EVALUATION OF *Bacillus thuringiensis* AND FLUBENDIAMIDE FOR CONTROLLING *Metisa plana* VIA AERIAL SPRAYING IN OIL PALM PLANTATION

Che Ahmad Hafiz Che Manan[1], Siti Noor Hajjar Md Latip[1,2*], Ayman Bin Che Razali[3] Syed Mazuan Syed Mohamed[4] & Cik Mohd Rizuan Zainal Abidin[5]

[1]Faculty of Plantation & Agrotechnology,
UiTM Melaka Jasin Campus,
77300 Merlimau, Melaka, Malaysia.
[2] Sustainable Crop Protection Research Group,
UiTM Shah Alam,
40450 Shah Alam, Selangor, Malaysia.
[3] Plantation Business Management,
Agricultural Chemicals (M) Sdn. Bhd.,
13600 Perai, Penang, Malaysia.
[4] Federal Land Development Authority,
Menara FELDA,50088, WP Kuala Lumpur, Malaysia.
[5] FGV Research & Development Sdn Bhd.,
Wisma FGV, 50350, WP Kuala Lumpur, Malaysia.
[*]Corresponding author: *noorhajar@uitm.edu.my*

ABSTRACT

Bagworm, *Metisa plana* (Lepidoptera: Psychidae) is one of the most serious and critical pests on oil palm. Aerial spraying is a treatment method that is used to control infestation especially in the large outbreak areas. Flubendiamide and *Bacillus thuringiensis kurstaki* (Btk) as potential environmentally friendly pesticide were chosen for the study based. Aerial spraying with aircraft of both pesticide were carried out at an oil palm plantation. Four plots: A, B, C and D were chosen; each plot measuring 20ha. The aim of this study is to evaluate the effective spray volume for Flubendiamide and to determine cost-effectiveness between Flubendiamide and *B. thuringiensis kurstaki* (Btk). Both Flubendiamide spray volume of 30 and 50 liters ha^{-1} successfully reduced 100% the population from 196 bagworm per frond (BPF) to 0 BPF at 68 days after treatment (DAT) for 30 liters ha^{-1} and from 266 BPF to 0 BPF at 68 DAT for 50 liters ha^{-1}. Application at 30 liters ha^{-1} of Flubendiamide were proven cost effective according to the cost benefit ratio (BCR). However, 50 liters ha^{-1} of Btk showed slight reduction in first treatment but increased the population to 195% from 99 BPF to 294 BPF at 68 DAT. Flubendiamide spray was proven to be more cost effective than Btk according to cost benefit ratio (BCR). Therefore, it is recommended for the management to use Flubendiamide with aerial spraying method for successive control of bagworm population below the economic threshold level (ETL).

Keywords: Aerial spraying, *Metisa plana*, flubendiamide, *Bacillus thuringiensis*

ABSTRAK

Ulat bungkus, *Metisa plana* (Lepidoptera: Psychidae) adalah salah satu perosak yang paling serius dan kritikal di ladang sawit. Semburan udara adalah salah satu kaedah rawatan yang digunakan untuk mengawal serangan terutamanya di kawasan yang luas. Flubendiamide dan *Bacillus thuringiensis kurstaki* (Btk) berdasarkan potensi pestisid yang mesra alam dipilih untuk kajian Semburan udara dengan kapal terbang dilakukan di ladang sawit. Empat plot: A, B, C dan D dipilih; setiap plot berukuran 20ha. Tujuan kajian ini adalah untuk menilai isi padu semburan berkesan bagi Flubendiamide dan menentukan keberkesanan kos antara Flubendiamide dan *B. thuringiensis kurstaki* (Btk). Kedua-dua isipadu semburan Flubendiamide 30 dan 50 liter ha^{-1} berjaya mengurangkan 100% populasi daripada 196 ulat per pelepah (BPF) menjadi 0 BPF pada 68 hari selepas rawatan (DAT) bagi isipadu semburan 30 liter ha^{-1} dan dari 266 BPF hingga 0 BPF pada 68 DAT bagi isipadu semburan 50 liter ha^{-1}. Penggunaan Flubendiamide dengan isipadu semburan 30 liter ha^{-1} terbukti efektif dari segi kos mengikut nisbah faedah kos (BCR). Walau bagaimanapun, isipadu semburan 50 liter ha^{-1} bagi Btk menunjukkan sedikit penurunan dalam rawatan pertama tetapi populasi meningkat 195% dari 99 BPF menjadi 294 BPF pada 68 DAT. Semburan udara dengan Flubendiamide terbukti lebih berkesan daripada Btk mengikut nisbah faedah kos (BCR). Oleh itu, disarankan kepada pihak pengurusan untuk menggunakan Flubendiamide dengan kaedah semburan udara bagi mengawal populasi ulat bungkus di bawah tahap ambang ekonomi (ETL).

Kata kunci: Semburan udara, *Metisa plana*, flubendiamide, *Bacillus thuringiensis*

INTRODUCTION

Malaysia is the second biggest oil palm producer in the world after Indonesia, supplying up to 29% of world palm oil production and accountings for 9.5% and 19.7% of the world's total production and export of oils and fats (MPOC 2019). The rapid development of oil plantations in Malaysia coincides with the emergence of various pests that threaten the oil palm production in this country. In recent decades, the biggest challenge faced in the oil palm industry is the bagworm outbreak which has resulted in significant yield loss. In Malaysia, bagworms, *Metisa plana* are one of the most serious and critical pests to the oil palm industry (Basri et al. 1988; Norman et al. 2014) and latest by Wood & Norman (2019). Bagworms are polyphagous insects and start eating immediately upon hatching by scraping the leaves' surface and leaving a hole when it dries. Thus, it can lead to a significant yield reduction of 30 to 44% for two years after infestation, which was revealed by Wood et al. (1972), Basri et al. (1993) and latest by Cheong et al. (2010). *Metisa plana* undergoes seven larval instars each of which is protected within the larval bag (Basri & Kevan 1995). Early instar (1-4) of the larvae was the most vulnerable to the chemical than late instars (5-7).

Currently, there are several methods of chemical control through fogging, spraying either ground or aerial, and trunk injection. Trunk injection is an effective method, but it is labor-intensive as mentioned by Hasber et al. (2015), while aerial spraying was found to be cost effective when it can cover a large outbreak area (Mohd Najib et al. 2012). Spray volume also needs to be properly studied as insect control depends not only on the amount of material deposited on a vegetative element but also on the uniformity of coverage over the surface of that element (MacNichol et al. 1997).

In Malaysia, biopesticide and chemical pesticide both were used for aerial spraying by aircraft. *Bacillus thuringiensis kurstaki* (Btk) based products are the most popular biological control for *M. plana*. Btk based products are generally safe to non-target organisms, low environmental residues and suitable to be used when insect pest develops resistance to chemical (NPTN 2004) but it is slow action due to its mode of action consist of 5 steps starting with the ingestion of bacteria, solubilization of crystal, activation protein, binding protein to receptors, membrane pore formation, and cell disruption (Schunemann et al. 2014)). During population outbreaks, chemical control is the fastest and most effective method of suppressing and maintaining *M. plana* populations below the action threshold (Yap 2000). While most chemical pesticides are harmful to untargeted insects, several types of potential pesticides can be integrated with Integrated Pest Management (IPM)strategy such as Flubendiamide which is under Diamide group. It can be classified as a new class of pesticide with a new mode of action by exhibits larvicidal activity as an orally ingested toxicant targeting $Ca2^{+}$ balance resulting rapid cessation of feeding and extended residue control (Bayer 2003; Das et al. 2017; Masanori et al. 2005) and much safer for non-targeted insects such as oil palm pollinating weevil (*Elaidobius kamerunicus*) as study latest by Priwiratama et al. (2018) and Syed Mazuan (2018). These properties of Flubendiamide make it suitable for controlling lepidopterous pests under IPM programs (Masanori et al. 2005). The study was conducted by Hasber (2015) found that among tested pesticides (Triclorfon, Cypermethrin, Lamdha-cyhalothrin and *Bacillus thuringiensis*) using ground application techniques (two-nozzle) power sprayer, chemical is the best cost effective in reducing the *M. plana* population better than *B. thuringiensis*. Flubendiamide and *B. thuringiensis* was chosen for the study as both pesticides displayed no significant reduction on the oil palm pollination weevil population after spraying, which exhibit the characteristic of environmentally friendly pesticide (Syed Mazuan 2018).

Cost benefit analysis by using benefit-cost-ratio (BCR) was used in this study to compare and assess the investment of both pesticides specific to cost effectiveness. The main objectives were to evaluate the effective spray volume for Flubendiamide, and to determine cost-effectiveness between Flubendiamide and *B. thuringiensis kurstaki* (Btk) via aerial spray (aircraft).

MATERIAL AND METHODS

Sampling Site and Treatment

This study was conducted in an oil palm plantation in Keratong, Pahang, Malaysia (coordinate 2˚57’25” N, 102˚56’26” E). Four plots namely A, B, C and D of 20 hectares each at 8 years of planting age were selected for this study based on the current infestation. Plot A was treated with 30 liters per ha spray volume of Flubendiamide, plot B was treated with 50 liters per ha spray volume of Flubendiamide, plot C was treated with 50 liters per ha spray volume of Btk and plot D was untreated control plot. A total of 30 liters spray volume for Flubendiamide was decided based on the current practice for application with Btk (Noorhazwani et al. 2017). Due to the poor efficiency of Btk (Hasber et al. 2015), Btk treatment has been advised to increase spray volume to improve its efficiency by increasing its deposition into the canopy.

Aerial spraying service was operated by a certified aviation company upon approval of flying permit by Civil Aviation Authority Malaysia (CAAM) and approval of pesticide by the Department of Agriculture (DOA) Malaysia, Pesticide & Fertilizers Control Division. Fix wing aircraft model DROMADER was used for this trial with CP nozzle and set to fly at a constant speed for all plots. Flubendiamide and Btk rates were calculated and calibrated as recommended by the pesticide supplier. At 30 liters ha^{-1} spray volume, a total of 600 liters dilution was sprayed at each 20ha plot, whereas at 50 liters ha^{-1} spray volume, 1000 liters dilution was sprayed at 20ha plot. Before application, the sprayer was calibrated at desired coverage of droplet into the oil palm canopy.

Sampling and Experimental Design

The plots were arranged based on Complete Randomized Design (CRD). A 0.3 percent sampling census was done every 20 ha plots, and each sampling point was marked with Global Positioning System (GPS) for continuous systematic monitoring. *Metisa plana* population census was taken at 0, 7, 14, 21 and 68 days after treatment (DAT). A gap between 21 and 68 DAT indicates that the change from first generation of *M. plana* cycle to newly hatch of second generation. Bagworm per frond (BPF) was calculated by cutting down 1 frond at 45° angled each sampling point and all live *M. plana* instars [early (L1-L4), late (L5-L7) and pupae] were counted at both sides.

Population Reduction

Percentage of population reduction was calculated by following formula (Equation 1) (Abbott 1925).

$$\text{Population reduction} = \frac{T - C}{T} \times 100$$

Where,
T = Mean population before treatment
C = Mean population after treatment

The cost of treatment was recorded in Ringgit Malaysia (RM) and the Cost-Benefit Ratio (BCR) is an indicator of the relative economic performance of the treatment (Aziz et al. 2012). The cost of aerial spraying was RM45.00 per hectare and cost of airstrip rental was RM1000-2000 per day. The cost of Btk is RM 75.00 per liter and the cost of Flubendiamide is RM 508.00 per kg. Cost-Benefit Ratio (BCR) was calculated using the following formula;

Cost-Benefit Ratio (BCR)

Cost-Benefit Ratio (BCR) was calculated by following formula (Equation 2) (Aziz et al. 2012).

$$BCR = \frac{T}{C}$$

Where,
T = Benefit return
C = Cost spent

Statistical Analysis

Mean number of *M. plana* (BPF) data each plot was analyzed using analysis of variance (ANOVA) (SPSS Version 16) to find out the factors that significantly explain the population reduction every 7 days at first generation and at 68 days for newly hatch at second generation in relation between all treatments. A probability of $p<0.05$ is considered statistically significant.

RESULTS

One-way ANOVA results showed no significant difference in the mean number of *M. plana* for all treatments relation to the untreated control plot at 0 DAT [$df = 19$, $f = 1.53$, $p>0.05$] and 14 DAT [$df = 19$, $f = 1.52$, $p>0.05$] (Table 1). However, there is a significant difference in the mean number of *M. plana* for all treatments related to the untreated control at 7 DAT [$df = 19$, $f = 11.77$, $p<0.05$], 21 DAT [$df = 19$, $f = 16.49$, $p<0.05$] and 68 DAT [$df = 19$, $f = 24.72$, $p<0.05$]. Plot A and B (Flubendiamide) was comparable and showed a significant reduction ($p<0.05$) as early as 7 DAT with no live bagworms recorded from 14 DAT until 68 DAT. However, both plots, C (Btk) and D (Untreated control) did not show a significant reduction from 0 DAT until 68 DAT. At 68 DAT, a significant difference ($p<0.05$) was recorded as the mean bagworm population in plot C was higher than plot D. As expected, Plot A and B had the highest effectiveness (100%) than plot C and D as the larval population increased by 195% and 35% respectively. Population reduction percentages were calculated as per Equation 1. Summary of the results for all treatments are shown in Table 1.

Table 1. Mean ± SE and results of one-way ANOVA *M. plana* number before and after the treatments. The percentage of reduction in the bagworms population in relation to control plots is shown in brackets

Plot	Treatment	0 DAT	7 DAT	14 DAT	21 DAT	68 DAT
A	FLUBENDIAMIDE 30L	196± 8.10[a]	6.20±1.96[b] (96.83)	0.00±0.00[b] (100)	0.00±0.00[b] (100)	0.00±0.00[c] (100)
B	FLUBENDIAMIDE 50L	266±109.5[a]	2.00±1.1[b] (99.24)	0.00±0.00[b] (100)	0.00±0.00[b] (100)	0.00±0.00[c] (100)
C	BACILLUS THURINGIENSIS 50L	99.6±12.75[a]	100.2±11.8[a] (-0.6)	91.4±5.41[a] (8.18)	75.4±7.11[a] (24.29)	294.4±48.9[a] (-195)
D	UNTREATED CONTROL	97.4±7.68[a]	85.6±15.99[a] (12.11)	134.2±43.1[a] (-37.9)	74.4±9.44[a] (23.6)	132.2±20.6[b] (-35.7)
	ANOVA F-value	1.53	11.77	1.52	16.49	24.72
	P-value	0.24	0.01	0.24	0.00	0.00

Note: Mean within the column with the different connecting letters are significant at the $p<0.05$ level by Tukey's test between treatments.
DAT = Day after treatment

The effect on every instar was also evaluated in all plots (Table 2). Both Flubendiamide plots successfully reduce 100% early and late larvae with single application as early as 7 day after treatment (DAT). In 30 liters plot A, mean numbers of larval for early instar showed a reduction from 88.8 larvae per frond (LPF) to 0 LPF in 14 DAT. For late instar, reduction of mean numbers from 107.2 LPF to 0 LPF in 14 DAT was recorded. However, no numbers of pupae were recorded from 0 DAT until 68 DAT. In 50 liters plot B, the percentages of early instar showed a reduction from 46.4 larvae per frond (LPF) to 0 LPF at 14 DAT. The same goes for late instar, a reduction from 219.8 LPF to 0 LPF also after 14 DAT was recorded. However, no numbers of pupae were recorded from 0 DAT until 68 DAT.

For Plot C, it was the plot that was sprayed with Btk at high spray volumes at 50L ha^{1}. The percentage of early instar in plot C showed a reduction from 75.4 LPF to 48.2 LPF in 7 DAT and 0 LPF in 14 DAT. The number of late instars fluctuates from 24.2 LPF increase to 52.0 LPF (7DAT) then decrease to 46.4 LPF (14DAT) and 15.6 LPF (21DAT). The numbers of live pupae recorded increased from 0 PPF to 45 PPF at 14 DAT and 59.8 PPF at 21 DAT. At 68 DAT, second generation of *M. plana*, a majority early instar was recorded at 285.4 LPF (97%). For Plot D, it was untreated control plot. The percentage of early instar in plot D fluctuates from 20.4 LPF increase to 21.6 in 7 DAT and decrease to 0 LPF in 14 DAT. The number of late instars also fluctuates from 77.0 LPF decrease to 64.0 BPF (7DAT) then increase to 83.6 LPF (14DAT) and decrease to 3.00 LPF (21DAT). The numbers of live pupae recorded increased from 0 PPF to 50.6 PPF at 14 DAT and 71.4 PPF at 21 DAT. At 68 DAT, second generation of *M. plana*, early instar was recorded at 100.6 LPF (76%).

Table 2. Mean ± SE and results of one-way ANOVA *M. plana* number every instar before and after the treatments

Treatment	Instar	0 DAT	7 DAT	14 DAT	21 DAT	68 DAT
	Early	88.8 ± 12.62	2.80 ±0.96	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
FLUBENDIAMIDE 30L	Late	107.2 ± 11.90	3.40 ±1.28	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
	Pupae	0.00 ± 0.00	0.00 ±0.00	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
	Early	46.40 ± 8.04	0.20 ±0.20	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
FLUBENDIAMIDE 50L	Late	219.8 ± 102	1.60 ±1.12	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
	Pupae	0.00 ± 0.00	0.00 ±0.00	0.00 ±0.00	0.00 ± 0.00	0.00 ± 0.00
	Early	75.4 ± 8.82	48.2 ±10.01	0.00 ±0.00	0.00 ± 0.00	285 ± 44.49
BACILLUS THURINGIENSIS 50L	Late	24.2 ± 8.74	52.0 ±4.21	46.4 ±3.04	15.6 ± 2.50	9.0 ± 4.77
	Pupae	0.00 ± 0.00	0.00 ±0.00	45.0 ±3.11	59.8 ± 6.66	0.00 ± 0.00
	Early	20.4 ± 1.86	21.6 ± 9.96	0.00 ±0.00	0.00 ± 0.00	100 ±14.13
UNTREATED CONTROL	Late	77.0 ± 6.44	64.0 ± 6.89	83.6 ±30.8	3.00 ± 0.31	31.6 ±15.25
	Pupae	0.00 ± 0.00	0.00 ± 0.00	50.6 ±14.3	71.4 ± 9.39	0.00 ± 0.00

Note: DAT = Day after treatment

Operational Productivity and Cost Benefit Analysis

The productivity of the aerial spray using aircraft was calculated at 80 hectare trip^{-1} (2500 liters load) at 30 minutes spraying time. This productivity depended on distance to the airstrip and spray volume ha^{-1}. Maximum 20 daily trips with 8 hours effective spraying time resulted in 1600 hectares sprayed area covered with a total cost per hectare of RM45. Labor cost consisted of 5 field workers (RM43 daily rate) totaled up RM129 day^{-1} with cost ha^{-1} RM0.15. Chemical cost ha^{-1} was calculated at RM59.30 ha^{-1} for Flubendiamide plus an additional RM3.67 ha^{-1} for KINETIC surfactant and RM97.50 ha^{-1} for Btk, both at the recommended rate by the supplier. Airstrip rental cost RM2000 day^{-1} total up with other costs at RM8.00 ha^{-1}. Summary of cost ha^{-1} is shown in Table 3.

Table 3. Estimation of cost treatment to control bagworm infestation by aircraft, aerial spraying technique

Treatment	**Rate Ha^{-1}**	**Cost RM Ha^{-1}**				
		Chemical	**Labour**	**Aerial**	**Other**	**Total**
FLUBENDIAMIDE	100gm	62.97	0.15	45	8	116.12
BACILLUS THURINGIENSIS	1.3 Liters	97.50	0.15	45	8	150.65

Note: Cost shown is subjective to the study area in other places

Benefits-cost ratio (BCR) was calculated to analyse the best treatment, which shows maximum control of the pest and resulting in maximum yield with a minimum cost (Aziz et al. 2012) (Equation 2). Cost was calculated based on single application for Flubendiamide and double application for Btk to achieve the good result. The yield recorded after the treatment for all plots was estimated at 20mt oil palm yield ha^{-1} after the infestation recorded below economic threshold level (ETL). Untreated control plot recorded only 14mt^{-1} after 30%-44% yield reduction after 2 years due to *M. plana* infestation based on an earlier study by Basri et al. (1993) and Wood et al. (1972). The total benefits were estimated RM2,700 ha^{-1} at commodities price RM 450 mt^{-1} fresh fruit bunch (FFB). BCR ratio for Flubendiamide was 1:23 that is for every RM1 spent, the estimated return in RM23, whereas for Btk was 1:9 that is for every RM1 spent, the estimated return is only RM9. To conclude, Flubendiamide was proven to be more cost-effectiveness than Btk as per BCR formula. The summary of BCR is shown in Table 4.

Table 4. Cumulative Cost-benefit ratio (BCR) calculated for all treatments

Treatment	Treatment RM cost ha^{-1}	Treatment round	Total treatment RM cost ha^{-1}	Yearly yield mt^{-1}	Increased Yield over Control mt^{-1}	Estimated total yield benefits ha^{-1}	BCR
FLUBENDIAMIDE	116.12	1	116.12	20	6	2,700	1:23
BACILLUS THURINGIENSIS	150.65	2	301.30	20	6	2,700	1:9
UNTREATED CONTROL	0	0	0	14	0	0	0

Note: Benefit was calculated as per FFB prices estimated at RM450 mt^{-1}

DISCUSSION

All treatment has been done at multiple instars of *M. plana* [early (L1-L4) and late (L5-L7)] in all plots. Early instar of the larvae was the most vulnerable to the pesticide but due to no monitoring, normally planters found the larvae in late stages which less vulnerable even to the chemical pesticide. It was important to do the treatment in early stages of larvae to get a good result. Each instar has the period at average of 6-8 days thus census at 7 days interval is a practical method to find out the effect of the chemical at field trial in relation to different pesticide.

Both treatment plots with Flubendiamide 30 and 50 liters spray volume ha^{-1} successfully reduced the total *M. plana* population. The reduction was significant at $p<0.05$ as early as 7 DAT compared to Btk and untreated control plots. Mortality of early and late larvae was good on both Flubendiamide treatments, thus avoiding late larval metamorphosis to the pupal stage. The fast-acting (rapid cessation of feeding) and the photolysis of Flubendiamide on soil surface gave calculated half-life of 11.56 days (Das et al. 2017) was 7 days longer than Btk half-life. The longer half-life of Flubendiamide will increase its effectiveness to both early and late instar. This explains why no pupa was detected throughout the DAT. Overall, both spray volumes of 30L and 50L of Flubendiamide were effective in controlling the *M. plana* population in a single treatment.

It was a different situation in the Btk plot with the population of *M. plana* fluctuating and recurring infestation in second generation at 68 DAT. This shows bagworm larvae have metamorphosed to pupae stage after first treatment due to the Btk treatment were less effective to late-stage larvae. Btk toxins target insect larvae when eaten and break down their guts then the insect dies of infection and starvation. In comparison with early instars, late instars may tolerate a long period of starvation (Stockhoff 1991) and that is why most of the late instars were successfully metamorphosed to the pupae stage. Based on the study Btk toxins were broken down easily by sunlight (half-life 1-4 days) and Btk droplets sprayed on the leaf need to be eaten immediately by the insect before it is broken down (Perez et al. 2015). At 68 DAT, Btk plot shows the new generation of early instar significantly higher $p<0.05$ than the control plot as shown in table 1. Early instar was the majority in Btk plot at 68 DAT due to treatment of Btk being only effective in early stages of the first treatment compared to control plot without treatments. The challenge comes when most of the male larvae were metamorphosed to pupae earlier than female larvae and both reduced their feeding activities and remained active only in their case (Kok et al. 2011). A correct timing of aerial spraying of Btk applied at early stages is most important for a success bagworm control (Mazmira et al. 2010) and was supported by Basri (1993) aerial spraying of Btk was not recommend if more than 70% of the population at the late instars. As Btk managed to bring down from multiple stage instar to single stage instar, it is advisable to go for second round of treatment as similar result by Mohd Najib et al. (2012) and Noorhazwani et al. (2017). Based on this result, treatment of Btk at high spray volume is not effective in controlling the multistage infestation below ETL in a single treatment.

At the untreated plot, only slight *M. plana* reduction (Early and late larvae) was observed with a total number of live pupae that were still high recorded at 21 DAT. This slight population reduction is due to biotic and abiotic factors and was supported by Basri (1993) and Ho (2002), biotic interaction plays an important role in suppressing the *M. plana* population. At 68 DAT mean numbers of new generation *M. plana* was significantly lower than the Btk plot due to different time of hatching. This low population of *M. plana* may be due to the richness of predators and parasitoids that cause additional mortality to the bagworms. Referring to Cheong et al. (2010), about 27.2% to 35.9% of bagworm mortality was caused by parasitoid and fungal infection. Although bagworm population at untreated control plot was lower than Btk plot at 68 DAT, untreated plot recorded multiple stage of instars due to no treatment carried out. There will be a recurred infestation in third generation of bagworm in untreated control plot.

CONCLUSION

This was the first study on the aerial application with Flubendiamide. Based on the percentage of reduction (effectiveness), both Flubendiamide aerial spray at 30L ha^{-1} (100%) and 50L ha^{-1} (100%) were effective to control *M. plana* population below economic threshold level (ETL) with a single application. Thus, Flubendiamide at 30L per $hectare^{-}$ recommended for better cost effectiveness. At the Btk plot, with high spray volume at 50L ha^{-1} was still not effective in controlling (-195%) *M. plana* population below ETL in single application. Cost analysis calculated at spray volume 50L ha^{-1} for Flubendiamide was proven with better cost-effectiveness (1:23) than Btk (1:9).

The aerial spraying is suitable and cost effective for large infestation areas. The advantages of this aerial application are high productivity, quick and less labour usage than conventional ground spraying or trunk injection. An important factor to a successful treatment should also depend on the coverage of the application. Imperfect coverage on the foliage due to unsuitable climatic conditions may result in poor control of *M. plana* despite highly effective pesticide used. Future research on treatment effectiveness under different climatic variability and droplets distribution in oil palm canopy are strongly recommended.

ACKNOWLEDGMENTS

The authors would like to thank the Federal Land Development Authority (FELDA) for the approval of study site and financial support for the study, FGV Research & Development Sdn. Bhd. and Agricultural Chemicals (M) Sdn. Bhd for assisting the study and also support from Ministry of Higher Education through the FRGS Research Grant (600-IRMI/FRGS 5/3/ 058/2019).

REFERENCES

Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. *J. Econ. Entomol* 18: 265-267.

Aziz, M.A., Hasan, M.U., Ali, A. & Iqbal, J. 2012. Comparative efficacy of different strategies for management of spotted bollworms, *Earias spp*. on okra, *Abelmoschus esculentus* (L). Moench. *Pakistan J. Zool*. 44(5):1203-1208.

Basri, M.W. 1993. Life history, ecology and economic impact of the bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae) on the oil palm, *Elaeis guineensis* Jacquin. (Palmae), in Malaysia. Ph.D. Thesis, University of Guelph.

Basri, M.W., Abdul, H.H. & Zulfikri, M. 1988. *Bagworm (Lepidoptera: Psychidae) of Oil Palms in Malaysia*. Bangi: PORIM.

Basri, M.W. & Kevan, P.G. 1995. Life history and feeding behavior of the oil palm bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae). *Elaeis* 7(1): 18-34.

Bayer Crop Science. 2003 Report MR-202/03, Laboratory Project ID: P601030020, Leverkusen.

Cheong, Y.L., Sajap, A.S., Hafidzi, M., Omar, D. & Abood, F. 2010. Outbreaks of bagworms and their natural enemies in an oil palm, *Elaeis guineensis*, plantation at Hutan Melintang, Perak, Malaysia. *Journal of Entomology* 7(3): 141-151.

Das, S.K., Mukherjee, I. & Roy, A. 2017. Flubendiamide as new generation insecticide in plant toxicology: A policy paper. *Adv Clin Toxicol* 2(2): 000122.

Hasber, S., Che Salmah, M.R., Abu Hassan, A. & Salman, A.A. 2015. Efficacy of insecticide and bioinsecticide ground sprays to control *Metisa plana* Walker (Lepidoptera: Psychidae) in oil palm plantations, Malaysia. *Tropical Life Sciences Research* 26(2): 73-83.

Ho, C.T. 2002. Ecological studies of *Pteroma pendula* Joannis and *Metisa plana* Walker (Lepidoptera: Psycidae) towards improved integrated management of infestation oil palm. Ph.D. Thesis, Universiti Putra Malaysia.

Kok, C.C., Ooi, K.E., Abdul Rahman, R. & Adzemi, M.A. 2011. Microstructure and life cycle of *Metisa plana* Walker (Lepidoptera: Psychidae). *Journal of Sustainability Science and Management*. 6: 51-59.

MacNichol, A.Z., Teske, M.E. & Barry, J.W. 1997. A technique to characterize spray deposit in orchard and tree canopies. *American Society of Agricultural Engineers* 40(6):1529-1536.

Malaysian Palm Oil Council (MPOC). 2019. Malaysian Palm Oil Industry. http://mpoc.org.my/malaysian-palm-oil-industry/ (1st October 2019)

Masanori, T., Hayami, N., Takashi, F., Akira, S., Hiroki, K., Kenji, T. et al. 2005. Flubendiamide, a novel insecticide highly active against lepidopterous insect pests. *J. Pestic. Sci.* 30(4): 354-360.

Mazmira, M.M.M., Ramlah, A.A.S., Najib, M.A., Norman, K., Kushairi, A.D. & Basri, M.W. 2010. Integrated pest management (IPM) of bagworms in southern Perak via aerial spraying of *Bacillus thuringiensis* (Bt). *Oil Palm Bulletin* 63: 24-33.

Mohd Najib, A., Siti Ramlah, A.A., Idris, A.S. & Norman, K. 2012. Mechanization of pest & disease control. *Palm Mech Conference*, Bangi, Selangor. October 2012.

Norhazwani, K., Siti Ramlah, A.A., Mohamed Mazmira, M.M., Mohd Najib, A., Che Ahmad Hafiz, C.M. & Norman, K. 2017. Controlling *Metisa plana* Walker (Lepidoptera: Psychidae) outbreak using *Bacillus thuringiensis* in an oil palm plantation in Slim River, Perak, Malaysia. *Journal of Oil Palm Research* 29(1): 47-54.

Norman, K., Siti Ramlah, A.A., Mohd Najib, A., Mazmira, M. & Othman, A. 2014. Controlling oil palm bagworms (Lepidoptera: Psychidae) by mass trapping of moths and *Bacillus thuringiensis* in Perak, Malaysia. *Pheromones and other Semiochemicals IOBC-WPRS Bulletin* 99: 159-163.

NPTN. 2004. *Bacillus thuringiensis* Technical Fact Sheet. Oregon State University.

Perez, J. Bond, C., Buhl, K. & Stone, D. 2015. *Bacillus thuringiensis* (*Bt*) General Fact Sheet. National Pesticide Information Center, Oregon State University Extension Services.

Priwiratama, H., Rozziansha, T.A.P. & Prasetyo, A.E. 2018. Effects of flubendiamide against nettle caterpillar *Setothosea asigna* Van Eecke, bagworm *Metisa plana* Walker, bunch moth *Tirathaba rufivena* Walker of oil palm and it's impacts to the activity of pollinator weevil *Elaeidobius kamerunicus* Faust. *Jurnal Penelitian Kelapa Sawit* 26(3): 129-140.

Schunemann R., Knaak, N. & Fiuza, L.M. 2014. Mode of action and specificity of *Bacillus thuringiensis* toxins in the control of caterpillars and stink bugs in soybean culture. *International Scholarly Research Notices* 2014 (Article ID: 135675): 1-12.

Stockhoff, B.A. 1991. Starvation resistance of gypsy moths, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidea): Tradeoffs among growth, body size, and survival. *Oecologia* 88: 422-429.

Syed Mazuan, S.M. 2018. Efficacy of five insecticides against bagworm, *Metisa plana* Walker and their side effects on oil palm pollinator, *Elaeidobius kamerunicus* Faust. Master Thesis, Universiti Putra Malaysia.

Wood, B.J., Corley, R.H.V. & Goh, K.H. 1972. Studies on the effect of pest damage on oil palm yield. In. Wastie, R.I. & Earp, D.A. (ed.). *Advances in Oil Palm Cultivation*, pp. 360-379. Kuala Lumpur: Incorporated Society of Planters.

Wood, B.J. & Norman, K. 2019. Bagworm (Lepidoptera: Psychidae) infestation in the centennial of the Malaysian oil palm industry: A review of cause and control. *Journal of Oil Palm Research* 31(3): 364-380.

Yap, T.H. 2000. The intelligent management of Lepidoptera leaf-eaters in mature oil palm by trunk injection (A review of principles). *The Planter* 76(887): 99-107.