Ecological Management of Insect Pests in Rice (*Oryza sativa L.*) Using Refugia Plants and Biopesticides: A Case Study in Northern Sumatera, Indonesia

Ameilia Zuliyanti Siregar[1*], *Ravindra C.* Joshi[2*], *Liana Dwi Sri* Hastuti[3], and *Nismah* Panjaitan[4]

[1]Faculty of Agriculture, University Sumatera Utara, Jl. Dr. A. Sofyan No. 3, Medan 20155, Sumatera Utara, Indonesia
[2]College of Agriculture and Related Sciences, University of Southeastern Philippines, Tagum City, Davao del Norte, Philippines
[3]Faculty of Mathematics and Natural Sciences, University Sumatera Utara, Jl. Biotechnology No.1, Medan 20155, Sumatera Utara, Indonesia
[4]Faculty of Engeneeering, University Sumatera Utara, Jl. Almamater Medan 20155, Sumatera Utara, Indonesia

Abstract. This study evaluated the ecological management of insect pests in rice (Oryza sativa L.) through the integrated use of refugia plants (Zinnia elegans Jacq., Cosmos caudatus Kunth, Tagetes erecta L.), biopesticides (Carica papaya L. leaf extract, Cocos nucifera L., water, PGPR, and Beauveria bassiana), and control in Lubuk Bayas Village, Northern Sumatera, Indonesia. A total of 21 insect species from 13 families and 6 orders were recorded across both treatment and control plots. Rice fields incorporating refugia and biopesticides demonstrated significantly higher insect abundance (2,686 individuals) compared to control plots (1,678 individuals). Furthermore, these ecologically managed fields exhibited greater species richness ($R' = 0.29$ vs. 0.14 in controls), greater evenness ($E = 0.85$ vs. 0.56 in controls), and increased diversity ($H' = 2.86$ vs. 2.27 in controls). The results showed that the ANOVA test was not significant between the use of refugia, but was significant for biopesticide and control. These findings highlight the substantial potential of integrating refugia plants with biopesticides as a sustainable strategy to enhance insect biodiversity and foster ecological pest regulation within rice agroecosystems. Ultimately, this approach can contribute to improved rice productivity and strengthen national food security in Indonesia.

1 Introduction

Rice (*Oryza sativa L.*) is a staple food crop fundamental to global food security, especially in Asia, where it underpins the dietary base for billions of people. In Indonesia, rice

* Corresponding author: ameilia@usu.ac.id; rcjoshi@usep.edu.ph

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cultivation is not only critical for subsistence but also for rural livelihoods and the national economy. Despite its importance, rice production is persistently threatened by insect pests, leading to significant yield losses and adverse impacts on farmers' welfare. Within agroecosystems, insects play complex roles. In contrast, some insects are vital for pollination and natural pest control, and herbivorous species constitute major pests, damaging rice plants during both vegetative and reproductive stages.

A study conducted across Sumatra between 2020 and 2024 reported that the yellow stem borer, Scirpophaga incertulas Walker, inflicted severe damage to rice crops, with infestation intensities reaching up to 90% and estimated yield losses of 125,000 tonnes per planting season . In other key rice-producing regions, the brown planthopper, *Nilaparvata lugens* Stål, has caused annual production declines of 20–25%. In extreme cases, N. lugens Stal. Infestations have resulted in a national reduction of up to two million tonnes of rice [6]. Conventional rice systems commonly face infestations from pests such as rice earhead bug, Leptocorisa acuta Thunberg, green leafhopper (*Nephotettix virescens* Distant), and S. *incertulas* Walker. The prevalence and intensity of these pest outbreaks are often exacerbated by factors such as the cultivation of susceptible varieties, suboptimal planting patterns, prevailing climatic conditions, and excessive reliance on synthetic chemical pesticides.

Historically, pest control in Indonesia has heavily depended on chemical pesticides. While these compounds offer short-term efficacy, their frequent use causes collateral damage by eliminating non-target organisms, disrupting ecological balance, and inducing the development of pesticide resistance. Consequently, sustainable alternatives, particularly ecological pest management strategies, are gaining considerable momentum. Among these, the integrated use of refugia plants and biopesticides offers environmentally sound solutions for pest suppression.

Refugia plants, sometimes referred to as banker plants, are strategically intercropped with rice to enhance the presence of beneficial arthropods, especially predators and parasitoids of rice pests. These flowering plants provide essential resources such as nectar, pollen, and shelter, thereby fostering a more biodiverse and resilient agroecosystem. Specific species, such as marigold (*Tagetes erecta* L.) and wild cosmos (*Cosmos caudatus* Kunth), have demonstrated proven efficacy in attracting beneficial insects, including lady beetles, lacewings, and parasitic wasps. When implemented appropriately, refugia plantings support predator–prey dynamics that naturally regulate pest populations.

Biopesticides, derived from biological sources including bacteria, fungi, viruses, and botanical extracts, further complement ecological pest control systems. These agents specifically target pest species, thereby reducing the risk of resistance development and ensuring readily decomposable residues in the environment, which minimises their presence in food and water [1,2].

This study was conducted in Lubuk Bayas Village, Perbaungan District, Serdang Bedagai Regency, Northern Sumatra, Indonesia. This village, situated at an elevation of 5–15 meters above sea level, experiences an average annual temperature of 30°C and approximately 200 mm of rainfall. Covering an area of 462 hectares, with 405 hectares dedicated to rice cultivation, Lubuk Bayas comprises four hamlets and is representative of the typical rice-producing landscape in the region. The present research aims to evaluate the effectiveness of combining refugia plants and biopesticides as a holistic ecological strategy for managing insect pests in O. sativa L. fields within this specific regional context [3].

2 Methodology

This experimental study was conducted from April to May 2025 in Lubuk Bayas Village, Perbaungan District, Serdang Bedagai Regency, North Sumatra, Indonesia (3°33′54.000″N), which experiences relative humidity ranging from 75% to 90%. The primary objective was

to evaluate the effectiveness of an integrated ecological strategy, combining refuge plants and biopesticides, in managing insect pests in rice (Oryza *sativa* L.) agroecosystems. The methods involved cultivating refugia plants, applying biopesticides, sampling insects, installing traps, and conducting quantitative analyses of insect pest populations. Insect identification was carried out at the Plant Pest Laboratory, Faculty of Agriculture, Universitas Sumatera Utara (USU).

2.1 Experimental design and treatment conditions

Two distinct treatment conditions were established within the rice fields:

1. Rice fields planted with refugia plants along their perimeters and treated with a biopesticide.
2. Untreated control fields, which received neither refugia plants nor biopesticide applications.

2.1.1 Refugia cultivation

Three species of refugia plants were cultivated: Zinnia (Z. *elegans* Jacq.), wild cosmos (C. caudatus Kunth), and marigold (T. erecta L.). These species were chosen for their established efficacy in attracting beneficial insects. The refugia were planted in 15 x 60-meter plots. Seedlings were established along the perimeter of the rice fields, creating a continuous refuge strip on one side of each bund. This perimeter planting involved a continuous row of the three refugia species along one side of the paddy field bund. A consistent planting distance of 30 cm was maintained between individual seedlings.

2.1.2 Biopesticide preparation and application

Land preparation and Seed Treatment.
Land ploughing was conducted 15 days before planting. Eighteen days before planting, Ciherang rice seeds were soaked in a 10% Plant Growth Promoting Rhizobacteria (PGPR) solution. PGPR was chosen for its multifaceted benefits, including its role as a biological control agent, a plant growth promoter, and a decomposer. The treated seeds were then spread onto the prepared land.

Biopesticide Application.
At the time of seed sowing, a biopesticide mixture containing C. papaya L. (papaya) leaf extract, C. nucifera L. (coconut) water, PGPR, and Beauveria bassiana was applied. This mixture was applied twice. The biopesticide was prepared freshly before each application to ensure maximum efficacy. The application concentration was 10 mL of biopesticide per liter of water, with a total of 20 liters of water and 200 mL of biopesticide used.

Field Preparation and Transplanting.
Five days before planting, the land was harrowed to a level surface. Subsequently, 2 kg of bokashi fertilizer was uniformly spread across the land. Rice seedlings, 18 days after sowing, were then ready for transplanting. The planting process utilized a spacing of 25 x 25 cm, with 2–3 seedlings per clump.

2.2 Insect sampling and trapping

Insect monitoring was conducted using a combination of sweep netting, direct visual collection, and trap installation, adapted from the protocol. Sampling was conducted during the generative phase of the rice crop and continued four times per week over a four-week period. Two types of insect traps were systematically deployed in both treatment and control plots:

2.2.1 Yellow sticky traps

To monitor diurnal flying insects, yellow sticky traps were deployed. Each trap consisted of an adhesive paper sheet (20 cm × 30 cm) affixed to a wooden board of identical dimensions, which was then mounted on a vertical wooden pole. A total of five replicate traps were installed per plot at 06:30 hrs. The traps were strategically positioned at the centre and in each corner of the rectangular plots to maximise sampling coverage, with a spacing of 30 meters between traps. Each set of traps remained in place for seven consecutive days within its respective plot before being replaced.

2.2.2 Light traps

Four light traps were installed in each plot and operated daily from 18:00 to 06:00 hours, targeting the nocturnal insect fauna. The dual-trap system ensured a comprehensive assessment of both diurnal and nocturnal insect populations across the experimental fields.

2.3 Field observations

Field observations were conducted consistently across both treatment and control rice field plots. The study employed the Integrated Pest Management (IPM) approach by visually monitoring insect populations at eight observation points, which were aligned perpendicularly to the refugia plant strip. Observations were conducted every five days, beginning 30 Days After Planting (DAP) and continuing until the rice crop neared harvest. Each observation was conducted between 06:00 and 09:00 a.m. At each of the eight observation points, four rice hills were randomly selected as sampling units. Direct visual observation of insects on these plants was conducted in situ to record their presence and abundance, Additionally, sweep net sampling was performed during daylight hours, employing 50 random sweeps per subplot to capture active flying and foliage-dwelling insect species.

2.4 Insect collection, preservation, and identification

Captured insects were carefully preserved in appropriately labelled film vials containing 70% ethanol. Each vial was tagged with collection details, including site location (3°33′54.000″N), date of collection, and the name of the collector, ensuring proper traceability and specimen integrity. Small-sized specimens, such as green leafhopper (*N. virescens* Distant) and zig-zag leafhopper (*R. dorsalis* Motschulsky) were prepared for identification using the whole mount technique, while larger specimens were examined under a stereomicroscope (Olympus SZX2) to assess external morphological features critical for taxonomic classification. Specimens were initially identified to the morpho-species level through morphological comparisons aided by photographic matching. The iNaturalist platform was utilised to assist with preliminary identification based on uploaded images of collected insects. Identification results were subsequently cross-verified using entomological

databases such as BugGuide.net and validated against classical entomological keys and literature. The taxonomy was standardised following scientific naming conventions, listing insects by order, family, genus, and species where possible, in line with the protocols. The data were analysed using diversity analysis followed by the Difference test at a 5% significance level, as implemented in SPSS version 24.00.

2.5 Data analysis

Biodiversity data were analysed using Microsoft Excel. The following ecological indices were calculated to assess insect community structure: species diversity, evenness, species richness, and dominance.

2.5.1 Shannon-Wiener diversity indez (H')

The species diversity index was calculated using the Shannon–Wiener formula:

$$H' = -\Sigma(\frac{\text{ni}}{\text{N}} In \frac{ni}{N})$$

Where:
H' = Species diversity index
n_i = Number of individuals of each species
N = Total number of individuals
ln = Natural logarithm

2.5.2 Evenness index (E)

Species evenness, which reflects how evenly individuals are distributed among species, was calculated following the formula:

$$E = \frac{H'}{In\ S}$$

Where:
E = Evenness index (value between 0 and 1)
H' = Shannon diversity index
S = Total number of species
ln = Natural logarithm

2.5.3 Margalef species richness index (R)

Species richness was computed using the Margalef index as :

$$R = \frac{S - 1}{In\ (N)}$$

Where:
R = Species richness index
S = Total number of species observed
N = Total number of individuals observed
ln = Natural logarithm

2.5.4 Simpson's dominance index (C)

Species dominance was calculated using Simpson's index:

$$C = \Sigma(\frac{ni}{N})^2$$

Where:
C = Dominance index
n_i = Number of individuals of each species
N = Total number of individuals

These indices provided insight into the ecological balance and effectiveness of refugia plants and biopesticides in managing insect pest populations within the rice agroecosystem.

3 Results and Discussion

3.1 Identification of hydroxyapatite function groups

A total of 2,686 insect individuals were recorded in rice fields treated with refugia plants and a biopesticides composed of C. *papaya* leaf extract, C. *nucifera* water, and plant growth-promoting rhizobacteria (PGPR). This was notably higher compared to 1,678 individuals found in untreated control plots. The identified insect belonged to six orders: Coleoptera, Diptera, Hemiptera, Lepidoptera, Orthoptera, and Odonata, encompassing 13 families and 21 distinct species. Among these, Lepidoptera and Hemiptera exhibited the highest species diversity, while Odonata dominated among predatory insects. Notably, five species (*R. dorsalis, C. medinalis, E. fabae, N. virescens,* and *S. incertulas*), accounted for the highest pest abundance across both treatments, indicating their significance as major rice pests in the study area (Table 1).

The findings for key pests corroborate previous studies. For example, also documented *C. suppressalis* (Lepidoptera: Crambidae) and *Aulacophora indica* (Coleoptera: Chrysomelidae) as among the most prevalent pests in both treated and untreated plots. The larvae of *C. suppressalis* are known to bore into rice stems, disrupting plant growth and significantly impacting yield. Similarly, *C. medinalis* and *C. spectra* (Hemiptera: Cicadellidae) were more prevalent during the vegetative stage of rice. They also noted that *R. dorsalis*, *Nephotettix* spp., and *S. furcifera* (Hemiptera: Delphacidae) dominated in later growth phases. Our data align with this, showing higher numbers of S. furcifera in A1 (91 individuals) compared to A2 (43 individuals). *Leptocorisa acuta* (Hemiptera: Alydidae), a typical rice bug, was also more abundant in A1 (86 individuals) than in A2 (47 individuals), consistent with observations during the flowering and milk stages in lowland rice in South Sumatra..

Insect communities in rice fields are influenced by multiple factors throughout the crop's growth cycle, from the vegetative to the post-harvest stages. In this study, the use of refugia plants alongside biopesticides provided diversified niches and microhabitats that contributed to an overall increase in insect abundance and richness. Conversely, rice fields without refugia and biopesticides may exhibit more intense interspecific competition for limited resources, thus reducing pest abundance but also limiting the populations of beneficial natural enemies.

Table 1. Population of insect pests in rice fields with and without refugia and biopesticide application.

Order	Family	Species	A1	A2
Coleoptera	Chrysomelidae	*Aulacophora indica* (Gmelin)	21	10
		Chrysochus cobaltinus LeConte	5	3
	Lycidae	*Erotides* spp.	1	0
Diptera	Cecidomyiidae	*Orseolia oryzae* (Wood-Mason)	5	3
	Dolichopodidae	*Hercostomus germanus* (Wiedemann)	34	29
Hemiptera	Alydidae	*Leptocorisa acuta* (Thunberg)	86	47
	Cicadellidae	*Cicadella viridis* (L.)	26	12
		Cofana spectra (Distant)	45	23
		Empoasca fabae (Harris)	97	25
		Recilia dorsalis (Motschulsky)	597	364
		Nephotettix virescens (Distant)	334	225
	Delphacidae	*Sogatella furcifera* (Horváth)	91	43
Lepidoptera	Crambidae	*Scircophaga incertulas* (Walker)	426	267
		Chilo suppressalis (Walker)	62	56
	Pyralidae	*Cnaphalocrocis medinalis* (Guenée)	523	368
Orthoptera	Pyrgomorphidae	*Atractomorpha crenulata* (F.)	18	4
	Tettigonidae	*Tettigonia* spp.	12	6
Odonata	Coenagrionidae	*Agriocnemis femina* (Brauer)	85	46
		Ischnura senegalensis (Rambur)	72	55
		Pantala flavescens (F.)		
	Libellulidae	*Orthetrum sabina* (Drury)	67	40
			79	52
Total			2686	1678

Footnote: A1= With Treatment (Refugia + Biopesticide); A2 Without Treatment (Control).

The higher abundance of certain Coleoptera species in the treated plots, such as *A. indica* and *Chrysochus cobaltinus*, might be attributed to the group's generalist feeding habits and their capacity to adapt to various microenvironments created by the refugia [4]. Although biopesticides aim to reduce pest populations, their application can temporarily disturb the ecological balance, potentially benefiting some pest species while suppressing others. As noted by [5], uneven distributions of insect species often arise from resource competition, which is significantly influenced by habitat quality and food availability.

Beneficial arthropods such as *Agriocnemis femina* (Odonata: Coenagrionidae), *Ischnura senegalensis* (Odonata: Coenagrionidae), *Orthetrum sabina* (Odonata: Libellulidae), *Pantala flavescens* (Odonata: Libellulidae), *Atractomorpha crenulata* (Orthoptera: Pyrgomorphidae), and *Tettigonia* sp. (Orthoptera: Tettigonidae) were also observed. These species, documented , serve important roles as predators or bioindicators. Notably, [6] reported that *Orthetrum sabina* is preyed upon by kingfishers and lizards, while [7] highlighted the role of adult *A. femina* as an important predator in rice ecosystems. Enhancing populations through habitat management can improve the effectiveness of biological control.

Refugia plants, such as Z. elegans Jacq., C. caudatus Kunth, and T. erecta L., Provided supplementary food resources (nectar and pollen), oviposition sites, and shelter, thereby enhancing the survival of both pests and their natural enemies. The temporary increase in pest populations in treated plots may be attributed to a lag in the natural enemy's adaptation to the enriched habitat. Furthermore, although foliar biopesticides can suppress specific pest taxa, they may not provide broad-spectrum control, thereby creating opportunities for certain pests to proliferate before natural enemies regain ecological control.

The insect pest diversity in the experimental rice fields was classified as moderate, with a Shannon-Wiener diversity index (H′) of 2.86 in the treated plots (refugia plants + biopesticides) compared to 2.27 in the untreated control plots. The evenness index (E′) was notably higher in the treated fields (0.85) than in the controls (0.56), indicating a more

uniform distribution of species in the managed habitat, where no single species overwhelmingly dominated. The species richness index (R′) also reflected greater biodiversity in treated plots (0.29) relative to the control (0.14), confirming a higher number of unique species.. In terms of dominance (C′), higher values were observed in the treatment (0.45) compared to the control (0.26), indicating a moderately dominant species presence across both treatments. All diversity indices generally fell within low to moderate categories (Table 2).

Table 2. Diversity indices in rice fields based on species diversity index (H'), evenness (E'), richness (R'), and dominance (C') indices.

Calculation	Treatments A1 (Refugia + Biopesticide)	Without Treatment A2 (Control)
Diversity	5	4
Order number	6	6
Family number	14	13
Species number	21	20
Diversity (H')	2.86	2.27
Evenness (E')	0.85	0.56
Richness species (R')	0.29	0.14
Dominance (C')	0.45	0.26

The higher diversity, richness, and evenness indices observed in the refugia-treated plots suggest that the combined use of refugia plants and biopesticides fosters a more complex agroecosystem that supports diverse insect pest communities. Refugia plants increase plant variety and structure within the habitat, offering diverse food sources and microhabitats that sustain a broader range of herbivorous insects and, by extension, their natural enemies. This aligns with findings by [8], who reported that the introduction of refugia enhances habitat complexity, thereby influencing pest population dynamics and their distribution.

While greater pest diversity was recorded in the refugia-treated fields, as seen in the higher H′ value, this does not necessarily translate to an immediate increase in detrimental pest pressure. As indicated by [9], the presence of flowering plants does not always result in immediate pest suppression but instead supports the gradual buildup of beneficial arthropods that contribute to longer-term pest regulation. The enhanced structural and trophic complexity in refugia plots may initially attract a broader range of pests but eventually support natural enemies that regulate these populations.

Fig. 1. Location of research plots in Lubuk Bayas Village: (A1) Treatment plot (Refugia + Biopesticide) and (A2) Control plot (Without Treatment).

The higher species richness index (R′) in treated plots reflects increased biodiversity, consistent with the assertion by [9] and [10] that species richness increases with the number

of identified species. Moreover, the elevated evenness index (E′ = 0.85) in treated plots indicates a more balanced species distribution, with no single species overwhelmingly dominant. This uniformity suggests a more ecologically stable environment, which is critical in maintaining long-term pest regulation and reducing outbreaks.

Evenness is a valuable ecological indicator, especially when assessing species dominance within an agricultural canopy. Index values ranging from 0.54 to 0.78, as supported by five separate sampling tools in this study, indicate a balanced insect community. This finding is consistent with the results of [11] in Sungai Pinang Village, where the insect community also exhibited well-distributed population structures. A high evenness value suggests that competition among insect species is minimized due to sufficient habitat heterogeneity and resource availability.

The higher dominance index (C′) in the refugia plots (0.45) could be attributed to the initial increase in a few pest species exploiting the diversified resources. However, such dominance may be transient, as refugia are known to support the eventual proliferation of beneficial predators and parasitoids that contribute to natural pest suppression. In contrast, the lower dominance value in the control plots (0.26) likely reflects fewer species competing over limited resources in a less diverse environment.

If a particular canopy-dwelling insect species dominates the community, this will typically be reflected in a lower evenness index. The diversity index values recorded in the study ranged from 2.02 to 2.45, indicating a moderate level of species diversity within the canopy insect community. These values indicate a relatively balanced distribution of individuals among various insect species, which supports ecosystem stability and reduces pest outbreaks. The dominance index values, ranging from 0.65 to 0.84, indicate a moderate degree of species dominance. A lower dominance index reflects the absence of a single dominant species, whereas a higher value suggests the prevalence of one or a few species. These findings align with those of [12], who reported similar observations in rice agroecosystems, where moderate dominance implied the coexistence of multiple species without a single taxon becoming ecologically overpowering. The data presented here, particularly the increased diversity and evenness, strongly support the premise that ecological management strategies enhance the resilience and stability of rice agroecosystems against insect pests.

Table 3 presents the characteristic functional status of insect species collected from rice fields in Lubuk Bayas Village, Perbaungan District, Serdang Bedagai Regency, Northern Sumatera. The functional classification provides insight into the ecological roles of the insect species present in the studied habitat, categorising them as herbivore-pests, pests, predators, or other insects.

A total of 12 secondary pest species were identified across the study area. These included two species from Coleoptera: Chrysomelidae, two from Diptera (one from Cecidomyiidae and one from Dolichopodidae), one from Hemiptera: Alydidae, four from Hemiptera: Cicadellidae, and two from Orthoptera (one from Pyrgomorphidae and one from Tettigonidae) (Table 3).

Additionally, five primary pest species were identified. These comprised one species from Hemiptera: Delphacidae, one from Hemiptera: Cicadellidae, two from Lepidoptera (one from Crambidae and one from Pyralidae), and one from Lepidoptera: Crambidae (Table 3). These species are known to cause severe damage to rice crops either through direct feeding, such as stem boring by S. incertulas and C. suppressalis or defoliation by C. medinalis, or by acting as vectors of viral diseases, as is common for leafhoppers like N. virescens.

Four predatory species were observed, all belonging to the Order Odonata: two from Coenagrionidae and two from Libellulidae (Table 3). These beneficial insects play a crucial role in the biological control of rice pests, as they feed on herbivorous insects and help maintain ecological balance within the agroecosystem.

Table 3. Functional status of insects recorded in rice fields in Lubuk Bayas Village, Perbaungan District, Serdang Bedagai Regency, Northern Sumatra.

Status Function	Order	Family	Species
Secondary Pest	Coleoptera	Chrysomelidae	*Aulacophora indica* (Gmelin)
Secondary Pest	Coleoptera	Chrysomelidae	*Chrysochus cobaltinus* (LeConte)
Other insects	Coleoptera	Lycidae	*Erotides* spp.
Secondary Pest	Diptera	Cecidomyiidae	*Orseolia oryzae* (Wood-Mason)
Secondary Pest	Diptera	Dolichopodidae	*Hercostomus germanus* (Wiedemann)
Secondary Pest	Hemiptera	Alydidae	*Leptocorisa acuta* (Thunberg)
Secondary Pest	Hemiptera	Cicadellidae	*Cicadella viridis* (L.)
Secondary Pest	Hemiptera	Cicadellidae	*Cofana spectra* (Distant)
Secondary Pest	Hemiptera	Cicadellidae	*Empoasca fabae* (Harris)
Secondary Pest	Hemiptera	Cicadellidae	*Recilia dorsalis* (Motschulsky)
Primary Pest	Lepidoptera	Delphacidae	*Nephotettix virescens* (Distant)
Primary Pest	Lepidoptera	Crambidae	*Sogatella furcifera* (Horváth)
Primary Pest	Lepidoptera	Crambidae	*Chilo suppressalis* (Walker)
Primary Pest	Lepidoptera	Pyralidae	*Scircophaga incertulas* (Walker)
Primary Pest	Lepidoptera	Pyrgomorphidae	*Cnaphalocrocis medinalis* (Guenée)
Secondary Pest	Orthoptera	Tettigonidae	*Atractomorpha crenulate* (F.)
Secondary Pest	Orthoptera	Tettigonidae	*Tettigonia* spp.
Predator	Odonata	Coenagrionidae	*Agriocnemis femina* (Brauer)
Predator	Odonata	Coenagrionidae	*Ischnura senegalensis* (Rambur)
Predator	Odonata	Libellulidae	*Pantala flavescens* (F.)
Predator	Odonata	Libellulidae	*Orthetrum sabina* (Drury)

Only one species, Erotides spp. (Coleoptera: Lycidae), was categorised under "other insects," indicating limited representation of taxa that do not fall under clear pest or predator categories in this study area. The remaining insect species were clearly distinguishable as either pest or predatory in nature.

Moreover, two parasite species (Culex spp., Anisopus spp.), eleven pest species (C. medinalis, Hydrellia spp., L. oratorius, N. lugens, O. oryzae, among others), and two parasitoid species (Tabanus spp., Aphis spp.) were reported. Two insect species (Stanicophora spp. and Battilaria spp.) could not be identified in their ecological roles, indicating a potential need for further research.

The findings from this study are consistent with previous research by [13], who reported a higher diversity of insect fauna in rice ecosystems with integrated pest management practices. Their records included 23 predator species such as *A. pygmaea, A. lata, C. septempunctata, Camponotus spp., C. servilia, D.trivialis, Formicafurcatus spp., Hydrophilus spp., Hydrobius spp., Leptispa spp., Lycosa spp., N. terminata, N. ramburii, N. tullia, Paederus spp., P. rubriceps, Tetragnatha spp., T. aurora, and T. tillarga.*

According to [14], N. lugens, N. virescens, S. furcifera, S. incertulas, C. suppressalis, and S. litura were the major pests recorded in the paddy plantation of Mekar Sari Village, Gunung Sari District, Bali.

These results demonstrate that rice fields managed using refugia plants and biopesticides support a more prosperous and more functionally diverse insect population. Such ecological management strategies promote the presence of beneficial predatory species while maintaining moderate levels of pest presence, ultimately contributing to more sustainable pest regulation and ecosystem health.

4 Conclusion

This study documented a total of 21 insect species across 13 families and 6 orders, including *Agriocnemis femina, Atractomorpha crenulata, Aulacophora indica, Cicadella viridis, Chrysochus cobaltinus, Cofana spectra, Cnaphalocrosis medinalis, Erotides spp., Empoasca fabae, Hercostomus germanus, Ischnura senegalensis, Leptocorisa acuta, Nephotettix virescens, Orseolia oryzae, Orthetrum sabina, Pantala flavescens, Recilia dorsalis, Scirpophaga incertulas, Silba capsicarum, Sogatella furcifera,* and *Tettigonia* spp. A total of 2,686 individual insects were recorded in rice fields treated with refugia plants and biopesticides, compared to 1,678 individuals in the untreated (control) plots.

The species richness index (R′) was higher in the treated fields (0.29) than in the control (0.14), while the evenness index (E′) indicated a more balanced distribution in treated plots (0.85) than in the control (0.56). Dominance index (C′) values were 0.45 in the treated plots and 0.26 in the control plots, suggesting a moderately structured community in both, with a greater ecological balance in the refugia-based system. Shannon-Wiener diversity index (H′) values were 2.86 in treated plots and 2.27 in control plots, indicating a moderate but enhanced species diversity associated with the ecological interventions.

In summary, the integration of refugia plants and biopesticides significantly improved insect species richness, diversity, and evenness, contributing to a more stable and ecologically balanced arthropod community in rice ecosystems. Although some pest species demonstrated increased abundance, the presence of natural enemies and functional biodiversity in treated plots underscores the potential of refugia-biopesticide systems as a viable and sustainable approach for ecological pest management in rice agroecosystems in Northern Sumatera and comparable tropical lowland settings.

To support sustainable rice production and long-term food security in Indonesia, national policies should integrate ecological pest management approaches, such as the combined use of refugia plants and biopesticides, into rice cultivation programs. Strengthening farmer training and extension services is crucial to ensure the effective implementation and adoption of initiatives at the community level. Government support should also include subsidies and regulatory frameworks for the development and distribution of biopesticides, particularly for smallholder farmers. Incorporating habitat management into field design can enhance the presence of natural enemies and reduce pest outbreaks. Continued investment in research and alignment with climate-smart agriculture initiatives will further reinforce the ecological, economic, and environmental benefits of these strategies across diverse rice-growing regions.

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