, light traps, and identification of insect morphospecies using a digital microscope and supporting literature. The identification results showed 7 orders and 21 genera of natural enemies with a total of 4,679 individuals in integrated fields and 2,792 individuals in conventional fields. The species diversity index (H'=2.11), evenness (E'=0.69), species richness (R'=2.37), and dominance (C'=0.18) indicated that the integrated system was more supportive of biodiversity. Ecological engineering through refugia has been shown to increase the population diversity of natural enemies, thereby strengthening biological control in rice ecosystems.

1. INTRODUCTION

Rice plant (*Oryza sativa* L.) is a staple food source for the majority of Indonesia's population. Besides supporting national food security, rice cultivation also supports the social and economic aspects of rural communities (Basit, 2020). However, rice plants are highly susceptible to attacks by plant pests (OPT), especially insect pests, which has the potential to cause significant crop losses if not properly controlled. In conventional farming practices, pest management largely depends on employing synthetic chemical pesticides. Although this method provides immediate results, it brings about adverse effects like pests evolving resistance, contamination of the environment, and a decline in the variety of living organisms, notably the species that naturally prey on or parasitize pests. An emerging substitute that is increasingly being recognized involves biological control rooted in ecological principles, leveraging the existence of naturally occurring predators and parasites to manage pests. Compared to synthetic pesticides, this strategy is seen as more sustainable and gentler on the environment (Adriani & Hafizah, 2016).

Integrated farming systems are a strategic alternative to improve the sustainability of rice cultivation. This approach combines various environmentally friendly techniques, such as the use of biopesticides, refugia plant deployment, and monitoring pest populations. It is well-documented that refugia plants like zinia anggun (*Zinnia elegans*) and kenikir (*Cosmos caudatus*) act as crucial habitats and food providers, offering sanctuary to beneficial creatures including spiders, dragonflies, and predatory beetles (Ilhamiyah *et al*., 2020). Refugia flowers supply vital nectar, acting as an energy reservoir for parasitoids and mature predatory insects, alongside their physical plant structure offering protection against environmental stresses and predators (Nurmala & Haryadi, 2023). Evidence suggests that introducing refugia boosts both the quantity and activity of natural enemies, thereby naturally suppressing pest populations.

Various research indicates that diversity of natural pest controllers tends to be higher in environmentally conscious agricultural systems, such as organic or integrated farming systems. Allifah *et al*. (2019) pointed out that elements such as humidity, vegetation density, and crop type have a major impact on the spatial and temporal distribution of natural enemies. Lestari & Rahardjo (2022) further mentioned that conventional agricultural methods show lower levels of natural enemy diversity because they rely heavily on chemical pesticides. This is supported by Ratna *et al*. (2016), who reported that regularly using insecticides with active ingredient imidacloprid can greatly decline the population of predators such as ladybirds (*Coccinellidae*). Many farmers, however, still adopt conventional farming system because of quicker and more effective for handling pest infestations. Yet, this leads to problems such as damaged land, pests becoming resistant to pesticides, and a decrease in biodiversity over time. Thus, additional comparative studies are required to ascertain how well integrated farming practices can enhance the diversity of natural pest controllers relative to conventional farming methods.

The purpose of this study was to determine the kinds, functions, and numbers of natural enemies of rice pests in two distinct agricultural systems: an integrated farming system and a traditional farming system. The variety of natural enemy communities in each system was also assessed using an ecological index study that included species diversity (*H*'), evenness (*E*'), species richness (*R*'), and dominance (*C*'). The results are expected to provide useful information in the development of sustainable, ecologically based pest control strategies. Thus, through an ecological approach to pest management, it is hoped that a more environmentally friendly, efficient, and productive agricultural system will be created. Expanding knowledge about the diversity and function of natural enemies can also support the conservation of biodiversity in agricultural land and maintain overall ecosystem stability.

2. RESEARCH MATERIALS AND METHODS

2.1. Time and Place

The study was conducted from January to April 2025. This study was conducted in rice cultivation land in Besur Village, Sekaran sub district, Lamongan Regency, East Java, at an altitude of 7 meters above sea level. Besur Village is chosen because it is one of the villages that has implemented integrated farming, but the data used is less than optimal, so an update was carried out in the hope of optimizing the missing data.

2.2. Tools and Materials

The tools used in this study are sweep net, yellow trap, light trap, stationery, mobile phone cameras, tweezers, pipettes, plywood, wood, hand counters, clips, vials, cutters, scissors, digital microscopes. Introducing of insect book (Triplehor & Johnson, 2005), The Insects: an Outline of Entomology book (Gullan & Cranston, 2014), and inaturalist applications. The materials used in this study were rice plants, bugenvil flowers (*Bougainvillea spectabilis*), kenikir flowers (*Cosmos caudatus*), 70% alcohol, gauze, and ethyl acetate.

2.3. Research Procedures

This research was conducted in Besur Village, Sekaran District, Lamongan Regency, East Java, on two plots of land, each measuring 500 m², cultivated using two different systems, namely, integrated and conventional farming. Planting was carried out with a spacing of 25 × 25 cm using a jajar legowo pattern. Mentik Wangi Susu is known as a local variety with a distinctive aroma and high economic value, but is more susceptible to certain pest attacks, such as brown planthoppers and stem borers. Meanwhile, MR 319 is an introduced superior variety that has relatively higher resistance to several types of pests, especially in intensive land with pesticide use. Differences in genetic and physiological characteristics between these two varieties can potentially affect the presence and diversity of natural enemies, because the main pests and their infestation levels can also differ.

In the integrated system, refugia plants such as Zinnia elegans and Cosmos caudatus are planted around the land as a border with a spacing of 25 cm. Refugia function as food providers (nectar and pollen) and alternative habitats for natural enemies. The biopesticide Beauveria bassiana is applied at a dose of 5 g/L of water using a low-pressure sprayer at 7, 14, and 35 days after planting (DAP). Fertilization using compost fertilizer of 10 tons/ha is carried out before planting. The conventional system uses chemical fertilizers Urea and Phonska each 12.5 kg per plot, applied twice during the vegetative phase, as well as synthetic pesticides with the active ingredients imidacloprid and abamectin adjusted to farmer recommendations.

This study used a completely randomized design (CRD) with two treatments and one replication for each treatment, adjusted for land and resource limitations. To address the limited number of replications, observations were conducted periodically every seven days from the time the plants were 7 days after planting until harvest. Data were collected from the same observation location using a uniform number and type of traps to ensure ecological validity of the results.

Natural enemy observation is conducted using four methods: direct observation, sweep nets, yellow traps, and light traps. The nets are used to sweep 10 meters along each side of the field between 7:00 and 9:00 a.m. Western Indonesian Time. Four yellow traps are placed at the four corners of each field (1 meter from the edge), while light traps used a 6-volt/1-watt solar panel and a 1-watt LED lamp installed at the center of the field at a height of 150 cm (Figure 1). Four yellow traps are placed in each field.

The specimens obtained are preserved using two methods: wet preservation using 70% alcohol and dry preservation (sun-dried and stored in an entomology box). Identification is performed based on external morphology using a digital microscope, a determination key book (Triplehorn & Johnson, 2005), and the iNaturalist application.

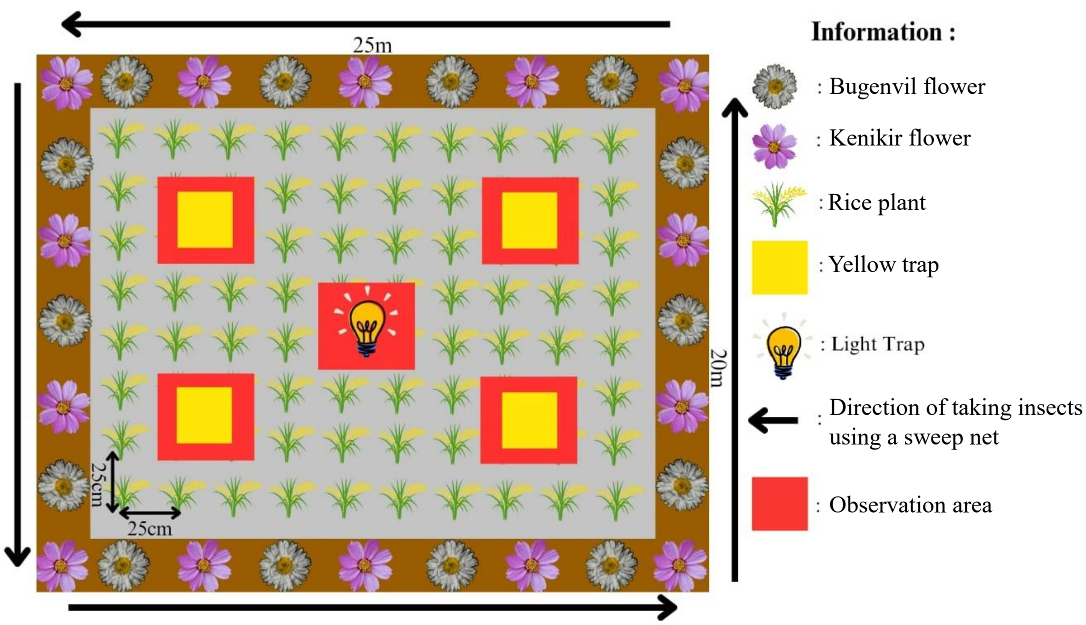

Figure 1. Layout of yellow trap, light trap, and refugia planting on integrated farming system land

2.4. Observation and Measurement

Natural enemy observations in this study were conducted using four main methods: direct observation, sweep net, yellow trap, and light trap. These four methods were used in an integrated manner to obtain representative data on the presence and activity of natural enemies in both farming systems.

Direct observations were conducted using the diagonal point method on each plot, with a total of five observation points per plot. At each point, 40 clumps of plants were observed, thus covering a fairly large and even area. Observations were conducted periodically every seven days, starting from 7 days after planting (DAP) until just before harvest. Observations were divided into two time periods to capture daily fluctuations in natural enemies: in the morning from 5:30–7:30 a.m and in the afternoon from 3:00–5:00 p.m.

Insect nets were used by sweeping the plant canopy along the field embankments. Catching was carried out systematically by swinging the net over the tops of the rice plants while circling the plots, based on a modification of a previous method. Observations were conducted every seven days from 7 days after planting until harvest, with the time being 7:00–8:00 a.m.

Yellow traps were used to capture active flying insects, primarily from the orders *Diptera*, *Hymenoptera*, and *Hemiptera*. Four yellow traps were placed in each plot, each at four corners of the plot approximately 1 meter from the plant border. A total of eight traps were used for both systems. Traps were replaced and monitored every three to four days (twice a week) to maintain their catching effectiveness.

Light traps are used to capture nocturnal insects attracted to light sources, such as several species of the Coleoptera and Lepidoptera orders. Each plot is equipped with a light trap unit consisting of a 6-volt/1-watt solar panel and a 1-watt LED lamp, installed 150 cm above the ground and placed in the center of the plot. Observations and cleaning of the light traps are carried out twice a week.

2.5. Data Analysis

Microsoft Excel was used to tabulate and analyze the collected data. Tables and graphs were used to visualize the data. The Bray-Curtis Index, which shows the degree of species similarity and abundance between two environments, was used to assess the degree of similarity of insect populations between systems. High similarity is shown by index values close to 1, whilst significant differences in insect community structure are indicated by index values near 0. The species diversity index, species evenness index, species richness index, and dominance index were among the calculated metrics. The following formulas were used in the observation parameters:

a. Species Diversity Index (*H*')

The species diversity index is a value that indicates the diversity of species found in the field. The insect diversity index was calculated using the Shannon-Wiener index (*H*') (Magurran, 2004), as the following:

$$H' = -\sum\left(\frac{n_i}{N}\ln\frac{n_i}{N}\right) \quad (1)$$

where *ni* is number of individuals of all species, and *N* is total individuals observed. The results of the diversity values are classified as low ($H' < 1$), moderate ($1 < H' < 3$), and high ($H' > 3$).

b. Evenness Index of Species (*E*')

The species evenness index aims to determine the balanced distribution of an individual across all species in a community. The evenness index (*E*) was calculated from number of types (*S*) using Equation (2) (Krebs, 1989). The benchmark values were as follows: low evenness or depressed communities ($0 < E < 0.4$), medium evenness or unstable community ($0.4 < E < 0.6$), and high evenness or stable community ($0.6 < E \leq 1$).

$$E = \frac{H'}{\ln S} \quad (2)$$

c. Species Richness Index (*R*')

The species richness index is the simplest measure of biodiversity because it only takes into account the differences in the number of species within a community. The species richness index (*R*') was calculated using Equation (3) (Maguran, 2004). The diversity index is categorized into three class: low ($R < 3.5$), medium ($3.5 < R < 5$), and high ($R > 5$).

$$R = \frac{S-1}{\ln(N)} \quad (3)$$

d. Dominance Index (*C*')

The dominance index is a calculation to determine the dominance or dominance of a species within a community. The dominance index (*C*') was measured using Simpson's formula (Krebs, 1989) as presented in Equation (4). The dominance index is classified as low dominance with $0 < C' \leq 0.5$, and high dominance with $0.5 < C' \leq 1$.

$$C = \sum\left(\frac{ni}{N}\right)^2 \quad (4)$$

e. Community Similarity Index (*Bray-Curtis*)

The Bray-Curtis Index was used to assess the similarity of morphospecific composition and can also be used to calculate similarities and dissimilarities between two research objects. The value generated from the Bray-Curtis Index varies from 0 to 1. A value of 0 indicates that the research objects are different, whereas the closer the value is to 1, the more identical or similar the research objects are (Solikah, 2019). The calculation of the Bray-Curtis community similarity index (IS) uses the following formula:

$$IS = 1 - \frac{\sum(Xij - Xik)}{\sum(Xij + Xik)} \quad (5)$$

with X_{ij} and X_{ik} is number of individuals of species *i* in habitat 1 and habitat 2, respectively

3. RESULTS AND DISCUSSION

3.1. Types, Roles and Populations of Pest Natural Enemies

Observations were conducted over a 12-week period, from January to April 2025. Observations were conducted on two rice fields using integrated and conventional farming systems. The following are the types, roles, and populations of natural enemies of pests found in the rice fields, presented in Table 1. The results showed that the number and types of natural enemies of pests were higher in the integrated farming system (4,679 individuals) compared to the conventional system (2,792 individuals). The natural enemies found came from 7 orders, with Araneae dominating, especially the *Oxyopidae* family as active predators. While the use of pesticides in the conventional farming decreased the presence of non-target *entomophagous* insects, the integrated farming system that uses refugia and biopesticides offers a supportive

Table 1. Types, roles, and populations of natural enemies of pests in rice fields (integrated vs. conventional farming systems)

No.	Types of Insects			Role	∑ Population (head)	
	Ordo	Family	Genus		Integrated	Conventional
1.	*Odonata*	*Coenagrionidae*	*Agriocnemis*	Predator	137	84
2.		*Libellulidae*	*Diplacodes*	Predator	94	14
3.	*Mantodea*	*Hymenopodidae*	*Hierodula*	Predator	5	0
4.	*Araneae*	*Araneidae*	*Argiope*	Predator	237	173
5.		*Salticidae*	*Artabrus*	Predator	63	0
6.		*Tetragnathidae*	*Tetragnatha*	Predator	638	157
7.		*Lycosidae*	*Trochosa*	Predator	1,068	763
8.		*Oxyopidae*	*Oxyopes*	Predator	1,434	838
9.	*Coleoptera*	*Coccinellidae*	*Cheilomenes*	Predator	192	167
10.			*Coccinella*	Predator	144	92
11.			*Hyperaspidius*	Predator	11	8
12.		*Dytiscidae*	*Dytiscus*	Predator	0	1
13.		*Carabidae*	*Ophionea*	Predator	103	35
14.			*Pheropsophus*	Predator	69	16
15.		*Staphylinidae*	*Paederus*	Predator	157	98
16.	*Hemiptera*	*Reduviidae*	*Ectrychotes*	Predator	12	4
17.		*Notonectidae*	*Buenoa*	Predator	283	326
18.	*Hymenoptera*	*Vespidae*	*Ropalidia*	Predator	7	2
19.		*Formicidae*	*Solenopsis*	Predator	6	4
20.		*Encyrtidae*	*Microterys*	Parasitoid	1	0
21.	*Diptera*	*Sciomyzidae*	*Sepedon*	Predator	12	8
22.		*Tachinidae*	*Strongygaster*	Parasitoid	6	2
					4,679	2,792

habitat for natural enemies. This suggests that the ecological strategy is able to establish a more balanced and biologically stable agroecosystem situation.

This study supports the findings of Kusuma & Windriyanti (2022), who claimed that refugia boost the number of natural enemies by offering microhabitats and extra food sources like pollen and nectar. Ravelia *et al*. (2021) also reported that environmentally friendly systems support the presence of predatory orders such as *Mantodea*, *Hymenoptera*, and *Coleoptera*, that are sensitive to chemicals. While, Hendrival *et al*. (2017) noted that intensive pesticide use drastically reduces spider diversity in rice fields. Thus, integrated farming systems not only increase population of natural enemy, but also strengthen their ecological function in natural and sustainable pest control.

3.1.1. Predatory Insects

Predatory insects are insects that prey on small organisms and play an important role in naturally controlling plant pest populations (Kusuma *et al*., 2025). According to Muliani & Srimurti (2022), predators have characteristics such as preying on all stages of prey development, killing quickly, being carnivorous, and having a variety of feeding methods, both chewing and sucking the body fluids of prey. Predators can also undergo complete or incomplete metamorphosis and have monophagous, oligophagous, or polyphagous diets. The types of predatory insects found in the research area are shown in Figure 2.

Results of this study revealed the total number of predators found in the integrated farming was 4,672 individuals, higher than that of conventional farming system with only 2,790 individuals. This difference suggests that the implementation of an integrated farming system, particularly through the use of refugia plants, has an important impact on the number, type, and population of natural enemies. This is in line with the findings of (Heong *et al*., 2013), where the presence of plants as a habitat for natural enemies is an important strategy in integrated crop management because it increases the biodiversity and abundance of insects. Insect diversity also plays a role in maintaining agroecosystem stability through interactions between herbivorous insects (*phytophagous*) and predators (*entomophagous*). According to (Natuhara, 2013), integrated farming systems support environmental recovery and trophic networks, thus creating ideal conditions for the development of natural enemy populations. The low number of predators found in conventional fields is due to the use of chemical pesticides. The application of chemical pesticides affects the number of natural enemy populations because it can cause the death of predators and parasitoids (Melhanah *et al*., 2023). Applications of

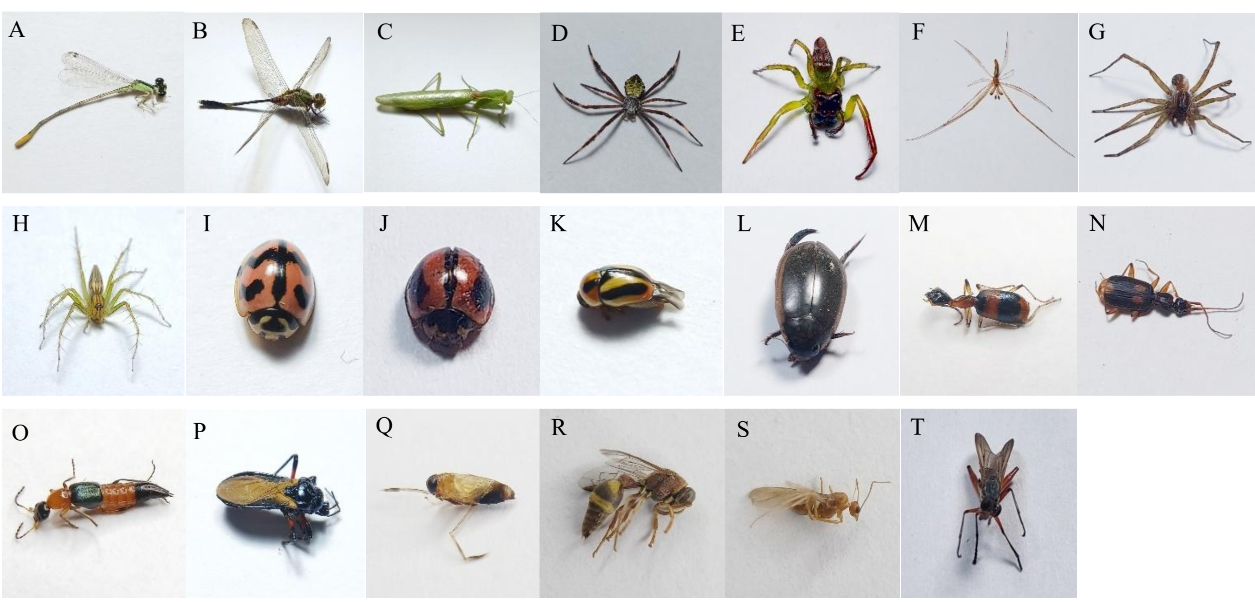

Figure 2. Predatory insects found in the rice fields: (A) *Agriocnemis*, (B) *Diplacodes*, (C) *Hierodula*, (D) *Argiope*, (E) *Artabrus*, (F) *Tetragnatha*, (G) *Trochosa*, (H) *Oxyopes*, (I) *Cheilomenes*, (J) *Coccinella*, (K) *Hyperaspidius*, (L) *Dytiscus*, (M) *Ophionea*, (N) *Pheropsophus*, (O) *Paederus*, (P) *Ectrychotes*, (Q) *Buenoa*, (R) *Ropalidia*, (S) *Solenopsis*, dan (T) *Sepedon*

chemical pesticide are effective for partial pest control, but they also kill natural enemies that could potentially act as biological pest control agents. The types and numbers of predators found during the study in the rice fields are shown in Figure 3.

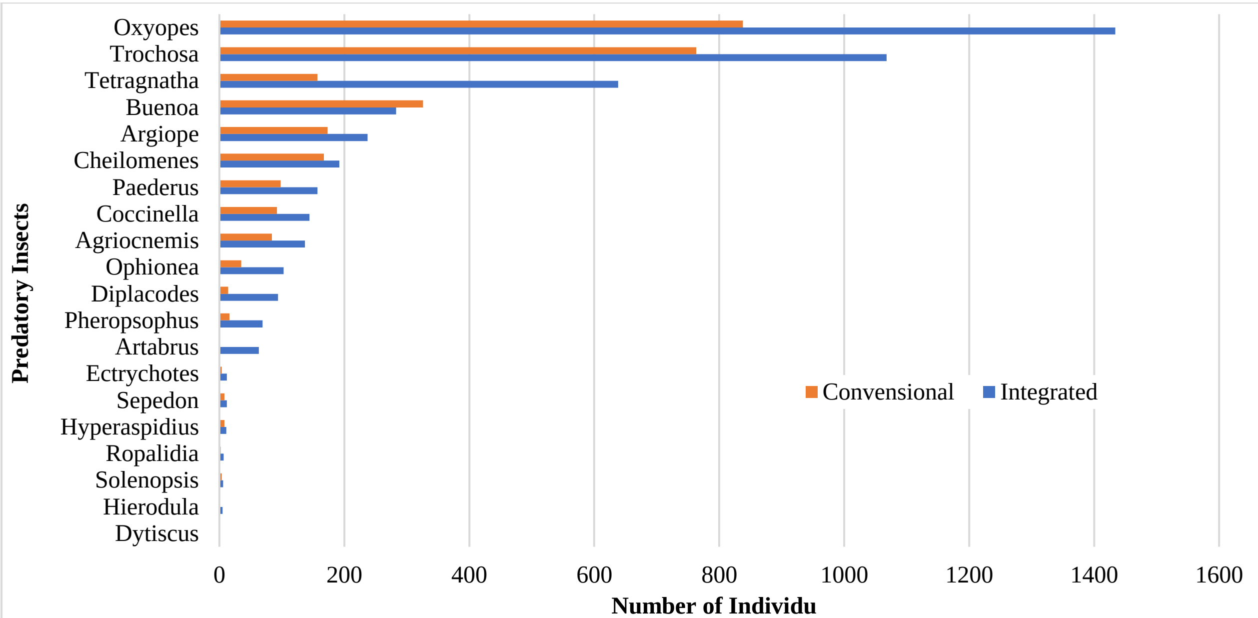

Figure 3. Number of predatory insect population

The results showed that the diversity and abundance of predatory insects are higher in the integrated farming system compared to the conventional farming system. A total of 4,672 predator individuals were found in the integrated farming system, while 2,790 individuals were recorded in the conventional farming system. The dominant family was *Oxyopidae* (a group of hunting spiders), with the genus *Oxyopes* being the most numerous predator in both systems. A total of 1,434 *Oxyopes* individuals were found in the integrated farming system and 838 individuals in the conventional farming system. According to Sulha *et al*. (2022), *Oxyopes* are energetic spiders that hunt without webs. They have long, spiny legs and a thin body posture that allows for high agility on leaf surfaces. In terms of biology, *Oxyopes* are visual predators that use their excellent vision to find prey including pest eggs, tiny insects, and planthopper nymphs. They attack the prey by ambushing from close range, then bite and inject digestive enzymes to paralyze and externally digest the prey's body tissue and finally sucking its fluids. The effectiveness of *Oxyopes* in preying on various major rice pests makes them an important indicator in ecologically based biological control systems.

This study supports the findings of (Choudhury *et al*., 2016), who showed that 12.72% of all spiders in rice fields belonged to the *Oxyopidae* family. Other hunting spider families, including *Lycosidae* and *Salticidae* were also detected in considerable quantities, with greater dominance in the integrated system. Additionally, web-building spiders from the *Araneidae* and *Tetragnathidae* families were also more prevalent in the integrated system. According to Herlinda *et al*. (2020), complex habitat structure and the availability of vegetation and insect prey have a significant impact on spider abundance. Predators from the order *Coleoptera*, particularly the families *Coccinellidae*, *Carabidae*, *Staphylinidae*, and *Dytiscidae*, were also found in significant numbers alongside the order *Araneae*. From the family *Coccinellidae*, the genera *Coccinella*, *Cheilomenes*, and *Hyperaspidius*, are predators of aphids (Surya *et al*., 2020). *Paederus* (family *Staphylinidae*), which preys on planthoppers and *Scirpophaga innotata*, was more abundant in the integrated field.

Agriocnemis and *Diplacodes*, two predators belonging to the order *Odonata*, are likewise more prevalent in integrated systems. As predators of pests such as *Nilaparvata lugens* and *Leptocorisa acuta*, dragonflies are indicator of healthy ecosystems. Dragonflies favor environments with unspoiled natural vegetation and clear water. They are indicator of good ecosystems because their nymphs feed on aquatic creatures in clean water, while adults hunt visually by using their strong teeth to attack small insects. Dragonflies are more prevalent as members of the predator community in agricultural systems based on heterogeneous vegetation. Other predators hunt by ambushing preys with sickle-shaped forelegs and biting them directly. One such predator is the *Hierodula* (order *Mantodea*), which is unique to integrated systems.

Similarly, *Ropalidia* and *Solenopsis* (order Hymenoptera) and *Sepedon* (order Diptera) are found more frequently in integrated systems. *Solenopsis* is known to prey on *Pomacea canaliculata* eggs, while *Sepedon* acts as a predator of aquatic snails like *Lymnaea*. In contrast, the genus *Buenoa* (Hemiptera, family Notonectidae) was found more abundantly in the conventional system, presumably due to the relatively stable standing water habitat and minimal vegetation disturbance, this predator hunts in the water by piercing and sucking the body fluids of its prey. This difference confirms that predator responses to habitat manipulation can vary between taxa.

3.1.2. Parasitoid Insects

Parasitoid is small organisms that develop in or on a host body and is parasitic during their larval stage but free-living as adults. According to Wardani (2017), parasitoid larvae kills their hosts as they develop, while adults feed on nectar or other fluids as an energy source. Figure 4 shows types of parasitoid insects found in the research area. In this study, a total of 7 parasitoid individuals were found in the integrated farming system, higher than that of conventional system with only 2 individuals. This difference indicates that the presence of refugia and a more complex environment support the existence of parasitoids. These results is in align with Ravelia *et al*. (2021), who reported that organic or ecologically based farming systems increase parasitoid abundance and diversity compared to conventional systems. Kusuma & Windriyanti (2022) stated that planting refugia supports parasitoid populations by providing microhabitats and food sources for adult such as nectar and honeydew.

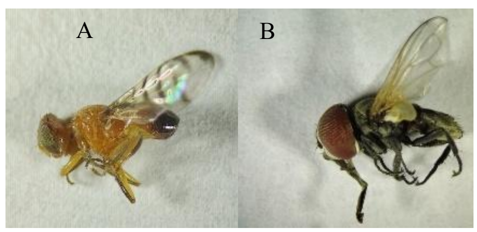

Figure 4. Parasitoid insects in observed rice fields. (A) *Mycroterys*, dan (B) *Strongygaster*.

The types and numbers of parasitoids observed in this study are presented in Figure 5a, indicating that the integrated farming system is more effective in supporting parasitoid presence than the conventional system. In general, both parasitoids, *Microterys* and *Strongygaster*, have a positive impact on rice cultivation because they act as biological pest control agents. *Microterys* is a parasitoid from the order *Hymenoptera* known to be effective in controlling mealybug (*Pseudococcidae*) populations. This parasitoid works by laying its eggs inside the mealybug's body, then the hatched larvae will feed on the host's tissue from the inside until the host dies. This process not only directly reduces the pest population but also suppresses the pest's overall reproductive cycle. Furthermore, *Microterys* has the ability to recognize specific hosts through chemical signals (kairomones) released by mealybugs, making it quite effective as a biological control agent. Meanwhile, *Strongygaster* (*Diptera*: *Tachinidae*) is a parasitoid whose larvae develop inside the bodies of host insects, such as caterpillars or other soft-bodied insects. *Strongygaster* larvae infect the host through direct oviposition or by laying eggs near the host. The larvae then penetrate the host body and develop inside, causing slow death of the host. The presence of these two parasitoids are crucial in maintaining the balance of pest populations in rice agroecosystems and supporting the sustainability of environmentally friendly biological control.

This study identified two parasitoid orders: *Hymenoptera* and *Diptera*. The genus *Microterys* (*Hymenoptera*) was found in only one individual in the integrated farming system. Its distinctive features include a small, dark brown body with a metallic green sheen on the back, transparent wings without venation, and downy antennae. *Microterys* is known to be a parasitoid of *Parthenolecanium corni*. Meanwhile, the genus *Strongygaster* (*Diptera*) was found in greater numbers, with six individuals in the integrated farming system and two in the conventional farming system.

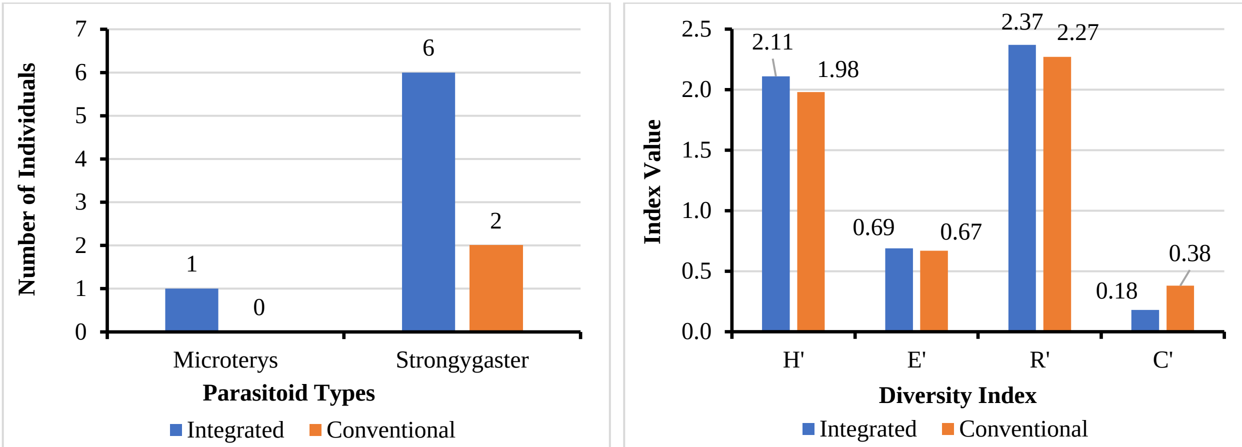

Figure 5. (a) Number of parasitoid insects, and (b) Diversity index of pest natural enemies found in rice field

The difference in the number of parasitoid individuals between the two systems is thought to be due to limited host availability and the possibility of interactions between natural enemies, such as host predation by predators before parasitoids develop. This is supported by (Septariani *et al*., 2019), that stated that parasitoid abundance and presence are highly dependent on the availability and density of host populations in the agroecosystem. Therefore, the low number of parasitoids in the conventional system indicates the negative impact of low habitat diversity and pesticide use on the stability of the trophic chain of natural enemy insects.

3.2. Diversity Index of Pest Natural Enemies

The diversity of natural enemies of pests is an important aspect of agricultural ecology. The diversity of natural enemies of rice pests in the implementation of integrated and conventional farming systems was analyzed using diversity indices and related indices. The species diversity index (*H*'), species evenness index (*E*'), species richness index (*R*'), and dominance index (C') are shown in Figure 5b.

3.2.1. Species Diversity Index (H')

The species diversity index (*H*') value in the integrated farming system was 2.11, higher than that of the conventional system at 1.98. Both values are included in the moderate category (1–3), indicating a fairly stable condition of the natural enemy community. The higher diversity in the integrated system indicates that the application of refugia plays an important role in increasing biodiversity. In accordance with (Septariani & Herawati, 2019) states that refugia are types of flowering plants as microhabitats for natural enemies, both predators and parasitoids, which aim to maintain the sustainability of natural enemies.

3.2.2. Species Evenness Index (E')

The species evenness index for the integrated system was 0.69 and the conventional system was 0.67, both of which are in the high category (0.6–1). This indicates that the natural enemy community is relatively evenly distributed without any particular species dominating. The availability of uniform habitat and food sources in the integrated system is thought to be the main factor. These results are supported by Mujalipah *et al*. (2019), who stated that a high evenness value reflects ecosystem stability and a balanced distribution of natural enemy insects.

3.2.3. Species Diversity Index (R')

The species diversity index (*R*') in the integrated system was 2.37 and in the conventional system 2.27. Both are in the low category (*R*' < 3.5). This low value indicates a limited number of different species within the community, which is likely due to the dominance of the order Araneae and habitat homogeneity. This finding is consistent to (Effendy *et al*., 2013) stating that the dominance of certain species and uniform vegetation structure can reduce species diversity.

3.2.4. Dominance Index (*C*')

The dominance index in the integrated farming system was 0.18 and in the conventional system 0.38. Both values fall into the low dominance category (*C*' < 0.5), indicating that no single species is dominant. This is related to the ecosystem heterogeneity and more complex habitat structure in integrated systems. (Effendy *et al*., 2013) stated that low dominance in insect communities generally occurs in balanced ecosystems and is not dominated by a single genus.

3.3. Bray-Curtis Habitat Similarity Index

The Bray-Curtis index is used to measure the similarity in composition and number of natural enemy species between two habitats. Values close to 1 indicate similar communities, while values close to 0 indicate significant differences (Suwena, 2007). Based on Figure 7, the results of the Venn diagram analysis show that there are 18 genera of natural enemies of pests found in both cultivation systems, namely integrated and conventional farming. These genera include: *Agriocnemis*, *Diplacodes*, *Argiope*, *Tetragnatha*, *Trochosa*, *Oxyopes*, *Cheilomenes*, *Coccinella*, *Hyperaspidius*, *Ophionea*, *Pheropsophus*, *Paederus*, *Ectrychotes*, *Buenoa*, *Ropalidia*, *Solenopsis*, *Sepedon*, and *Strongygaster*. The results of the Bray-Curtis index calculation showed a value of 0.736 or 73.6%, which indicates a high level of similarity in the composition of the natural enemy community between the two habitats, even though there are differences in terms of population abundance.

This high similarity can be explained by relatively similar environmental factors, such as microclimatic conditions (temperature and humidity), the structure of the rice field landscape, and the availability of irrigation water that support insect life in both conventional and integrated fields. Furthermore, the relatively homogeneous rice vegetation structure, despite varietal differences, still provides a basic habitat that supports the presence of a number of common predator and parasitoid genera. The presence of refugia and biopesticides in integrated fields may increase the abundance and effectiveness of certain predators, but does not eliminate the presence of natural enemies that are also able to survive in conventional systems by adapting to pesticide pressure.

This is in line with findings (Albab, 2019), which reported a Bray-Curtis similarity index value of 0.78 in two rice plantations with similar habitat structures. The diversity and similarity of insect communities are strongly influenced by vegetation cover, soil moisture, water availability, and other microclimatic conditions that contribute to the habitat's carrying capacity for natural enemies. Thus, despite differences in input practices (fertilizers, pesticides, and the use of refugia), the similar ecological structure of both fields still allows for the formation of relatively similar natural enemy communities in terms of composition, despite differences in the number of individuals.

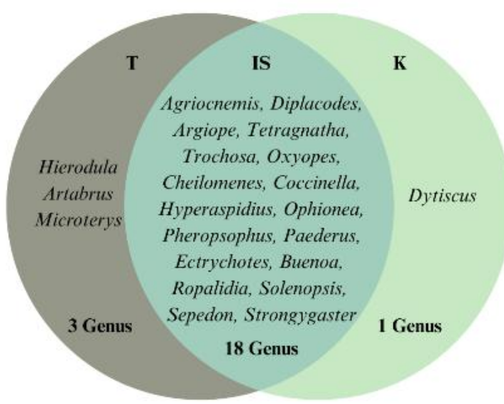

Figure 7. Slice of habitat similarity of pest natural enemies in rice fields [T = Integrated, K = Conventional, IS = Similarity Index]

4. CONCLUSION

Based on the results of research on the diversity of natural enemies of pests in rice fields with the application of integrated and conventional farming systems in Besur Village, Sekaran District, Lamongan Regency, it can be concluded that the total population of natural enemies in the integrated farming system reached 4,679 individuals consisting of 7 orders, 18 families, and 21 genera. Meanwhile, in the conventional farming system, 2,792 individuals from 6 orders, 16 families, and 19 genera were found. In both systems, the Araneae order was the most dominant group with a proportion of 73.52% in integrated land and 69.16% in conventional land. The ecological diversity index values also showed differences, with the integrated system recording a species diversity index (*H*') of 2.11 and the conventional system of 1.98; species evenness index (*E*') of 0.69 and 0.67; species richness index (*R*') of 2.37 and 2.27; and a dominance index (*C*') of 0.18 in the integrated system and 0.38 in the conventional system. These results indicate that the integrated farming system is able to support the diversity and stability of natural enemy communities better than the conventional farming system. Therefore, further research can be conducted by expanding the search for natural enemies of pests by not only observing known natural enemies, but also by exploring the potential for new natural enemies that can be found in the surrounding environment, including from groups of microorganisms (such as nematodes or pest-controlling microbes).

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