Malays. Appl. Biol. (2017) 46(3): 161–169

DIVERSITY AND GUILD STRUCTURE OF INSECTS DURING RICE FLOWERING STAGE AT A SELECTED RICE FIELD IN PENANG, MALAYSIA

NUR AIDA HASHIM[1*], MASNIZA ABD AZIZ[2], NORASMAH BASARI[2], KHADIJAH SAAD[1], AIMAN HANIS JASMI[3] and SUHAILA AB HAMID[4]

[1]*School of Food Science and Technology, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia*
[2]*School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Malaysia*
[3]*Dow AgroSciences (Malaysia) Sdn. Bhd., 46350 Petaling Jaya, Selangor, Malaysia*
[4]*School of Biological Sciences, Universiti Sains Malaysia, 11800 Penang, Malaysia*
[*]*E-mail: aida.hashim@umt.edu.my*

Accepted 6 September 2017, Published online 4 October 2017

ABSTRACT

A study on diversity of insects in rice field was conducted at Kg Terus, Guar Perahu in Penang. This study aims to determine the diurnality and guild structure of insect in rice field specifically during the flowering stage of rice. Insects were collected using sweep net method and light trap method. Overall, a total of 1936 insect specimens representing 28 species, 19 families and seven orders were collected. Twenty five species from 19 families were caught during day time while 17 species from 13 families were trapped at night. Coleopterans were the dominant insect captured during day time sampling with *Micraspis crocea* from family Coccinellidae captured in highest number (223). In contrast, Hemipterans was dominant during night time with *Nilaparvata lugens* from family Delphacidae found in highest number (258). The Odonata recorded the highest diversity index (H'= 1.2587) while Coleoptera recorded the highest richness index ($I_{margalef}$ = 5.8390) values for diurnal insect. For nocturnal insect, Hemiptera recorded the highest values for both diversity index (H'= 1.2655) and richness index ($I_{margalef}$ = 5.8390). In term of guild structure, the rice pest was the most dominant insect found in rice field for both diurnal and nocturnal group. This followed by predator, others (visitor/pollinator) and parasitoid groups. Result of this study will identify the classification of insect present during the flowering stage of rice allowing farmers to forecast pest population build up to assist in the pesticides selection that will be generally applied at the end of flowering stage. This consequently will help to conserve beneficial insects and lower the pest management cost.

Key words: Biodiversity, insect, pest, rice field, paddy, guild structure

INTRODUCTION

Rice is a staple food for at least 95 countries worldwide including Malaysia. In Malaysia, there are about 300 000 farmers involve in rice production. A total of 150 million hectares of land were reserved as rice cultivation areas (FAO, 2014). It was estimated that the rice imported by Malaysia from July 2014 until June 2015 was 1.1 million tons, increased from about one million tons of rice imported in 2013 to 2014 (FAO, 2014).

Annually, Malaysia needs to produce around 2.5 million metric tons of rice (Rashid & Dainuri, 2013) to support its population consumption. The rice production depends on many factors such as weather, water supply, and the presence of other beneficial or pest arthropods. The composition of arthropod communities in rice field depends largely on the growth of rice crop (Heong *et al.*, 1991). As other Asian countries, the common terrestrial arthropod communities that can be found in Malaysian rice fields are insects and spiders (Bambaradeniya & Amerasinghe, 2003). The rice plants, weeds, soil surface and water in the rice field are the areas inhabited by the insects (Bambaradeniya & Edirisinghe, 2008). Each insect presence in the rice field has their own unique role and can be differentiate by guild structure

* To whom correspondence should be addressed.

classification based on their function which are pest, predator and parasitoid. There are also some insects that have role as pollinator which are directly beneficial to the rice crop (Bambaradeniya & Edirisinghe, 2008).

Rice field is an ecosystem that support many organisms. According to Kiritani (2009), organisms inhabiting rice field consists many species with different functions in rice field ecosystem. Most of the rice fields in tropical areas are flooded where the young rice will be transferred and planted into the field (Fernando, 1993). Hence, rice fields may serve as a replacement of wetland habitat for some arthropod species (King *et al.*, 2010).

Insect pest is the most economically important guild as it can directly impact the rice production. Previous studies have reported over 800 species of insects that can cause damage to the rice plants. However, most of the insects are minor pest (Dale, 1994). Poolprasert and Jongjitvimol (2014) recorded about 70 species of insects that can be considered as rice pests and only 20 species of them were categorized as crucial importance. These species may be present at the field in abundant at certain rice stage, suitable to their life cycles.

Natural enemies and aquatic insects in rice fields all over the world is well documented. However, there are limited literatures on terrestrial insect diversity in rice field particularly during flowering stage. Insects are particularly important in contributing to the damage of rice plant. During flowering stage, farmers generally do not practice pesticide application to avoid damaging the flowers and eventually the grain formation. This allows some time for population build-up of some pest species making the fruiting stage to be vulnerable to pest. The insect pests will feed on the developing grains, causing the reductions of rice yield. As other group of insect may present in the rice field, it is very important to identify the function of each insect in rice field whether the insects are pest, predator, parasitoid and pollinators or visitors. The study on composition, structure and dynamics of arthropod communities in a rice agro ecosystem will allow farmers to carefully plan for pest management program and selection of pesticides in order to carry out sustainable and continuous rice cultivation cycles. Therefore, the present study was conducted to determine the diversity, diurnality and guild structure of insect in rice field during the rice flowering stage.

METHODOLOGY

Study site

The study was conducted in Kg Terus, Guar Perahu, Penang (5°26’45.6"N 100°26’49.8"E) located within the Penang rice granary area of 13,000 ha (Fig. 1). It is a village area with rice cultivation as the main income source for most villagers. The area vastly encompassed with anaerobic rice field as landscape. Farmers used pesticides as the main control method of the rice pests.

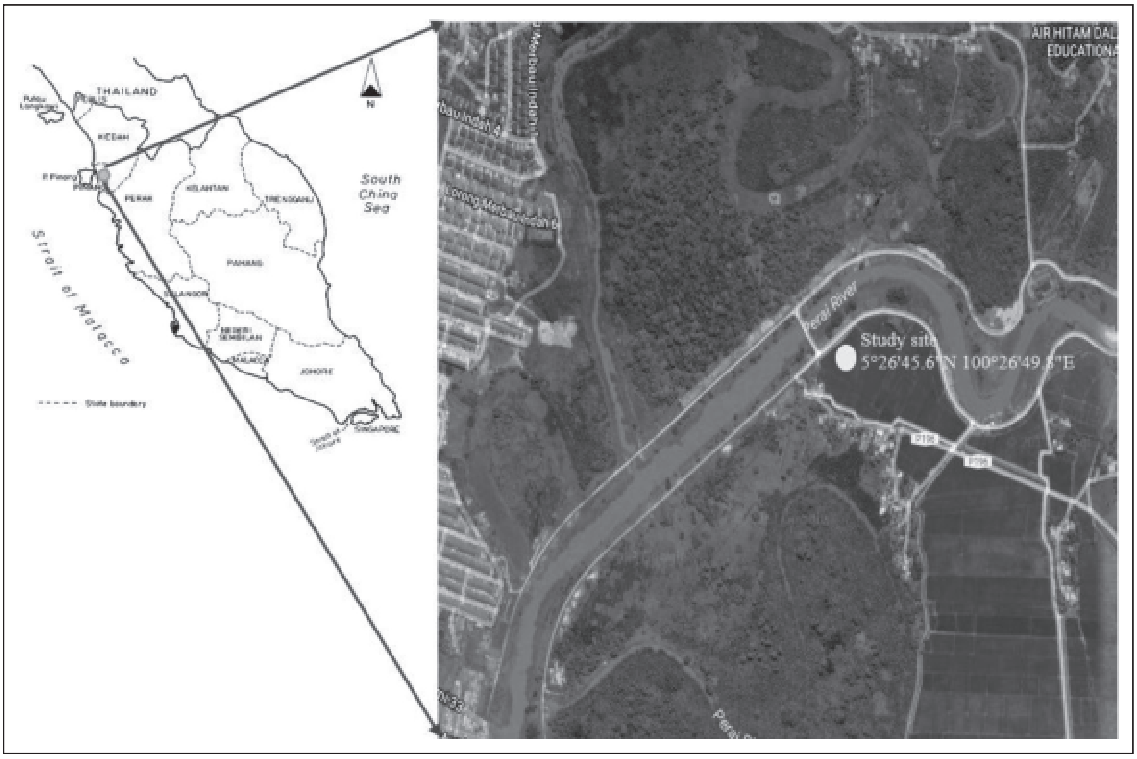

Fig. 1. Map of study site at Kampung Terus, Guar Perahu, Penang.

The plot selected for this study was located near a river that serves as source of water to irrigate the rice field. The plot was approximately 1.5 hectares in size and cultivated with MR263 rice variety by using direct seeding method. The age of the rice plants at the start of sampling was 70 days old which in flowering stage. Sampling activities were conducted within one week of the flowering stage from 18th of June to 24th June 2016.

Sampling method

A sweep net with 40.64 cm in diameter equipped with 150 cm length handle was used to collect insect in the rice field in daytime following method by Nasirudin and Roy (2012). The sweep net was swung about 180° arc such that the net rim strikes the top 6 to 8 inches of paddy growth. Each 180° arc was counted as one sweep. Each sample represent random ten sweeps of sweep net, every ten steps in the field. Ten samples were taken for each sampling day. The sampling was conducted from 0800 to 1100 h for six consecutive days. All samples were killed using chloroform, kept in plastic containers and brought back to laboratory for counting, preservation and identification.

Nocturnal insects were collected with simple light trap at the study site. The trap consisted of a 250 cm rope, tied so it spans between two poles that has been dug into soil, at about eye level. A white sheet was draped over the rope in order to allow one to two feet of the sheet to lie horizontally on the ground. A battery operated 30W LED lamp was suspended in front of the sheet which is near the top as source of light. Periodically, the sheet was monitored and checked for insects. A forceps and an aspirator were used to collect insects that landed on the sheet without damaging them. The light trap samplings were done three times during rice flowering stage. The samples were collected from 2000 to 2300 h per sampling occasion. Similarly, all samples were killed, kept in plastic container and brought back to laboratory for further processing.

Identification of species and guild structure classification

In the laboratory, the samples were segregated based on their order and family before preserved either in 70% of ethyl alcohol or pinned, labelled and mounted in collection boxes. The insect were then identified until genus or species level using available identification keys (Distant, 1977a,b,c,d; Triplehorn & Johnson, 2005: Richards & Davies, 1977; Aguda *et al.*, 1994) and from internet source (Insect Identification, n.d.). Once identified, the insects were classified into guilds based on Moran and Southwood (1982) and Heong *et al.* (1991). The guilds usually were assigned based on their feeding habits such as phytophagous pest, parasitoids, predators and others (visitor/pollinator).

Statistical analysis

Chi square test for goodness of fit was used to compare amongst the guilds structure for diurnal and nocturnal captures and also to determine the significant difference between the expected frequencies and the observed frequencies in one or more categories of guilds. Ecological indices were used to determine species diversity, richness and evenness. The formulas are as follows:

1) Shannon Wiener Index (Shannon & Wiener, 1949)

$H' = -\Sigma[p_i \ln(p_i)]$

Σ = summation

p_i = Number of individuals of species i/total number of samples

2) Evenness (Pielou, 1966)

E= H'/ Hmax

E= evenness

Hmax =Maximum diversity possible

3) Margalef Index (Margalef, 1958)

$I_{Margalef} = (S - 1) / \ln(N)$

S = Total number of species

N = Total number of individuals sampled

RESULTS

A total of 1936 individual insects representing 28 species, 19 families and seven orders were collected. From this, diurnal insects captured with sweep net method were represented by seven orders, 19 families and 25 species (Table 1) while nocturnal insects, captured using light trap were represented by seven orders, 12 families and 16 species (Table 2).

The highest number of insect collected during day time was from order Coleoptera which represented by four families and six species. The dominant species was *Micraspis crocea* of Coccinellidae with of 223 individuals. This followed by *Haltica cyanea* from family Chrysomelidae (212 individuals) and *Leptocorisa acuta* of order Hemiptera, family Alydidae (152 individuals). The lowest number of individuals captured was from order Lepidoptera, family of Sesiidae (one individual). Order Orthoptera and Diptera had the lowest number of species captured. Only *Acrida willemsei* from family Acrididae was captured for Orthoptera with total number individual of 77 while for order Diptera, 40 individulas from a single species *Hydrellia* sp. from family Ephydridae was captured.

Table 1. List of diurnal insects and guild structure classification captured in rice field using sweep net

Order	Family	Genus/Species	Total no captured	Guild Structure
Diurnal				
Hemiptera	Alydidae	*Leptocorisa acuta*	152	Pest
	Coreidae	*Cletus punctiger*	18	Pest
	Cicadellidae	*Nephotettix virescens*	18	Pest
	Delphacidae	*Nilaparvata lugens*	22	Pest
Coleoptera	Coccinellidae	*Micraspis crocea*	223	Predator
	Staphylinidae	*Paederus fuscipes*	17	Predator
	Cantharidae	*Cantharis pellucida*	12	Predator
	Chrysomelidae	*Haltica cyanea*	212	Pest
		Monolepta sp.	21	Pest
		Aulocophora indica	13	Pest
Lepidoptera	Pyraustidae	*Scirpophaga incertulas*	65	Pest
	Nymphalidae	*Junonia almana*	7	Others
	Crambidae	*Cnaphalocrosis medinalis*	21	Pest
	Sesiidae	Species unidentified	1	Others
Odonata	Coenagrionidae	*Agriocnemis pygmaea*	116	Predator
		Pericnemis stictica	51	Predator
	Libellulidae	*Trithemis aurora*	18	Predator
		Pantala flavescens	12	Predator
		Orthetrum sabina	8	Predator
		Orthetrum pruinosum	5	Predator
Hymenoptera	Ichneumonidae	*Xanthopimpla flavolineata*	90	Parasitoid
	Pompilidae	*Auplopus mellipes*	44	Pest
	Apidae	*Apis cerana indica*	9	Others
Orthoptera	Acrididae	*Acrida willemsei*	77	Pest
Diptera	Ephydridae	*Hydrellia* sp.	40	Others
Total			1272	

Table 2. List of nocturnal insects and guild structure classification captured in rice field using light trap

Order	Family	Genus/Species	Total no captured	Guild Structure
Nocturnal				
Hemiptera	Alydidae	*Leptocorisa acuta*	14	Pest
	Cicadellidae	*Nephotettix virescens*	123	Pest
		Recilia dorsalis	36	Pest
		Cofana spectra	2	Pest
	Delphacidae	*Nilaparvata lugens*	258	Pest
		Sogatella furcifera	66	Pest
Coleoptera	Chrysomelidae	*Haltica cyanea*	38	Pest
	Staphylinidae	*Paederus fuscipes*	26	Predator
Lepidoptera	Crambidae	*Cnaphalocrosis medinalis*	25	Pest
	Pyraustidae	*Scirpophaga incertulas*	13	Pest
Odonata	Coenagrionidae	*Agriocnemis pygmaea*	14	Predator
		Pericnemis stictica	5	Predator
	Libellulidae	*Pantala flavescens*	3	Predator
Hymenoptera	Ichneumonidae	*Xanthopimpla flavolineata*	11	Parasitoid
Orthoptera	Acrididae	*Acrida willemsei*	18	Pest
Diptera	Ephydridae	*Hydrellia* sp.	12	Others
Total			664	

For nocturnal insects, Hemiptera had the highest number of species collected with six species from three families. *Nilaparvata lugens* from family Delphacidae was captured with highest number (258 individuals). The lowest number of insect captured was *Cofana spectra*, family Cicadellidae and also from order Hemiptera. Both *N. lugens* and *C. spectra* are the important pest in rice field. Hymenoptera, Orthoptera and Diptera were also captured at night with only one species respectively (*Xanthopimpla flavolineata,* 11 individuals; *A. willemsei*, 18 individuals and *Hydrellia* sp., 12 individuals).

Diversity index

The ecological indices for each order of insect captured from the rice field were calculated (Table 3). For diurnal insect captured, the most diverse was from order Odonata with the highest value of Shannon–Wiener Index (H'), 1.2587 while the lowest were order Orthoptera and Diptera, (0). However, Coleoptera showed the highest value for Margalef Index, ($I_{Margalef}$) (5.8390) followed by Odonata at 5.8131. The Orthoptera and Diptera showed the lowest value for $I_{Margalef}$ as the value was 0.7696 and 0.7290 respectively.

Hemipterans are the most diverse nocturnal insect with the H' value of 1. The lowest H' belong to order Hymenoptera, Orthoptera and Diptera with the value of 0. The highest Margalef Index value was also belong to order Hemiptera with the value of 5.8390 for Margalef Index. The lowest Margalef Index too was observed for Hymenoptera, Orthoptera and Diptera.

Guild structure classification of insect in rice field

The collected insect specimens were classified into four major group namely pest, predator, parasitoid and others (visitor/pollinator). The highest percentage of insect captured belong to pest (65%) followed by predator (26%), parasitoid (5%) and others (visitors/ pollinators) (4%) [X^2(3, N=100) = 97.68, p<0.05]. Overall percentage of guild structure classification of insects captured from the rice field during flowering season was shown in Fig. 2.

For diurnal insect, the highest percentage of insect collected belong to pest group (52%). This is followed by predator (36%), parasitoid (7%) and others (5%) [X^2(3, N=100) = 58.16, p<0.05]. Similarly, the highest percentage for nocturnal insect was recorded for pest (89%) followed by predator (7%), parasitoid (2%) and others (2%) [X^2 (3, N=100) = 58.16, p<0.05] (Table 4).

Five orders from 10 species and nine families captured during day time were classified as pest group (Table 1). The predators consisted of three order of insect with nine species from five families. Of these, Odonata had the highest number of species which was six species. In the group of others, three order of four species were recorded. In this group, order Lepidoptera recorded the highest number of species (two species). Only one order of insect was collected for parasitoid group. Of all, Coleopterans recorded the highest species number with six species captured during sampling.

Table 3. The ecological indices for each order in diurnal and nocturnal insects in rice field

Order	Family	Species	Shannon Wiener Index(H')	Evenness (E)	Margalef Index($I_{Margalef}$)
Diurnal					
Hemiptera	4	4	0.8915	0.6413	3.8131
Coleoptera	4	6	1.1570	0.6464	5.8390
Lepidoptera	4	4	0.8329	0.5992	3.7797
Odonata	2	6	1.2587	0.7031	5.8131
Hymenoptera	3	3	0.8269	0.7518	2.7984
Orthoptera	1	1	0	0	0.7696
Diptera	1	1	0	0	0.7290
Total	19	25			
Nocturnal					
Hemiptera	3	6	1.2655	0.7070	5.8390
Coleoptera	2	2	0.6744	0.9774	1.7596
Lepidoptera	2	2	0.6424	0.9310	1.7253
Odonata	2	3	0.8941	0.8128	2.6764
Hymenoptera	1	1	0	0	0.5833
Orthoptera	1	1	0	0	0.6540
Diptera	1	1	0	0	0.5968
Total	12	16			

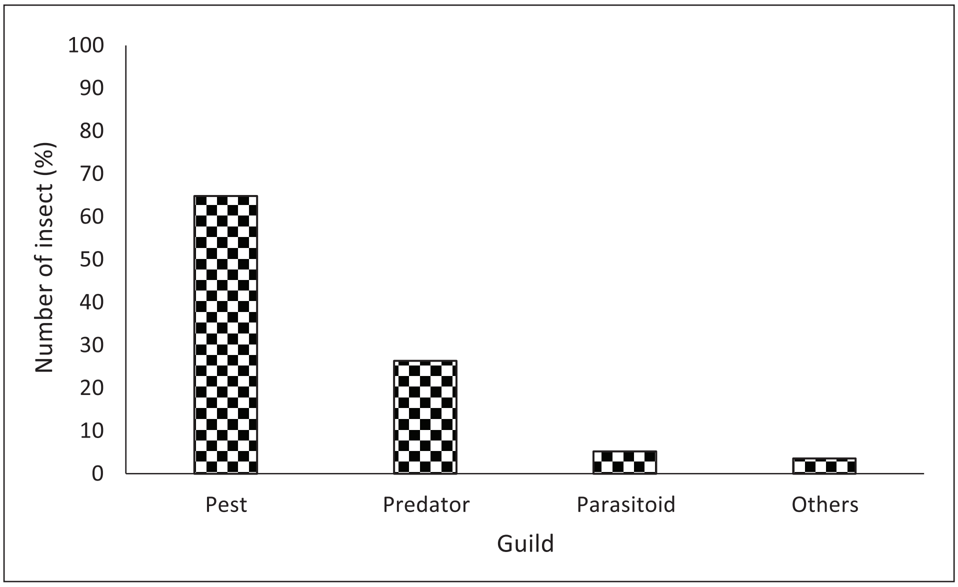

Fig. 2. Composition of insect captured during rice flowering stage in Penang, Malaysia.

Table 4. Occurrence of diurnal and nocturnal insect based on their guilds structure classification

Guild structure classification	Diurnal (%)	Nocturnal (%)
Pest	52	89
Predator	36	7
Parasitoid	7	2
Others	5	2
Total	100	100

For the species captured during night time, 10 species belonging to seven families and four orders were classified into the pest group. Of these, Hemiptera shows the highest number of species (6 species) from three families. While three species of two families from order Odonata were grouped into predator (Table 2).

DISCUSSION

During this study, we managed to capture 1936 insects using both sweep net method during day-time and light trap method in the night-time which consisted of 28 species belonging to 19 families and under eight insect orders. Of these, 65% were pests of rice, 25% were predators, 6% were parasitoids and 4% were others which included pollinators and visitors. The number of species found during this study is low compared to previous studies (Bambaradeniya & Edirisinghe, 2008; Acosta *et al.*, 2017) possibly due to the being conducted only during flowering stage of rice plants (70–80 days of rice planting stage).

In term of guild structures, our finding was closely similar to previous study by Heong *et al.* (1991), and Schoenly *et al.* (1996) where they recorded highest number of pest followed by predators and parasitoids consecutively. The high number of pest in the field may have contributed to the high number of predators in rice field. The growth and development of rice plant consequently affecting the abundance of prey in rice field. During flowering stage, the rice field provides additional niches for insects. Farmers practice of not applying insecticides at this stage and draining of water in the field allows insect population to flourish at this growth stage. Draining of the rice field builds new habitat through the revealing the base of the plant part which allows more rooms for brown plant hopper, *N. lugens* to colonize, explaining the high abundance of this species in the study. According to Ane and Hussain (2016), the effects of nitrogen fertilizers on growth and reproduction of herbivores insects and major rice pests should be considered. An excessive and long term use of nitrogen fertilizers accommodate the flourishing of herbivores and major insect pests such as plant hoppers, leaf hoppers, leaf folders and stem borers (Ane & Hussain, 2016; Xian *et al.*, 2001). Managing the nutrient level could play a key role in the suppression of herbivore populations in natural environment (Wetzel *et al.*, 2016). With the increase of pest population, the predator and parasitoid populations will also increase. Bambaradeniya and Edirisinghe (2008) reported that there was a significant positive relationship between the natural enemies that were predator and parasitoid with the pest in rice field.

In our study, we found Hemiptera as the most dominant insect in the rice field during flowering stage of rice plants. Our findings are comparable to Nasiruddin and Roy (2012) as they also observed high number of hemipteran pest during flowering stage of rice plant. They used similar sampling method as current study, which is swept net. Norela *et al.* (2013) also captured high number of Hemiptera during tillering stage until the flowering stage of rice plant. Highest number of individuals of Coleoptera captured using the sweep net method was the predator, *Micraspis crocea* (223 individuals) from family Coccinellidae, while for Hemiptera, *Nephotettix virescens* (family Cicadellidae) and *Nilaparvata lugens* (family Delphacidae) recorded the highest number of captured insects. Sap feeding pest such as *N. lugens* were captured in abundant in night time as they mostly reside at the base of the plant during day time at which the sweep net method limits the pest collection. Only the macropterous form of *N. lugens* was collected using the light trapping method. Most hemipterans captured are known as plant sap feeding pest in rice field that caused damaged to the rice plant and also acted as vector for some of rice viral diseases. *Nilaparvata lugens* was a major pest that caused huge losses in rice field (Dyck & Thomas, 1979). In fact, the other rice producing countries such as China and Vietnam also faced the same problem with this species (Heong & Sogawa, 1994; Ane & Hussain, 2016). *Nephotettix virescens* was recognized as the vector for virus that caused tungro disease to rice plant (Thresh, 1989).

The presence of various weed species also can be observed during flowering stage of rice particularly along the rice field boundary. Weeds are the host for various insects in the rice field. Bund weed cover is a conducive sites for proliferation of coleopterans and it also serves as resting site for odonates (Ooi & Shepard, 1994). The dominance of *Leptorica acuta* from family Alydidae could be highly related with the abundance of numerous graminaceous weeds in rice field as it can be as alternate hosts among the pest (Rajapakse, 1996). However, in the present study, we captured comparatively less *L. acuta* due to the fact that *L. acuta* is grain feeders that is expected to increase in population as the grain start to form after the flowering stage ended. The different diversity of insect in rice field might be influenced by some factors such as the feeding behaviour, resting behaviour, response to the food and habitat resources distribution and level of water and hill density of the rice field (Gogoi & Bora, 2012). The weed cover on rice field may act as reservoirs for predators and parasitoids and may well influence the relationship among the pest and predators (Ooi & Shepard, 1994).

Within the short time of sampling, we managed to capture high number of insects in rice field. Pest, predator, parasitoid and other types of insects (visitors/ pollinators)were present during this study. Rice field is a unique and productive ecosystem because even with harsh modification particularly after harvesting and during land preparation and pesticide usage that renders it unfavourable for quite some time, it still able to withstand populations of insects through rapid colonization and exploitation of available niches. During flowering stage in the rice field, high diversity of insects is expected due to its stable environment. This also indicates that natural balance present among the insect guilds structure in rice field. Chelliah and Bharathi (1994) suggested that the declining of predator, parasitoid and also insect pest were affected by the undiscriminating in the usage of pesticide. Pesticide and fertilizer usage in excessive manner coupled with unplanned landscape alteration not only destroyed habitat supplied by rice field but also can cause water and soil pollution (Gabel & Gabhel, 2017). Alerting and educating farmers on the importance of conserving biodiversity in rice agro ecosystems is important for safer environmental approach and effective integrated pest management strategies. Pesticides applications should be conducted only when the pest population reached its economic threshold level and selective pesticides should be used. Preserving beneficial insects such as predators and parasitoids may be able to reduce pest management cost through their role as natural biological control while pollinators can assist to increase crop yield. This could be implemented through proper usage and correct selection of insecticide.

ACKNOWLEDGEMENTS

We deeply grateful to Rosmadi Ibrahim, Mohammad Syamim Asyraf Sarum and Nurmusyaiba Omar for their technical support. This research was funded by Dow AgroSciences Malaysia Sdn. Bhd., Vot 53151.

REFERENCES

Acosta, L.G., Jahnke, S.M., Redaelli, L.R. & Pires, P.R.S. 2017. Insect Diversity in Organic Rice Fields Under Two Management Systems of Levees Vegetation. *Brazilian Journal of Biology*. http://dx.doi.org/10.1590/1519-6984.19615.

Aguda, R.M., Barrion, A.T., Bharathi, M., Chelliah, S., Dale, D., Gallagher, K.O., Heinrichs, E.A., Kiritani, K., Litsinger, J.A., Loevinsohn, M.E., Naba, K., Ooi, P.A.C., Parada, O., Roberts, D.W., Rombach, M.C., Shepard, B.M., Smith, C.M. & Weber, G. 1994. Biology and Management of Rice Insects. International Rice Research Institute, Los Baños, Philippines.

Ane, N.U. & Hussain, M. 2016. Diversity of Insect Pests in Major Rice Growing Areas of the World. *Journal of Entomology and Zoology Studies,* **4(1)**: 36-41.

Bambaradeniya, C.N.B. & Amerasinghe, F.P. 2003. Biodiversity associated with the rice field agroecosystem in Asian countries: a brief review, working paper 63. International Water Management Institute, Colombo. Sri Lanka. 29 pp.

Bambaradeniya, C. & Edirisinghe, J. 2008. Composition, structure and dynamics of arthropod communities in a rice agro-ecosystem. *Ceylon Journal of Science (Biological Sciences)*, **37(1)**: 23-48.

Chelliah, S. & Bharathi, M. 1994. Insecticide management in rice. In *Biology and Management of Rice Insects*. : E.A. Heinrichs (Ed.). Wiley Eastern Ltd., India & IRRI, Manila, Philippines. pp. 657-680.

Dale, D. 1994. Insect pests of the rice plant, their biology and ecology. In: *Biology and Management of Rice Insects*. E.A. Heinrichs (Ed.). Wiley Eastern Ltd., India & IRRI, Manila, Philippines. pp. 363-487.

Distant, W.L. 1977a. The Fauna of British India Including Ceylon and Burma, Rhynchota. Vol. I (Heteroptera). Today and Tomorrow's Printers and Publishers, New Delhi, India. 438pp.

Distant, W.L. 1977b. The Fauna of British India Including Ceylon and Burma, Rhynchota. Vol.II (Heteroptera). Today and Tomorrow's Printers and Publishers, New Delhi, India. 600pp.

Distant, W.L. 1977c. The Fauna of British India Including Ceylon and Burma, Rhynchota. Vol. VI (Homoptera). Today and Tomorrow's Printers and Publishers, New Delhi, India. 248pp.

Distant, W.L. 1977d. The Fauna of British India Including Ceylon and Burma, Rhynchota. Vol.11I (Homoptera). Today and Tomorrow's Printers and Publishers, New Delhi, India. 210pp.

Dyck, V.A. & Thomas, B. 1979. The brown plant hopper problem. In: *Brown plant hopper: threat to rice production in Asia.* International Rice Research Institute, Los Banos, Philippines. pp. 3-17.

Edirisinghe, J.P. & Bambaradeniya, C.N.B. 2006. Rice Fields: An ecosystem rich in Biodiversity. Journal of the National Science Foundation of Sri Lanka, **34(2)**: 57-59.

Fernando, C.H. 1993. Rice field ecology and fish culture – an overview. *Hydrobiologia,* **259**: 91-113.

FAO (Food and Agriculture Organization of the United Nations). 2014. Food Outlook Biannual Report on Global Food Markets. Rome, Italy.

Gabel, K. & Gabhel, M. 2017. Biodiversity of Insect Effect on Rice Field and Their Management in the Fingeshwar Region. *International Journal of Science and Research*, **6(1)**: 979-984.

Gogoi, H. & Bora, D. 2012. Spatial distribution of *Nymphula depunctalis* Guenée larvae (Lepidoptera: Pyralidae), an early vegetative pest of *Oryza sativa* L. *Academic Journal of Entomology,* **5(1)**: 41-46.

Heong, K.L., Aquino, G.B. & Barrion, A.T. 1991. Arthropod community structures of rice ecosystems in the Philippines. *Bulletin of Entomological Research*, **81**: 407-416.

Heong, K.L. & Sogawa, K. 1994. Rice insect pest management – critical issues. In: *Advances in Rice Pest Science and Management.* Teng, P.S., Heong, K.L. & Moody, K. (Eds.).IRRI, Los Banos, Philippines.

Insect Identification. n.d. Insect Identification for the casual observer. Retrieved from http://www.insectidentification.org/

King, S.L., Elphick, C.S., Guadagnin, D., Taft, O. & Amano, T. 2010. Effects of landscape features on waterbird use of rice fields. *Waterbirds,* **33(1)**: 151- 159.

Kiritani, K. 2009. A Comprehensive List of Organisms Associated with Paddy Ecosystems in Japan. Saga, Daido Printing Co. Ltd.

Margalef, R. 1958. Temporal succession and spatial heterogeneity in phytoplankton. In: *Perspectives in Marine Biology*. Buzzati-Traverso (Ed.). University California Press, Berkeley. pp. 323-347.

Moran, V.C. & Southwood, T.R.E. 1982. The guild composition of arthropod communities in trees. *Journal of Animal Ecology*, **51**: 289-306.

Nasiruddin, M. & Roy, R.C. 2012. Rice Field Insect Pests during the Rice Growing Seasons in Two Areas of Hathazari, Chittagong Bangladesh. *Journal of Zoology*, **40(1)**: 89-100.

Norela, S., Anizan, I., Ismail, B.S. & Maimon, A. 2013. Diversity of pest and non-pest insects in an organic paddy field cultivated under the System of Rice Intensification (SRI): A case study in Lubok China, Melaka, Malaysia. *Journal of Food, Agriculture & Environment,* **11(3&4)**: 2861-2865.

Ooi, P.A.C. & Shepard, B.M. 1994. Predators and parasitoids of rice insects. In: *Biology and Management of Rice Insects*. E.A. Heinrichs (Ed.). Wiley Eastern Ltd., India & IRRI, Manila, Philippines. pp. 613-656.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology,* **13**: 131-144.

Poolprasert, P. & Jongjitvimol, T. 2014. Arthropod communities inhabiting organic rice agro-ecosystem. *Measurement*, **29(30)**: 1-5.

Rajapakse, R.H.S. 1996. Survival of rice bug *Leptocorisa oratorius* on graminaceous weeds in a tropical forest environment in Southern Sri Lanka. Proc. IUFRO Symp. On impact of diseases and insect pests in tropical forests. pp. 448-452.

Rashid, R. & Dainuri, M.S. 2013. Food and livelihood security of the Malaysian paddy farmers. *Economy and Technology Management Review*, **8**: 59-69.

Richards, O.W. & Davies, R.G. 1977. A General Textbook of Entomology. Vol. 2. 9th Edition. Chapman and Hall, London. 1354 pp.

Schoenly, K., Cohen, J.E., Heong, K.L., Litsinger, J.A. 1996. Food Web Dynamics of Irrigated Rice Fields at Five Elevations in Luzon, Philippines. *Bulletin of Entomological Research*, **86(4)**: 451-466.

Shannon, C.E. & Wiener, W. 1949. The mathematical theory of communication. University of Illinois Press, Urbana. 177 pp.

Thresh, J.M. 1989. Insect-borne viruses of rice and green revolution. *Tropical Pest Management*, **35(3)**: 264-272.

Triplehorn, C.A. & Johnson, N.F. 2005. Borror and Delong's Introduction to the Study of Insects. Brooks/Cole, Cengage Learning, U.S.A. 864 pp.

Wetzel, W.C., Kharouba, H.M., Robinson, M., Holyoak, M. & Karban, R. 2016. Variability in Plant Nutrients Reduces Insect Herbivore Performance. *Nature*, **539**: 425-427.

Xian, L.X., Ping, Y.X., Heong, K.L. & Cui, H. 2001. Effect of Nitrogen Fertilizer on Herbivores and Its Stimulation to Major Insect Pests in Rice. *Rice Science*, **14(1)**: 56-66.