IMPACT OF MULTIPLE AERIAL SPRAYING OF *Bacillus thuringiensis* ON BAGWORM CONTROL IN OIL PALM SMALLHOLDINGS IN JOHOR, MALAYSIA

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ABSTRACT

The outbreak of bagworm has been a severe threat, causing significant loss to the oil palm industry in Johor, Malaysia. This study investigated the impact of multiple aerial applications of *Bacillus thuringiensis* (Bt)-based biopesticides in controlling the bagworm outbreak at two smallholdings in Johor, namely Smallholding A (Sh.A) and Smallholding B (Sh.B). Two types of agricultural aircrafts used in this study were Grumman G-164 A Super AgCat and M-18 Dromader. The results showed that a significant reduction of bagworms (83.5%) was recorded after the third round of aerial spray in Sh.A. Whilst, Sh.B recorded a significant reduction of bagworms (83.5%) after the fourth round of aerial spray. The result indicated that multiple applications of Bt aerial spray at the precise timing and strategy based on the bagworm's life cycle are crucial in ensuring the application's effectiveness in bringing down the bagworm population to below the economic threshold level (ETL). A census conducted in 2019 and 2020 recorded that the bagworm population in both areas maintained below the threshold level even after more than three years of application. With the implementation of a long-term Integrated Pest Management (IPM) strategy, such as planting beneficial plants, the bagworm population can be maintained under ETL even after years of aerial sprays.

Keywords: *Bacillus thuringiensis*, biopesticides, aerial spray, *Metisa plana*

ABSTRAK

Serangan ulat bungkus telah menjadi ancaman teruk yang menyebabkan kerugian yang besar ke atas industri sawit di Malaysia. Kajian ini mengkaji kesan aplikasi semburan udara berulang menggunakan biopestisid berasaskan *Bacillus thuringiensis* (Bt) dalam mengawal serangan ulat bungkus di dua kawasan ladang pekebun kecil di Johor, Malaysia iaitu pekebun kecil A (Sh.A) dan pekebun kecil B (Sh.B). Dua jenis kapal terbang pertanian yang digunakan dalam kajian ini ialah Grumman G-164 A Super AgCat dan M-18 Dromader. Hasil kajian menunjukkan bahawa pengurangan ulat bungkus yang signifikan (83.5%) dicatat setelah pusingan ketiga penyemburan udara di Sh.A. Sementara, Sh.B merekodkan penurunan signifikan ulat bungkus (83.5%) selepas pusingan keempat semburan udara. Hasil menunjukkan bahawa pengulangan aplikasi penyemburan udara Bt pada waktu dan strategi yang tepat berdasarkan kitaran hidup ulat bungkus sangat penting dalam memastikan keberkesanan aplikasi dalam menurunkan populasi ulat bungkus ke bawah tahap ambang ekonomi (ETL). Bancian yang dilakukan pada tahun 2019 dan 2020 mencatatkan bahawa populasi ulat bungkus di kedua-dua kawasan tersebut tetap di bawah tahap ambang walaupun setelah lebih dari tiga tahun aplikasi semburan. Dengan perlaksanaan strategi jangka panjang Pengurusan Perosak Bersepadu (PBB) seperti menanam tanaman bermanfaat, populasi ulat bungkus dapat dikekalkan di bawah ETL walaupun setelah bertahun-tahun penyemburan udara dilakukan.

Kata kunci: *Bacillus thuringiensis*, biopestisid, semburan udara, *Metisa plana*

INTRODUCTION

Integrated Pest Management (IPM) is the best approach for pest management that aims to control pest population below the economic injury level (EIL). Globally, the extensive application of chemical pesticides has led to severe complications, such as resistance of pests to treatment, excess of dangerous residue in the environment, and annihilation of beneficial insects (Wood & Norman 2019a). Therefore, the IPM approach has been accepted as a sustainable alternative in controlling agricultural pests (Wood & Norman 2019b). IPM programme uses up-to-date, inclusive information of pests' life cycles and their interaction with the environment.

The severe bagworm outbreak in Malaysia, especially in Johor and Perak has led the Malaysian Palm Oil Board (MPOB) to take the initiative to implement an IPM programme, specifically for controlling the pest. The species of bagworm capable of causing outbreaks in the oil palm plantation are *Metisa plana* Walker, *Pteroma pendula* Joannis, and *Mahasena corbetti* Tams. In Peninsular Malaysia, *M. plana* has been reported as the most atrocious and dominant pest of oil palm (Norman & Basri 2007; Noorhazwani et al. 2017; Norman et al.1994; Ramlah et al. 2007a, 2007b; Sankaran 1970; Wood & Norman 2019a, 2019b). Defoliation of approximately 10% to 13% due to bagworm attack might cause about 33% to 40% yield loss (Basri 1993).

For bagworm control, the IPM integrates four core components, which include the application of *Bacillus thuringiensis* (Bt)-based bioinsecticides, planting of beneficial plants to attract the beneficial insects, and installation of pheromone traps. The synergism between these core components contributes to reducing the pest population below the economic injury level (EIL). It also provides long-term protection against the pest and avoids recurring infestation (Mazmira et al. 2010). Bt-based bioinsecticides have the advantages of being biologically degradable, selectively active on pests, and less likely to cause resistance. In Malaysia, Bt is mainly used to combat bagworms, which are the most dangerous defoliating pest for the oil palm (Norman & Basri 2007; Wood & Norman 2019a). Besides, Bt products are harmless to beneficial insects, such as the oil palm pollinator, *Elaeidobius kamerunicus* and beneficial insects associated with *Cassia cobanensis* (Najib et al. 2009; Peter & Norman 2018). The impact of IPM implementation through aerial spraying with Bt for controlling bagworm outbreaks in oil palm smallholdings in Johor is discussed in this study.

MATERIALS AND METHODS

Mass Propagation of *Bacillus thuringiensis* (Bt)

The mass production of Bt-based bioinsecticides developed by MPOB for controlling bagworm has been patented (Patent No. PI2011000307). The formulated Bt product, Ecobac-1 Emulsified Concentrate (EC), is derived from an indigenous isolate, known as MPOB Bt1 (Mazmira et al. 2010; Noorhazwani et al. 2017; Ramlah & Basri 1997). The active ingredients (a.i.) of Ecobac-1 (EC) comprised of spores and δ-endotoxins, which are standardised to 1600 international unit (IU) mg^{-1}.

Aircraft Models for Aerial Spraying

The bagworm infested area was mapped with a global positioning system (GPS) and sprayed using agricultural aircraft (model AgCat and Dromader). AgCat was the first model used for aerial spraying, operated from 2012 until April 2014, while Dromader was used since October 2014. Two types of aircraft were used for aerial spraying in the two smallholdings namely *Grumman G-164 A* Super AgCat (Figure 1a) and *Mielec M-18* Dromader (Figure 1b). The description of the two aircraft models is as in Table 1.

Figure 1. Type of agricultural aircraft used for the Bt aerial spraying, (a) Grumman G-164 A Super AgCat, (b) Mielec M-18 Dromader

Table 1. Description of aircraft model used in this study

Description	*Grumman G-164 A* Super AgCat	*Mielec M-18* Dromader
Performance	Maximum speed: 237 km/h (128 kt), typical working speed range from 130 to 160 km/h (70 – 86 kt). The initial rate of climb: 1,080 ft/min	Maximum speed: 256 km/h (138 kt), cruising speed: 205 km/h (110 kt), typical operating speed: 230 km/h (124 kt). Initial rate of climb: 1,360 ft/min
Weights	Empty: 1429 kg (3,150 lb), maximum takeoff load: 3,184 kg (7,020 lb)	Empty: 2,690 kg (5,930 lb), maximum take-off load: 4,700 kg (10,360 lb)
Dimensions	Wing span: 10.95 m (35 ft 11 in), length: 7.11 m (23 ft 4 in), height:	Wing span: 17.70 m (58 ft 1 in), length 9.47 m (31 ft 3 in), height over

	3.27 m (10 ft 9 in). Wing area: 20.5 m2 (328 sq ft)	tail 3.70 m (12 ft 2 in). Wing area 40.0 m2 (430.5 sq ft)
Coverage	Approximately 500 to 700 ha/day depending on weather conditions and location of airstrip	Approximately 800 to 1,000 ha/day depending on weather conditions and location of airstrip

Aerial Spraying Operation Using Ecobac-1 (EC) Bt-based Bioinsecticide.

Aerial spraying of Bt is an exclusive application method, and it is a more effective approach to cover vast outbreak areas than ground spraying because the spraying needs to be cautiously strategized. The biopesticides mixture preparation needs to be carried out carefully at the airstrip to ensure the correct dosage of application (Figure 2). It is crucial that the spraying is conducted at the beginning of the pest generation, as the younger larvae are more susceptible than the mature ones. Therefore, spraying should not be carried out during the pupal stage, except during the occurrence of multi-stages infestation. The series of Bt application in the Sh.A and Sh.B were applied from 2012 to 2016, as listed in Table 2.

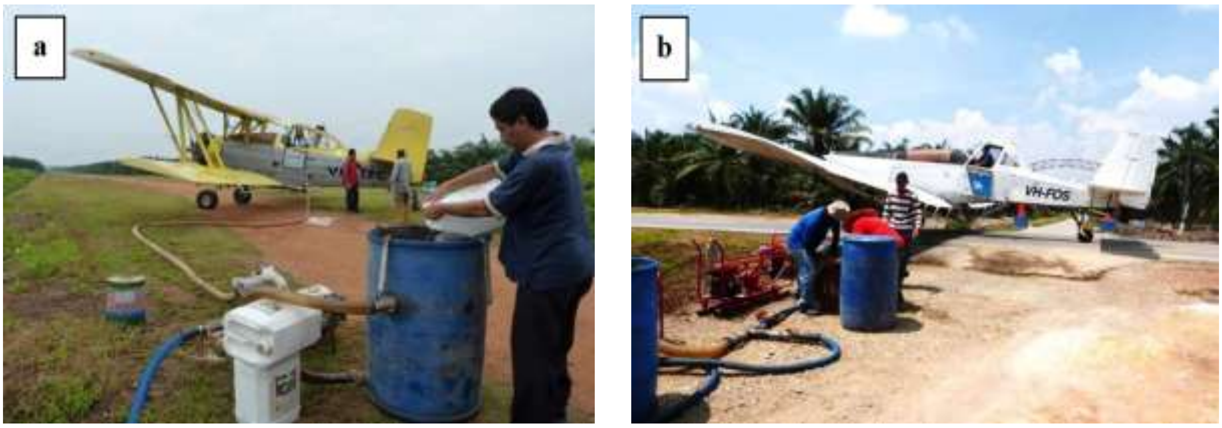

Figure 2. Filling of Bt based biopesticides and water to the aircraft at the airstrip, (a) Grumman G-164 A Super AgCat, (b) M-18 DromaderM18 Dromader

Table 2. List of Bt aerial sprays in oil palm plantations, ie. smallholding A and B

	Area	Date	Hectarage (ha)
1st spray		16 January 2012	
2nd spray	Smallholding A	18 April 2013	944
3rd spray		21 October 2013	
1st spray		18 April 2013	
		25 November 2015	
2nd spray	Smallholding B	2 February 2016	3,336
3rd spray		11 February 2016	
4th spray		2 May 2016	

The aerial spraying of Bt using Ecobac-1 (EC) via aircraft in controlling bagworm in smallholding Awas commenced on 16 January 2012. The operation covered approximately 944 ha of bagworm infested areas in Sh.A (Figure 3), while the first generation of aerial spraying in Sh.B, which covered 3,336 ha began on 18 April 2013.

Figure 3. First aerial spray conducted using AgCat at Smallholding A in 2012

Bagworms Census

The Standard Operation Procedure **(**SOP) Guidelines for Bagworm Control (2016) stated that the census should be conducted on at least 1% of the outbreak area. Census was at 0, 7, 14, and 28 days after treatment (DAT) (Figure 4). Ten percent of the infested area had to be censused, which worked out to 1 frond/palm from every tenth palms (SOP Guidelines for Bagworm Control 2016). The control procedure should be conducted once the female pupal bags hatched into early larval stages (Norman et al. 2004; Ramlah et al. 2007a, 2007b). Control measures should start immediately when the larval population is at the early instars and the number is above the threshold level. The threshold level for *M. plana* is 10 larvae/frond (Wood 1971; Wood & Norman 2019b). The spray should then be postponed if more than 70% of the larval populations are at the late instars or pupal stage (Basri 1993; Mazmira et al. 2010; Noorhazwani et al. 2017; Ramlah et al. 2007a, 2007b).

Figure 4. Bagworm census at the infested smallholding

After carrying out 3 rounds of multiple spray at Sh.A and 4 rounds at Sh.B, the post-census of the bagworm population was carried out at Sh.A (1 October 2020) and Sh.B (7 November 2019). This is in order to monitor the areas and determine the efficacy of the bagworm control operation.

Data Analysis

Data of bagworm survival after multiple Bt sprays were analysed using the analysis of variance (ANOVA) at $P=0.05$ and means were separated using the Least Significant Difference (LSD) analyses run using Sigma-plot.

RESULTS AND DISCUSSION

Multiple Bt Aerial Spraying at Smallholding A

The pooled average bagworm data recorded after the first aerial spray at Sh.A showed that the bagworm had gradually reduced from 94.1 bagworms per frond (BPF) to 34.9 BPF at 28 days after treatment (DAT) with 63% of bagworm reduction. The average pupae that survived the aerial spray at 28 DAT was 12 pupae per frond (PPF) (Table 3). Since most of the population was still above the threshold level, a follow-up aerial spray was required to control the subsequent generation of the bagworm.

Table 3. Bagworm survival after multiple aerial spraying using Ecobac-1 (EC) at Smallholding A in Johor, Malaysia

	DAT	**Total larvae**		**Pupae**		**Total bagworm**		**Bagworm reduction (%)**
		Range	**Average**	**Range**	**Average**	**Range**	**Average**	
1st spray	0	0–154	94.1±2.6	0–0	0–0	0–154	94.1±2.6	-
	14	0–54	30.5±1.0	0–0	0–0	0–54	30.5±1.0	67.6
	28	0–24	23.0±0.8	0–24	12.0±0.5	0–59	34.9±1.2	62.9
2nd spray	0	0–42	25.0±1.0	0–0	0–0	0–42	25.0±1.0	-
	14	0–4	1.2±0.1	0–21	12.7±0.5	0–23	14.6±0.6	41.6
	28	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*
3rd spray	0	0–125	97.1±4.1	0–0	0–0	0–125	97.1±4.1	-
	14	0–61	46.7±2.1	0–0	0–0	0–61	46.7±2.1	51.9
	28	0–21	11.8±0.6	0–9	4.2±0.4	0–29	16.0±1.0	83.5
Post census		0-0	0±0	0	0±0	0-0	0±0	0

Note: NR – not recorded

Due to some problems with the aircraft conditions, the second round of aerial spray at Sh.A was conducted on 18 April 2013, which was almost 14 months after the first aerial spray. The bagworm population in Sh.A recorded an average of 25 BPF larvae compared to 23 BPF recorded in February 2012 at 28 DAT after the first spray. This stable population of bagworms in the area could be attributed to several factors, such as the weather conditions and the presence of natural enemies in the area. Cheong et al. (2010) stated that the natural enemies, such as predators and pathogens helped to reduce or decrease the population of bagworms in the oil palm plantations. From a study conducted by Halim et al. (2017), it was found that *Cotesia metesae* was the highest parasitoid in reducing bagworm population in Yong Peng. *Cotesia metesae* scored the highest percentage of emergence with 51%, *Brachymeria carinata* 21%, followed by *Buysmania oxymora* 13%, *Goryphus bunoh* 8%, *Pediobius* sp. 5%, and lastly *Eupelmus cotoxanthae* 2%.

Moreover, a study by Mohammad Helmi et al. (2021) found that parasitoids had favorable relationships with the occurrence of bagworms at various time intervals. The population of Ichneumonidae was expected to rise after two to six weeks due to an increase in the population of middle instar bagworms (L3 to L4), whereas the population of Braconidae was expected to rise after six to 12 weeks due to an increase in the population of bagworms, regardless of instar stages. However, the infestation had spread to other areas, including Sh.B (Table 4). The spreading of bagworm was likely due to many factors, including strong wind, vehicles, humans, and animals (Cheong & Tey 2012). One such aspect could be the shape of the interconnected frond canopy's cover, which shields the bagworm from direct sunshine and heavy rainfall. Besides, bagworms rest beneath oil palm leaflets, which give them protection from rain droplets (Nor Ahya et al. 2012).

As recorded in Table 3, the second round of aerial spray at Sh.A had effectively reduced the bagworm population from 25.0 BPF at 0 DAT to 14.6 BPF at 14 DAT with 41.6% of larvae reduction (Table 3). The third round of Bt aerial spray in Sh.A was conducted on 21 October 2013. In the third round of Bt aerial spray, the average number of bagworms recorded at 0 DAT was 97.1 BPF, which had been successfully reduced to 16.0 BPF at 28 DAT with 83.5% of total larvae reduction. The average total pupae survived at 28 DAT was 4.2 pupae/frond, which was below the threshold level (Table 3). The census on 16 May 2019 at Sh.A recorded that the bagworm was below the threshold level of which only one pupa was found, indicating that the

Bt treatment indeed contributed to long-term protection against bagworm within the area. However, there was a recurring infestation during the second generation of aerial spray. Based on Table 3, pupae were present at 28 DAT after the first generation spraying of Ecobac-1 (EC), whereby the pupae per frond (PPF) were 12 PPF. Therefore, the occurrence of eggs hatching from the previous generation caused a higher larval population before the treatment.

At 0 DAT of the third generation of EC aerial spraying, it was noted that the pupae per frond (PPF) had significantly decreased to 4.2 PPF with a range of 0–9 PPF (Table 3). This showed that the bagworm population had reduced significantly for the third-generation spray. Unfortunately, in 2014, the aerial spray was not conducted due to the aircraft breakdown which stemmed from the electrical short circuit from which caused failure of the radio transmitter and mechanical part. The post-census conducted at Sh.A on 1 October 2020 resulted there was no live bagworm found in the area.

Multiple Bt Aerial Spraying at Smallholding B

The first aerial spray at Sh. B had significantly decreased the bagworm population from 162.5 BPF to 74.1 BPF at 14 DAT with 54.4% reduction of the population (Table 4). The average total bagworm of 266.6 BPF at 0 DAT had reduced to 129.9 BPF at 28 DAT with the total bagworm reduction of 42.7% after the second generation. The increase of the bagworm population in the second generation was likely due to the high number of pupal population present in the first generation, which was 69.7 PPF. A study by Noorhazwani et al. (2017) proved that the high number of pupal populations caused the increase of bagworm instars in the next generation. Besides, the increase of the bagworm population in Sh.B after the first aerial spray was also possibly due to the dry conditions which could have induced the bagworm to feed more (Noorhazwani et al. 2017). The bagworm census indicated that *M. plana* infestation in Sh.B had significantly reduced from 192.0 BPF to 61.1 LPF at 14 DAT (Table 4) with 68.2% reduction of bagworm population.

The effect of multiple Bt aerial sprays was seen at 28 DAT thereby reducing the bagworm population up to 70.7%. The fourth Bt aerial spraying in Sh.B had recorded a significant reduction of the bagworm population from 137.7 LPF to 64.7 LPF at 14 DAT (Table 4) with 53.0% reduction. The Bt's multiple aerial sprays had reduced the total bagworm population by 84.0% at 28 DAT. The average number of pupae was only 8.3 PPF at 28 DAT. The post-census conducted at Sh.B on 7 November 2019 showed a successful control of bagworms; thus there was no live bagworm found in the area.

Table 4. Bagworm survival after multiple aerial spraying using Ecobac-1 (EC) at Smallholding B in Johor, Malaysia

	DAT	Total larvae		Pupae		Total bagworm		Bagworm reduction (%)
		Range	Average	Range	Average	Range	Average	
1st spray	0	0–294	162.5±6.1	0–0	0±0	0–294	162.5±6.1	-
	14	0–8	4.3±0.3	0–109	69.7±2.7	0–112	74.1±2.9	54.4
	28	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*	*NR*
2nd spray	0	0–259	226.6±6.0	0–0	0±0	0–259	226.6±6.0	-
	14	0–158	193.7±5.1	0–0	0±0	0–158	193.7±5.1	14.5
	28	0–161	129.9±1.0	0–0	0±0	0–161	129.9±1.0	42.7
3rd spray	0	0–196	192.0±4.3	0–0	0±0	0–196	192.0±4.3	-
	14	0–138	61.1±3.4	0–0	0±0	0–138	61.1±3.4	68.2
	28	0–128	56.2±3.0	0–0	0±0	0–128	56.2±3.0	70.7

4^{th} spray	0	0–42	137.7±1.3	0–0	0±0	0–42	137.7±1.3	-
	14	0–119	64.7±2.7	0–0	0±0	0–119	64.7±2.7	53.0
	28	0–32	13.8±0.7	0–23	8.3±0.5	0–54	22.1±1.2	84.0
Post census		0-0	0±0	0	0±0	0-0	0±0	0

Note: NR – not recorded

It was observed that bagworm infestations tend to recur in the study location even after two rounds of Bt aerial spray. Several factors have been recognized as the possible sources for the outbreaks, namely high pupae population, continuous usage of chemical insecticides, lack of beneficial plants in the plantation to attract natural enemies, and infestation from neighboring areas (Ramlah et al. 2007b). The polyphagous nature of *P. pendula*, inadequate management of bagworm infestations by smallholders due to high pesticide costs and the mono-cropping strategy in oil palm plantations, which favors bagworm infections, are all probable reasons (Cheong et al. 2010). Noorhazwani et al. (2017) stated that the high number of pupae population caused the high number of bagworm instars in the next generation; thus, costed more in controlling bagworm. In a study carried out at Hilir Perak in 2010, it was reported that aerial sprays of Bt in estates with a well establishment of beneficial plants successfully reduced the bagworm population under threshold compared to the estate without establishment and non-existence of beneficial plants (Mazmira et al. 2010).

Uncontrolled usage of chemical pesticides without a systematic approach would lead to a more severe infestation over the years. The blanket usage of herbicides to eliminate ground cover could also lead to a more severe outbreak because clearing ground covers affects the population of beneficial insects, which is essential as a biocontrol agent to reduce the bagworm infestation. In providing a good understanding of the IPM programme, MPOB has been educating the smallholders on the right strategies in controlling the bagworm outbreak.

CONCLUSION

Multiple aerial sprays of Bt conducted at the oil palm smallholdings in Johor had shown significant reductions in the bagworm population. The history of the bagworm outbreaks in the areas was possibly due to the massive outbreak ascribed to the uncontrolled application of chemicals, which was worsened by the absence or lack of beneficial plants. The precise timing of the aerial spray based on the bagworm's life cycle is crucial in ensuring the effectiveness of the application. Multiple aerial sprays of Bt at heavily infested areas between generations of bagworm are considered a critical strategy to bring down the larvae and pupa populations below the economic threshold level.

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