

RESEARCH ARTICLE

Selected monocots and eudicots as alternative host plants for promoting arthropod populations in paddy cultivation area

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Abstract

Aim of study: To investigate the relationship between selected alternative host plant species and the abundance of arthropods throughout the growth of rice plants.

Area of study: Southwest of Malaysia (Melaka).

Material and methods: Sampling of arthropods was conducted in four rice field plots, each containing five sampling plots based on the selected alternative hosts: *Chloris barbata* Sw. and *Oryza sativa* L. (monocots); and *Ageratum conyzoides* L., *Spermacoce verticillata* L., and *Euphorbia heterophylla* L. (eudicots). Yellow sticky traps, yellow pan traps, and sweep nets were set up and used, and sampling was conducted during the vegetative, reproductive, and mature stages of rice growth. Analysis of variance (ANOVA) and regression analysis were performed to determine the diversity and relationship between alternative host plants with arthropods.

Main results: A total of 2,227 arthropod individuals from 11 orders and suborders, 32 families, and 40 species were recorded. The results showed a strong correlation between alternative host plants and pests ($R^2 = 0.965$), predators ($R^2 = 0.758$), and other insects ($R^2 = 0.987$), while a weaker correlation ($R^2 = 0.369$) was observed with parasitoids. A significant pest decline was observed in *A. conyzoides* ($\beta = -0.725$, $P = 0.040$) and *S. verticillata* ($\beta = -1.505$, $P = 0.034$), while there was a substantial population increase in *C. barbata* ($\beta = 1.854$, $P = 0.026$). Other insects showed a significant population increase in *O. sativa* ($\beta = 0.752$, $P = 0.030$). However, predatory insects and parasitoids did not show significant population trends during the sampling period in any of the alternative hosts.

Research highlights: The planting of alternative hosts in rice cultivation areas can attract natural enemies of insects and improve Integrated Pest Management (IPM) practices in rice fields.

Keywords: Potential host, insect diversity, pests, predators, parasitoids.

Monocotiledóneas y eudicotiledóneas seleccionadas como plantas huésped alternativas para promover poblaciones de artrópodos en arrozales

Resumen

Objetivo del estudio: Investigar la relación entre especies seleccionadas de plantas huésped alternativas y la abundancia de artrópodos a lo largo del crecimiento de las plantas de arroz.

Área de estudio: Suroeste de Malasia (Melaka).

Material y métodos: Se llevó a cabo el muestreo de artrópodos en cuatro parcelas de arroz, cada una con cinco subparcelas de muestreo basadas en las plantas huésped alternativas seleccionadas: *Chloris barbata* Sw., y *Oryza sativa* L. (monocotiledóneas); *Ageratum conyzoides* L., *Spermacoce verticillata* L. y *Euphorbia heterophylla* L. (eudicotiledóneas). Se utilizaron trampas adhesivas amarillas, trampas de recipiente amarillo y redes de barrido, realizándose el muestreo durante las etapas vegetativa, reproductiva y madura del crecimiento del arroz. Se aplicaron análisis de varianza (ANOVA) y análisis de regresión para determinar la diversidad y la relación entre las plantas huésped alternativas y los artrópodos.

Principales resultados: Se registraron un total de 2,227 individuos de artrópodos pertenecientes a 11 órdenes y subórdenes, 32 familias y 40 especies. Los resultados mostraron una fuerte correlación entre las plantas huésped alternativas y las plagas ($R^2=0.965$), los depredadores ($R^2=0.758$) y otros insectos ($R^2=0.987$), mientras que se observó una correlación más débil con los parasitoides ($R^2=0.369$). Las plagas presentaron una disminución significativa en *A. conyzoides* ($\beta = -0.725$, $P = 0.040$) y *S. verticillata* ($\beta = -1.505$, $P = 0.034$), mientras que hubo un aumento sustancial de su población en *C. barbata* ($\beta = 1.854$, $P = 0.026$). Otros insectos mostraron un incremento significativo en *O. sativa* ($\beta = 0.752$, $P = 0.030$). Sin embargo, los insectos depredadores y los parasitoides no mostraron tendencias poblacionales significativas durante el periodo de muestreo en ninguna de las plantas huésped alternativas.

Aspectos destacados de la investigación: La siembra de plantas huésped alternativas en áreas de cultivo de arroz puede atraer enemigos naturales de los insectos y mejorar las prácticas de Manejo Integrado de Plagas en los arrozales.

Palabras clave: Huésped potencial, diversidad de insectos, plagas, depredadores, parasitoides.

The translation of the title, abstract, and keywords from the original version in English to Spanish has been generated using OpenAI, ChatGPT GPT-4o mini (2025).

La traducción al español del título, resumen y palabras clave de la versión original en inglés ha sido generada utilizando OpenAI, ChatGPT GPT-4o mini (2025).

Citation: Khalid, F; Che-Ismael, CNF; Idris, A; Rakibe, I; Mohammed, MA; Yaakop, S (2025). Selected monocots and eudicots as alternative host plants for promoting arthropod populations in paddy cultivation area. Spanish Journal of Agricultural Research, Volume 23, Issue 1, 21021. <https://doi.org/10.5424/sjar/2025231-21021>.

Received: 28/01/2024. **Accepted:** 25/09/2024. **Published:** 27/03/2025.

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Introduction

Alternative hosts refer to plant species that are not grown for other types of agricultural products but can be used as replacements for insects' food sources or habitats, specifically parasitoids and predators (Denys & Tschardt, 2002). These host plants have a significant impact on the biology and population dynamics of plant pests. Alternative hosts provide shelter and resources for arthropods during unfavorable seasons, enabling them to survive and thrive so that they can complete their entire life cycle on alternative hosts even when their preferred host is absent. Alternative hosts can also serve as breeding grounds, supporting the reproduction and population expansion of arthropods (Kumar et al., 2021). Hence, to develop more effective pest control tactics, it is crucial to comprehend the relationship between arthropods and alternative hosts (Sudbrink et al., 1998). By identifying and implementing strategies to manage alternative hosts, farmers can reduce pest populations in rice fields effectively and minimize crop damage. Common pest management strategies include suppressing weeds and employing trap plants to target pests on different hosts (Pasini et al., 2018).

Some alternative hosts discovered in rice farming areas are *Ageratum conyzoides* L., *Spermacoce verticillata* L., *Euphorbia heterophylla* L., and *Chloris barbata* L. *Ageratum conyzoides* is commonly referred to as wild goat weed. These plants may be employed as trap plants within a push-pull strategy for pest management in cereal harvests. They have been successfully reported to repel pests while simultaneously attracting natural enemies, thereby diminishing pest populations when intercropped with cereals such as wheat, maize, and barley (Huss et al., 2022). In addition, *A. conyzoides* can serve as a valuable source of livestock feed and generate multiple streams of supplementary income for

farmers (Khan et al., 2014). The weed survey investigation identified *S. verticillata*, also known as Shrubby False Buttonwood, as one of the predominant species observed in cassava plants. According to Miléo et al. (2016), *S. verticillata* can be an alternative host plant in agricultural settings.

Furthermore, an investigation into the foraging habits of the *Larra bicolor* F. stinger, a parasitic insect that preys on *Scapteriscus* grasshoppers, revealed that *S. verticillata* is the favored choice of food for the stinger when compared to other nearby plant species (Portman et al., 2010). The data indicate that *S. verticillata* can be a beneficial resource for multiple kinds of parasitoid insects. *Euphorbia heterophylla* has been identified as a potentially beneficial plant for enhancing the population of parasitoids, such as *Goryphus bunoh* Gauld, *Dolichogenidea metesae* Nixon, and *Brachymeria carinata* Joseph, Narendran and Joy, to manage the bagworm *Metisa plana* Walker infestations in oil palm (Ahmad Ali et al., 2007; Sahari et al., 2023). Meanwhile, on *C. barbata*, *Coccinella transversalis* F. was recorded feeding on *Sitobion* sp. in a rice field during harvest (Chitra et al., 2018). As a result, diverse plant species can promote a wider range of insect species. The inclusion of various plant species, such as weeds, contributes to the overall biodiversity of the ecosystem, benefiting both animal and plant lives. This, in turn, reinforces the ecosystem's ability to withstand disturbances and offers a range of valuable ecosystem services (Berg et al., 2016).

Nevertheless, observers sometimes consider alternative host plants as unsightly and undesirable weeds. The lack of precise knowledge regarding the impact of alternative hosts on insect diversity in rice-growing areas contributes to the damage to rice crops. Therefore, this study aims to determine the number of insect species on various alternative hosts and evaluate the ecological diversity of insects on each alternative host plant. Additionally, this study seeks to clarify the beneficial role that rice farmers could exploit by incorporating these alternative host plants in their paddy fields.

Material and methods

Sampling location

The insect sampling took place at a paddy field located in Kampung Tengah Padang, Merlimau, Malacca, Malaysia, at the coordinates of 2.13814 N and 102.4219 E (Figure 1). The rice fields in this region are planted with the MR220 rice variety. The direct seeding technique of the MR220 variety was implemented at the rate of 180 kg/ha, with planting initiated from mid-August 2019 to mid-November 2019. Throughout the planting season, fertilizer was applied four times to ensure optimal plant growth and development. The first application occurred 20 days after seeding, utilizing NPK compound fertilizer with a ratio of 17:15:10 at the rate of 140 kg/ha during the vegetative stage. The second application took place 35 days after seeding, where urea (46% N) was administered at the rate of 80 kg/ha to support active tillering. The third application was conducted 50 days after seeding and involved both NPK compound fertilizer (at the ratio of 17:15:10) and 17:3:25 + 2 MgO, each applied at the rate of 100 kg/ha. Finally, the fourth application occurred 80 days after seeding, involving NPK compound fertilizer (17:3:25 + 2 MgO) at the rate of 50 kg/ha during the critical tillering and fruiting phases. Additionally, pesticide applications for pest and disease management were conducted only when necessary, beginning 40 days after transplanting, with a maximum of six applications throughout the planting season, as recommended by the Department of Agriculture (DOA, 2022).

Selection of alternative host plot

A preliminary observation was conducted to determine whether *A. conyzoides*, *S. verticillata*, *E. heterophylla*, and *C. barbata* were present along the bund and cliff of the rice block, as these species were the most abundant among others. The selection of rice blocks is based on the existence of each host plant species with a clump length of at least 10 m to ease sampling and attract a larger range of arthropods. The positioning of sampling plots was then determined based on alternative host plants for each rice block.

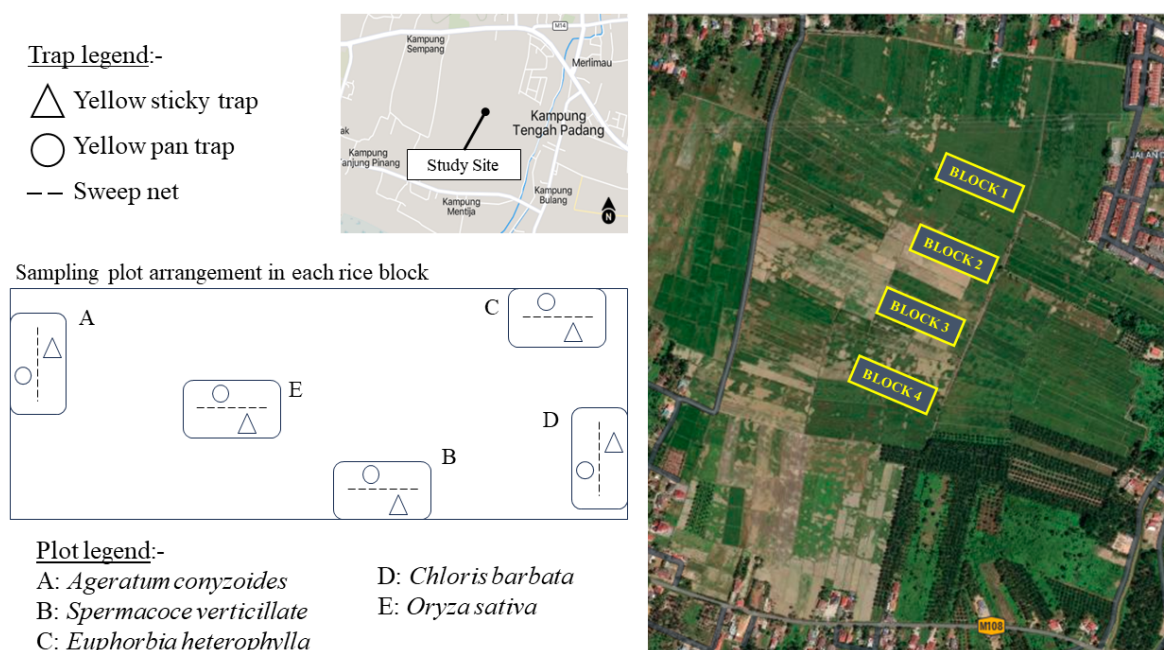


Figure 1. Sampling location in Kampung Tengah Padang, Merlimau, Malacca rice fields with five sampling hosts (*Ageratum conyzoides* L., *Spermacoce verticillata* L., *Euphorbia heterophylla* L., *Chloris barbata* L., and *Oryza sativa* L.) and three traps (yellow sticky trap, yellow pan trap, and sweep net)

This study utilized four rice fields owned by farmers, each measuring 1.2 ha. Each field was divided into five sampling plots, measuring 6×10 m.

Arthropods sampling

In this study, sampling was performed in four rice blocks, each containing five sampling plots to ensure a comprehensive assessment of insect populations. Three types of insect sampling methods were employed within each plot, i.e., sweep net, yellow sticky traps, and yellow pan traps. A sweep net was used to catch flying insects in each plot by sweeping it in a zig-zag pattern along a 10-m transect involving 10 swings. The yellow sticky trap was made of a 20×25 cm two-sided sticky plastic sheet that was fixed to a pole stand at the height of the rice plant canopy. At every sampling date, the height was changed to correspond with the growth of the rice plants. Meanwhile, the yellow pan trap was set up on the ground to collect ground-dwelling insects. The components of the yellow pan trap include a plastic tray 30 cm in diameter and 10 cm deep, which was filled with 300 mL of a detergent solution (1 mL detergent/1 L water). The method allows the captured insects to sink, preventing them from escaping and enabling precise identification and easier counting. The sampling was conducted three times during each growth stage of the rice plants, i.e., vegetative, reproductive, and mature stages, to capture the dynamics of insect populations throughout the growing season. The data collection process involved using *O. sativa* (paddy) as a control parameter to facilitate comparisons with other hosts. The collected arthropod specimens were placed in a container filled with 60 % alcohol solution to kill them and then transported to the laboratory for counting and identification.

Identification of species and roles of arthropods in the ecosystem

The specimens were identified at the Entomology Laboratory 3, Faculty of Plantation and Agrotechnology, UiTM Melaka Branch, Jasin Campus, Melaka, Malaysia. The identification of

species was based on the hierarchical classification of family, genus, and species, as described by Siwi and Van Doesburg (1984), Khan (1991), Achterberg (1993), Schaefer (2004), and Triplehorn et al. (2005). The specimens were identified by examining their external morphological characters using a stereo microscope, StemiD4, Germany. The role of these species in rice fields is supported by previous studies (Reissig, 1985; Shepard et al., 1987, 1995; Pathak & Khan, 1994; Heinrichs, 2004). Samples were then further confirmed by insect taxonomists from the Centre for Insect Systematics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM).

Data Analysis

Species composition and abundance of arthropods

Logarithmic transformation was used to normalize the data collected. Since the data set involved small values, $\log(X + 1)$ was used, with X as the original data (Gomez & Gomez, 1984). Then, analysis of variance (ANOVA) was performed to ascertain the presence of significant differences in the arthropods' population across various host plant species and growth phases of rice plants. Tukey's Honestly Significant Difference (HSD) test was conducted on every statistically significant result obtained from ANOVA. The data analysis was conducted using IBM-SPSS software version 22. Meanwhile, the analysis of diversity was conducted using the Shannon-Wiener diversity index (H'), the Simpson diversity index (D'), the uniformity index (E'), and the Margalef richness index (R'). The Paleontological Statistics Program (PAST) version 4.13 was utilized for this objective.

Relationships between host plants and arthropods

The relationships between arthropods, their population trends, and the alternative hosts were determined using regression analysis. A positive slope coefficient (β) indicates an increasing trend in the insect population, while a negative value indicates a decreasing trend. A value of the regression coefficient (R^2) above 0.5 indicates a moderate to strong relationship, suggesting that more than half of the variability in the arthropod population could be explained by the alternative host. The significance of the relationship was tested at the 5% level. The analysis was conducted using IBM-SPSS version 22 software.

Results

Composition and abundance of arthropod species

Approximately 2,227 arthropod individuals, composed of insects and spiders, were gathered, as shown in Table 1. Of these, 1,354 individuals (61%) were identified as pests, 87 individuals (4%) as predators, 232 individuals (10%) as parasitoids, and 554 individuals (25%) as other insects. Other insects refer to species that do not fall within any specific group mentioned in this study. The species mentioned include *Anthophila fabriciana* L., *Blatella germanica* L., *Camponotus* sp., *Halictus scabiosae* R., *Hystrihopus* sp., *Musca domestica* L., and *Paederus littoralis* G. However, it is important to note that these species can also play an essential role as pollinators, alternative hosts or prey, and decomposers in maintaining ecosystem balance.

A total of 11 orders, 32 families, and 40 insect species were identified from the 1,354 pest individuals (Table 1). The Hemiptera has the largest number of specimens, comprising 1,185 individuals, representing 53% of the total. The Hymenoptera includes 369 individuals, accounting for 17% of the total. In comparison, the Diptera comprises 268 individuals, representing 12% of the total. The order Coleoptera accounts for 223 individuals, i.e., 10% of the total. Additional orders that exhibit significantly low population counts include Lepidoptera, consisting of 96 individuals (4%); Araneae with 32 individuals (1%); Blattodea (Blattaria) with 12 individuals (1%); Orthoptera with 26 individuals (1%); Odonata with 8 individuals (0.4%); Hemiptera (Homoptera) with 6 individuals (0.3%); and Blattodea (Isoptera) with 2 individuals (0.1%).

Table 1. List of arthropods composed of insect and spider species recorded by order, family, and species in Kampung Tengah Padang, Merlimau, Malacca, Malaysia.

No.	Order	Family	Species	Role	Total	%
1	Blattodea	Ectobiidae	<i>Blatella germanica</i>	Others	12	0.5
2		Kalotermitidae	<i>Incisitermes minor</i>	Pest	2	0.1
3	Coleoptera	Carabidae	<i>Hystrichopus</i> sp.	Others	154	6.9
4		Coccinellidae	<i>Micraspis discolor</i>	Predator	40	1.8
5		Carabidae	<i>Ophionea nigrofasciata</i>	Predator	1	0.04
6		Staphylinidae	<i>Paederus littoralis</i>	Others	28	1.3
7	Diptera	Muscidae	<i>Musca domestica</i>	Others	218	9.8
8		Tipulidae	<i>Tipula</i> sp.	Pest	50	2.2
9	Hemiptera	Alydidae	<i>Leptocaris oratorius</i>	Pest	130	5.8
10		Cicadellidae	<i>Nephrotettix virescens</i>	Pest	1	0.04
11			<i>Recilia dorsalis</i>	Pest	336	15.1
12		Delphacidae	<i>Sogatella furcifera</i>	Pest	706	31.7
13		Reduviidae	<i>Rhynocoris iracundus</i>	Pest	5	0.2
14			Triatominae	Pest	6	0.3
15			<i>Zelus luridus</i>	Predator	1	0.04
16		Coreidae	<i>Riptortus linearis</i>	Pest	6	0.3
17	Hymenoptera	Formicidae	<i>Componotus</i> sp.	Others	129	5.8
18		Vespidae	<i>Eumenes pomiformis</i>	Predator	5	0.2
19		Halictidae	<i>Halictus scabiosae</i>	Others	3	0.1
20		Braconidae	<i>Opius</i> sp.	Parasitoid	9	0.4
21		Eulophidae	<i>Tetrastichus schoenobii</i>	Parasitoid	154	6.9
22		Pteromalidae	<i>Trichomalopsis apantelectena</i>	Parasitoid	69	3.1
23	Lepidoptera	Choreutidae	<i>Anthophila fabriciana</i>	Others	10	0.4
24		Pyalidae	<i>Chilo suppressalis</i>	Pest	34	1.5
25		Crambidae	<i>Chilo infuscatellus</i>	Pest	1	0.04
26			<i>Cnaphalocrocis medinalis</i>	Pest	8	0.4
27			<i>Herpetogramma licarsisalis</i>	Pest	6	0.3
28			<i>Nymphula depunctalis</i>	Pest	4	0.2
29		Erebidae	<i>Hyphantria cunea</i>	Pest	7	0.3
30			<i>Laelia suffusa</i>	Pest	3	0.1
31		Noctuidae	<i>Spodoptera mauritia</i>	Pest	4	0.2
32		Tineidae	<i>Tineola bisselliella</i>	Pest	19	0.9
33	Odonata	Libellulidae	<i>Acisoma panorpoides</i>	Predator	4	0.2
34		Agrionidae	<i>Agriocnemis pygmaea</i>	Predator	4	0.2
35	Orthoptera	Gryllidae	<i>Metioche vittaticollis</i>	Pest	7	0.3
36		Acrididae	<i>Oxyca chinensis</i>	Pest	19	0.9
37	Araneae	Araneidae	<i>Argiope catenulata</i>	Predator	10	0.4
38		Linyphiidae	<i>Atypena formosana</i>	Predator	8	0.4
39		Tetragnathidae	<i>Tetragnatha maxillosa</i>	Predator	12	0.5
40			<i>Tetragnatha</i> sp.	Predator	2	0.1

Species abundance according to their function

Two pest species, *Sogatella furcifera* Horváth (Hemiptera: Delphacidae) and *Recilia dorsalis* (Motschulsky; Hemiptera: Cicadellidae), have exceptionally high populations. *Sogatella* accounts for 706 individuals, 31.7%, while *R. dorsalis* has 336 individuals, making up 15.1% of the whole (Table 1). *Micraspis discolor* F. (Coleoptera: Coccinellidae) has the largest population of predatory insects, comprising 40 individuals (1.8% of the total). *Tetrastichus schoenobii* F. (Hymenoptera: Eulophidae) is the most abundant parasitoid species, consisting of 154 individuals, i.e., 6.9% of the total population. *Musca domestica* L., a member of the Muscidae (Diptera) family, is found in other insect categories, with 218 individuals accounting for 9.8% of the total.

Insect abundance according to alternative hosts

The study revealed a significant difference ($df = 4;115$, $F = 27.602$, $P < 0.01$) in the quantity of insect pests among alternative hosts. However, the study indicated no significant difference in the number of insects in the categories of predators ($df = 4;115$, $F = 2.052$, $P > 0.05$), parasitoids ($df = 4;115$, $F = 1.967$, $P > 0.05$), and others ($df = 4;115$, $F = 0.830$, $P > 0.05$) between different types of alternative hosts. Among all alternative hosts, insect pests exhibit the highest population density relative to other insect groups, including other insects, parasitoid insects, and predatory insects (Figure 2).

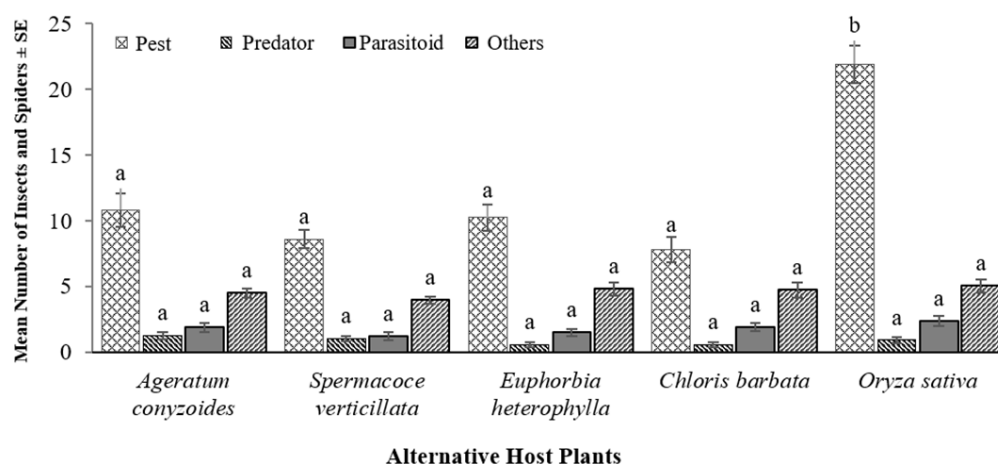


Figure 2. Mean number of insects $\pm$ Standard Error according to their categories (pests, predators, parasitoids and others) on different alternative host plant species (*A. conyzoides*, *S. verticillata*, *E. heterophylla*, *C. barbata*, and *O. sativa*). Mean of insects and spider categories with the same letter in each alternative host plant species were not significantly different ($p > 0.05$).

Furthermore, a significant difference is noted in the population density of insect pests ($df = 2;117$, $F = 4.130$, $P < 0.05$) as well as other insects ($df = 2;117$, $F = 6.498$, $P < 0.05$) throughout the different growth stages of rice. No significant differences are observed in the number of predators ($df = 2;117$, $F = 2.486$, $P > 0.05$) and parasitoids ($df = 2;117$, $F = 0.186$, $P > 0.05$) between different tree growth stages in rice. Pests are the insect category with the most significant population size across all phases of rice plant growth, surpassing other categories such as parasitoid and predatory insects (Figure 3).

Species diversity according to host crops and rice growth

The H' index showed no significant differences ($df = 2;5$, $F = 2.173$, $P > 0.05$) between alternative hosts. However, the D' index demonstrates a substantial affinity for the *O. sativa* host, with a precise value of 0.2034 (Table 2). The host plant *S. verticillata* exhibits a low value of 0.1362. The insect species richness of the host *O. sativa* is minimal but high on the *S. verticillata* host. The *S. verticillata* host has the highest E' index value, i.e., 0.4542. The host *O. sativa* has the lowest measured value of 0.3149. However, both hosts exhibit low homogeneity in terms of species. The R' index reached its peak value of 5.005 on the *E. heterophylla* host, while the minimum reading was documented on the *O. sativa* host, with a value of 3.667. This shows that both hosts exhibit a moderate level of insect diversity. The H' index revealed that the *S. verticillata* host exhibits the greater diversity value (2.469), whereas the *O. sativa* host has the lowest diversity value of 2.063. Overall, the *O. sativa* host exhibited reduced insect homogeneity and variety compared to other hosts. Furthermore, the *S. verticillata* host exhibited greater uniformity and diversity than other hosts.

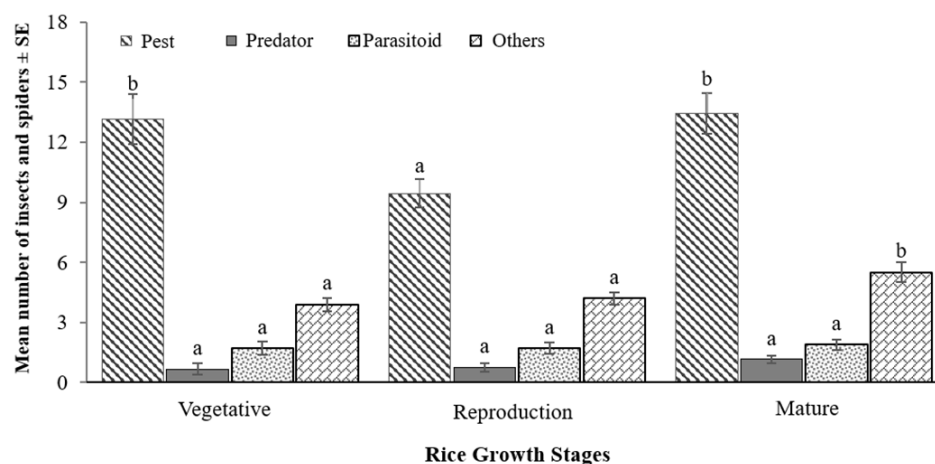


Figure 3. Mean number of insects and spiders $\pm$ Standard Error according to their categories (pests, predators, parasitoids and others) at different rice growth stages (vegetative, reproductive and mature). Mean of insects and spider categories with the same letter in each rice growth stage were not significantly different ($p > 0.05$).

Table 2. Ecological indices of insect abundance according to alternative hosts in Kampung Tengah Padang, Merlimau, Malacca, Malaysia.

Alternative Hosts	Species counts	Ecological Indices			
		D'	E'	R'	H'
<i>Ageratum conyzoides</i>	30	0.1676	0.3634	4.792	2.389
<i>Spermacoce verticillate</i>	26	0.1362	0.4542	4.293	2.469
<i>Euphorbia heterophylla</i>	31	0.1577	0.3629	5.005	2.42
<i>Chloris barbata</i>	27	0.1475	0.3803	4.476	2.329
<i>Oryza sativa</i>	25	0.2034	0.3149	3.667	2.063

[D'] Simpson diversity index, [E'] Uniformity index, [R'] Margalef richness index & [H'] Shannon-Wiener diversity index

Statistically, the H' index showed no significant differences ($df = 4;10$, $F = 0.444$, $P > 0.05$) across different phases of rice growth. However, the D' index exhibits an elevated value of 0.1676 during the vegetative stage, as indicated in Table 3. The breeding stage exhibits a low value of 0.147. This indicates the possibility of a narrower range of insect species being present during the vegetative stage, while a broader variety of species could be observed during the reproductive stage (Nur Aida et al., 2017). The vegetative stage exhibits the highest E' index value of 0.3413. Meanwhile, the lowest value, 0.3135, is reported at the mature stage. In general, insect species have a low homogeneity on both the rice plant's upper and lower parts. The most significant value of the R' index, 5.089, is observed during the mature stage. The minimum value occurs during the vegetative stage, at 4.416. The diversity of bug species is moderate in both growth phases of rice plants. The H' index indicates that the reproductive stage exhibits a higher diversity index of 2.443, whereas the vegetative stage has the lowest index value of 2.292. Overall, this study showed that the growth of rice plants during the reproductive and mature stages exhibited consistent patterns and a moderate level of species richness. The development of rice plants during the vegetative stage exhibited slightly consistent patterns and species richness.

Table 3. Ecological indices of insect abundance according to rice growth stage in Kampung Tengah Padang, Merlimau, Malacca, Malaysia.

Rice Growth Stage	Species count	Ecological Indices			
		D'	E'	R'	H'
Vegetative	29	0.1676	0.3413	4.416	2.292
Reproduction	34	0.147	0.3386	5.048	2.443
Mature	36	0.1486	0.3135	5.089	2.424

[D'] Simpson diversity index, [E'] Uniformity index, [R'] Margalef richness index & [H'] Shannon-Wiener diversity index

Correlation between selected alternative host plants with the abundance of arthropod species

The results of correlation analysis showed a strong relationship between alternative hosts and pests ($R^2 = 0.965$), predators ($R^2 = 0.758$), and others ($R^2 = 0.987$). In addition, a weak correlation between alternative hosts and parasitoids ($R^2 = 0.369$) is also observed. The pest showed a significant trend of population decrease in the hosts *A. conyzoides* ($\beta = -0.725$, $P = 0.040$) and *S. verticillata* ($\beta = -1.505$, $P = 0.034$). On the contrary, a considerable trend of increase is observed with the host *C. barbata* ($\beta = 1.854$, $P = 0.026$). Additionally, the role of other insect groups showed a significant increasing trend in the host *O. sativa* ($\beta = 0.752$, $P = 0.030$; Table 4). Insect predators and parasitoids did not show a population trend throughout the sampling period on all alternative hosts (Figure 4).

Table 4. Significance of population trends according to the role of insects on each alternative host in Kampung Tengah Padang, Merlimau, Malacca, Malaysia.

Alternative Host	Regression value	Role of Insect			
		Pest	Predator	Parasitoid	Others
<i>Ageratum conyzoides</i>	β coefficient	-0.725	-0.915	-1.631	-0.487
	p value	0.040 ^[1]	0.532	0.632	0.07
<i>Spermacoce verticillata</i>	β coefficient	-1.505	-1.443	1.575	-0.355
	p value	0.034 ^[1]	0.606	0.608	0.515
<i>Euphorbia heterophylla</i>	β coefficient	0.105	2.232	-0.003	0.154
	p value	0.532	0.384	0.999	0.561
<i>Chloris barbata</i>	β coefficient	1.854	4.965	0.758	0.797
	p value	0.026 ^[1]	0.48	0.567	0.051
<i>Oryza sativa</i>	β coefficient	0.173	1.776	0.403	0.752
	p value	0.127	0.388	0.868	0.030 ^[1]
	R^2 value	0.965	0.758	0.369	0.987
	F value	11.326	1.256	0.234	31.465

[1] Significant level at $\alpha=0.05$

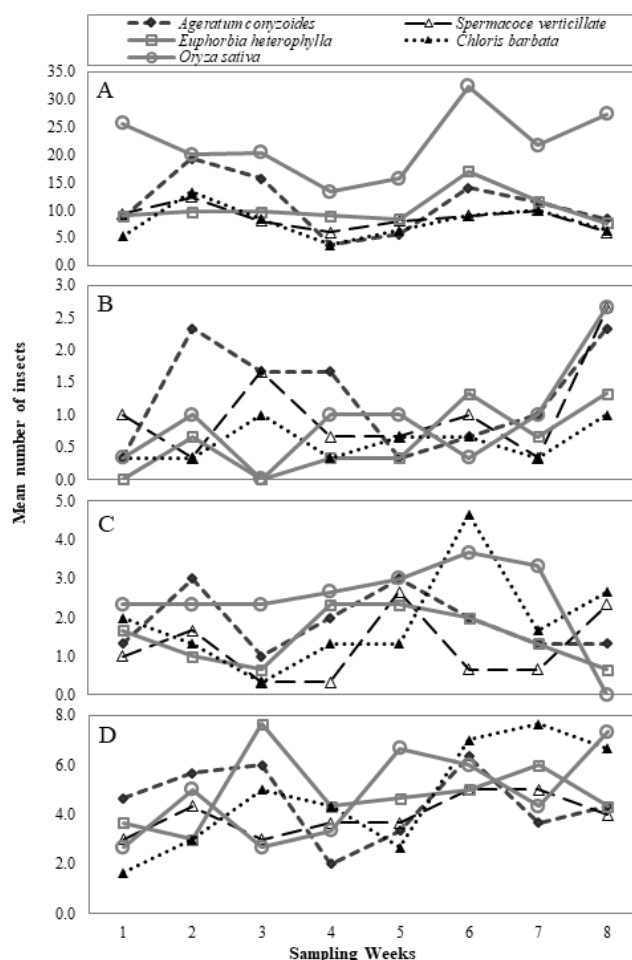


Figure 4. Arthropod population trends according to alternative hosts on insect categories (A) pests, (B) predators, (C) parasitoids, and (D) other insects.

Discussion

This study has revealed that the insect orders Hemiptera, Hymenoptera, and Diptera have the highest documented population sizes among all other orders, with 1,191, 369, and 268 total individuals, respectively. This finding aligns with prior research indicating that Hemiptera (Razali et al., 2015; Yaakop et al., 2022; Khalid et al., 2024), along with Lepidoptera (Sulaiman et al., 2013), exhibit a greater presence in Malaysian rice fields. Lepidoptera exhibited the greatest richness among the organisms studied, comprising 10 species. However, it is worth noting that *Chilo auricilius* Ddgn. was reported to be the most commonly found species in the study conducted by Yaakop et al. (2020). However, the research results may deviate from the actual perspective of species abundance due to climate change considerations that would impact the rice fields in Malaysia (Tang, 2019), influencing both species richness and abundance.

The two pest species with the largest population in this study were *S. furcifera* and *R. dorsalis*, both of which were found in every host examined in this investigation. *S. furcifera*, also known as the white-back planthopper, is a significant Asian rice pest (Li et al., 2016; Yaakop et al., 2022). On the other hand, *R. dorsalis* serves as the primary carrier for transmitting rice dwarf virus (RGDV), playing a significant role in agriculture (Chen et al., 2013). Therefore, understanding these interactions is crucial for developing strategies to control RGDV and protect rice crops from reduced output.

Arthropods were found to be more diverse and uniform on *S. verticillata* compared to other host species. The diversity of host plant species is an important factor in arthropod diversity, which provides more ecological niches to support a wider range of arthropod species (Jaworski et al., 2023). Diverse arthropod species can be promoted through the provision of diverse food resources, such as varied prey or host species. This suggests that having a variety of host plants can support more diverse arthropod communities (Schowalter, 2017; Jaworski et al., 2023). Engel et al. (2020) also found that alternative host plants, specifically *Eustachys retusa* K., *Andropogon bicornis* L., and *Saccharum angustifolium* N., play a significant role in supporting predatory arthropods in areas surrounding soybean-corn succession systems. The diversity and abundance of these predatory species are also influenced by environmental factors such as the clump diameter of the plants and air temperature during the off-season (Engel et al., 2020). Maintaining diverse plant habitats to enhance the presence of beneficial predatory arthropods is important, which contributes to sustainable pest management in agricultural settings. Integrating alternative host plants into farming practices could improve pest control and promote biodiversity within agroecosystems (Ebeling et al., 2018). Alternative host plants could also play a crucial role in maintaining arthropods when the main crops are absent.

Different growth stages of plants can attract various arthropod communities. Young plants may support different species compared to mature plants, influencing the overall diversity present at different times (Ali et al., 2022). The structural complexity of rice plants at different growth stages provides various niches for arthropods. For example, taller and denser vegetation during the vegetative and reproductive stages can support a wider array of species, including both pests and beneficial insects (Norazliza et al., 2014; Jauharlina et al., 2019). As rice plants grow, they produce different types of foliage and reproductive structures, which can attract a variety of arthropods. The flowering stage, in particular, is critical for pollinators and beneficial insects while also supporting pest species that may increase in number during this time.

The diversity of arthropods can also be affected by the presence of pest species that thrive during certain growth stages. For example, the reproductive stage often sees an increase in pest populations, which can influence the dynamics of predator-prey relationships and overall arthropod diversity in the ecosystem (Thei et al., 2020). The interactions between different arthropod species, including competition and predation, are influenced by the growth stage of the rice plants. This can lead to shifts in community composition, with some species thriving in certain stages while others decline (Ali et al., 2022).

Although there was a correlation between the alternative hosts with predatory insects and parasitoids, their effectiveness in doing so is relatively low compared to pest insects. The most frequently collected parasitoid species was *T. schoenobii*, which plays a significant role in the rice ecosystem by parasitizing the eggs of the stem borer, *S. incertulas* (Sitepu et al., 2018). Therefore, it can help manage insect populations and minimize damage to rice plants (Wilyus et al., 2012). However, in this study, *T. schoenobii* has shown a non-significant correlation among the tested alternative hosts. *T. schoenobii* has been observed to be attracted to certain types of flowering plants, including *Tagetes erecta* L. This attraction is probably triggered by specific chemicals found in plant extracts, such as benzaldehyde, limonene, linalool, and phenylacetaldehyde (Sharma et al., 2019). Alternative hosts may provide essential resources, such as nectar and pollen, which support beneficial insects like pollinators and natural enemies of pests. This can enhance the overall balance of the ecosystem. The attraction of insects to weeds can also lead to increased biodiversity within agricultural ecosystems (Kleiman & Koptur, 2023). While alternative hosts can attract beneficial insects, they may also attract pest species. This dual role suggests that managing weed populations carefully is essential for maximizing benefits while minimizing potential drawbacks, such as increased pest pressure (Madden et al., 2021). For example, specific chemicals like methyl salicylate and other fatty acids have been shown to lure natural enemies and pests alike, indicating that the chemical composition of weeds can influence the diversity and abundance of insect populations in agricultural settings (Jakubská-Busse et al., 2023).

Micraspis discolor is a prominent predator that plays a vital role in managing harmful organisms and minimizing crop damage. Its presence and distribution in paddy fields fluctuate throughout various stages of rice growth. For instance, Mukherjee and Khan (2017) revealed that the population of *M. discolor* peaked during the rice growth stage, aligning with optimal harvest conditions. Although their population trend showed an overall increase during the planting season, there was no significant difference, with slightly higher numbers observed during the mature stage. This species tends to emerge later in rice fields, likely influenced by factors such as food availability. In the early growth stages, when pest populations are generally lower, *M. discolor* may not be as abundant. However, as pest populations surge, especially during the reproductive phase of rice, *M. discolor* populations also rise in response to increased food resources. Similar observations have been reported by several researchers, who suggest that the presence and behavior of these beetles are influenced by prey availability and suitable habitats during specific phases of rice cultivation (Woïin et al., 2006; Yudha et al., 2022). *M. discolor* is particularly effective at preying on aphids such as *Aphis fabae* Scopoli and *Aphis craccivora* Koch, which are commonly found in crops (Islam et al., 2016; Rain et al., 2016). However, it is noteworthy that during the flowering period, the abundance of adult *M. discolor* may indicate a preference for pollen consumption over entomophagy (Chitra et al., 2013).

Plants use a combination of floral scents, colors, and nectar rewards to attract insects (Garbuzov & Ratnieks, 2013). Plants produce several volatile organic compounds in their flowers that act as semiochemicals, mediating interactions with insects (Kong et al., 2005; Bouwmeester et al., 2019). Certain colors are particularly attractive to specific insect pollinators. Nectar, which is mainly composed of sugars, amino acids, lipids, and sometimes toxins, serves as a crucial factor in attracting insects to flowers (Jakubská-Busse et al., 2023). The study suggests that *S. verticillata* blooms have a significant capacity to attract insects, as evidenced by the increased uniformity and diversity observed in the *S. verticillata* compared to other hosts. Furthermore, Procheş et al. (2009) suggested a positive association between the diversity of plant phylogeny, the number of plant genera in each area, and the diversity of insect species.

The population of insect species is higher during the reproductive and mature stages of rice growth. This could be due to the many seedlings and a larger canopy area compared to the vegetative stage. Multiple studies have supported this finding, particularly in the Hemiptera species (Yaakop et al., 2022). Similar patterns have been observed in rice stem borer caterpillars (Lepidoptera; Yaakop et al., 2020), as well as in paddy areas implementing the System of Rice Intensification (SRI) for rice cultivation (Sulaiman et al., 2013). Bambaradeniya et al. (2004) also noted that variations in the richness and abundance of these species result from differences in the phenology of rice growth. This is influenced by variations in the fertilizer used, water level, and insecticide application. According to (Su et al. 2015), the Hemiptera species have abundant food supplies and exhibit the greatest abundance during the mature stage of the rice plant.

This study found a strong correlation between pests, predators, and other insects with alternative hosts. These findings indicate that alternative hosts have specific preferences for insects, probably serving as reliable food sources and providing protection from adverse weather conditions (Afun et al., 1999). Kohli et al. (2006) reported that *A. conyzoides* exhibited rapid growth, a short life cycle, significant reproductive capacity, and strong competitive ability. These characteristics make it an ideal alternative host for insects, especially pests. *A. conyzoides* grows quickly and completes its life cycle in a short period. The short life cycle coupled with high reproductive capacity means that *A. conyzoides* can produce numerous seeds in a short time, allowing it to spread rapidly and colonize large areas, further intensifying competition. With continuous seed production, this weed can maintain a persistent presence in agricultural fields, requiring consistent and costly management efforts (Kaur et al., 2023). Additionally, *A. conyzoides* might also attract natural enemies of pests, potentially aiding in biological control. However, this benefit depends on the specific ecological interactions and the management practices in place (Rioba & Stevenson, 2017).

On the contrary, *A. conyzoides* can harbor insect pests, providing them with a continuous food source and habitat, especially during periods when rice is not in its most vulnerable stages. This can lead to a buildup of pest populations that may subsequently move to rice plants, causing damage and potentially reducing yields if not managed properly (Kaur et al., 2023). However, this investigation showed a significant decline in the pest population of *A. conyzoides* and *S. verticillata* hosts. It is likely that while rice plants are growing and able to provide ample food and protection from favorable weather conditions, most pests have shifted their focus to rice plants. This has resulted in a decrease in insect pests on *A. conyzoides*, as confirmed by the sampling conducted in this study. The host plant *S. verticillata* is more attractive to parasitoids (Portman et al., 2010) than to insect pests because it releases nectar, which serves as a food supply for the parasitoids. Parasitoids have indirectly contributed to reducing pests on alternative hosts of *S. verticillata*. However, the observed trend of parasitoids was not statistically significant.

It has been observed that parasitoids have a limited association with alternative hosts when the number of individuals on those hosts is low. Previous research has indicated that *S. verticillata* is the main source of nectar for parasitoids, particularly the *L. bicolor* species, compared to other native plants such as *Spermacoce remota* Lamarck or *Spermacoce prostrata* Aubl. The abundance of immature wasps parasitizing mole crickets was found to increase with host density but decrease with distance from *S. verticillata* plots. The findings also imply that establishing patches of *S. verticillata* at least 400 m apart could potentially help reduce mole cricket populations when *L. bicolor* wasps are present in the area (Portman et al., 2010). On the other hand, this study has shown that *S. verticillata* does not appear as a preferred host plant for a wide variety of parasitoid species. The absence of parasitoid species in this study can be attributed to the lack of nectar sources provided by alternative hosts for adult parasitoids. During the adult phase, predators and parasitoids frequently consume nectar from plant blossoms. Therefore, the presence of plant food (such as nectar) enhances survival and also other parameters that contribute to increasing its intrinsic growth rate (r_m ; Russell, 1989; Capinera, 2005). This would serve as a food source and alternative habitat for parasitoids and other biological control agents, consequently increasing their population (Ali et al., 2019, 2021). This ecological engineering approach is highly effective in promoting the implementation of Integrated Pest Management (IPM) on rice crops, which is known for its ecologically friendly and sustainable practices (Badrulhadza et al., 2018).

Conclusion

The specific alternative hosts displayed higher levels of consistency and variety in the arthropod population inside the rice farming environment. Although it has the potential to improve insect control and soil quality, its invasive characteristics and toxicity necessitate cautious evaluation. Efficient management strategies and more research are crucial for optimizing the benefits and minimizing the drawbacks of rice cultivation. Alternative hosts possess the ability to rapidly develop, reproduce, and compete, enabling them to outperform rice growth in agricultural areas by acquiring vital resources. Additionally, they can also facilitate the rapid growth of arthropod populations that may subsequently target rice and cause harm to crops. The growth of rice plants and the diversity of arthropods have a significant impact on ecological interactions, ecosystem services, and the composition of arthropod populations in different contexts. Comprehending the impact of different stages of plant growth on the diversity of arthropods is essential for developing efficient strategies for managing pests. Farmers could synchronize their actions, such as applying pesticides, with stages of growth in order to reduce the negative impact on helpful arthropods and improve the effectiveness of natural pest control methods. Thus, it is recommended to promote these naturally growing alternative host plants as well as cultivating different types of nectar-rich plants, such as *T. erecta* (marigold), *Cosmos* sp. (cosmos), *Helianthus annuus* L. (sunflower), and *Sesamum indicum* L. (sesame), along the banks and borders of rice farming areas to encourage the presence of indigenous predatory insects. This aligns with the objectives specified in the Integrated Pest Management (IPM) approach, which is currently being embraced by rice producers.

Acknowledgements: We would like to express our deep gratitude to Mr. Rahmat bin Kamisan and the other rice farmers in Kampung Tengah Padang, Merlimau, Melaka, Malaysia for their invaluable assistance in logistics and data collection for this project.

Competing interests: The authors have declared that no competing interests exist.

Authors' contributions: **Fairuz Khalid:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft. **Che Nor Fahadaina Che Ismail:** Investigation, Methodology, Visualization, Writing – original draft. **Abd-Ghani Idris:** Conceptualization: Investigation, Methodology, Project administration, Supervision, Writing – original draft. **Ismail Rakibe:** Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Muhamad Azmi Mohammed:** Writing – review & editing. **Salmah Yaakop:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing – original draft.

Funding: The authors received no specific funding for this work.

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