Article

BIOEDUSCIENCE
ISSN: 2614-1558
http://journal.uhamka.ac.id/index.php/bioeduscience

Fostering Biodiversity: Unleashing the Potential of Refugia to Enhance Arthropod Diversity in Chili (*Capsicum annuum* L.) Farms

Catur Putri Enggit Reksiana [1], Wiwin Windriyanti [1], Ramadhani Mahendra Kusuma [1 *]

[1] Agrotechnology, Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Jl. Rungkut Madya Gunung Anyar, Surabaya 602942, Indonesia
* Correspondence: ramadhani_mahendra.agro@upnjatim.ac.id

Abstract

Background: The utilization of Integrated Pest Management (IPM) offers a solution to chili cultivation pest challenges by implementing ecological engineering strategies, such as planting refugia. These refugia serve as SNAP (Shelter, Nectar, Alternative Food, and Pollen) sources for beneficial insects. This study aimed to assess the impact of refugia planting on arthropod-type diversity and explore the influence of abiotic factors on arthropod populations. **Methods:** Conducted from February to May 2023, the research utilized various traps (sweep net, yellow trap, pitfall trap, and light trap) and visual control for specimen collection. **Results:** The identification revealed the presence of three classes, ten orders, and 31 families. Arthropod populations in chili fields with refugia totaled 867 individuals, whereas those without refugia amounted to 475. **Conclusions:** Planting refugia led to an elevated diversity index and evenness of arthropods, coupled with a lower dominance index compared to fields without refugia. Surprisingly, temperature and air humidity did not exhibit a significant impact on the arthropod population in chili fields.

Keywords: Arthropods, Abiotic Factors, Diversity, Ecological Engineering

Article history
Received: 19 Jul 2023
Accepted: 11 Sep 2023
Published: 31 Dec 2023

Citation:
Reksiana et al., 2023. Fostering Biodiversity: Unleashing the Potential of Refugia to Enhance Arthropod Diversity in Chili (*Capsicum annuum* L.) Farms. BIOEDUSCIENCE, 7(3), 251-260. doi: 10.22263/jbes/12350

Introduction

Chili (*Capsicum annuum* L.) is Indonesia's most widely cultivated horticultural crop because it is a food ingredient that must always be present in every dish. The need for chili in Indonesia always increases yearly, both on a household scale, market demand, and exports. According to Badan Pusat Statistik (2018), the chili consumption data in Indonesia was 481,071 tons per year in 2017. In addition, chili is also a vegetable with the highest production in Indonesia compared to other vegetables. Chili is an essential economic commodity with good market potential (Kementan, 2021).

Chili cultivation in Indonesia is still experiencing various problems, one of which is pest attacks that cannot be controlled optimally, causing substantial losses such as decreased quality and loss of yields (Suarsana et al., 2020). Pest control that farmers often apply is using chemical pesticides continuously. Pest control that farmers often apply is using chemical pesticides continuously. Pesticides harm the environment because they kill main pests and put down natural enemies and non-target organisms, causing a decrease in diversity and a shift in species (Sengonca, 2020). Another control to prevent pests that farmers have implemented is the polyculture or intercropping system. However, the polyculture system often still uses plants from the same family so that the same pests will attack them (Brotodiojo, 2016).

Recognizing the magnitude of the negative impact of using pesticides and the ineffectiveness of planting polycultures with plants of the same family, so necessary to carry out other more effective control alternatives, such as environmental engineering through planting refugia. Refugia plants can provide SNAP for beneficial insects such as predatory insects, parasitoids, and pollinators (Kusuma & Windriyanti, 2022). Some insects also use the soft tissue of the refugia plant to lay their eggs (Zhang et al., 2021). According to Laha et al. (2022), refugia plants attract various arthropod families with different ecological roles.

Refugia planting includes IPM which can balance pest populations and natural enemies through ecological engineering, so the presence of pests in cultivation is no longer detrimental (Josephrajkumar et al., 2022). Khafagy et al. (2020) reported that planting refugia can reduce the population of whiteflies on tomato plants along with the size of the population of natural enemies. The existence and diversity of arthropods are very beneficial for agricultural ecosystems because they can determine the ecosystem's stability and influence plant growth and production. According to Abdullah et al. (2023), the diversity of organisms that interact with each other in an ecosystem causes the stability of the ecosystem to be higher. This study aimed to analyze the effect of planting refugia on type, diversity of arthropods, and the influence of abiotic factors on arthropod populations.

Method

Selection of Research Locations and Time

This research was conducted in February-May 2023 on two chili fields with different treatments, consisting of fields with refugia planted and without in Made Village, Sambikerep District, Surabaya, Indonesia. Arthropod identification was carried out at the Laboratory of Plant Health, Faculty of Agriculture, Universitas Pembangunan Nasional "Veteran" Jawa Timur.

Refugia Planting

The refugia used in this study were common zinnia (*Zinnia sp.*), king's salad (*Cosmos caudatus*), and marigold (*Tagetes sp.*). The three types of refugia plants were planted as border crops, which are planted tightly and alternately around the edge of the field (Karimzadeh & Besharatnejad, 2019). The spacing used was 15x15 cm between common zinnia, 40x40 cm between marigolds, and 0.5 meters from rows of chili plants. The basil plants (*Ocimum basilicum*) were planted in rows between the chili plants.

Arthropod Data Collection and Abiotic Factor Measurement

Arthropod data collection was carried out when the refugia plants were 6 weeks after planting or when the flower bloomed > 30% (Gloanec et al., 2017) and when chili plants entered the generative phase. The observation time interval is twice a week for two months. Sampling is carried out simultaneously three times a day: in the morning at 07.00 - 08.30 WIB, in the afternoon at 12.00 - 13.30 WIB, and in the evening at 15.00 - 16.30 WIB. Specimen collection was carried out using traps (sweep net, yellow trap, pitfall trap, and light trap) and visual control. The research also conducted observations of temperature and air humidity factors measured using an HTC-2 digital thermohygrometer.

Morphological Identification and Data Analysis

Insect identification was carried out on the family based on Borror's identification book (Triplehorn & Johnson, 2005), iNaturalist software (Unger et al., 2021), and the website https://bugguide.net (Yunus et al., 2022). Data from the arthropod population were analyzed quantitatively, then analyzed using the diversity Shannon-Wienner index (H'), evenness index (E), and dominance index (C). For the Shannon-Wienner (H') index calculation method, use the formula (Hill et al., 2005 *in* Wijayanto et al., 2022):

$$H' = -\sum (ni/N) \ln (ni/N)$$

H' : Diversity index
Ni : The number of individuals of each type

ln : Natural logarithm
N : The total number of all individuals

The Evenness Index (Index of Evenness) is calculated by the following formula (Krebs, 1989):

$$E=H'/(\ln S)$$

E : Evenness index
H' : Diversity of types
ln : Natural logarithm
S : Number of types

The dominance index is calculated using the Simpson dominance index as follows (Krebs, 1989):

$$C=\Sigma(ni/N)^2$$

D : Simpson dominance index
Ni : Total number of individuals of each species
N : The total number of individuals of all species

The t-test was then used to compare arthropod populations between chili fields with and without refugia and the diversity index between the two fields. All analyses were performed using IBM SPSS 26 software (SPSS Inc. Chicago, IL, USA).

Result and Discussion

Arthropod Type, Population, and Composition

The results showed that 867 individuals in chili fields with refugia were found in the arthropod population and 475 individuals in chili fields without refugia (Table 1). The arthropods consisted of three classes: Diplopoda, Arachnida, and Insecta, belonging to 10 orders: Polydesmida, Chilognatha, Aroneceae, Araneae, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, and Odonata. The identification results showed 31 families: Xystodesmidae, Chilognathae, Lycosidae, Agelenidae, Coccinellidae, Staphylinidae, Lampyridae, Brentidae, Carabidae, Hydrophilidae, Muscidae, Tephritidae, Calliphoridae, Dolichopodidae, Tachinidae, Pentatomidae, Anthocoridae, Miridae, Cicadellidae, Aleyrodidae, Aphididae, Coreidae, Formicidae, Vespidae, Sphecidae, Apidae, Papilionidae, Coleophoridae, Erebidae, Noctuidae, and Libellulidae.

Total arthropods in chili fields with refugia were four times higher than those without refugia. Refugia flowers grown on chili fields have bright colors like yellow, white, pink, and orange. The bright colors of refugia flowers can attract arthropods around the field to increase their species and population. Adawiyah et al. (2020) conducted similar research using Pink Flowers from Zinnia sp. refugia, yellow flowers from Cosmos caudatus, and orange flowers from marigolds (Tagetes sp.). The results showed that pink flowers attract insects such as ladybugs and wasps, yellow flowers attract ladybirds, army flies, and butterflies, and orange attract ladybugs and butterflies.

The most common arthropod family found in chili fields is the Formicidae. The abundance of the Formicidae is thought to be due to the availability of food for these predators, namely aphids, the main chili plants' main pests. According to Safitri et al. (2021), the presence of the Formicidae in the field is supported by herbivorous insects from the order Hemiptera, such as *Myzus persicae*. However, not all types of ants become predators of aphids. Some species, such as worker ants and *Formica podzolic* species, have a mutual symbiosis with aphids because the ants will get honeydew, and the aphids will get protection from attacks by their natural enemies.

The following are the types of arthropods found in chili fields with and without refugia planting in Made Village, Surabaya City, with their roles and population numbers in Table 1.

Table 1. Arthropod Populations Found in Chili Fields with and without Refugia

Classification * Order ** Family	Roles	Population (Number of Individuals) Refugia	Population (Number of Individuals) Without Refugia
***Coleoptera**			
**Coccinellidae	Natural Enemy	28	17
**Staphylinidae	Natural Enemy	10	8
**Lampyridae	Natural Enemy	3	0
**Carabidae	Natural Enemy	7	0
**Hydrophilidae	Natural Enemy	5	7
***Diptera**			
**Muscidae	Pollinator	62	13
**Tephritidae	Herbivores	16	9
**Calliphoridae	Pollinator	5	8
**Dolichopodidae	Natural Enemy	26	32
**Tachinidae	Natural Enemy	142	113
***Hemiptera**			
**Pentatomidae	Herbivores	3	0
**Anthocoridae	Natural Enemy	1	0
**Miridae	Natural Enemy	4	0
**Cicadellidae	Herbivores	7	1
**Aleyrodidae	Herbivores	137	0
**Aphididae	Herbivores	59	5
**Coreidae	Herbivores	0	1
***Hymenoptera**			
**Formicidae	Natural Enemy	332	252
**Vespidae	Natural Enemy	1	0
**Sphecidae	Natural Enemy	2	0
**Apidae	Pollinator	1	0
***Lepidoptera**			
**Papilionidae	Herbivores	7	3
**Coleophoridae	Natural Enemy	1	0
**Erebidae	Herbivores	0	2
**Noctuidae	Herbivores	0	1
***Odonata**			
**Libellulidae	Natural Enemy	4	3
***Polydesmida**			
**Xystodesmidae	Detrivitor	1	0
***Chilognatha**			
**Chilognathae	Detrivitor	1	0
***Aroneceae**			
**Lycosidae	Natural Enemy	1	0
***Araneae**			
**Agelenidae	Natural Enemy	1	0
	Grand Total	**867**	**475**

The two study sites were dominated by the orders Hymenoptera (38.75% on chili fields with refugia and 53.05% on fields without refugia) followed by Diptera (28.95% on fields with refugia and 36.84% on fields without refugia). Orders that were also found on chili fields with and without refugia were the orders Hemiptera (24.34% and 1.47%, respectively), Coleoptera (6.11% and 6.74%, respectively), Lepidoptera (0.92% and 1.26% respectively), and Odonata (0.46% and 0.63% respectively) (Figure 1). According to Bhatt & Karnatak (2020), the arthropods found in chili fields consist of the orders Hemiptera, Lepidoptera, Coleoptera (pest), and the orders Coleoptera, Diptera, Hymenoptera, Odonata, and Arachnida (natural enemy). In this current study, orders Araneae, Aroneceae, Chilognatha, and Polydesmida were only found in fields with refugia.

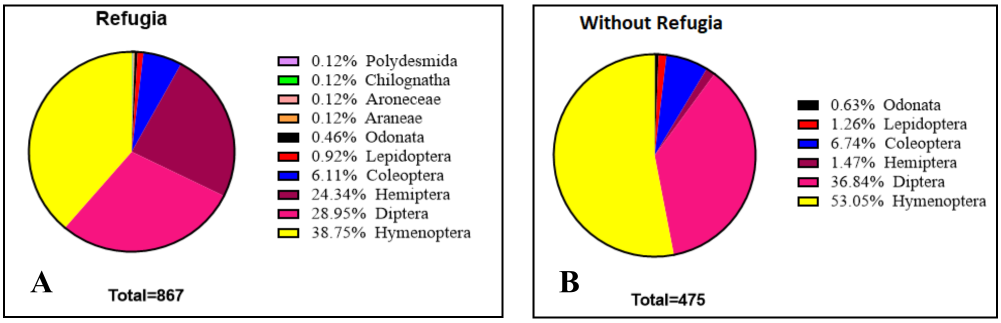

Figure 1. Comparison of Arthropod Populations in Chili Fields with and without Refugia Based on Order: (A) Refugia (B) Without Refugia

The dominance of Hymenoptera and Diptera in the two locations was due to the humid environmental conditions and the abundant feed availability. Hymenoptera is one of the four largest insect orders whose members are numerous and ubiquitous, and many are beneficial as natural enemies and pollinators (Borowiec et al., 2021). Adnan & Wagiyana (2020) add that humid environmental conditions and the presence of abundant weeds can lead to high populations of the order Diptera.

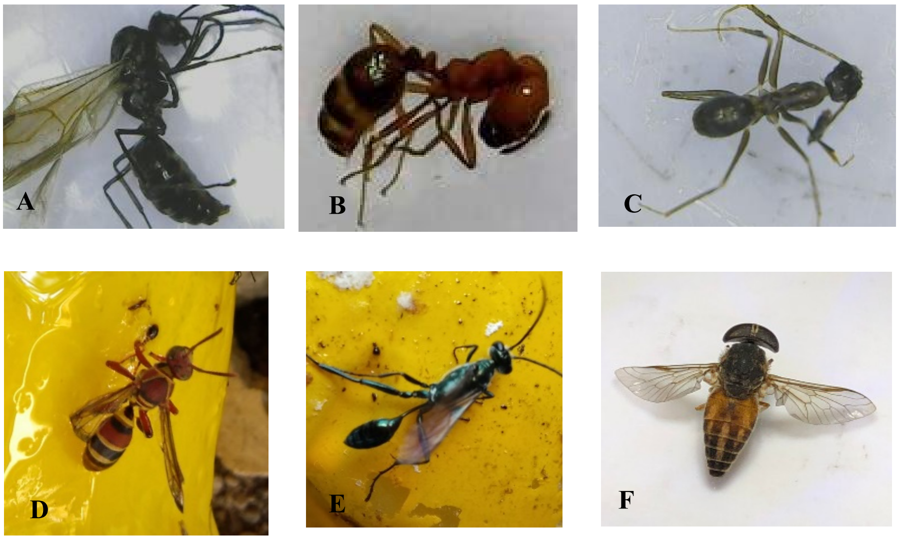

Figure 2. Arthropoda of the Orders Hymenoptera: (A) *Monomorium,* (B) *Pheidole,* (C) *Dolichedorus.* (D) *Polistes,* (E) *Chalybion,* (F) *Apis.*

The statistical analysis showed that the arthropod population found in chili fields with and without refugia was significantly different (sig 0.028 < 0.05) (Table 2). The number of individual arthropods on chili fields with refugia was higher than in fields without refugia. Total individual arthropods were quite high, with a percentage of 54.7%, almost the same as fields with refugia. More arthropods were found on the fields with refugia planting because the diversity of vegetation can increase the diversity of herbivorous and carnivorous arthropods so that the population in the field will increase (Kleiman & Koptur, 2023).

Table 2. The Arthropods (Herbivores, Natural Enemies, Pollinators, and Detritivores) Found in Chili Fields with and without Refugia

	Refugia	Without Refugia	t value	Df	sig (2-way)
Total Arthropods	867	475	2.312	30	0.028
Total Herbivores	235	25	1.447	30	0.158
Total Natural Enemies	566	432	1.587	30	0.123
Total Pollinators	68	21	0.956	30	0.347
Detritivores	2	0	1.438	30	0.161

The number of individual herbivore arthropods in fields with refugia was not significantly different from those without refugia (sig 0.158 > 0.05). Fields with refugia have more individual arthropods than fields without refugia because chili plants have entered the generative phase. In addition, the unsynchronized planting time of chilies around the study area caused a high frequency of attacks by herbivorous arthropods because arthropods can move from one plant to another (Lailiyah & Haryadi, 2021). The low percentage of herbivores on chili fields without refugia is because farmers control using chemical pesticides with spraying intervals every four days. Applying chemical pesticides on the field can cause many arthropods to die, decreasing their populations (Sengonca, 2020).

The arthropods found in chili fields were dominated by natural enemies, with 566 individuals in fields with refugia and 432 without refugia. The number of natural enemy arthropods found in chili fields with and without refugia was not significantly different (sig 0.123 > 0.05). However, when viewed from the number of individuals, the total number of individual natural enemies found in fields with refugia was higher than in fields without refugia. Refugia can provide food sources (nectar and pollen) and shelter for natural enemies (González-Chang et al., 2019). Several studies in agricultural ecosystems have shown that increasing the diversity of arthropod predators and parasitoids can affect prey consumption (Lopes et al., 2017).

The number of individual pollinator arthropods in fields with refugia was not significantly different from those without refugia (sig 0.347 > 0.05). The number of individual pollinators on refugia land is three times higher than fields without refugia (Table 2). The pollinators found came from bees and flies. Flies were found to actively visit chili and refugia plants in the morning and afternoon. Pollinators are phototrophic and are attracted to bright colors, such as flowers and yellow traps (Wulandari & Kamilah, 2021).

Detritivore arthropods had low individual numbers in both fields. In fields with refugia, detritivore found two individuals and not found in fields without refugia. The detritivore was found in the Diplopoda class, a ground-level arthropod. The low level of ground surface arthropods can act as detritivores because the chili fields used as a research location are waterlogged, according to Manalu (2017), who obtained results due to the research site being inundated, causing the fauna to decrease.

Planting refugia can increase the diversity of arthropods in chili fields but has not been able to reduce pest populations. Integrated Pest Management (IPM) is needed to balance pest and natural enemy populations. IPM combines several control techniques in one unified program to achieve maximum economic benefits and provide a safe impact on the environment. Refugia planting can be combined with other controls such as physical/mechanical control, biological control, botanical pesticides, and improving farmers' skills in assessing pest attacks on fields (Ilhamiyah et al., 2020).

Value of Diversity, Evenness, and Dominance of Arthropods

The diversity index calculation showed that the value of the species diversity index (H') on fields with refugia is 2.18 and on fields without refugia is 1.84, which is in the medium category. The evenness index (E) value on fields with refugia is 0.63, and on fields without refugia is 0.61 (Table 3). These values are included in the high category so that all arthropods spread evenly on the fields without dominating. The evenness index value is directly proportional to the species diversity value as evidenced by the species diversity values in the two fields, which are almost the same (medium category) and the species evenness values practically the same (high category) (Wahyuningsih et al., 2019).

Table 3. Value of Diversity, Evenness, and Dominance Index in Chili Fields

Index	Refugia	Without Refugia
Diversity Index (H')	2.18	1.84
Evenness Index (E)	0.63	0.61
Dominance Index (C)	0.18	0.25

The dominance index is inversely proportional to the evenness index of the species, where if the evenness index is high, no species dominates, so the dominance index is low (Lestari & Rahardjo, 2022). Dominance index values (C) for both fields were in a low category, each with 0.18 on the field with refugia and 0.25 without (Table 3). The low dominance index indicates that no arthropod species dominate in both fields. The arthropod community prefers the field with a low dominance index because it has relatively balanced species preservation. The ecosystem tends to be stable and leads to good conditions (Wijayanti et al., 2021).

Abiotic Factors

Abiotic factors such as temperature and humidity affect the bioecology of the arthropods. The correlation of climatic factors with arthropod populations in chili fields can be determined through data analysis with linear regression (Sianipar et al., 2017). The linear regression analysis showed the level of correlation between weather factors and fluctuations in the arthropod population on the fields. The results of the regression analysis in this study are shown in Table 4.

Table 4. Correlation of Abiotic Factors with Arthropod Populations

Climate Factor	Regression Equation	R^2	df	t-count	Sig
Temperature	= -887.180+35.379x	0.155	7	1047	0.335
Humidity	= 93.455+1.009x	0.006	7	0.197	0.850

The regression analysis showed that the temperature factor positively correlated with the regression equation (= -887.180+35.379x; R2 0.155; sig. 0.335) (Table 4). This positive correlation indicates that if there is an increase in field temperature by 1°C, the arthropod population in the field will also increase by 35,379 individuals. The correlation between the temperature factor and the arthropod population is weak because the R2 obtained is 0.155 < 0.25. The significance value obtained from the regression analysis was 0.335 > 0.05, indicating that the temperature factor does not affect the arthropod population in chili fields.

According to Sattar et al. (2021), arthropod populations will change over time, influenced by birth, immigration, death, emigration due to changes in temperature, availability of food or nutrients, and shelter. The temperature range recorded during the study ranged from 29°C - 30°C, which is the optimal temperature for insects in the tropics. According to Horgan et al. (2021), the temperature range between 25°C to 30°C is the optimum and tolerant temperature for insect activity in the tropics.

The regression analysis results show that the humidity factor positively correlates with the regression equation = 93.455+1.009x; R2 0.006; sig. 0.850) (Table 4). This positive correlation indicates that if there is an increase in humidity in the field by 1%, the arthropod population in the fields will also increase by one individual. However, the linear regression equation shows that the humidity factor has a significant value of 0.850 > 0.05, so it does not significantly affect the arthropod population in chili fields. The R2 value obtained was 0.006, indicating no correlation between humidity and the arthropod population in chili fields. Humidity recorded at the study site is around 70% -76%. Wardani (2015) stated that the range of air humidity tolerance for insects would be optimum at 73% - 100%.

Conclusions

The arthropod population in the on-season was found in 867 individuals in chili fields with refugia planted and 475 individuals without refugia, consisting of 3 classes, ten orders, and 31 families. The diversity index (H') and evenness index (E) of arthropods in chili fields with refugia were higher than those without refugia. In contrast, refugia's dominance index (C) values were lower than without refugia. The respective index values on refugia and without refugia were 2.18 and 1.84 (diversity index), 0.63 and 0.61 (evenness index), and 0.18 and 0.25 (dominance index). The regression analysis showed that temperature and air humidity did not affect the arthropod population in chili fields.

Acknowledgments

The author would like to express gratitude to Mr. Selaji and Ponirin, the chili field owner, for permitting the study's conduct. To my lecturer, Dr. Ir. Wiwin Windriyanti, M.P. and Ramadhani Mahendra K., S.P, M.P, M.Sc., for guidance in completing the research study. Also, special appreciation to Vadila Mulia Putri, who supported me in finishing this article.

Declaration Statement

The authors reported no potential conflict of interest.

References

Abdullah, T., Wirid, N., Ramlan, N. S., & Lea, V. C. (2023). Kompleks dan kelimpahan arthropoda pada pertanaman jagung *Zea mays*. *Bioma : Jurnal Biologi Makassar*, *8*, 11–21.

Adawiyah, R., Aphrodiyanti, L., & Aidawati, N. (2020). Pengaruh warna refugia terhadap keanekaragaman serangga pada pertanaman tomat (*Solanum lycopersicum*). *Proteksi Tanaman Tropika*, *3*(2), 194–199. https://doi.org/10.20527/jptt.v3i2.410.

Adnan, M., & Wagiyana. (2020). Keragaman arthropoda herbivora dan musuh alami pada tanaman padi lahan rawa di Rowopulo Kecamatan Gumukmas Kabupaten Jember. *Jurnal Proteksi Tanaman Tropis*, *1*(1), 27–32. https://doi.org/10.19184/jptt.v1i1/5586.

Bhatt, B., & Karnatak, A. K. (2020). Arthropoda Fauna Prevailing on Chilli Crop. *Journal of Entomology and Zoology Studies,* 8(5), 1366–1369. https://dx.doi.org/10.22271/j.ento.

Borowiec, M. L., Moreau, C. S., & Rabeling, C. (2021). Ants: Phylogeny and Classification. *Encyclopedia of Social Insects*, 52–69. https://doi.org/10.1007/978-3-030-28102-1_155.

[BPS] Badan Pusat Statistik. (2018). *Statistik Indonesia: Statistik Year Book of Indonesia 2018*. Badan Pusat Statistik.

Brotodiojo, R. R. R. (2016). Pengendalian hama dengan pengelolaan agroekosistem dalam kerangka pertanian berkelanjutan untuk mendukung ketahanan pangan. *Jurnal Pangan*, *18*(55), 17–24. https://doi.org/10.33964/jp.v18i3.241.

Gloanec, C., Deguine, J. P., Vincenot, D., Laurent, P., Jacquot, M., & Graindorge, R. (2017). Application of Agroecological Crop Protection to Fruit Crops: The BIOPHYTO Experience. *Agroecological Crop Protection*, 77–107. https://doi.org/10.1007/978-94-024- 1185-0_3.

González-Chang, M., Tiwari, S., Sharma, S., & Wratten, S. D. (2019). Habitat management for pest management: limitations and prospects. *Annals of the Entomological Society of America*, *112*(4), 302–317. https://doi.org/10.1093/aesa/saz020.

Hill, D., Fasham, M., Tucker, G., Shewry, M., & Shaw, P. (2005). *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring*. Cambridge University Press.

Horgan, F. G., Arida, A., Ardestani, G., & Almazan, M. L. P. (2021). Elevated temperatures diminish the effects of a highly resistant rice variety on the brown planthopper. *Scientific Reports*, *11*(1), 1–13. https://doi.org/10.1038/s41598-020-80704-4.

Ilhamiyah, I., Ni'mah, G. K., Zuraida, A., & Widaningsih, N. (2020). Sosialisasi dan pemanfaatan tanaman refugia sebagai alternatif pengendali hama tanaman. *Jurnal Pengabdian Al-Ikhlas*, *6*(1), 10–22. https://doi.org/10.31602/jpaiuniska.v6i1.3356

Josephrajkumar, A., Mani, M., Anes, K. M., & Mohan, C. (2022). Ecological engineering in pest management in horticultural and crops. *Trends in Horticultural Entomology*, 123–155. https://doi.org/10.1007/978-981-19-0343-4_4.

Karimzadeh, J., & Besharatnejad, M. H. (2019). Ecological control of *Plutella xylostella* (Lepidoptera, Plutellidae) using trap cropping and Bt applications. *Archives of Phytopathology and Plant Protection*, *52*(19–20), 1326–1347. https://doi.org/10.1080/03235408.2019.1707930.

[Kementan] Kementerian Pertanian. (2021). *Analisis Kinerja Perdagangan Cabai Merah*. Pusat Data dan Sistem Informasi Pertanian. Sekretariat Jenderal. Kementerian Pertanian.

Khafagy, I., Samy, M., & Hamza, A. (2020). Intercropping of some Aromatic plants with sugar beet, its effects on the tortoise beetle *Cassida vittata* vill. Infestation, appearance predators, and sugar beet yield. *Journal of Plant Protection and Pathology*, *11*(2), 103–110. https://doi.org/10.21608/jppp.2020.85987.

Kleiman, B., & Koptur, S. (2023). Weeds enhance insect diversity and abundance and may improve soil conditions in mango cultivation in South Florida. *Insects*, *14*(1). https://doi.org/10.3390/insects14010065.

Krebs, C. J. (1989). *Ecological Methodology* (2nd ed.). An Imprint of the Addition Wesley Longman.

Kusuma, R. M., & Windriyanti, W. (2022). Effective behavior of insects pollinators of flowers in Gadung mango clone 21 variety. *Jurnal Ilmu Pertanian Indonesia*, *27*(4), 596–605. https://doi.org/10.18343/jipi.27.4.596.

Laha, S., Chatterjee, S., Das, A., Smith, B., & Basu, P. (2022). Selection of non-crop plant mixes informed by arthropod-plant network analyses for multiple ecosystem services delivery towards ecological intensification of agriculture. *Sustainability (Switzerland)*, *14*(3). https://doi.org/10.3390/su14031903.

Lailiyah, I., & Haryadi, N. T. (2021). Keragaman arthropoda pada pertanaman padi dengan pemanfaatan gulma sebagai tanaman border. *Jurnal Hama Dan Penyakit Tumbuhan*, *9*(1), 21–27. https://doi.org/10.21776/ub.jurnalhpt.2021.009.1.4.

Lestari, O. A., & Rahardjo, B. T. (2022). Keanekaragaman arthropoda hama dan musuh alami pada lahan padi jajar legowo dan konvensional. *Jurnal Hama Dan Penyakit Tumbuhan*, *10*(2), 73–84. https://doi.org/10.21776/ub.jurnalhpt.2022.010.2.3.

Lopes, S., Ramos, M., & Almeida, G. (2017). The role of mountains as refugia for biodiversity in Brazilian Caatinga: conservationist implications. *Trop Conserv Sci*, *10*, 1–12. https://doi.org/10.1177/1940082917702651.

Manalu, C. J. (2017). Pemanfaatan Fauna Tanah untuk Keberlanjutan Lahan Pertanian Padi. *Prosiding Seminar Nasional Fakultas Pertanian UNS*, *1*, 345–348.

Safitri, N., Sayuthi, M., & Pramayudi, N. (2021). Potensi tanaman refugia terhadap keanekaragaman seranga parasitoid pada pertanaman cabai merah (*Capsicum annum* L.). *Jurnal Ilmiah Mahasiswa Pertanian*, *7*(3), 582–592. https://doi.org/10.17969/jimfp.v7i3.21182.

Sattar, Q., Ehsan, M., Rabia, E., & Sana, A. (2021). Review on climate change and its effect on wildlife and ecosystem. *Open Journal of Environmental Biology*, *6*, 008–014. https://doi.org/10.17352/ojeb.000021.

Sengonca, C. (2020). *Natural Enemies: Conservation. In Managing Biological and Ecological Systems* (2nd ed.). CRC Press.

Sianipar, M.S., Purnama, A., Santosa, E., Soesilohadi, R. H., Natawigena, W. D., Susniahti, N., & Primasongko, A. (2017). Populasi hama wereng batang coklat (*Nilaparvata lugens* Stal.), Keragaman musuh alami predator serta parasitoidnya pada lahan sawah di dataran rendah Kabupaten Indramayu. *Agrologia*, 6(1), 44-53. http://doi.org/10.30598/a.v6i1.245.

Suarsana, M., Parmila, P., Wahyuni, P. S., & Suarmika, I. G. M. (2020). Pengaruh serangan hama penggerek batang dan penyakit tungro terhadap produktivitas sembilan varietas padi di Lokapaksa, Bali. *Agro Bali : Agricultural Journal*, *3*(1), 84–90. https://doi.org/10.37637/ab.v3i1.461.

Triplehorn, C. A., & Johnson, N. (2005). *Borror and Belongs's Introduction to the Study of* Insects (7th ed.). Thomson Brooks/ Cole.

Unger, S., Rollins, M., Tietz, A., & Dumais, H. (2021). iNaturalist as an engaging tool for identifying organisms in outdoor activities. *Journal of Biological Education*, *55*(5), 537–547. https://doi.org/10.1080/00219266.2020.1739114.

Wahyuningsih, E., Faridah, E., Budiadi, & Syahbudin. (2019). Komposisi dan keanekaragaman tumbuhan pada habitat ketak di Pulau Lombok. *Jurnal Hutan Tropis*, *7*(2), 1–13. http://dx.doi.org/10.20527/jht.v7i1.7285.

Wardani, S.K. (2015). Studi komparatif usahatani jajar legowo dan sistem tanam padi konvensional di Desa Sidoagung Kecamatan Godean Kabupaten Sleman. *Jurnal Online Agroteknologi*, *1*(2), 1–14.

Wijayanti, A., Windriyanti, W., & Rahmadhini, N. (2021). Peran refugia sebagai media konservasi arthropoda di lahan padi Desa Deliksumber. *VIABEL: Jurnal Ilmiah Ilmu-Ilmu Pertanian*, *15*(2), 17–32. https://doi.org/10.35457/viabel.v15i2.1626.

Wijayanto, M. A., Windriyanti, W., dan Rahmadhini, N. (2022). Biodiversitas arthropoda permukaan dan dalam tanah pada kawasan agroforestri di Kecamatan Wonosalam Jombang Jawa Timur. *Jurnal Pertanian Agros*, *24*(2), 1090–1102.

Wulandari, A., & Kamilah, M. (2021). Studi kunjungan harian arthropoda pada tanaman *Ageratum conyzoides* dan *Acalipa australis* di area pertanian Dusun Ketanon Kecamatan Diwek sebagai bahan pengembangan e-katalog arthropoda. *BIO-EDU: Jurnal Pendidikan Biologi*, *6*(2), 102–112. https://doi.org/10.32938/jbe.v6i2.1187.

Yunus, M., Nasir, B., Lasmini, S. A., & Piri, R. L. (2022). Biodiversity and community structure of Arthropod in tropical rice fields under organic and conventional ecosystems. *Australian Journal of Crop Science*, *16*(4), 531–535. https://doi.org/10.21475/ajcs.22.16.04.p3551.

Zhang, L., Qin, Z., Liu, P., Yin, Y., Felton, G. W., & Shi, W. (2021). Influence of plant physical and anatomical characteristics on the ovipositional preference of Orius sauteri (hemiptera: Anthocoridae). *Insects*, *12*(4). https://doi.org/10.3390/insects12040326