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Variations in the Relative Abundance of Hemipteran Species in Different Seasons and Stages of Rice Growth Depending on Weather Variations

Fairuz Khalid[a,b], Noor Shuhaina Shaikh Mazran[b], Ismail Rakibe[b], Muhamad Azmi Mohammed[c], Ameyra Aman-Zuki[c], Salmah Yaakop[a*]

[a]*Centre for Insect Systematics, Department of Biological Science and Biotechnology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, MALAYSIA*

[b]*Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Melaka Branch, Jasin Campus, 77300 Merlimau, Melaka, MALAYSIA*

[c]*Department of Crop Science, Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, 97008 Bintulu, Sarawak, MALAYSIA*

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Corresponding Author: Salmah Yaakop, E-mail: salmah78@ukm.edu.my
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ABSTRACT
Rompin has played an active role in Malaysia's rice production for several decades. However, rice production faces a threat, particularly from the hemipteran insect pests. There is limited documentation on the abundance of these insects and their relationship with weather factors. Therefore, this study aimed to determine the abundance of hemipterans in different growth stages and to understand the effects of weather factors on their population in rice fields. The study was conducted in farmers' rice fields in Rompin, Pahang, Malaysia, during the main and off-season rice planting. Sweep nets, yellow sticky traps, and yellow pan traps were utilized in each plot. Trapped insects were identified based on the rice planting seasons and growth stages. The trends of weather factors such as rainfall, temperature, light intensity, and wind speed were analysed and correlated with insect abundance. A total of 23 023 individuals belonging to six families and eleven species of the hemipteran order were recorded. Nine of these species were pests, namely *Leptocorisa oratorius* (Fabricius) (2.05%), *Maiestas dorsalis* (Motschulsky) (41.93%), *Nephotettix virescens* (Distant) (1.52%), *Nephotettix nigropictus* (Stål) (0.03%), *Scotinophara* sp. (4.92%), *Nilaparvata lugens* (Stål) (28.18%), *Sogatella furcifera* (Horváth) (17.75%), *Nezara viridula* (Linnaeus) (0.01%) and *Scotinophara coarctata* (Fabricius) (2.88%). The other two species were predators, *Cyrtorhinus lividipennis* (Reuter) (0.55%) and *Polytoxus fuscovittatus* (Stål) (0.19%). *Maiestas dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp. were found in significantly (df=10, F=5.707, P<0.01) higher numbers and exceptionally high during rice's late vegetative and early reproductive stages. The maximum temperature significantly ($R^2>0.5$ & $P<0.05$) increased during the main season, while wind speed increased significantly ($R^2>0.5$ & $P<0.05$) during the off-season. Wind speed significantly positive correlated ($r>0.5$ & $P<0.05$) with *N. virescens*, *S. furcifera*, *L. oratorius*, and *Scotinophara* sp. On the other hand, rainfall exhibited a significant negative correlation ($r>-0.5$ & $P<0.05$) with *L. oratorius*. Various pest species and their high populations in this study pose a significant threat to plants due to their preferences for different plant parts and strata.

Keywords: Hemiptera, Pest, Trap, Rice growth stage, Weather factors

1. Introduction

In 2021, Malaysia's total rice planted area was 647 859 hectares, which resulted in a total production of 2 428 893 tons (DOA 2022a). Specifically in Pahang state, the rice production amounted to 37 817 tons planted on 13 497 hectares of land (DOA 2022b). Pahang state ranked tenth among the 14 granary areas in Malaysia, with an average rice production of 2 802 kg/ha (DOA 2022). To ensure a sufficient supply of this essential food, the Rompin granary area has consistently played a significant role in rice production activities within Pahang state. In Rompin, rice was cultivated across a total area of 5 272 hectares, resulting in a production of 24 306 tons in 2021 with an average rice yield of 4 610 kg/ha (DOA 2022). However, similar to other rice planting areas, Rompin faces the threat of insect pests, particularly those from the hemipteran order. Hashim et al. (2017) discovered that in Penang, Hemipterans were the most prevalent throughout the night, with *Nilaparvata lugens* from the Delphacidae family being the most abundant. The study conducted by Razali et al. (2015) found that Tanjong Karang, Selangor likewise exhibited a high prevalence of hemipteran insects.

Hemiptera, also known as true bugs, is an insect order distinguished by their specialised mouthparts adapted for piercing and sucking. This group encompasses a wide range of insects, including planthoppers (Delphacidae), leafhoppers (Cicadellidae), broad-headed bugs (Alydidae), and seed bugs (Lygaeidae) (Schuh & Slater 1995; Duman & Mutlu 2019; Mutlu et al. 2016; Win et al. 2011; Abdullah et al. 2017). Hemipterans generally possess two sets of wings, with the forewings frequently exhibiting partial hardening. They can be located in a wide range of habitats, spanning from land-based to water-based ecosystems. Hemipterans have important ecological roles as herbivores, predators, and occasional parasites. Certain organisms, such as aphids, are detrimental to agriculture, whilst others serve as advantageous predators that regulate pest populations. Due to their wide range of species and capacity to adjust to different environments, insects are an essential group in various ecosystems (Moir & Brennan 2007). Planthoppers are small insects that can harm rice crops by feeding on plant sap and spreading plant pathogens like viruses. Two species that are often found in rice fields are the brown planthopper, *Nilaparvata lugens* (Heong & Hardy 2009), and the white-backed planthopper, *Sogatella furcifera* (Zhou et al. 2008). When their population is high, *N. lugens* can cause "hopper burn" resulting in a 70% loss in yield (Krishnaiah et al. 2008). Rice leafhoppers, like the green leafhopper, *Nephotettix* spp., also feed on sap and can transmit Rice Tungro Baciliform Virus (RTBV) and Rice Tungro Spherical Virus (RTSV) (Dai & Beachy 2009). Rice stink bugs, such as *Leptocorisa* spp., feed on rice plants by piercing and sucking sap from the stems, leaves, and developing grains (Jauharlina et al. 2019). Rice seed bugs, on the other hand, feed on developing rice grains, potentially causing damage to the crop (Abdullah et al. 2017). While some hemipterans are considered pests in agriculture, others play important roles as pollinators or predators of other insects (Johnson & Triplehorn 2020).

Apart from pest insects, there are also predator insects from the hemipteran order, specifically the mirid bugs (Miridae). An example of a beneficial insect is *Cyrtorhinus lividipennis*, which feeds on rice pests like planthoppers and leafhoppers (Xiao et al. 2014). In addition to these terrestrial insects, there are a few aquatic species predators that can be found in rice fields, such as water striders (Gerridae), water scorpions (Nepidae), and backswimmers (Notonectidae). These insects are commonly found on the water surface of rice fields and they prey on smaller insects and aquatic organisms, thus helping to control pest populations. However, water boatmen (Corixidae) are herbivorous insects and feed on algae and aquatic plants (Shepard et al. 1987).

However, currently there is limited information available regarding the abundance of hemipterans and how weather factors influence their populations in Rompin's rice fields. Thus, the main goal of this study were to i) collect data on the population and distribution of hemipterans during different growth stages of rice plants, and ii) examine the relationship of weather factors on the population of hemipterans in the rice fields of Rompin, Pahang, Malaysia.

2. Material and Methods

2.1. Location and duration of study

The study was conducted in Kampung Paya Laka, Rompin, Pahang, Malaysia, which is a rice granary area (GPS coordinates: 103.384378 N, 2.799604 E), as shown in Figure 1. In Malaysia there are two rice planting seasons practiced by the farmers which were the main season and the off-season.

The main season is the optimal period for rice cultivation based on local climate conditions (rainy season) and does not rely heavily on irrigation systems. The main season is defined as the period during which rice is planted, with planting dates falling between August 1st and February 28th/29th of the following year. The off-season however, corresponds to the dry period when rice cultivation typically depends on irrigation systems (dry season). The off-season is defined as the period during which rice is planted, with planting dates falling between March 1st and July 31st of the current year (DOA 2022b). This study covered both main season (August 2017 to February 2018) and off-season (March to July 2018). The MR269 variety was cultivated by the farmers in Rompin, Pahang in both seasons. This variety is well-suited for cultivation throughout various granary regions in Malaysia. The crop reaches maturity between 104 and 109 days after planting, and the height of the plant ranges from 72 to 83 cm. It has the potential to yield 9.2 tonnes per hectare (DOA 2022b).

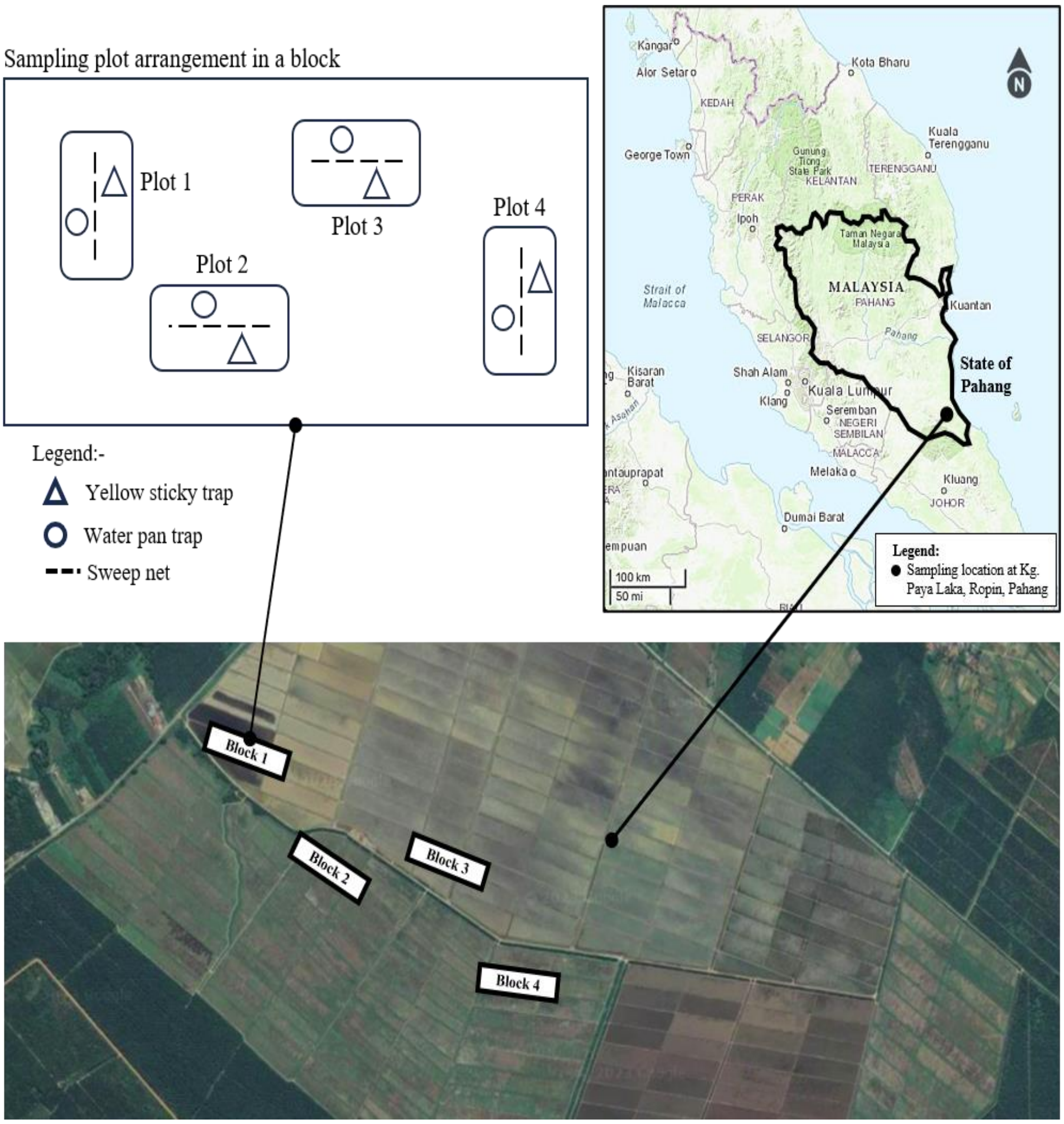

Figure 1- Location of study and sampling plot layout in Kampung Paya Laka, Rompin, Pahang, Malaysia

2.2. Insect sampling

Insect sampling in the main season was done starting from the 20th August 2017 until 29th October 2017 while the sampling during the off-season were commenced from 17th March 2018 until 26th May 2018. The sampling was conducted in the farmers' existing rice fields, with a block size of 1.2 hectares. The sampling consisted of four rice blocks, each containing four sampling plots. Each sampling plot had one yellow sticky trap and one yellow tray trap installed in each sampling plot. Sweep nets were also applied to each sampling plot based on the transect line. This resulted in four replications for each rice block.

Yellow stick traps were made from two-sided sticky plastic sheets (20 cm × 25 cm), which were mounted on a pole stand at the height of the rice plant canopy. The height of the yellow sticky traps was adjusted every sampling week based on the height of the rice plant. Yellow tray traps, on the other hand, were made of a 30 cm diameter by 10 cm deep plastic tray. They were filled with approximately 250 mL of detergent solution to allow arriving samples to sink. Yellow tray traps were set in open areas so that insects could clearly notice them. In terms of the yellow hue, both sticky and tray traps were referred to the *Reichs-Ausschuss für Lieferbedingungen* (RAL) CLASSIC colour collection system. The closest match between the RAL codes for yellow sticky and yellow tray trap was found to be 1026 (limunous yellow). Sticky and tray traps were replaced weekly, and the old ones were brought to the laboratory for counting. Observations using the tray trap were made once a week. The sweep net measures 38 cm in diameter, 50 cm in depth, and has a handle length of 1 metre. The sweep nets were swung in each plot to collect actively flying insects using a zig-zag pattern along a 10-meter transect (Figure 1) with 10 swings (one swing per meter). The action of sweeping was performed at the level of the plant canopy (Masika et al. 2017). Preventive measures were taken to avoid disturbing the rice flower and fruits while collecting samples. Data were collected for 11 consecutive weeks, starting two weeks after transplanting, with a seven-day interval between each collection. The field collection time began as early as 07.00 hours, due to the insects' active behaviour during that time (Kritsky & Young 2011).

2.3. Species identification and identification of role

Insect counting was conducted for each trap and insects were identified up to the species level using their external morphological characteristics (Elzinga 2004; Gullan & Cranston 2014; Johnson & Triplehorn 2020). The role of species in rice fields was determined whether they were categorised as pests, predators, or parasites. These characteristics were based on earlier research on the species' behaviour towards rice plants and other insects (Wilson & Claridge 1991; Heinrichs 2004; Pathak & Khan 1994; Reissig 1985; Shepard et al. 1987; Shepard et al. 1995).

2.4. Weather data

The weather data used in this study included rainfall (mm), temperature (°C), sunshine (hours), and wind speed (km/h). These data were obtained from the Meteorological Department of Malaysia (MET Malaysia). The daily data was averaged for each sampling date, the weather data were then plotted by sampling week basis according to each planting seasons using clustered column-line charts.

2.5. Data analysis

The number of individual insects during different planting seasons was determined using an independent Student's t-test. Meanwhile, the differences in rice growth stages between species were determined using ANOVA. Additionally, ANOVA was used to analyse the differences in the number of species during each planting season. Subsequently, any significant results were subjected to Tukey's Honestly Significant Difference (HSD) for multiple pairwise comparisons (Clewer & Scarisbrick 2001). The trend of each weather factor was determined using the coefficients a, b, R^2, and P from the regression analysis. An R^2 value greater than 0.5 was considered to indicate a significant increasing or decreasing trend at $P<0.05$. On the other hand, significant relationships between hemipteran species and weather factors were evaluated using Pearson's correlation. A Pearson's coefficient value, r greater than 0.6 at $P<0.05$, was considered to indicate a significant relationship (Southwood 2013). Results were analysed for overall data of insects from each plot in each planting season. However, the results presented in this study did not differentiate the number of insects collected between traps. All analyses were performed using IBM-SPSS version 22.

3. Results

A total of 11 species from six families of the hemipteran order were recorded during this study, conducted over two seasons of rice planting. Among these species, nine were pests and two were predators. The nine pest species identified were *Leptocorisa oratorius*, *Maiestas dorsalis*, *Nephotettix virescens*, *N. nigropictus*, *Scotinophara* sp., *Nilaparvata lugens*, *Sogatella furcifera*, *Nezara viridula*, and *Scotinophara coarctata*. The two predator species were *Cyrtorhinus lividipennis* and *Polytoxus fuscovittatus*. The four species with significantly higher numbers were *M. dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp., as shown in Table 1. This study also found significant differences in the number of individuals (df=10, F=5.707, $P<0.01$) among the hemipteran species. In Rompin, the species with significantly higher numbers were *M. dorsalis*, with 9654 individuals, followed by *N. lugens*, *S. furcifera*, and *Scotinophara* sp., with 6488, 4087, and 1132 individuals, respectively.

In terms of species abundance between planting seasons, the study showed a significant result for *L. oratorius* (df=10, t=-2.536 & P=0.020). It was found to be significantly higher during the off-season planting, with 396 individuals collected compared to 75 in the main season (Table 2). The rest of the hemipteran species were found to be insignificant between the main and off-seasons.

The weekly abundance of insects during the main season demonstrated significant differences (df=10; F=17.325 & P=0.0016) in the number of individuals among the collected species. Specifically, *N. lugens* (4605 individuals), *M. dorsalis* (6226 individuals), and *S. furcifera* (2609 individuals) were significantly more abundant in the third to fifth week of sampling. In contrast, during the off-season, there was a notable difference (df=10; F=8.112 & P=0.0048) in the number of insect individuals among Hemiptera species. Once again, *N. lugens* (1883 individuals), *M. dorsalis* (3428 individuals), and *S. furcifera* (1478 individuals) were significantly higher in the third to sixth week of sampling. Both planting seasons exhibited a surge in population during the late vegetative and early reproductive growth stages. Following this, the population of Hemipterans declined and remained relatively steady during the mature growth stage of rice (Figure 2).

Table 1 - The total number of hemipteran species collected according to different role of insect in both seasons of rice planting at Rompin, Pahang

No.	*Type*	*Family*	*Species*	*Common name*	*Total**
1	Pest	Alydidae	*Leptocorisa oratorius*	Slender rice bug	471 a
2		Cicadellidae	*Maiestas dorsalis*	Zig-zag winged rice leafhopper	9654 **c**
3			*Nephotettix virescens*	Green paddy leafhopper	349 a
4			*Nephotettix nigropictus*	Rice green leafhopper	7 a
5		Delphacidae	*Nilaparvata lugens*	Brown planthopper	6488**bc**
6			*Sogatella furcifera*	White-backed planthopper	4087**ab**
7		Pentatomidae	*Scotinophara* sp.	Rice bug	1132**ab**
8			*Nezara viridula*	Southern green stink bug	2 a
9			*Scotinophara coarctata*	Black rice bug	662 a
10	Predator	Miridae	*Cyrtorhinus lividipennis*	Plant bug	127 a
11		Reduviidae	*Polytoxus fuscovittatus*	Assassin bugs	44 a
				Total	23023

*: Same letter within this column was not significantly different at 0.05 confidence level

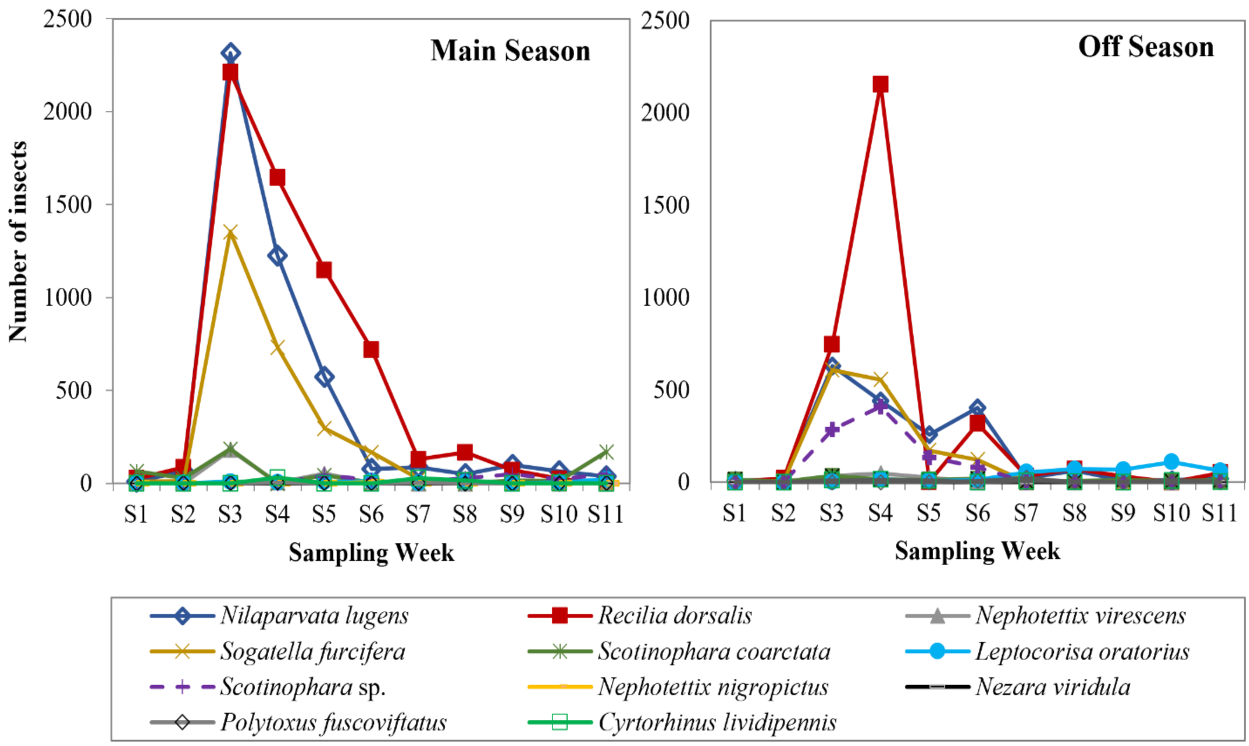

Figure 2 - Population of hemipterans species collected according to different rice growth stages during eleven sampling weeks in the main season (20th August 2017 - 29th October 2017) and off-season (17th March 2018 - 26th May 2018) of rice planting in Rompin, Pahang

The population of *Scotinophara* sp. was significantly lower in the vegetative stage, but significantly higher in the mature stage during the main season (df=2; F=5.175 & P=0.036) (Table 3). On the other hand, the population of *P. fuscovittatus* was significantly higher in the reproductive stage but significantly lower in the mature stage during the same season (df=2; F=6.994 & P=0.018) (Table 3). In the off-season, however, *L. oratorius* was significantly lower in the vegetative and reproductive stages but significantly higher in the mature stage (df=2; F=16.015 & P=0.002) (Table 3). Other insect species in this study were found not significant between main and off-seasons.

Table 2 - Total number of hemipterans species collected in main and off seasons of rice planting at Rompin, Pahang

Category	*Family*	*Species*	*Main Season*	*Off-Season*	*t (Sig.) value*
Pest	Alydidae	*Leptocorisa oratorius*	75	396	-2.536 (0.020)*
	Cicadellidae	*Maiestas dorsalis*	6226	3428	0.835 (0.414)
		Nephotettix virescens	238	111	0.666 (0.513)
		Nephotettix nigropictus	7	0	1.000 (0.329)
	Delphacidae	*Nilaparvata lugens*	4605	1883	1.078 (0.294)
		Sogatella furcifera	2609	1478	0.697 (0.494)
	Pentatomidae	*Scotinophara* sp.	218	914	-1.481 (0.154)
		Nezara viridula	2	0	1.000 (0.329)
		Scotinophara coarctata	526	136	1.738 (0.098)
Predator	Miridae	*Cyrtorhinus lividipennis*	76	51	0.578 (0.570)
	Reduviidae	*Polytoxus fuscovittatus*	13	31	-0.761 (0.456)

Note. * = P<0.05

The Figure 3 illustrates the weekly pattern and distribution of rainfall in the study area of Rompin. It was observed that the fifth sampling week (S6) experienced the highest average rainfall, measuring 148.6 mm, during the main planting season. Conversely, the lowest average rainfall of only 1.2 mm was recorded in the tenth sampling week (S10). Moreover, the third sampling week (S3) had the lowest minimum temperature, measuring 22.44 °C, whereas the highest maximum temperature, reaching 34.24 °C, was observed in the eighth sampling week (S8). Additionally, the tenth sampling week (S10) had the highest recorded average maximum sunlight hours of 7.74 hours, whereas the seventh sampling week (S7) had the lowest average minimum sunlight hours of 3.45 hours. Furthermore, the highest wind speed recorded was 3.05 km/h in the tenth sampling week (S10), while the lowest wind speed of 0.93 km/h was observed in the seventh sampling week (S7).

Table 3 - Mean number (± S.E) of hemipterans species collected in different growth stages of rice during the main and off-season

Species	*Main Season*			*Off-Season*		
	*V**	*R**	*M**	*V*	*R*	*M*
Leptocorisa oratorius	4.3 ± 2.8 a	6.7 ± 2.5 a	8.7 ± 4.2 a	0.3 ± 0.3 a	21.7 ± 10.8 a	77.0 ± 10.8 b
Recilia dorsalis	774.6 ± 718.8 a	910.2 ± 321.7 a	65.2 ± 36.5 a	256.6 ± 244.7 a	626.7 ± 514.3 a	37.7 ± 14.8 a
Nephotettix virescens	60.0 ± 60.0 a	14.5 ± 12.8 a	0.0 ± 0.0 a	11.6 ± 11.6 a	18.0 ± 11.4 a	1.0 ± 1.0 a
Scotinophara sp.	0.3 ± 0.3 a	17.2 ± 9.6 ab	37.0 ± 7.6 b	95.0 ± 95.0 a	156.2 ± 88.3 a	1.0 ± 1.0 a
Nilaparvata lugens	796.6 ± 759.3 a	491.2 ± 270.6 a	62.5 ± 12.9 a	218.3 ± 205.8 a	280.7 ± 94.4 a	26.2 ± 12.0 a
Sogatella furcifera	458.6 ± 447.6 a	305.0 ± 153.0 a	3.2 ± 3.2 a	207.3 ± 200.3 a	212.5 ± 120.0 a	1.5 ± 1.5 a
Scotinophara coarctata	92.3 ± 47.0 a	12.0 ± 10.3 a	50.2 ± 40.0 a	16.6 ± 9.1 a	13.0 ± 3.4 a	8.5 ± 2.0 a
Cyrtorhinus lividipennis	0.0 ± 0.0 a	14.7 ± 8.5 a	4.2 ± 3.9 a	3.3 ± 3.3 a	6.7 ± 2.6 a	3.5 ± 1.9 a
Polytoxus fuscoviftatus	0.6 ± 0.3 ab	2.5 ± 0.6 b	0.2 ± 0.2 a	0.0 ± 0.0 a	7.5 ± 5.4 a	0.2 ± 0.2 a
Nephotettix nigropictus	0.0 ± 0.0 a	1.7 ± 1.7 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
Nezara viridula	0.0 ± 0.0 a	0.0 ± 0.0 a	0.5 ± 0.5 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a

Note. Row with the same letter was not significantly different at 0.05 confidence level.

In contrast, the weather conditions during the off-season for rice cultivation in Rompin showed that the highest average rainfall was recorded in the seventh sampling week (S7) with 98.6 mm, while the lowest average rainfall was in the second sampling week (S2) with only 2.1 mm. The lowest minimum temperature was 21.51 °C, recorded in the third sampling week (S3), while the highest maximum temperature was reached in the third week (S3) at 33.73 °C. The highest recorded average sunshine hours was 7.6 hours in the tenth sampling week (S10), while the lowest average minimum sunshine hours were 2.75 hours in the seventh sampling week (S7). On the other hand, wind speed recorded its highest value of 2.72 km/h in the fourth sampling week (S4), while the lowest wind speed was 1.17 km/h in the seventh sampling week (S7).

During the main planting season, the study identified a significant positive trend in maximum temperature throughout the sampling weeks (Table 4), with an R^2 value of 0.534 and a significance level of $P<0.05$. In contrast, during the off-season, wind speed showed a significant trend with an R^2 value of 0.628 and a significance level of $P<0.01$. The study revealed a significant trend in wind speed, with an R^2 value of 0.628 and a significance level of $P<0.01$. However, no other weather factors showed significant trends within the sampling weeks.

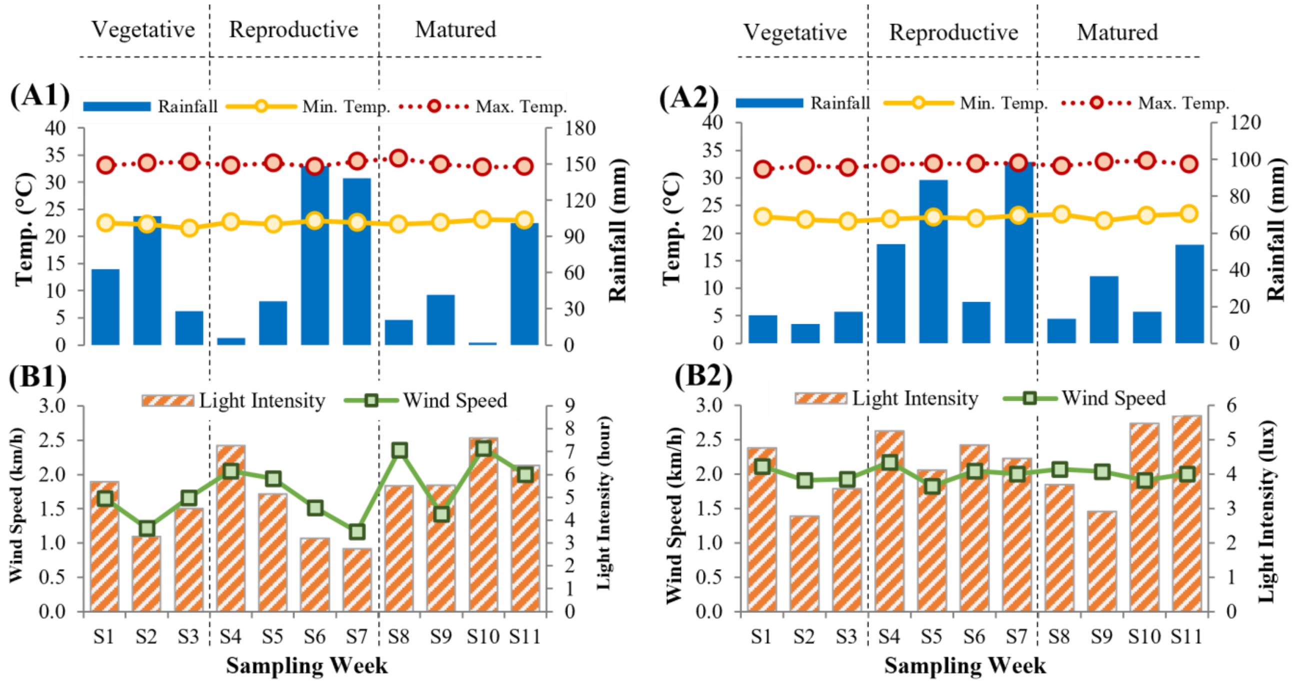

Figure 3 - Weather pattern in Rompin, Pahang, according to different rice growth stages. (A1) Rainfall, minimum and maximum temperature in the main planting season. (A2) Rainfall, minimum and maximum temperature in the off-season of planting. (B1) Light intensity and wind speed in the main planting season. (B2) Light intensity and wind speed in the off-season of planting

There was no statistically significant correlation between the hemipteran species and weather factors during the main planting season in Rompin (Table 5). Notably, a significant negative correlation (r=-0.655 & P=0.029) was observed between rainfall and *L. oratorius*. Additionally, wind speed exhibited substantial positive correlations with several species, including *N. virescens* (r=0.610 & P=0.046), *S. furcifera* (r=0.696 & P=0.017), *L. oratorius* (r=-0.709 & P=0.015), and *Scotinophara* sp. (r=0.614 & P=0.045) (Table 6).

4. Discussions

The insect species composition in Rompin fluctuates at any given time and depends on several factors, such as rice varieties, field management practices, the use of chemical pesticides, water quality, and weather conditions (Luo et al. 2014; Norazliza et al. 2014). This study found significantly higher populations of the following species: *Maiestas dorsalis*, *Nilaparvata lugens*, *Sogatella furcifera*, and *Scotinophara* sp. Similar species ranges have also been observed in other locations, as reported by various researchers (Abdul Hakim et al. 2013; Hegazy et al. 2021; Jauharlina et al. 2019; Jayanthi & Bambaradeniya 2006; Mariana et al. 2009; Norela et al. 2013; Yaakop et al. 2022). This probably due to favourable weather condition. Warm temperatures and high humidity during certain seasons which created an ideal condition for these pests to thrive. These conditions may also can accelerate their reproductive cycles and increase survival rates (Ahmed et al. 2013). On the other aspect, continuous monoculture of rice provides a stable and abundant food source for these pests, facilitating their population growth (Mir et al. 2022). The use of broad-spectrum insecticides can reduce populations of natural predators and parasitoids that help control these pests. Overreliance on chemical pesticides can lead to the development of resistance among pest populations, reducing the effectiveness of control measures (Gurr 2009).

Table 4 - Regression coefficient for weather factors trend analysis in Rompin, Pahang

Planting Season	*Weather Factors*	*Regression coefficient*		
		R^2	*Slope (x)*	*P value*
Main Season	Rainfall (mm)	0.039	1.862	0.560
	Min. temperature (°C)	0.250	0.070	0.118
	Max. temperature (°C)	0.534	0.101	0.011*
	Light intensity (Lux)	0.103	0.096	0.335
	Wind speed (km/h)	0.002	-0.002	0.884
Off-Season	Rainfall (mm)	0.143	-3.531	0.252
	Min. temperature (°C)	0.138	0.046	0.261
	Max. temperature (°C)	0.012	-0.020	0.751
	Light intensity (Lux)	0.043	-0.064	0.539
	Wind speed (km/h)	0.628	-0.102	0.004**

Note. *= P<0.05, **= P<0.01

These pest insects are highly dangerous because they can spread viruses. Wei et al. (2018) identified four species of leafhoppers (*Nephotettix cincticeps*, *N. nigropictus*, *N. virescens*, and *M. dorsalis*) and three species of planthoppers (*Laodelphax striatellus*, *N. lugens*, and *S. furcifera*) as vectors of major viral diseases in rice plants. Therefore, it is crucial to pay more attention to the presence of these species and take early steps to control their populations during the initial stages of planting. The high incidence of these pests in rice fields poses a threat to the production of high-quality rice.

The study found that the population of pest species peaked during the late vegetative and early reproductive growth stages for both planting seasons. This was especially true for species such as *M. dorsalis*, *N. lugens*, *S. furcifera*, and *Scotinophara* sp.. After reaching its peak, the population of hemipterans declined and remained constant during the mature stage. Chancellor et al. (1996) also discovered similar findings, noting that *M. dorsalis* was more abundant during early rice planting in the Philippines. Additionally, Yang et al. (2017) demonstrated that *M. dorsalis* could transmit RSMV virus disease to the seedlings during the early planting stage. Wada and Nik Mohd. Noor (1992) observed that *N. lugens* and *S. furcifera* populations peaked in an early-planted field, while low levels were observed in a late-planted field. Furthermore, the population of *N. lugens* and *S. furcifera* tends to increase during the tillering and heading stages of rice plants, which are favorable for their reproduction and development (Faruq et al. 2018).

Table 5 - Correlation matrix between weather factors and insect species during the main season of rice planting in Rompin, Pahang

Species	*Coefficients (N=11)*	*Rainfall*	*Min. Temp.*	*Max. Temp.*	*Light Intensity*	*Wind Speed*
Nilaparvata lugens	Pearson's r	-0.015	-0.576	-0.341	-0.111	-0.096
	p-value	0.964	0.064	0.305	0.745	0.779
Maiestas dorsalis	Pearson's r	0.092	-0.563	-0.257	-0.036	-0.072
	p-value	0.788	0.071	0.446	0.917	0.833
Nephotettix virescens	Pearson's r	-0.069	-0.494	-0.413	-0.259	-0.401
	p-value	0.84	0.122	0.207	0.442	0.221
Sogatella furcifera	Pearson's r	-0.042	-0.579	-0.354	-0.077	-0.056
	p-value	0.903	0.062	0.285	0.822	0.87
Scotinophara coarctata	Pearson's r	-0.092	-0.072	-0.456	0.098	-0.255
	p-value	0.787	0.833	0.159	0.775	0.449
Leptocorisa oratorius	Pearson's r	0.029	0.282	0.079	0.536	-0.13
	p-value	0.934	0.401	0.817	0.089	0.704
Scotinophara sp.	Pearson's r	0.279	0.255	0.51	0.026	-0.233
	p-value	0.405	0.45	0.109	0.939	0.491
Nephotettix nigropictus	Pearson's r	-0.174	-0.092	0.142	0.175	0.135
	p-value	0.609	0.789	0.677	0.607	0.693
Nezara viridula	Pearson's r	-0.272	0.405	-0.156	-0.21	0.231
	p-value	0.419	0.217	0.648	0.536	0.494
Polytoxus fuscovittatus	Pearson's r	0.535	-0.1	0.157	0.304	0.31
	p-value	0.09	0.771	0.645	0.363	0.354
Cyrtorhinus lividipennis	Pearson's r	0.451	0.206	0.132	0.194	0.515
	p-value	0.164	0.544	0.699	0.567	0.105

Note. * P<0.05, ** P<0.01

Furthermore, *C. lividipennis* was found to coexist with *N. lugens*, which has been observed by other researchers in their studies as well (Wang et al. 2011; Yaakop et al. 2022). However, the population of *C. lividipennis* in this study was not significant enough to effectively regulate *N. lugens* incidence. *C. lividipennis* preys on the eggs and nymphs of *N. lugens*, using its piercing mouthparts to suck the eggs (Chua & Mikil 1989). To enhance the effectiveness of *C. lividipennis*, it is important to reduce the use of insecticides since most insecticides tested in the study by Reissig et al. (1982) significantly decreased the population of *C. lividipennis*. In other research on insecticides, endosulfan, chlorpyriphos, acephate, and methyl parathion have been considered safe for *C. lividipennis* based on specific spraying criteria (Preetha et al. 2010).

Table 6 - Correlation matrix between weather factors and insect species during the off-season of rice planting in Rompin, Pahang

Species	*Coefficients (N=11)*	*Rainfall*	*Min. Temp.*	*Max. Temp.*	*Light Intensity*	*Wind Speed*
Nilaparvata lugens	Pearson's r	0.295	-0.147	-0.151	0.149	0.598
	p-value	0.378	0.665	0.658	0.663	0.052
Maiestas dorsalis	Pearson's r	-0.125	-0.1	0.079	0.142	0.467
	p-value	0.714	0.769	0.817	0.677	0.148
Nephotettix virescens	Pearson's r	0.079	-0.393	-0.061	0.255	0.610
	p-value	0.819	0.232	0.859	0.449	0.046 *
Sogatella furcifera	Pearson's r	0.06	-0.219	-0.071	0.283	0.696
	p-value	0.862	0.517	0.835	0.399	0.017 *
Scotinophara coarctata	Pearson's r	0.224	-0.115	-0.06	0.173	0.572
	p-value	0.508	0.735	0.862	0.61	0.066
Leptocorisa oratorius	Pearson's r	-0.655	0.293	0.133	-0.046	-0.709
	p-value	0.029 *	0.382	0.698	0.892	0.015 *
Scotinophara sp.	Pearson's r	0.085	-0.277	-0.019	0.222	0.614
	p-value	0.804	0.409	0.956	0.512	0.045 *
Polytoxus fuscovittatus	Pearson's r	0.032	0.244	-0.515	-0.059	-0.124
	p-value	0.927	0.47	0.105	0.863	0.717
Cyrtorhinus lividipennis	Pearson's r	-0.278	-0.466	-0.137	0.459	0.431
	p-value	0.407	0.149	0.689	0.156	0.186

Note. *= P<0.05, **= P<0.01

The trend of weather factors in this study seems to be consistent in both planting seasons, except for the maximum temperature in the main season and the wind speed in the off-season. A survey conducted in granary areas in Malaysia on climate change revealed a noticeable increase in both maximum and minimum temperatures. It is also predicted that the average maximum and minimum temperatures in these Malaysian granary areas will continue to rise until 2045. However, the trend in rainfall showed a somewhat insignificant positive trend (Tan et al. 2021).

The influence of climate on insect incidence depends on the preferences of each species on rice plant parts. If they are in exposed positions, such as at the top (rice grains), they will be more easily affected. These species require alternative shelters to hide from unfavourable weather conditions such as strong wind, heavy rain, and high temperatures. If they are in a sheltered location, such as at the base of the plant or just above the water creases, insects are less affected by the weather. *L. oratorius* was found to have a significant negative correlation with rainfall and wind speed, meaning that higher rainfall and wind speed can reduce their population. *L. oratorius* usually attacks rice grains during the milky stage, when the rice grains are located at the topmost part of the rice plant (Van den Berg & Soehardi 2000). In this position, insects, particularly *L. oratorius*, are more exposed to the weather than the lower parts of the rice plant. Therefore, they are more susceptible to weather conditions, especially rainfall and wind speed. Since *L. oratorius* is commonly found in the upper part of rice plants, they are easily regulated by rainfall and wind. The incidence of *L. oratorius* in Assam also revealed a similar relationship with rainfall, and a significant positive correlation was also shown with sunshine hours (Das et al. 2021). In other studies, the minimum temperature has a significant negative correlation with *L. oratorius*, while no significance was found with the maximum temperature (Raj Kumar et al. 2018). However, Khare et al. (2020) found a positive correlation between relative humidity and *L. oratorius*, whereas the other parameters negatively correlated with the *L. oratorius* population. Since the weather factor has less influence on the insect population, the adaptation of agricultural practices at the farm level is critical to prevent more significant attacks by pest insects.

5. Conclusions

Hemipteran species such as *Maiestas dorsalis*, *Nilaparvata lugens*, *Sogatella furcifera*, and *Scotinophara* sp. are significant rice pests, particularly in Southeast Asia. They are most prevalent during the late vegetative and early reproductive stages of rice growth, with their presence starting early in the planting season. To effectively control these pests and minimize economic losses, it is crucial to understand the population dynamics of hemipterans. Monitoring their population levels and implementing appropriate management strategies can help safeguard rice crops from the damage they cause. Additionally, adapting agricultural practices at the farm level is vital in preventing more severe pest attacks, as they are less influenced by weather factors.

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