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BIODIVERSITAS
Volume 21, Number 7, July 2020
Pages: 3076-3083

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d210727

Impact of mycoinsecticides and abamectin applications on species diversity and abundance of aquatic insects in rice fields of freshwater swamps of South Sumatra, Indonesia

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Manuscript received: 11 April 2020. Revision accepted: 15 June 2020.

Abstract. *Herlinda S, Alesia M, Susilawati, Irsan C, Hasbi, Suparman, Anggraini E, Arsi. 2020. Impact of mycoinsecticides and abamectin applications on species diversity and abundance of aquatic insects in rice fields of freshwater swamps of South Sumatra, Indonesia. Biodiversitas 21: 3076-3083.* Aquatic insects in rice fields generally are predators of rice insect pests. The application of insecticides may reduce the abundance and species diversity of these predators. This study aimed to determine the impact of mycoinsecticides and abamectin application on species diversity and abundance of aquatic insects in rice fields. Mycoinsecticides were made from *Beauveria bassiana* s.l., *Metarhizium anisopliae* s.l. and *Cordyceps militaris* s.l. with carrier from shrimp shell flour compost extract, vegetable oil, and Tween®. The treatments were the mycoinsecticides and abamectin. The results showed there were eight aquatic insects species obtained in this study, i.e. unidentified Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Ranatra* sp., *Anisops* sp., *Microvelia* sp., unidentified species of Veliidae, and *Orthetrum* sp. belong to 7 families (Dytiscidae, Corixidae, Mesoveliidae, Nepidae, Notonectidae, Veliidae, Libellulidae), and three orders (Coleoptera, Hemiptera, and Odonata). All of the species were predatory insects. The application of mycoinsecticides did not reduce the abundance and species diversity of the aquatic predatory insects, but the application of abamectin reduced the abundance and species diversity of the predators. The highest insect species diversity was in the plots applied with *C. militaris* s.l., followed by the *B. bassiana* s.l. and *M. anisopliae* s.l. plots and the lowest one was found in the abamectin plot. So, the application of mycoinsecticides from *B. bassiana* s.l., *M. anisopliae* s.l. and *C. militaris* s.l. is safe for the aquatic predatory insects and to control rice insect pests than that of abamectin.

Keywords: *Beauveria bassiana*, *Cordyceps militaris*, *Metarhizium anisopliae*, mycoinsecticides, aquatic predatory insects

INTRODUCTION

The agricultural potential of the swampy area in Indonesia approximately 39.6 Mha, and 11.9 Mha is located in Sumatra (Margono et al. 2014) which is generally dominated by freshwater swamps. A freshwater swamp is a wetland ecosystem that generally floods with river water or rain throughout the year. The duration of stagnant water depends on the typology of the land. Our observation over the past 7 years in Ogan Ilir District of South Sumatra, Indonesia showed that flooding in the deep freshwater swampy typology is almost all year-round (October to July), middle freshwater swamps from November to June, and embankment freshwater swamps or shallow freshwater swamps from November to April. Due to stagnant water, the smallholder farmers underutilize their lands and start to plant rice and vegetables approaching the dry season.

Crops cultivated in various typologies of freshwater swamps vary depending on their adaptation to stagnant water. Rice is the most planted in freshwater swamps in South Sumatra (Lakitan et al. 2018a, b; Prabawati et al. 2019). Besides rice, chilies (Johari et al. 2014, 2016), bitter melon, long beans, eggplants, pumpkins, and cucumbers are also cultivated (Siaga et al. 2019). Rice is generally planted once a year (Hanif et al. 2020). Currently, some farmers earn>100 ha land who start planting rice two to three times a year, and several smallholder farmers grow rice two times a year by utilizing the remaining ratoons of the previous season's rice harvest (Lakitan et al. 2018b; Prabawati et al. 2019).

Intensive rice cultivation in freshwater swamps will increase the use of insecticides due to the increasing insect population (Prabawati et al. 2019). Commonly used insecticides are synthetic insecticides (Hanif et al. 2020) and sometimes bioinsecticides (Karenina et al. 2019; Prabawati et al. 2019; Hanif et al. 2020). Commonly insecticide used in rice fields in Indonesia is abamectin (Luo et al. 2013). Entomopathogenic fungi such as *Beauveria bassiana* (Ascomycota: Hypocreales) and *Metarhizium anisopliae* (Ascomycota: Hypocreales) are the most commonly used bioinsecticides (Prabawati et al. 2019). *B. bassiana* and *M. anisopliae* are widely used because they are easily found in freshwater swamps (Herlinda et al. 2018b; Safitri et al. 2018; Gustianingtyas et al. 2020). and able to kill important insect pests such as brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae) (Sumikarsih et al. 2019) and *Spodoptera litura* (Lepidoptera: Noctuidae) (Ayudya et al. 2019). Although the entomopathogenic fungi are generally reported to be host-specific (Hanif et al. 2020), it is necessary to monitor the impact of these mycoinsecticides on the abundance of beneficial arthropods.

The impact of synthetic insecticide applications on beneficial arthropods has been widely studied (Azod et al. 2016; Khan et al. 2018). However, there is not much information on the impact of synthetic insecticide and mycoinsecticides application on aquatic insects. Aquatic insects in the rice field are generally dominated by predatory insects (Thirumalai et al. 2002). The abundance and diversity of the beneficial aquatic insect species in the rice field are high (Settle et al. 1996; Herlinda et al. 2019a,b). The commonly found of the aquatic insects were *Microvelia douglasi*, *Mesovelia vittigera*, *Anisops barbatus*, *Ranatra elongata*, and *Micronecta scutellaris* (Thirumalai et al. 2002). These aquatic insects play an important role in the aquatic ecosystem (Dunbar et al. 2010) as natural enemies of rice insect pests (Heong et al. 2009).

The *B. bassiana*, *M. anisopliae* and *Cordyceps militaris* (Ascomycota: Cordycipitaceae) do not reduce abundance and species diversity of canopy predatory arthropods in the rice field (Prabawati et al. 2019), but the effect of the fungi on the species diversity and abundance of aquatic insects has not been studied. The intensive application of insecticides and mycoinsecticides may have an impact on the abundance and species diversity of the aquatic insects. The high abundance and species diversity of arthropod in water is an indicator of healthy aquatic ecosystems (Salachna and Olearczyk 2020). This study aimed to determine the effect of the mycoinsecticides application of *B. bassiana*, *M. anisopliae*, and *C. militaris* and abamectin on the species diversity and abundance of aquatic insects in the rice field.

MATERIALS AND METHODS

Study area

The field experiment was carried out in the center of the freshwater swampy rice field in the *Pelabuhan Dalam* Village of Pemulutan Subdistrict, Ogan Ilir District of South Sumatra Province. The area of freshwater rice fields in the study site was more than 800 ha. The experimental plot covers 1 ha of the freshwater swampy rice field that divided into 12 subplots for 4 treatments, each treatment has 3 replicates. This study uses a Randomized Block Design. Field trials were conducted from May to August 2018 and continued with the identification of collected aquatic insects until December 2018. The four treatments used in this study were the application of mycoinsecticides derived from *B. bassiana, M. anisopliae, C. militaris,* and abamectin as a positive control. *B. bassiana* s.l. (BPCmS isolate) and *M. anisopliae* s.l. (MSwTp1 isolate) were used in this study from the exploration in the South Sumatra (Indonesia) soil by Safitri et al. (2018), while *C. militaris* s.l. (CmKT isolate) was collected from Central Kalimantan. The identification of three entomopathogenic fungal species used in this experiment was carried out by Dr. Suwandi (a mycologist from Universitas Sriwijaya). The fungi were identified based on microscopic and macroscopic characteristics.

Preparation of land and rice planting

Rice cultivation was carried out through the stages of tillage, seed preparation, planting, and maintenance as carried out by local farmers. Soil processing was carried out using a *singkal* plow machine and then smoothed using a hoe added running water so the soil becomes muddy. After the soil was cultivated, the rice was grown and added with a dose of 1 ton ha^{-1} manure and flooded with water for 14 days before planting.

Seed sowing by local farmers includes seed treatment, seed curing, and seed sowing. The seeds used were certified Mekongga variety at a dose of 50 kg ha^{-1}. The seeds were soaked for 24 hours with shrimp shell flour compost at a dose of 0.5 mL L^{-1}. Composting of shrimp shell flour was made according to the method of Suwandi et al. (2012). To facilitate germination after 24 hours soaking, broadcast the seeds in moist conditions on the rice field dike that has been coated with rice mud and moist manure. The seeds were broadcast by sprinkling called *Samir*.

Insecticides used in this study were mycoinsecticides and abamectin, while weeding was done mechanically without using herbicides. Watering was done by using a pump, and manure was used as fertilizer. Shrimp shell flour compost extract at a dose of 2 L ha^{-1} was applied every 2 weeks until the milky stage (milk-cooked phase) by spraying to increase soil fertility. Rice was planted using a *legowo* row of 2: 1 planting system with a spacing of 12.5x50x50 cm^3. It was conducted by transplantation using 7-10 days old seedlings. Seedlings were transplanted with a maximum water level of half of rice seedlings height. The higher the rice plants, the more water was pumped into the fields. The plants were watered daily to accommodate and maintain the presence of aquatic insects inhabiting the rice field water. The rice field was inundated until nearing the ripe phase of milk and after the grains of rice were at the ripening stage, the fields began to be dried and the experiment was stopped.

Production and application of mycoinsecticides and abamectin

Mycoinsectides used as treatments in this study were derived from 3 species of entomopathogenic fungi, i.e. *B. bassiana* s.l., *M. anisopliae* s.l. and *C. militaris* s.l. and commercial insecticides abamectin as a positive control. Production of mycoinsecticides was following the modified method of Mascarin et al. (2015). Entomopathogenic fungi were cultured on Sabouraud Dextrose Agar (SDA, Merck) solid media and incubated for 10 days at room temperature. Entomopathogenic fungi grew on solid media were transferred into Sabouraud Dextrose Broth (SDB, Merck) liquid media and incubated for 7 days under agitation at 120 rpm. Liquid fungal culture with a minimum density of $1x10^9$ conidia mL^{-1} was used as the active ingredient of mycoinsecticides. The mycoinsecticides were made from a mixture of 600 mL of liquid entomopathogenic fungal culture, 400 mL carrier made from shrimp shell flour compost extract, 10 mL vegetable oil, and 10 mL of a sterile aqueous solution of 0.04% polyoxyethyl-189 ene sorbitan mono-oleate (Tween®). Mycoinsectides were applied at a dose of 2 L ha^{-1} every two weeks, starting on the 14th, 28th, 42nd, and 56th days after transplanting (DAT), while abamectin was applied according to the manufacturer's instructions with the same spraying schedule with the mycoinsecticides.

Samplings of aquatic insects

One day after mycoinsecticides and abamectin were sprayed on the rice field, the sampling of aquatic insects was carried out, which were on the 15th, 29th, 43rd, and 57th DAT, i.e. 2nd of June 2018, 16th June 2018, 30th June 2018, and 17th July 2018, while the next sampling was not carried out because the rice fields began to dry out. The sampling of aquatic insects following the method of Salmah et al. (2017) by using a fishnet (0.4 mm mesh) conducted at 6.00-7.00 a.m.

Sampling was carried out by swinging the net into rice field water with a 2x2 m^2 sampling area for each treatment and repeated three times. The obtained insects were put into a vial containing 96% ethanol and then taken to the laboratory for identification. The taxonomic identification of aquatic insects using morphological features based on Basu et al. (2016) and Miller and Bergsten (2016) up to the genus level.

Statistical analyses

Data on the number of each species were used to calculate species abundance and diversity. The obtained data on species abundance were subjected to Analysis of variance (ANOVA) followed by Tukey's Honestly Significant Different (HSD) to determine significant differences among treatments at a level of 5% using the software program of SAS University Edition 2.7 9.4 M5. Analysis of the species diversity was carried out using the Shannon index (H'). The diversity level was also evaluated by the Evenness index (J') derived from the Shannon function and Berger-Parker dominance biodiversity indices.

RESULTS AND DISCUSSION

Aquatic insect species

This study successfully collected 8 species of aquatic insects from all experimental plots, namely unidentified species of Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Ranatra* sp., *Anisops* sp., *Microvelia* sp., unidentified species of Veliidae, *Orthetrum* sp. (Figure 1) belong to 7 families (Dytiscidae, Corixidae, Mesoveliidae, Nepidae, Notonectidae, Veliidae, Libellulidae), 3 orders (Coleoptera, Hemiptera, and Odonata), (Table 1). The number of species found in the plot applied with *B. bassiana* s.l. was 6 species (unidentified species of Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Anisops* sp., *Microvelia* sp., and *Orthetrum* sp.) and in the plot applied with *M. anisopliae* s.l. were 6 species (unidentified species of Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Microvelia* sp., unidentified species of Veliidae, and *Orthetrum* sp.). In the plot applied with *C. militaris* s.l. were 7 species (unidentified species of Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Anisops* sp., *Microvelia* sp., unidentified species of Veliidae, and *Orthetrum* sp.). While in the abamectin plot there were only 5 species found (*Mesovelia* sp., *Ranatra* sp., *Anisops* sp., *Microvelia* sp. and *Orthetrum* sp.). In total, eight aquatic insect species were collected, all of the species were predators of rice insect pests.

Abundance and diversity of aquatic insect species

The abundance of aquatic insects tends to increase in plots applied with the mycoinsecticides (*B. bassiana, M. anisopliae,* and *C. militaris* s.l.), however, the abundance of the aquatic insect in the abamectin plot was not increased (Figure 2). The plots applied with *C. militaris* s.l. had the most abundant insects, while the plots applied with the abamectin had the lowest abundant insects. The abundance of each species was not significantly different, but in total, aquatic insect abundance was significantly different among treatments. The highest abundance of *Micronecta* sp. was in plot applied with *C. militaris* s.l. (37.67 individual 4 m^{-2}) but significantly different from that of plots applied with *B. bassiana* (30.33 individual 4 m^{-2}), *M. anisopliae* (30.33 individual 4 m^{-2}) and abamectin (0 individual 4 m^{-2}) (Table 2). The plot applied with abamectin showed a significant decrease in *Micronecta* sp.

The aquatic insects collected in the mycoinsecticides plots applied were belonging to 3 orders (Coleoptera, Hemiptera, and Odonata), while in the abamectin plot there were only 2 orders of aquatic insects (Hemiptera, and Odonata) (Figure 3). The most dominant order in all plots was Hemiptera. Species composition in the plots applied with mycoinsecticides was different from the abamectin plots (Figure 4). The species composition in the three mycoinsecticide plots had the same tendency. *Micronecta* sp. was not found in the abamectin plots, but *Micronecta* sp. was the most dominant species in the plots applied with mycoinsecticides. The presence and composition of aquatic insect species can be used as an indicator of the water quality.

The results of the study showed that the diversity of aquatic insect species increased with increasing age of rice. The species diversity was higher in plots applied with mycoinsecticides than plots applied with abamectin (Table 3). The highest species diversity on the 15th and 29th DAT was in the plots applied with *C. militaris* s.l., followed by those applied with *B. bassiana* s.l. However, the highest species diversity on the 43rd-57th DAT was in the plots applied with *B. bassiana*.

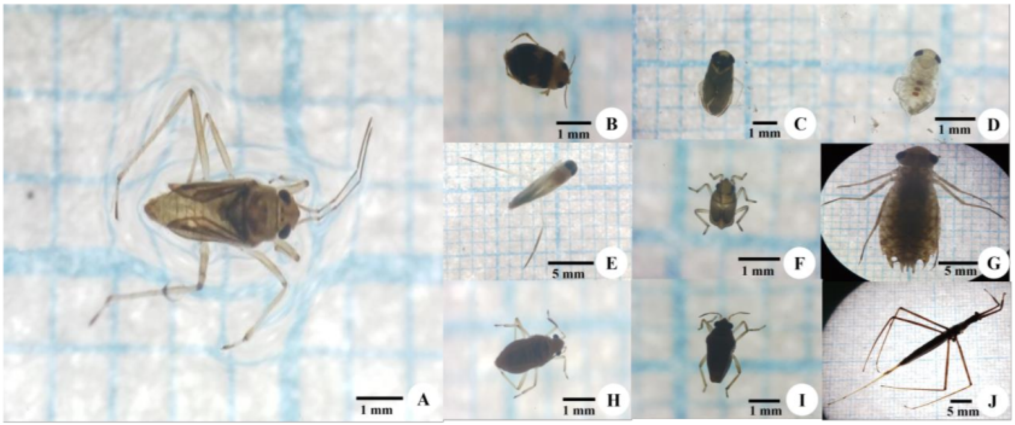

Figure 1. Aquatic insect species obtained in complete rice production cycle: A. *Mesovelia* sp., B. Unidentified species of Dytiscidae, C. *Micronecta* sp. adult, D. *Micronecta* sp. nymph, E. *Anisops* sp., F. Unidentified species of Veliidae, G. *Orthetrum* sp., H-I. *Microvelia* sp., J. *Ranatra* sp.

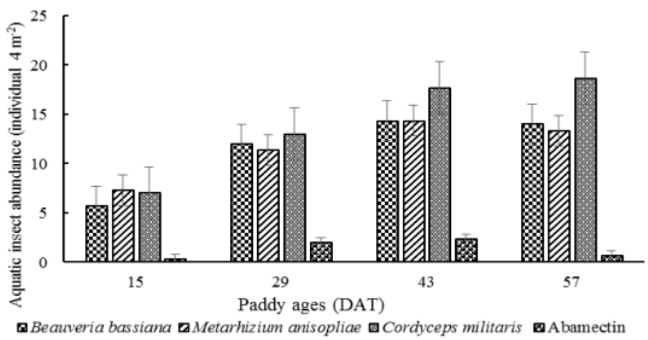

Figure 2. Aquatic insect abundance in rice field applied with mycoinsecticides of: A. *Beauveria bassiana* s.l., B. *Metarhizium anisopliae* s.l., C. *Cordyceps militaris* s.l., D. Abamectin

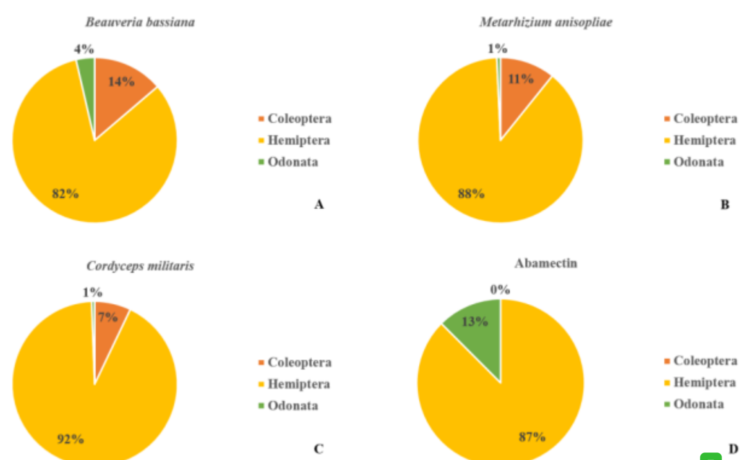

Figure 3. The relative abundance of the order of aquatic insect in rice field applied with mycoinsecticides of: A. *Beauveria bassiana* s.l., B. *Metarhizium anisopliae* s.l., C. *Cordyceps militaris* s.l., D. Abamectin

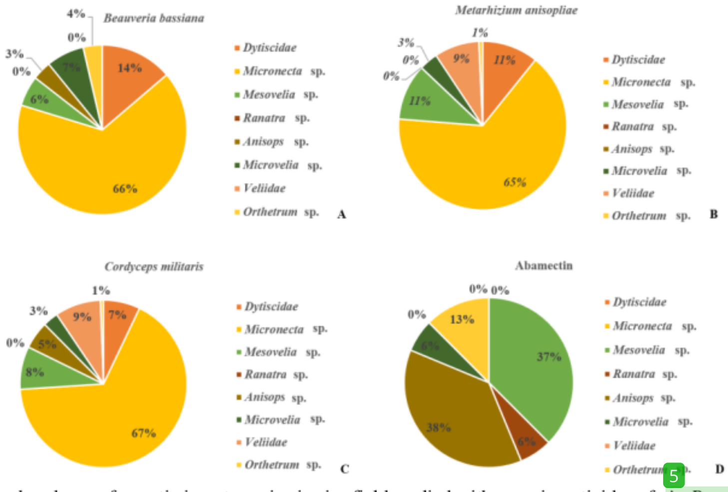

Figure 4. The relative abundance of aquatic insect species in rice field applied with mycoinsecticides of: A. *Beauveria bassiana* s.l., B. *Metarhizium anisopliae* s.l., C. *Cordyceps militaris* s.l., D. Abamectin

Table 1. Aquatic insect in rice field applied with mycoinsecticides of *Beauveria bassiana* s.l., *Metarhizium anisopliae* s.l. and *Cordyceps militaris* s.l. and abamectin

Order	Family	Species	Insecticide treatment			
			***Beauveria bassiana* s.l.**	***Metarhizium anisopliae* s.l.**	***Cordyceps militaris* s.l.**	**Abamectin**
Coleoptera	Dytiscidae	Unknown species	+	+	+	-
Hemiptera	Corixidae	*Micronecta* sp.	+	+	+	-
	Mesoveliidae	*Mesovelia* sp.	+	+	+	+
	Nepidae	*Ranatra* sp.	-	-	-	+
	Notonectidae	*Anisops* sp.	+	-	+	+
	Veliidae	*Microvelia* sp.	+	+	+	+
		Unknown species	-	+	+	-
Odonata	Libellulidae	*Orthetrum* sp.	+	+	+	+

Note: + insects found,-no insects found

Discussion

Eight aquatic insect species were obtained in the center of freshwater swamps from June 2nd to July 17th. In the dried rice field after July 17 the aquatic insects were no longer found. However, in the rice fields that still inundated; the aquatic insects still could be found. Therefore, the presence of deep freshwater swamp is important for conserving aquatic insects in the dry season.

All species of aquatic insects collected in this study were predatory insects that attack rice insect pests. All species belonging to Dytiscidae (unidentified species) or diving beetles were predators of insects whose habitat is close to the water surface (Watanabe 2019) such as living on the stems and lower leaves and attacking the rice insect pests, such as *Gryllotalpa orientalis* (Ohba 2009). *Micronecta* sp. and *Mesovelia* sp. are predatory insects commonly found and suck out the internal body fluids of the rice insect pests (Wakhid et al. 2020). *Ranatra* sp. is predators that have a role in regulating the balance of insect populations of the rice insect pests (Thongphak and Iwai 2016). *Anisops* sp. is commonly found in rice field water in Indonesia and also known as a predator for rice insect pests (Wakhid et al. 2020). *Microvelia* sp. and Veliidae (unidentified species) were reported as predators of brown planthoppers (Heong, 2009). Immature and adult stages of *Orthetrum* sp. prey on various insect species from various families (Salmah et al. 2017; Wakhid et al. 2020). The aquatic insects in rice fields obtained in this study generally attack rice insect pests that inhabit the base of the stem, such as brown planthopper (*N. lugens*) (Heong 2009).

The results showed that the abundance of aquatic insects decreased significantly in the abamectin plot, but it remained high in all three plots applied with mycoinsecticides. Abamectin is an insecticide that is commonly applied in the rice field to control brown planthoppers in Indonesia. Abamectin is contact poison and stomach poison and widely chosen and applied by farmers in Indonesia because it has a broad spectrum that kills many species of insect pests (Luo et al. 2013). Abamectin that flows into the rice field water will poison and cause the death of aquatic insects.

The abundance of aquatic insects in the three plots applied with mycoinsecticides from *B. bassiana* s.l., *M. anisoplia* s.l. and *C. militaris* s.l. remain high since these mycoinsecticides did not poison the aquatic insects. These three entomopathogenic fungal species have specific hosts, i.e. the order of Lepidoptera or Homoptera (Shrestha et al. 2012), while the aquatic insects obtained in this study belong to the orders of Hemiptera, Coleoptera, and Odonata. *B. bassiana* is effective in poisoning and killing *S. litura* (Lepidoptera) (Ayudya et al. 2019), and *N. lugens* (Homoptera) (Sumikarsih et al. 2019). *M. anisoplia* effectively attacks Lepidoptera (Ayudya et al. 2019), while *C. militaris* generally attacks insect pests of which attacks palm oil leaves (Lepidoptera) (Shrestha et al. 2012). Prabawati et al. (2019) reported that application of *B. bassiana, M. anisoplia,* and *C. militaris* in rice fields reduce insect pest population, but do not harm predatory arthropods inhabiting the canopy and rice soil surfaces. Therefore, the application of *B. bassiana, M. anisopliae,* and *C. militaris* in rice fields are beneficial in reducing rice insect pests and safe for the aquatic insect as predators of rice insect pests.

Table 2. The abundance of aquatic insect species in rice field applied with mycoinsecticides of *Beauveria bassiana* s.l., *Metarhizium anisopliae* s.l. and *Cordyceps militaris* s.l. and abamectin

Rice age (DAT)	Species of aquatic insect	The abundance of aquatic insects (individual 4 m^{-2})				F value	P value	Tukey's HSD test
		Beauveria bassiana s.l.	*Metarhizim anisopliae* s.l.	*Cordyceps militaris* s.l.	Abamectin			
15 DAT	Dytiscidae	0.00	0.00	0.00	0.00	-	-	-
	Micronecta sp.	5.33	6.33	5.67	0.00	0.25^{ns}	0.86	-
	Mesovelia sp.	0.00	0.67	0.67	0.00	0.57^{ns}	0.65	-
	Ranatra sp.	0.00	0.00	0.00	0.00	-	-	-
	Anisops sp.	0.00	0.00	0.00	0.00	-	-	-
	Microvelia sp.	0.00	0.00	0.67	0.33	0.62^{ns}	0.63	-
	Veliidae	0.00	0.00	0.00	0.00	-	-	-
	Orthetrum sp.	0.33	0.33	0.00	0.00	0.57^{ns}	0.65	-
29 DAT	Dytiscidae	0.00	0.00	0.00	0.00	-	-	-
	Micronecta sp.	11.67	7.00	6.00	0.00	1.51^{ns}	0.30	-
	Mesovelia sp.	0.00	4.33	4.00	2.00	0.41^{ns}	0.75	-
	Ranatra sp.	0.00	0.00	0.00	0.00	-	-	-
	Anisops sp.	0.00	0.00	3.00	0.00	1.00^{ns}	0.45	-
	Microvelia sp.	0.00	0.00	0.00	0.00	-	-	-
	Veliidae	0.00	0.00	0.00	0.00	-	-	-
	Orthetrum sp.	0.33	0.00	0.00	0.00	1.00^{ns}	0.45	-
43 DAT	Dytiscidae	3.00	2.67	1.33	0.00	0.78^{ns}	0.55	-
	Micronecta sp.	7.00	10.00	11.33	0.00	1.80^{ns}	0.25	-
	Mesovelia sp.	0.00	0.00	0.00	0.00	-	-	-
	Ranatra sp.	0.00	0.00	0.00	0.00	-	-	-
	Anisops sp.	1.67	0.00	0.00	2.00	0.57^{ns}	0.65	-
	Microvelia sp.	1.67	1.67	0.00	0.00	1.00^{ns}	0.45	-
	Veliidae	0.00	0.00	5.00	0.00	1.00^{ns}	0.45	-
	Orthetrum sp.	1.00^{c}	0.00^{a}	0.00^{a}	0.33^{b}	8.00*	0.02	0.22
57 DAT	Dytiscidae	3.33	2.33	2.67	0.00	1.33^{ns}	0.35	-
	Micronecta sp.	6.33	7.00	14.67	0.00	1.54^{ns}	0.30	-
	Mesovelia sp.	2.67	0.00	0.00	0.00	1.00^{ns}	0.45	-
	Ranatra sp.	0.00	0.00	0.00	0.33	1.00^{ns}	0.45	-
	Anisops sp.	0.00	0.00	0.00	0.00	-	-	-
	Microvelia sp.	1.67	0.00	1.00	0.00	0.59^{ns}	0.64	-
	Veliidae	0.00	4.00	0.00	0.00	3.50^{ns}	0.09	-
	Orthetrum sp.	0.00	0.00	0.33	0.33	0.57^{ns}	0.65	-
Total	Dytiscidae	6.33	5.00	4.00	0.00	2.57^{ns}	0.15	-
	Micronecta sp.	30.33^{b}	30.33^{b}	37.67^{c}	0.00^{a}	13.91*	0.00	1.67
	Mesovelia sp.	2.67	5.00	4.67	2.00	0.11^{ns}	0.95	-
	Ranatra sp.	0.00	0.00	0.00	0.33	1.00^{ns}	0.45	-
	Anisops sp.	1.67	0.00	3.00	2.00	0.27^{ns}	0.84	-
	Microvelia sp.	3.34	1.67	1.67	0.33	0.88^{ns}	0.50	-
	Veliidae	0.00	4.00	5.00	0.00	1.17^{ns}	0.40	-
	Orthetrum sp.	1.66	0.33	0.33	0.66	2.60^{ns}	0.15	-

Note: ns = not significantly different; * = significantly different; values within a row followed by the same letters were not significantly different at $P < 0.05$ according to Tukey's HSD test. Original data were transformed using $\sqrt{(n_i+0.5)}$ transformation before statistical analysis

Table 3. Characteristics of aquatic insect communities in rice field applied with mycoinsecticides of *Beauveria bassiana* s.l., *Metarhizium anisopliae* s.l. and *Cordyceps militaris* s.l. and abamectin

Rice age (DAT)	Characteristics of communities	Insecticides			
		***Beauveria bassiana* s.l.**	***Metarhizium anisopliae* s.l.**	***Cordyceps militaris* s.l.**	**Abamectin**
15 DAT	Abundance of aquatic insect species (N) (individual 4 m^{-2})	5.67	7.33	7.00	0.33
	Shanon wiener index (H')	0.22	0.49	0.62	0.00
	Evennes index (E)	0.32	0.44	0.56	0.00
	Dominance index (D)	0.94	0.86	0.81	1.00
29 DAT	Abundance of aquatic insect species (N) (individual 4 m^{-2})	12.00	11.33	13.00	2.00
	Shanon wiener index (H')	0.13	0.67	1.06	0.00
	Evennes index (E)	0.18	0.96	0.96	0.00
	Dominance index (D)	0.97	0.62	0.46	1,00
43 DAT	Abundance of aquatic insect species (N) (individual 4 m^{-2})	14.33	14.33	17.67	2.33
	Shanon wiener index (H')	1.36	0.81	0.84	0.41
	Evennes index (E)	0.85	0.74	0.76	0.59
	Dominance index (D)	0.49	0.70	0.64	0.86
57 DAT	Abundance of aquatic insect species (N) (individual 4 m^{-2})	14.00	13.33	18.67	0,66
	Shanon wiener index (H')	1.27	1.00	0.70	0.69
	Evennes index (E)	0.92	0.91	0.50	1.00
	Dominance index (D)	0.45	0.53	0.79	0.50
Total	Abundance of aquatic insect species (N) (individual 4 m^{-2})	46,00	46.33	56.33	5.33
	Shanon wiener index (H')	1.14	1,12	1,17	1,34
	Evennes index (E)	0,64	0,63	0,60	0.83
	Dominance index (D)	0,66	0,65	0,67	0,38

Abundance and species diversity of aquatic insect are increasing along with the increasing age of rice in the plots treated with mycoinsecticides. The more complex the structure of plants are, the more complex the species of insects associated with the plants (Settle et al. 1996) and the more abundant and diverse insect pests in the rice canopy with increasing age of rice plants (Prabawati et al. 2019). The abundance of pests in rice are prey for aquatic insects (Cheong 2009)

The diversity of aquatic insect species in plots applied with abamectin was lower than those applied with the mycoinsecticides. Three species were not found in the abamectin plots (unidentified species of Dytiscidae, *Micronecta* sp., and unidentified species of Veliidae). This could be due to the broad spectrum of abamectin that can kill various insect species (Luo et al. 2013) including the aquatic insects (Thongphak and Iwai 2016) in this study. These, three species were susceptible to abamectin. The *Micronecta* sp. is generally found in a healthy aquatic ecosystem. The decreasing number of species or diversity of aquatic insect species in the rice fields could be an indicator of decreasing water quality of the rice fields (Salmah et al. 2017).

It can be concluded that all eight aquatic insect species obtained in this study were predators of rice insect pests. The eight aquatic insect species were: unidentified species of Dytiscidae, *Micronecta* sp., *Mesovelia* sp., *Ranatra* sp., *Anisops* sp., *Microvelia* sp., unidentified species of Veliidae, and *Orthetrum* sp. belong to 7 families (Dytiscidae, Corixidae, Mesoveliidae, Nepidae, Notonectidae, Veliidae, and Libellulidae), and three orders (Coleoptera, Hemiptera, and Odonata). The application of mycoinsecticides from *B. bassiana* s.l., *M. anisopliae* s.l. and *C. militaris* s.l. did not reduce the abundance and species diversity of the aquatic predatory insects, while the application of abamectin reduces the abundance and species diversity of the predatory insects. The application of mycoinsecticides from *B. bassiana* s.l., *M. anisopliae* s.l. and *C. militaris* s.l. is a safe application for the aquatic predatory insects, and to control rice insect pests than that of abamectin applications.

ACKNOWLEDGEMENTS

This research was funded by the Competency-Based Research (PBK) for the 2018 fiscal year based on the Letter of Director of Research and Community Service, Directorate of Research and Community Service (*DRPM*), Directorate General of Research and Development Strengthening, Ministry of Research, Technology and Higher Education, Number: 0045/E3/LL/2018, January 16, 2018.

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