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Effect of refugia plant (*Zinnia* sp.) population on the presence of stem borer (*Scirpophaga innotata* Walker) and natural enemies in rice

OLSIVIANA[1], AMIR YASSI[2,♥], MELINA[3]
[1]Graduate School of Agricultural Systems Study Program, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km.10, Makassar 90245, South Sulawesi, Indonesia
[2]Program Study of Agrotechnology, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km.10, Makassar 90245, South Sulawesi, Indonesia. Tel.: +62-411-588243, ♥email: amiryassi32@gmail.com
[3]Program Study of Plant Pest and Disease, Faculty of Agriculture, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km.10, Makassar 90245, South Sulawesi, Indonesia

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Abstract. *Olsiviana, Yassi A, Melina. 2024. Effect of refugia plant (*Zinnia *sp.) population on the presence of stem borer (*Scirpophaga innotata *Walker) and natural enemies in rice. Biodiversitas 25: 2652-2660.* This study supports biological control by preserving natural enemies in rice cultivation through habitat modification. The research aimed to analyze the effects of different population levels of refugia (*Zinnia* sp.) on pest attack rates, the presence and diversity of natural enemies of rice stem borer (*Scirpophaga innotata* Walker 1863), and rice (*Oryza sativa* L.) production. The study was designed using a Randomized Group Design (RGD) with four population treatment levels: control (no *Zinnia* sp.), sparse population (32 polybags of *Zinnia* sp.), medium population (96 polybags of *Zinnia* sp.), and dense population (160 polybags of *Zinnia* sp.). The results showed that the dense population (160 polybags of *Zinnia* sp.) produced the lowest stem borer infestation rate in the eighth week of observation (1.67%). Pests in all treatments belonged to four orders: Lepidoptera, Hemiptera, Coleoptera, and Diptera, with Hemiptera being the most prevalent. Natural enemies of rice pests belonged to three orders: Coleoptera, Hymenoptera, and Orthoptera. The dense population treatment (160 polybags of *Zinnia* sp.) yielded the highest values for diversity index (H') at 2.1785, species richness index (R) at 2.1837, and evenness index (E) at 0.9915. This treatment also achieved the highest average rice production at 8.64 tons/ha. Meanwhile, the highest dominance value (C) of 0.2489 was found in the control treatment. Thus, this study supports the idea that increasing the population of *Zinnia* sp. as a refugia plant can increase the diversity of natural enemies, reduce rice stem borer infestation, and increase rice plant production.

Keywords: Habitat management, natural enemies, refugia, population, rice production, stem borer infestation, *Zinnia*

INTRODUCTION

Rice (*Oryza sativa* L.) is very important as the main food source in Indonesia, where demand continues to increase with population growth (BPS 2023a). In 2019, South Sulawesi ranked fourth as the largest rice-producing region in Indonesia (BPS 2023a), with a harvest area of 1.04 million hectares and production of 5.36 million tonnes (BPS 2023b). Nevertheless, the problem of crop failure remains a serious concern, especially in South Sulawesi. In 2022, land vulnerable to crop failure in Indonesia decreased compared to the previous year, and South Sulawesi is among the most vulnerable areas, especially to floods, droughts, and rice stem borer (*Scirpophaga innotata* Walker) attacks (BPS 2023b). North Luwu, one of the main rice producers in South Sulawesi (BPS Luwu Utara 2021), especially in Bone-Bone District, is an area that is not immune to this vulnerability.

The prolonged intensification of rice crops has led to ecological changes, fostering monoculture farming ecosystems that can trigger the emergence of destructive plant pest organisms (Bhattacharyya et al. 2016). Pests such as rice stem borers hamper rice production, causing huge losses without effective control (Khaled et al. 2022; Nakano et al. 2022; Zhu et al. 2022). Lack of crop rotation allows specific pests and pathogens to breed and persist in the soil, increasing the risk of pest and disease infestation (Wang et al. 2022). Reliance on synthetic pesticides harms the environment, causing pest resurgence, pest resistance, increase in secondary pests, decrease in natural enemies, and pollution (Ayilara et al. 2023). To reduce these adverse impacts, the use of environmentally friendly control methods, such as biological control through conservation of natural enemies, is essential (Begg et al. 2017; Nayak et al. 2018; Gontijo 2019; Romeis et al. 2019; Syahputra et al. 2019).

The abundance and efficiency of natural enemies are strongly influenced by habitat complexity, including the availability of prey, alternative hosts, pollen sources, nectar, shelter, and breeding sites. In agroecosystems, crop species diversification creates greater ecological opportunities for natural enemies. This approach involves manipulating vegetation at the edge of the rice layer, modifying plant species composition, and increasing plant density (Egerer and Philpott 2022; Hernández-Ochoa et al. 2022). The introduction of flowering plants and reduced use of synthetic insecticides can reduce habitat degradation (Ara and Haque 2021; Li et al. 2021; Cano et al. 2022; Yang et al. 2022). Flowering plants are attractive to natural enemies (predators and parasitoids), pollinators, and play a role in pest population regulation, crop pollination, and maintenance of biodiversity (Broadley et al. 2022; Fei et al. 2023; Kulkarni et al. 2023).

Flower characteristics such as color, shape, and scent can stimulate insects to search for, find, and land on flowers (Tanda 2023; Chen et al. 2023). Research by Desriani et al. (2021) showed that natural enemies are attracted to *Zinnia* flowers because these flowers provide pollen, nectar, and shelter that support their activities and survival. Aldini (2019) reported that most natural enemies are associated with *Zinnia elegans* Jacq. flowers, suggesting that these flowers provide a favourable environment for natural enemies.

This study used yellow *Zinnia* which attracts insects (Puspita 2017). Ali et al. (2023) confirmed the significant effect of refugia density on brown planthopper density in rice. Habibi and Fuadah (2021) found that refugia plants affected the even distribution of brown planthopper natural enemy populations. Brotodjojo et al. (2019) showed the number of natural enemies was higher in rice fields with more sunflowers than without sunflowers. This study applied habitat modification to enhance biological control and conserve natural enemies of rice by providing different population levels of refugia plants (*Zinnia* sp.). Previous research emphasized habitat modification with different types and placement of refugia plants (Habibi and Fuadah 2021; Aminatun et al. 2023).

The density of refugia plants affects resource competition and the effectiveness of natural enemies around rice plants (Khan 2013). Finding the optimal density is crucial to ensure natural enemies can move effectively and control pest populations efficiently. Therefore, in the context of the increasing need for sustainable agricultural practices, this research is important to determine the optimal density of refugia plants. This can help farmers increase crop yields, reduce losses due to pest attacks, increase the effectiveness of natural enemies in controlling pests, especially rice stem borers, naturally and sustainably.

MATERIALS AND METHODS

Research time and location

This research was conducted from April to August 2021 in Sidomukti Village, Bone-Bone Sub-district, North Luwu District, South Sulawesi, Indonesia. The research site was selected based on the high frequency of crop failures in the village, which led to a significant decline in agricultural production and negatively impacted the welfare of local farmers.

Research methods

The research was arranged in a Randomized Group Design (RGD) with 4 levels of refugia plant population treatment (*Zinnia* sp.), namely treatment without *Zinnia* sp. as control (p0), sparse population of 32 polybags (p1), medium population of 96 polybags (p2), and dense population of 160 polybags (p3).

Each treatment plot measured 8 m x 8 m with a distance of 5 meters between plots. In each plot, there are rice plants that function as borders. Each treatment consisted of 3 replications, so there were 12 experimental units. Each treatment plot was bordered by different colored ropes tied to bamboo poles at each corner plot to facilitate the observation process. The flowers used in this study were local yellow *Zinnia* flowers. Before being applied in the study, seedlings were sown from *Zinnia* seeds into 30 seedling trays with 32 planting holes per tray, resulting in 960 seedlings. The polybag size was 20 cm x 30 cm, with the planting medium being soil and manure from cow dung. The plants were nurtured for 2 months until they were ready to be transplanted to the rice field. According to the treatment plots, *Zinnia* seedlings planted in polybags were placed in the research location as planned. Some parameters observed in this study include these parts.

Intensity of rice stem borer attack

The intensity of rice stem borer attack was based on observations of absolute damage, namely by counting egg clusters per unit area (1 m^2), which was carried out visually in 1 plot of 10 clumps of plants, carried out every 10 days. The infested plant area percentage was calculated using the following formula (Kojong et al. 2019):

$$P = \frac{n}{N} \times 100\%$$

Where:
P : percentage of infected farms (%)
n : number of farms affected
N : number of clusters observed

Observations of pests and natural enemies

Observations of pests and natural enemies were also carried out every 10 days, from 14 days after planting until 14 days before harvest. Observations were made every 10 days for 8 times during the study period. Observations were conducted based on the Technical Guidelines for Observation and Reporting of Plant Disturbing Organisms, Directorate General of Food Crops (2018). Observations of the presence of pests and natural enemies were conducted using two methods, namely: (i) using a yellow tray trap measuring 26×26×13 cm (p×l×t), placed in the center of the treatment plot and filled with detergent solution as much as one-third of the tray height. The trays were set up before 09.00 in the morning and retrieved after 24 hours. The trapped specimens were filtered and picked up using a fine brush and put into a bottle containing 70% alcohol and then identified using the Insect Recognition Handbook (Borror et al. 1996). During observation, the plant clumps were shaken slightly so that pests and natural enemies could be caught. Pests and natural enemies caught were counted immediately in situ. Then, for the next 10 days, the detergent solution is replaced with a new one; (ii) using insect nets, this is done by swinging the net 3 times in each plot. All insects caught were put into a yellow tray trap containing a detergent solution to kill them;

Rice plant production

The rice plant production was calculated by converting the production amount for each treatment (kg/treatment) into units of tonnes/ha. The rice plant production was calculated using the following formula:

$$Y = \frac{10.000\ m^2}{L\ (m^2)} x \frac{X\ \text{kg}}{1.000\ kg}$$

Where:
Y : production (tons/ha)
X : production in 1 plot
L : plot area (m^2)

Diversity index

The Diversity Index (H') of natural enemies was calculated using the Shannon-Wiener formula (Kinasih et al. 2017):

$$H' = -\sum_{i=1}^{S} P_i \ln P_i$$
$$= -\sum_{i=1}^{S} \left[\left(\frac{n_i}{N}\right) ln \left(\frac{n_i}{N}\right)\right]$$

Where:
H' : species diversity value
ln : natural logarithm
Pi : ni/N (number of individuals of type i divided by the total number of individuals)
ni : number of individuals of type i
N : total number of individuals

Species richness index

The Species Richness Index (R) of natural enemies was calculated using the Margalef formula (Sulistyani et al. 2014):

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

Where:
R : species richness value
S : total number of species
In : natural logarithm
N : total number of individuals of all species

Evennes species index

The Evenness Species Index (E) of natural enemies was calculated using Evennes' formula (Sulistyani et al. 2014):

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

Where:
E : type uniformity value
H' : species diversity value
ln : natural logarithm
S : total number of species

Species Dominance Index

Species Dominance Index (C) of natural enemies calculated using Simpson's formula (Sulistyani et al. 2014):

$$C = \sum \left(\frac{n_i}{N}\right)^2$$

Where:
C : Simpson's dominance index
ni : number of individuals of a species i
N : total number of individuals of all species

Data analysis

The data obtained in this study were analyzed using SPSS Version 23 with the Analysis of Variance (ANOVA) test to see the effect of the *Zinnia* population at various population levels on the presence of pests and natural enemies in rice plants. If there were differences between treatments, LSD (Least Significance Difference), further test was conducted.

RESULTS AND DISCUSSION

Attack intensity of rice stem borer pests

The population of refugia plants (*Zinnia* sp.) significantly affected the intensity of rice stem borer attack on the 30th day of observation and very significantly from the 40th day to the 80th day (Table 1).

Observations showed the presence of pests in rice plants that can be identified as various species. Pests found in rice plants with various treatments of *Zinnia* sp. refugia populations (Table 2) generally come from four orders: Lepidoptera, Hemiptera, Coleoptera, and Diptera.

Presence and diversity of natural enemies

The results showed that several species of insects act as predators or parasitoids, which are natural enemies for rice plant pest organisms (pests) in various population treatments of *Zinnia* sp. Natural enemies found in rice plants with various population treatments of *Zinnia* sp. refugia derived from three orders: Coleoptera, Hymenoptera, and Orthoptera (Table 3).

The highest values of Diversity Index (H'), Species Richness Index (R), and Uniformity Index (E) of natural enemies in rice plants were obtained in the treatment of *Zinnia* sp. refugia population of 160 polybags (p3), with values of 2.1785; 2.1837; and 0.9915, respectively. Meanwhile, the highest dominance value (C) of natural enemies in rice plants was obtained in the control treatment (p0), which was 0.2489 (Table 4).

Table 1. Average intensity of rice stem borer attack (%)

Treatments	Observation (days)							
	10	20	30	40	50	60	70	80
p0	0.7071	0.7071	1.2864^a	1.7743^a	2.0378^a	2.2706^a	2.4814^a	2.4814^a
p1	0.7071	0.8797	0.9107^b	1.3435^b	1.6777^a	1.9543^a	2.1959^a	2.2706^a
p2	0.7071	0.7071	0.7937^b	0.7071^c	0.8797^b	1.3435^b	1.6777^b	1.9543^b
p3	0.7071	0.7071	0.7937^b	0.7071^c	0.8797^b	1.3435^b	1.4401^b	1.4401^c

Note: Numbers followed by the same letter (a,b,c) mean not significantly different at the BNT test level. α=0.05

Table 2. Pest species found in rice fields at different population levels of refugia *Zinnia* sp.

Treatments	Type of species	Family	Order
Control (p0)	*Spodoptera litura* Fabricius 1775	Noctuidae	Lepidoptera
	Batrocera spp.	Tephritidae	Diptera
	Nilaparvata lugens Stål 1854	Delphacidae	Hemiptera
	Ostrinia furnacalis Guenée 1854	Crambidae	Lepidoptera
	Aulacophora indica Gmelin 1790	Chrysomelidae	Coleoptera
	Carabus sp.	Carabidae	Coleoptera
	Scirpophaga innotata Walker 1863	Pyralidae	Lepidoptera
	Aphis fabae Scopoli 1763	Aphididae	Hemiptera
	Riptortus linearis Fabricius 1775	Alydidae	Hemiptera
	Siphanta acuta Walker 1851	Flatidae	Hemiptera
Population 32 polybags (p1)	*Leptocorisa oratorius* Fabricius 1794	Alydidae	Hemiptera
	Ostrinia furnacalis Guenée 1854	Crambidae	Lepidoptera
	Aulacophora indica Gmelin 1790	Chrysomelidae	Coleoptera
	Scirpophaga innotata Walker 1863	Pyralidae	Lepidoptera
	Spodoptera litura Fabricius 1775	Noctuidae	Lepidoptera
	Riptortus linearis Fabricius 1775	Alydidae	Hemiptera
	Carabus sp.	Carabidae	Coleoptera
	Siphanta acuta Walker 1851	Flatidae	Hemiptera
	Aphis fabae Scopoli 1763	Aphididae	Hemiptera
Population 96 polybags (p2)	*Scirpophaga innotata* Walker 1863	Pyralidae	Lepidoptera
	Siphanta acuta Walker 1851	Flatidae	Hemiptera
	Riptortus linearis Fabricius 1775	Alydidae	Hemiptera
	Carabus sp.	Carabidae	Coleoptera
	Leptocorisa oratorius Fabricus 1794	Alydidae	Hemiptera
	Aulacophora indica Gmelin 1790	Chrysomelidae	Coleoptera
	Nilaparvata lugens Stål 1854	Delphacidae	Hemiptera
	Aphis fabae Scopoli 1763	Aphididae	Hemiptera
	Spodoptera litura Fabricius 1775	Noctuidae	Lepidoptera
Population 160 polybag (p3)	*Nilaparvata lugens* Stål 1854	Delphacidae	Hemiptera
	Scirpophaga innotata Walker 1863	Pyralidae	Lepidoptera
	Aphis fabae Scopoli 1763	Aphididae	Hemiptera
	Siphanta acuta Walker 1851	Flatidae	Hemiptera
	Spodoptera litura Fabricius 1775	Noctuidae	Lepidoptera
	Aulacophora indica Gmelin 1790	Chrysomelidae	Coleoptera

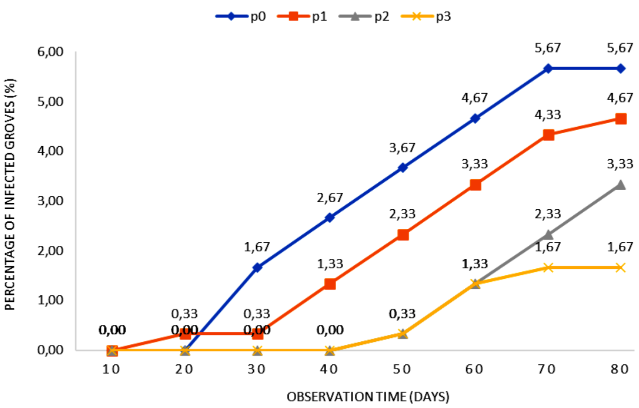

Figure 1. The average intensity of stem borer infestation from day 10 to day 80 of observation

Rice crop production

The population of refugia plants (*Zinnia* sp.) directly influences rice production in a hectare of paddy area. The treatment of the *Zinnia* sp. refugia plant population of 160 polybags (p3) produced the highest average rice production (8.64 tonnes/ha) (Table 5). It was significantly different ($p<0.05$) compared to the other *Zinnia* sp. refugia plant population treatments (p1 and p2).

Discussion

The results of statistical analysis showed that the intensity of stem borer attack on rice plants was higher in the control treatment without refugia compared to the refugia treatment population of 32 polybags (p1), 96 polybags (p2), and 120 polybags (p3), except in treatment p1 on the 20th day of observation, the intensity of rice stem borer attack was higher than the control treatment. This can be caused by several factors, including the initial adaptation of pests to new environmental conditions caused by the presence of refugia. In this initial phase, refugia may not be effective enough to significantly reduce the pest population, so the pest attack in treatment p1 is still higher than the control. In addition, refugia need time to attract and support populations of stem borer natural enemies. On day 20, refugia may not have reached optimal conditions to support predator and parasitoid populations that effectively control pests, so the intensity of pest attack in treatment p1 is higher.

Table 3. Natural enemy species found at different population levels of refugia (*Zinnia* sp.) in rice crops

Treatments	Role	Type of species	Family	Order
Control (p0)	Carnivores (Parasitoids)	*Tetrastichus* sp.	Eulophidae	Hymenoptera
	Carnivores (Predators)	*Chrysso scintillans* Thorell 1895	Theridiidae	Coleoptera
	Carnivores (Parasitoids)	*Telenomus rowani* Gahan 1925	Scelionidae	Hymenoptera
	Carnivores (Predators)	*Coccinella* sp.	Coccinellidae	Coleoptera
	Carnivores (Predators)	*Solenopsis invicta* Buren 1972	Formicidae	Hymenoptera
	Carnivores (Predators)	*Gryllus assimilis* Fabricius 1775	Grylludae	Orthoptera
Population 32 polybags (p1)	Carnivores (Predators)	*Chrysso scintillans* Thorell 1895	Theridiidae	Coleoptera
	Carnivores (Parasitoids)	*Telenomus rowani* Gahan 1925	Scelionidae	Hymenoptera
	Carnivores (Parasitoids)	*Tetrastichus* sp.	Eulophidae	Hymenoptera
	Carnivores (Predators)	*Paederus littoralis* Gravenhorst 1802	Staphylinidae	Coleoptera
	Carnivores (Predators)	*Lasius niger* Linnaeus 1758	Formicidae	Hymenoptera
	Carnivores (Predators)	*Gryllus assimilis* Fabricius 1775	Grylludae	Orthoptera
	Carnivores (Predators)	*Solenopsis invicta* Buren 1972	Formicidae	Hymenoptera
Population 96 polybags (p2)	Carnivores (Predators)	*Gryllus assimilis* Fabricius 1775	Grylludae	Orthoptera
	Carnivores (Predators)	*Lasius niger* Linnaeus 1758	Formicidae	Hymenoptera
	Carnivores (Predators)	*Chrysso scintillans* Thorell 1895	Theridiidae	Coleoptera
	Carnivores (Parasitoids)	*Tetrastichus* sp.	Eulophidae	Hymenoptera
	Carnivores (Parasitoids)	*Trichogramma* sp.	Trichogrammatidae	Hymenoptera
	Carnivores (Parasitoids)	*Telenomus rowani* Gahan 1925	Scelionidae	Hymenoptera
	Carnivores (Predators)	*Coccinella* sp.	Coccinellidae	Coleoptera
	Carnivores (Predators)	*Paederus littoralis* Gravenhorst 1802	Staphylinidae	Coleoptera
Population 160 polybags (p3)	Carnivores (Parasitoids)	*Telemonus rowani*	Scelionidae	Hymenoptera
	Carnivores (Predators)	*Chrysso scintillans* Thorell 1895	Theridiidae	Coleoptera
	Carnivores (Predators)	*Paederus littoralis* Gravenhorst 1802	Staphylinidae	Coleoptera
	Carnivores (Parasitoids)	*Tetrastichus* sp.	Eulophidae	Hymenoptera
	Carnivores (Predators)	*Gryllus assimilis* Fabricius 1775	Grylludae	Orthoptera
	Carnivores (Predators)	*Coccinella* sp.	Coccinellidae	Coleoptera
	Carnivores (Predators)	*Solenopsis invicta* Buren 1972	Formicidae	Hymenoptera
	Carnivores (Predators)	*Lasius niger* Linnaeus 1758	Formicidae	Hymenoptera

Table 4. Diversity index (H'), species richness index (R), diversity index (E), and dominance value (C) of natural enemies in rice fields under various refugia (*Zinnia* sp.) population treatments

Treatments	H'	R	E	C
Control (p0)	1.5192	1.4300	0.8479	0.2489
Population 32 polybags (p1)	1.8889	1.5499	0.9707	0.1580
Population 96 polybags (p2)	1.9333	1.9386	0.9297	0.1629
Population 160 polybag (p3)	2.1785	2.1837	0.9915	0.1151

Table 5. Average rice production (tonnes/ha)

Treatments	Average
Control (p0)	7.04c
Population 32 polybags (p1)	7.31bc
Population 96 polybags (p2)	7.79b
Population 160 polybag (p3)	8.64a

Notes: Numbers followed by the same letter (a, b) mean not significantly different at the BNT test level. α=0.05

The density of refugia in treatment p1 with 32 polybags may also not be high enough to provide maximum protection to rice plants from pest attacks. The lower density compared to p2 and p3 may cause a lack of shelter and food sources for natural enemies of pests. In addition, planting refugia may change the microclimate around the rice plants. In the initial phase, these changes may not immediately provide significant benefits in reducing pest populations, instead providing temporarily more favorable conditions for stem borers. With time, refugia are expected to create a more stable and favorable environment for the presence of natural enemies. In the following days, the intensity of rice stem borer infestation will be lower in the refugia treatment than in the control. These results indicate the importance of selecting the optimal number and distribution of refugia and the time required to achieve an effective ecological balance in controlling pests. However, apart from the p1 treatment on the 20th day of observation, in general, refugia planting was able to suppress the level of stem borer attack. This is thought to be due to the presence of refugia plants inviting the arrival of insects that are natural enemies of stem borers to reduce the population of stem borers, which is characterized by low intensity of attack on plants. This mechanism of pest attack reduction occurs due to the attraction of refugia plants to the rice stem borers' predatory insects. Flowering plants such as *Zinnia* sp. have morphological and physiological characteristics that attract insects because of their size, shape, color, aroma, and the nectar and pollen contents produced during the flowering period to conserve the population of natural enemies in an agroecosystem (Serée et al. 2022; Colazza et al. 2023). Furthermore, Septariani et al. (2019) added that refugia planting also serves as a food provider and a shelter for natural enemies of plant pests.

The results of further statistical analysis showed that the higher the number of *Zinnia* sp. refugia populations used would further reduce the intensity of the attack of rice stem borer pests; this can be seen in Table 1 and Figure 1, which shows that the treatment of *Zinnia* sp. refugia plant population of 160 polybags (p3) resulted in a lower attack rate (1.67%) and significantly different compared to the treatment of other *Zinnia* sp. refugia plant populations. The smaller the number of *Zinnia* sp. refugia plant populations, the higher the rice stem higher borer infestation intensity. This finding indicates that the presence of refugia plants with the highest population can ward off the presence of rice stem borer pests, resulting in the lowest population numbers. Research by Sarni and Sabban (2022) supports the concept that refugia plants are able to increase the presence of natural enemies living around refugia plants, making rice stem borers tend to avoid them because they feel threatened by the presence of these natural enemies.

The low level of stem borer pest attack on rice plants treated with *Zinnia* sp. refugia plant populations of 32, 96, and 120 polybags is thought to be due to the presence of refugia plants inviting the arrival of insects that are either predators or parasitoids, especially parasitoids that attack white rice stem borer eggs so that many groups of eggs do not hatch into larvae. In the rice plantation area studied, there are species of parasitoids of rice stem borer eggs and larvae; among these are egg parasitoids, namely *Tretrastichus* sp. and *Telemonusrowani* sp.. According to Pribadi et al. (2020), refugia is a microhabitat planted around cultivated plants for predators and parasitoids to breed. The benefits of refugia as a conservation area for natural enemies in rice fields are as pest trap plants, pest repellent plants, shelter, attracting natural enemies to live and breed in the area because it provides a source of nutrients and energy such as nectar, honey powder and honeydew needed by natural enemies so that the presence of natural enemies can balance the pest population at a harmless limit.

Other findings from this study also showed that in all treatments, there was an increase in the intensity of rice stem borer attack over time until the 70th day of observation and then became stagnant (stable) until the 80th day of observation (see Figure 1). This assumption arises because of the possibility of the existence of egg nests of rice stem borers before the rice planting season begins, both on land managed without refugia plants and on land with refugia plants. Before the entry of the rice planting season, it is estimated that many rice stem borers live in the grass in the rice field area and lay their eggs in the area. It was observed in this study that the number of eggs increased every 10 days until the 70th and 80th days of observation. However, the increase in the intensity of this pest attack can be suppressed by applying *Zinnia* sp. refugia plants at various population levels. These refugia plants are able to provide shelter which are also a food source for predatory insects or parasitoids of these pests. Suriyanto (2020) stated that one of the efforts to suppress the population of rice stem borers is by planting refugia plants. Refugia can provide spatial and temporal shelter for natural enemies and support biotic interaction components in the ecosystem, such as pollinators. Planting refugia plants in the bund is expected to invite the arrival of predatory arthropods and parasitoids earlier with a high enough population, so that it will be able to curb the development of rice plant pest populations. Thus, this treatment has a positive impact in reducing the attack of rice stem borers.

The study's results on the presence of pests in rice plants showed that most pest insects found were insect pests from the order Hemiptera and Lepidoptera with various species (Table 2). The ecological role of Hemiptera members found in the rice agroecosystem at the study site is to act as herbivores and predators. One of the pests included in this order is *Nilaparvata lugens* or brown planthopper. This pest is one of the main threats to rice plants and can significantly reduce rice production. Insects of the Hemiptera order have flat bodies varying in size from very small to large, thick wings at the base and webbed wings at the tip, called hemielitra (Taszakowski et al. 2022). They have long antennae, mouthparts that branch off from the front of the head, and no cerci. These insects are commonly known as ladybirds and mostly act as crop pests, while some also serve as predators and disease vectors. It lives by sucking the phloem fluid of rice plants, which causes the leaves to turn orange-yellow before turning brown, drying out, and then dying (Senewe et al. 2020).

The other most common pest identified in this study was Lepidoptera. This order is characterized by two pairs of wings, with the hind wings generally smaller than the forewings. Feathers or scales cover the wings, and imago of this order are known as butterflies if active during the day or moths if active at night. One of the main pests of rice plants from this order is *S. innotata* or white rice stem borer. According to Konno (2023), larval-stage insects often damage plants, while adults only suck nectar (honey) from flowers. *S. innotata* larvae damage the stems of rice plants by gnawing on the inside of the stem, resulting in decreased plant stability (Singh and Tiwari 2019; Rahimoon et al. 2023). This can cause the rice plant to collapse or die because it is unable to support the damaged stem structure. Larvae that bore into rice stems feed on plant tissues that contain essential nutrients. This can reduce the nutrients available for plant growth and development, negatively affecting plant health and productivity (Rahmawasiah et al. 2022).

Table 2 also shows that in addition to pests on rice plants such as *N. lugens*, *S. innotata*, and *L. oratorius*, pests were also found that were the main pests on corn plants such as *O. furnacalis* and pests on legumes such as *S. litura*, *A. fabae* and *R. linearis*. This is because there were maize and bean crops around the research site at the time of this research. In addition, many types of pests, including rice pests, were found because some pests are polyphagous.

According to Ilmi et al. (2016), polyphagous pests live and eat on various species in various families.

Pests from the order Diptera were also found in this study, namely *Bactrocera* spp. (fruit flies); this pest is not a pest of rice plants but of horticultural plants. The presence of these pests is due to the species of fruit flies entering the trap because they can fly well enough in search of hosts or food to survive in the field, allowing them to fly at a height of 85 cm or more. This follows Kuswadi (2013), who states that fruit flies are strong-flying insects; male flies can fly as far as 6.44-24.14 km, depending on wind speed and direction.

The importance of *Zinnia* sp. refugia plants in increasing the diversity and richness of natural enemy species can be seen from the variety of orders and families found in rice fields. Observations showed that the natural enemies found in rice plants with various treatments of *Zinnia* sp. refugia populations came from 3 orders: Coleoptera, Hymenoptera, and Orthoptera, which generally act as predators and parasitoids (Table 3). The number of insects from the Hymenoptera order was higher in all *Zinnia* sp. refugia population treatments compared to the Coleoptera and Orthoptera orders. According to Ramzan et al. (2021), Hymenoptera is one of the largest orders, with about 115,000 identified species. This number exceeds the number of vertebrates both on land and in water. This shows that Hymenoptera is one of the main components of faunal diversity, especially insects. Hymenoptera found at the research site included families such as Formicidae, Eulophidae, Scelionidae, and Trichogrammatidae, which act as natural enemies of pests. These insects help control pest populations in rice plants by laying their eggs inside the bodies of pests. Some members of Hymenoptera, such as ants (family Formicidae), play a dominant role as predators of pests in rice crops. They can help control the population of insects that can harm plants. In addition, ants can help compost the soil around rice plants. The activity of ants digging in the soil and moving organic matter can increase the movement of water and nutrients in the soil and improve soil structure (Ekka et al. 2020).

The natural enemies in these rice plants act as predators and parasitoids for rice pests. Predatory Hymenoptera includes the family Formicidae, while parasitoid families include Eulophidae, Scelionidae, and Trichogrammatidae. All pest species have natural enemies (parasitoids, predators, and pathogens) that attack them at various life stages. Treating refugia plants can increase the population and diversity of natural enemies of rice pests. Research by Septiani and Aminah (2021) found that planting refugia affects the population of pests and their natural enemies in rice fields. Kurniawati and Martono (2015) and Setyadin et al. (2017) added that refugia plants can boost the population of natural enemies such as spiders, predatory insects, and parasitoids.

The presence of predatory insects around rice fields is due to the availability of food from flowering plants, specifically refugia plants, which provide nectar and honey from flowers and harbor pest insects. According to Wahyuni et al. (2013), predators not only obtain nectar and honey from flowering plants they visit but also find prey hiding in them, making it easier for predators to capture their prey. Kurniawati and Martono (2015) further noted that habitat manipulation can be achieved by planting flowering plants (insectary plants) that serve as a food source, alternative hosts/prey, and refugia for natural enemies.

The availability of parasitoid insects is closely related to the presence of flowering plants around rice fields, which serve as shelters and hunting grounds. The more numerous and diverse the flowering plants in the field, the higher and more varied the potential presence of parasitoids. Pratama et al. (2013) stated that two factors influence the abundance of parasitoid populations. The first factor is intrinsic, referring to the genetic ability of each parasitoid individual to adapt to changes in hosts and the environment. The second factor is extrinsic, including food sources, competition for space, and the use of pesticides.

During observations, the number of natural enemy species found in rice plants showed that predator species were more numerous than parasitoid species. Specifically, there were 6 species of natural enemies from the predator group and 3 species from the parasitoid group. The population of predator and parasitoid natural enemies increased due to the morphological and physiological traits of refugia plants, which can attract natural enemies. This is consistent with Rahardjo et al. (2018), who stated that refugia attract the most natural enemies because they can attract insects using their morphological and physiological characteristics, such as size, shape, color, fragrance, blooming period, and pollen or nectar content.

One species found in this study was *Trichogramma* of the Trichogrammatidae family, which was only present in treatment p2 (96 *Zinnia* polybags) and not in the other treatments (p0, p1, p3). This suggests that an intermediate density of refugia plants creates optimal conditions for these egg-parasitic wasps. Trichogrammatidae are highly dependent on the availability of host eggs for parasitisation. *Zinnia* densities at p2 may favor certain pest populations whose eggs can serve as hosts, while at p1, host numbers may be insufficient. At P3, higher plant densities may alter host population dynamics or increase competition and predation. In addition, Trichogrammatidae may have a preference for habitat complexity at intermediate densities (p2), where densities that are too low (p1) or too high (p3) do not provide ideal environmental conditions. *Zinnia* density at p2 may also create more stable and favorable microclimate conditions, such as ideal humidity and temperature, necessary for Trichogrammatidae development and activity.

The value of the natural enemy diversity index (H') in rice plantations with refugia plants at various population levels of *Zinnia* is included in the medium category based on the criteria for the value of the Shannon-Wienner diversity index. This indicates that the presence of refugia plants, especially *Zinnia* with various population levels, contributes significantly to the diversity of natural enemies in rice fields.

Specifically, the H' value, which falls into the medium category, indicates that the diversity of natural enemies in these crops is not too low but also not too high. This indicates that using refugia plants from different population levels of *Zinnia* significantly increases the diversity of natural enemies; however, there is still potential for further improvement. One way to increase the diversity of natural enemies is to add more refugia plants other than *Zinnia*. Expanding the variety of refugia plants can attract more species of predatory insects and parasitoids, increasing the diversity of natural enemies in the crop. The planting pattern of refugia plants can also be optimized to maximize the effect of increasing natural enemy diversity. For example, placing refugia plants at a more regular spacing throughout the crop or mixing different types of refugia plants within a given area can create more hospitable conditions for different species of natural enemies. Li et al. (2022) stated that the factors that influence the value of species diversity (H') are environmental conditions, the number of species, and the distribution of individuals in each species. Environmental conditions strongly support the development of natural enemies by modifying the crop cultivation system, one of which is the addition of refugia plants.

The species richness index value in all treatments was in the low category. This means that the number of species of natural enemies found in rice cultivation is small. However, each treatment's evenness index (E) value was in the high category. This indicates that the distribution of individuals of natural enemy species in rice cultivation is relatively balanced, although the number is small. According to research by Wijana (2014), species richness (number of species) and evenness (distribution of individuals) can affect the value of the diversity index (H'). If richness and evenness have almost the same value, the diversity index value will be high or have a balanced contribution from each species. However, if richness and evenness have a large difference, then one of these components will contribute more to diversity. Thus it can be explained that although species diversity is low, the presence of natural enemy species present in rice plantations with the addition of *Zinnia* refugia plant populations still significantly contributes to pest control. The even distribution of these individuals can help maintain the stability of agricultural ecosystems and reduce the risk of excessive pest attacks.

The dominance value of natural enemies that falls into the low category indicates that no species dominates in all treatments. The absence of significantly dominating natural enemy species can reduce the risk of large population fluctuations that can disrupt ecosystem balance. This finding is consistent with the concept that balanced ecosystem will support biodiversity and balanced contribution of natural enemies to pest control (Kumar et al. 2021).

The results of the statistical analysis showed that the treatment with a population of 160 polybags of *Zinnia* sp. refugia (p3) produced the highest average rice yield (8.64 tons/ha) and was significantly different compared to other *Zinnia* sp. refugia plant population treatments (Table 5). This indicated that the greater the population of *Zinnia* sp. refugia plants, the higher the rice production obtained because refugia plants (*Zinnia* sp.) with higher populations found more natural enemies. Hence, the presence of natural enemies suppresses pest populations from rice growth to harvest. This follows the statement of Heong et al. (2015) that planting refugia is an alternative to biological control of rice pests that became a habitat for natural enemies because it affects the biodiversity and abundance of insects. Pradana et al. (2014) stated that insects in the rice ecosystem, directly or indirectly, affect both the quality and quantity of rice production. This research implies that increasing biodiversity in rice fields produced by refugia plants can positively contribute to rice production.

Additionally, the use of refugia plants, specifically yellow *Zinnia* flowers in this study, is also suspected to contribute to distracting target pests and reducing interference with rice plant growth, which in turn has the potential to increase yield (Takikawa et al. 2022). Flower color selection to become pest distraction has been the strategy that has proven effective in crop pest control. The yellow color is particularly attractive to several pests, which can divert their focus away from desirable rice plants (Azizah et al. 2022). Therefore, *Zinnia* sp. with yellow flowers can act as a visual trap that directs pest attention to these refugia plants. In addition, this diversion effect also has the potential to reduce pest incidence on rice plant growth, contributing to increased production yields. Research by Takikawa et al. (2022) provided a scientific basis for a refugia planting strategy using *Zinnia* sp., which has yellow flowers. This strategy focuses on protecting rice plants from pests and uses visual appeal to manage pest behavior more effectively. Thus, the flower color applications as a diversionary tool may be an approach that has the potential to stimulate more optimal growth and yield of rice plants.

The production yield can be optimized through proper planting patterns and maintenance. The importance of refugia population density to enhance rice production has been significantly demonstrated in this study, where refugia populations with the highest density also yielded the highest rice production. Therefore, combining planting patterns with flowering plants positively influences ecosystem diversity, especially through variations in refugia plant population densities. These findings are consistent with the views of Kurniawati and Martono (2015), who emphasize the crucial role of flowering plants in supporting environmental conservation, including maintaining populations of natural enemies in ecosystems.

In conclusion, the *Zinnia* sp. refugia plant population at the dense population level (160 polybags) showed the highest results in increasing the diversity of natural enemies, resulting in the lowest stem borer pest (*Scirpophaga innotata* Walker) infestation rate, and achieving the highest rice production. Thus, the strategy of habitat modification by increasing the population of refugia plants (*Zinnia* sp.) in rice cultivation can be considered an effective method for improving the balance of agricultural ecosystems and reducing yield losses due to crop-destroying pests.

REFERENCES

Aldini GM, Martono E, Trisyono YA. 2019. Diversity of natural enemies associated with refuge flowering plants of *Zinnia elegans*, *Cosmos sulphureus*, and *Tagetes erecta* in rice ecosystem. Jurnal Perlindungan Tanaman Indonesia 23 (2): 285-291. DOI: 10.22146/jpti.33947.

Ali MP, Clemente-Orta G, Kabir MMM, Haque SS, Biswas M, Landis DA. 2023. Landscape structure influences natural pest suppression in rice agroecosystems. Sci Rep 13 (1): 15726. DOI: 10.1038/s41598-023-41786-y.

Aminatun T, Suryadarma IGP, Suhartini S, Sujangka A. 2023. The effect of variation in refugia type and placement on insect abundance in rice field ecosystems. Jurnal Penelitian Saintek 28 (1): 1-13. DOI: 10.21831/jps.v1i1.58324. [Indonesian]

Ara ZG, Haque AR. 2021. A comprehensive review of synthetic insecticides: Toxicity to pollinators, risks related to food security, and management approaches. J Biosyst Eng 46: 254-272. DOI: 10.1007/s42853-021-00104-y.

Ayilara MS, Adeleke BS, Akinola SA, Fayose CA, Adeyemi UT, Gbadegesin LA, Babalola OO. 2023. Biopesticides as promising alternatives to synthetic pesticides: The case for microbial pesticides, phytopesticides, and nanobiopesticides. Front Microbiol 14: 1040901. DOI: 10.3389/fmicb.2023.1040901.

Azizah N, Ahadiyat YR, Farid N, Herliana O. 2022. The effect of refugia telekan flowers (*Tagetes erecta*) and paper flowers (*Zinnia elegans*) on arthropod population and rice yield. Jurnal Ilmu Pertanian Indonesia 27 (1): 54-61. DOI: 10.18343/jipi.27.1.54.

Begg GS, Cook SM, Dye R, Ferrante M, Franck P, Lavigne C, Birch ANE. 2017. A functional review of conservation biological control. Plant Protect 97: 145-158. DOI: 10.1016/j.cropro.2016.11.008.

Bhattacharyya A, Duraisamy P, Govindarajan M, Buhroo AA, Prasad R. 2016. Nano-biofungicides: A new trend in insect pest control. Adv Appl Fungal Nanobiotechnol 307-319. DOI: 10.1007/978-3-319-42990-8_15.

Borror DJ, Triplehorn CA, Johnson NF. 1996. Introduction to The Study of Insects 6th Edition. Gajahmada University Press, Yogyakarta.

BPS Luwu Utara [Badan Pusat Statistik Luwu Utara]. 2022. North Luwu Dalam Angka 2021. Central Bureau of Statistics of North Luwu Regency, Masamba. [Indonesian]

BPS [Badan Pusat Statistik]. 2023a. Official Statistical News. Central Bureau of Statistics, Jakarta. [Indonesian]

BPS [Badan Pusat Statistik]. 2023b. Harvest area and rice production in Indonesia 2022. Results of integrated food crop agricultural statistics data collection activities using the area sampling frame method. Directorate of Food Crops, Horticulture, and Plantation Statistics. Central Bureau of Statistics, Jakarta. [Indonesian]

Broadley HJ, Boettner GH, Schneider B, Elkinton JS. 2022. Native generalist natural enemies and introduced specialist parasitoids jointly control invasive forest insects. Ecol Appl 32 (8): e2697. DOI: 10.1002/eap.2697.

Brotodjojo RRR, Arochman T, Solichah C. 2019. Effect of flowering plants on population dynamics of rice stem borers and their natural enemies. IOP Conf Ser: Earth Environ Sci 250 (1): 012015. DOI: 10.1088/1755-1315/250/1/012015.

Cano D, Martinez-Nunez C, Perez AJ, Salido T, Rey PJ. 2022. Small flowerbeds are resistant reservoirs for wildflower visitor insects and pollination services in agricultural landscapes. Biol Conserv 276: 109789. DOI: 10.1016/j.biocon.2022.109789.

Chen S, Li M, Liu J, Feng Y, Yao J, Shi L, Chen X. 2023. Colour selection and olfactory responses of *Papilio demoleus* during foraging and courtship. Insects 14 (3): 249. DOI: 10.3390/insects14030249.

Colazza S, Peri E, Cusumano A. 2023. Chemical ecology of floral resources in conservation biological control. Ann Rev Entomol 68: 13-29. DOI: 10.1146/annurev-ento-120220-124357.

Desriani, Nurariaty A, Dewi VS. 2021. Presence of pests and their natural enemies in various embankment crops in rice field ecosystems. In IOP Conf Ser: Earth Environ Sci 807 (2): 022096. DOI: 10.1088/1755-1315/807/2/022096.

Directorate General of Food Crops. 2018. Technical guidelines for observation and reporting of plant disturbing organisms and climate change impacts. Ministry of Agriculture, Jakarta. [Indonesian]

Egerer M, Philpott SM. 2022. 'Tidy' and 'messy' management alter natural enemy communities and pest control in urban agroecosystems. PLoS One 17 (9): e0274122. DOI: 10.1371/journal.pone.0274122.

Ekka PA, Rastogi N, Singh H, Singh HB, Ray S. 2020. Lycaenid-tending ants can contribute to fitness gain of the infested host plants by providing nutrients. Arthropod-Plant Interact 14: 745-757. DOI: 10.1007/s11829-020-09785-2.

Fei M, Gols R, Harvey JA. 2023. Biology and ecology of parasitoid wasps of predatory arthropods. Ann Rev Entomol 68: 109-128. DOI: 10.1146/annurev-ento-120120-111607.

Gontijo LM. 2019. Engineering natural enemy shelters to enhance conservation biological control in field crops. Biol Control 130: 155-163. DOI: 10.1016/j.biocontrol.2018.10.014.

Habibi I, Fuadah AS. 2021. Effect of refugia plants on the population of natural enemies of brown planthopper (*Nilaparvata lugens* Stal.) in rice (*Oryza sativa* L.) cultivation. G-Tech: Jurnal Teknologi Terapan 4 (2): 319-325. DOI: 10.18343/jipi.27.1.54. [Indonesian]

Heong KL, Wong L, Delos Reyes JH. 2015. Addressing Leafhopper Threats to Rice Farming and Food Security in Asia: Improving Insecticide Misuse. In: Heong KL, Wong L, Reyes JHD (eds). Rice Planthoppers: Ecology, Management, Socio Economics and Policy. Springer, New York. DOI: 10.1007/978-94-017-9535-7_3.

Hernández-Ochoa IM, Gaiser T, Kersebaum KC, Webber H, Seidel S, Grahmann K, Ewert F. 2022. Model-based design of crop diversification through new land arrangements in spatially heterogeneous landscapes. A review. Agron Sustain Dev 42 (4): 74. DOI: 10.1007/s13593-022-00805-4.

Ilmi N. 2016. Populasi Arthropoda hama dan musuh alaminya yang terpapar pestisida kimiawi dan pestisida nabati pada pertanaman padi di Kecamatan Patampanua, Kabupaten Pinrang. Jurnal Agrotan 2 (2): 34-44. [Indonesian]

Khaled AY, Ekramirad N, Parrish CA, Eberhart PS, Doyle LE, Donohue KD, Adedeji AA. 2022. Non-destructive detection of codling moth infestation in apples using acoustic impulse response signals. Biosyst Eng 224: 68-79. DOI: 10.1016/j.biosystemseng.2022.10.001.

Khan MMH. 2013. Abundance and diversity of insect pests and natural enemies in coastal rice habitat. Bangladesh J Entomol 23 (1): 89-104.

Kinasih I, Cahyanto T, Ardian ZR. 2017. Differences in diversity and composition of soil surface insects in several zones in Gunung Geulis Forest, Sumedang. Jurnal Istek 10 (2): 1-14. [Indonesian]

Kojong EN, Montong VB, Kaligis JB, Pioh DD. 2019. The percentage of beetle pest attacks (*Oryctes rhinoceros* L.) on coconut plants (*Cocos nucifera* L.) in Tombatu District, Southeast Minahasa Regency. COCOS 11 (3): 1-10. DOI: 10.35791/cocos.v3i3.28746.

Konno K. 2023. High relative growth rate makes cabbage mealybug, *Pieris rapae*, a highly abundant and migratory global pest. Sci Rep 13 (1): 9697. DOI: 10.1038/s41598-023-36735-8.

Kulkarni A, Shigwan BK, Vijayan S, Watve A, Karthick B, Datar MN. 2023. Indian rock outcrops: A review of flowering plant diversity, adaptation, floristic composition and endemism. Trop Ecol 64 (3): 408-424. DOI: 10.1007/s42965-022-00283-5.

Kumar A, Saha T, Rachana R, Chandran N, Santosh K. 2021. Assessment of thrips (Thysanoptera) species diversity in Solanaceae vegetable crops. Indian J Ecol 48 (6): 1809-1814.

Kurniawati N, Martono E. 2015. The role of flowering plants as media for conservation of natural enemies of Arthropods. Jurnal Perlindungan Tanaman Indonesia 19 (2): 53-59. DOI: 10.22146/jpti.16615.

Kuswadi AN. 2013. Integrated pest control of fruit flies between mango production in Takalar District with Sterile Insect Techniques (SIT). Paper presented at the Appreciation of Fruit Fly Control Technology Application. Cisarua, 22 May 2013.

Li Q, Shi X, Zhao Z, Wu Q. 2022. Ecological restoration in the source area of Lancang River: Based on the relationship of plant diversity, stability and environmental factors. Ecol Eng 180: 106649. DOI: 10.1016/j.ecoleng.2022.106649.

Li S, Jaworski CC, Hatt S, Zhang F, Desneux N, Wang S. 2021. Flower strips adjacent to greenhouses help reduce pest populations and insecticide applications inside organic commercial greenhouses. J Pest Sci 94: 679-689. DOI: 10.1007/s10340-020-01285-9.

Nakano R, Ito A, Tokumaru S. 2022. Sustainable pest control inspired by ultrasound prey-prey interaction. Proc Nat Acad Sci 119 (43): e2211007119. DOI: 10.1073/pnas.2211007119.

Nayak SB, Elango K, Tamilnayagan T, Vinayaka KS. 2018. Role of ecological engineering in pest management. Entomol Appl Zool 2: 1-18.

Pradana RA, Gatot M, Sri K. 2014. Diversity of insects and spiders in organic and conventional rice crops. Jurnal HPT 2: 58-66. [Indonesian]

Pratama IP, Susila IW, Supartha IW. 2013. Diversity and abundance of *Liriomyza* spp. populations (Diptera: Agromyzidae) and their parasitoids on vegetable crops in medium and highlands of Bali. Agroekoteknologi Tropika 2 (4): 204-213. [Indonesian]

Pribadi DU, Purnawati A, Rahmadhini N. 2020. Implementation of refugia planting system as microhabitat for natural enemies in rice plants. Jurnal Solma 9 (1): 221-230. DOI: 10.29405/solma.v9i1.3108.

Puspita P. 2017. What Flower Colours Do Insects Like?. https://bobo.grid.id /read/08680014/warna-bunga-apa-yang-disukai-serangga?page=all

Rahardjo B, Ikawati S, Prasdianata M, Tarno H. 2018. Effect of refugia on spatial and temporal distribution of arthropods on rice agroecosystem (*Oryza sativa* Linn). Asian J Crop Sci 10 (3): 134-140. DOI: 10.3923/ajcs.2018.134.140.

Rahimoon MY, Ianjar AG, Bukero A, Hajano J, Rahimoon SA, Nahiyoon SA. 2023. Comparative efficacy of different botanicals for controlling white stem borer, *Scirpophaga innotata* (Walker) under field conditions. Pure Appl Biol 12: 1532-1540. DOI: 10.19045/bspab.2023.120154.

Rahmawasiah R, Abadi AL, Mudjiono G, Rizali A. 2022. The effect of integrated pest management on *Scirpophaga innotata* population and natural enemies on rice field in South Sulawesi, Indonesia. Biodiversitas 23 (9): 4510-4516. DOI: 10.13057/biodiv/d230917.

Ramzan U, Majeed W, Rana N, Nargis S. 2021. Occurrence of different insect species with emphasis on their abundance and diversity in different habitats of Faisalabad, Pakistan. Intl J rop Insect Sci 41: 1237-1244. DOI: 10.1007/s42690-020-00314-5.

Romeis J, Naranjo SE, Meissle M, Shelton AM. 2019. Genetically modified crops help support conservation biocontrol. Biol Control 130: 136-154. DOI: 10.1016/j.biocontrol.2018.10.001.

Sarni S, Sabban H. 2022. Utilization of refugia with "border plant" method to control fruit fly pests in bitter gourd plants. Jurnal Pertanian Khairun 1 (1): 51-55. DOI: 10.33387/jpk.v1i1.4783. [Indonesian]

Senewe RE, Permatasari S, Pesireron M. 2020. Response of brown planthopper *Nilaparvata lugens* Stal. (Hemiptera: Delphacidae) to resistance and susceptibility of rice varieties. Jurnal Budidaya Pertanian 16: 51-55. DOI: 10.30598/jbdp.2020.16.1.51. [Indonesian]

Septariani DN, Herawati A, Mujiyo M. 2019. Utilization of various refugia plants as natural pest controls in chili plants (*Capsicum annum* L.). PRIMA: J Comm Empower Service 3 (1): 1-9. DOI: 10.20961/prima.v3i1.36106.

Septiani T, Aminah S. 2021. Effectiveness of refugia on insect diversity and natural enemies in rice farming in Enrekeng Village, Ganra District, Soppeng Regency. Jurnal Pertanian Berkelanjutan 9 (1): 34-40. [Indonesian]

Serée L, Chiron F, Valantin-Morison M, Barbottin A, Gardarin A. 2022. Flower strips, crop management, and landscape composition effects on two aphid species and their natural enemies in faba bean. Agric Ecosyst Environ 331: 107902. DOI: 10.1016/j.agee.2022.107902.

Setyadin Y, Abida SH, Azzamuddin H, Rahmah SF, Leksono AS. 2017. Effect of corn (*Zea mays*) and yard long bean (*Vigna cylindrica*) refugia on insect visitation patterns in paddy fields (*Oryza sativa*) Dusun Balong, Karanglo, Malang. Jurnal Biotropika 5 (2): 54-58. DOI: 10.21776/ub.biotropika.2017.005.02.3. [Indonesian]

Singh DP, Tiwari T. 2019. Assessment of damage extent and yield loss caused by stem borers in rice. J Pharmacog Phytochem 8 (2): 2112-2115.

Sulistyani TH, Rahayuningsih M, Partaya. 2014. Species diversity of butterflies (Lepidoptera: Rhopalocera) in Ulolanang Kecubung Nature Reserve, Batang Regency. Unnes J Life Sci 3 (1): 9-17.

Suriyanto R. 2020. Effectiveness of refugia on the population of white stem borer (*Schirpophaga innotata*) in rainfed rice fields in West Malangke District, North Luwu Regency. Perbal: Jurnal Pertanian Berkelanjutan 8 (2): 87-92. [Indonesian]

Syahputra A, Asyiah IN, Iqbal M. 2019. An ethnobiological study of pest management in Situbondo District, East Java community. Pros Sem Nas Masy Biodiv Indon 5: 439-443. DOI: 10.13057/psnmbi/m050304.

Takikawa Y, Matsuda Y, Kakutani K, Nonomura T, Toyoda H. 2022. Trapping of unattended white flies repelled from tomato plants onto a yellow coloured dipolar electric field screen. Horticulturae 8 (9): 764. DOI: 10.3390/horticulturae8090764.

Tanda AS. 2023. Plant Biochemistry in Insect Pollination for Crop Improvement. In: Sahoo S, Pradhan PP, Borkakati RN (eds). In: Pradhan PP, Borkakati RN. Advances in Insect Pollination Technology in Sustainable Agriculture. I.K. International Pvt. Ltd, New Delhi.

Taszakowski A, Masłowski A, Brożek J. 2022. Labial sensory organs of two species of *Leptoglossus* (Hemiptera: Coreidae): Morphology and supposed function. Insects 14 (1): 30. DOI: 10.3390/insects14010030.

Wahyuni R, Wijayanti R, Supriyadi. 2013. Increasing floral plant diversity as predator attractants in rice pest management. J Agron Res 2 (5): 40-46.

Wang C, Wang X, Jin Z, Müller C, Pugh TA, Chen A, Piao S. 2022. The incidence of plant pests and diseases has largely increased in China since 1970. Nature Food 3 (1): 57-65. DOI: 10.1038/s43016-021-00428-0.

Wijana N. 2014. Analysis of plant species composition and diversity in the forest of Bali Aga Tigawasa Village, Buleleng-Bali. J Sci Technol 3 (1). DOI: 10.23887/jstundiksha.v3i1.2907.

Yang Q, Li Z, Ouyang F, Men X, Zhang K, Liu M, Ge F. 2022. Floral strips enhance natural enemies, provide efficient biocontrol of aphids, and reduce insecticide requirements in cotton crops. Entomol Gen 43: 421-432. DOI: 10.1127/entomologia/2022/1545.

Zhu L, Ma Q, Chen J, Zhao G. 2022. Recent advances in innovative pest detection techniques for stored cereal grains and their powders. Food Chem 396: 133706. DOI: 10.1016/j.foodchem.2022.133706.