SUSTAINABLE CONTROL OF BAGWORM (LEPIDOPTERA: PSYCHIDAE) IN OIL PALM PLANTATION: A REVIEW PAPER

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ABSTRACT

The oil palm industry is a key economic agriculture activity to contribute to Malaysia Gross Domestic Product (GDP). In 2019, it was reported that oil palm GDP was about RM38 Billion or 38% of the agricultural sector in Malaysia. However, the substantial yield reduction due to pest attacks are becoming main threats in the oil palm industry. The bagworm (Lepidoptera: Psychidae) is one important leaf eating pest that could cause severe leaf damage and yield losses up 43% without a proper treatment as stated by Malaysia Oil Palm Board (MPOB) in 2016. Integrated pest management (IPM) has been suggested in pest control measures by integrating various techniques such as biological controls, cultural controls, and chemical controls. Insect natural enemies consist of predators as a biological control agent that capture and feed on bagworm thus reducing the infestation outbreaks. The establishment of ground vegetation flowers such as beneficial plants able to increase the insect natural enemies’ population as a part of cultural controls. The presence of beneficial plants would provide nectar as a food source for predators. Chemical controls have been identified as an effective measure to reduce the incidence of bagworm in oil palm estate. The application of insecticides through Trunk Injection (TI) and aerial spraying are fast-acting to reduce the larval population of bagworm. The investigation of pheromone traps was carried out for trapping of male bagworm moths thus reducing the subsequent population of larvae due to reducing chances of mating. This paper deliberates on controlling the bagworm population through integrated pest management (IPM) that ensures sustainable control of bagworm in oil palm plantation.

Key words: Bagworm, IPM, biological controls, cultural controls, chemical controls, sustainable control

INTRODUCTION

Oil palm plantation has been expanding to the highest yielding vegetable oil crop per unit area (Murphy, 2009). In Malaysia, oil palm (Elaeis guineensis) is a major agriculture sector contributing to Malaysia Gross Domestic Product (GDP). However, the detrimental effects to the oil palm industry due to the emergence of various pests thus become a loss to the annual oil palm production (Yap, 2005). According to Wood (1971) and Corley and Tinker (2003) that insufficiency of predators as natural enemies in the environment is related to the existence of pests in oil palm plantations. In addition, the declining natural enemies’ diversity in poor habitat of agroecosystems lead to the pest outbreak (Kruess and Tscharntke, 1994; With et al., 2002). Basri et al. (1995) has reported that the existence of parasitoids has significance as a biological control to regulate bagworm population. The initiative of increasing the population of parasitoids and predators can be done by establishment of recommended beneficial plants to supply nectar as a food source for them. It has been confirmed by Basri et al. (1995) that the life span of adult parasitoids and predators in the laboratory with sufficient food supply. Gazhali et al. (2016) and Ashraf et al. (2018) have reported the decreasing of arthropod biodiversity due to monoculture oil palm of oil palm that caused damage to the foliage. According to Basri and Kevan (1993), a moderate defoliation of about 10%-13%. However, further defoliation is about 33%-40% may cause crop loss in oil palm plantations. Ecological functions in agroecosystems such as pollination and biological control are affected due to poor biodiversity in oil palm plantations (Feintrenie et al., 2010).

The bagworms are one of the major leaf-eating pests yield reduction in two years due to moderate defoliation (10 -13%) caused by Metisa plana Walker (Lepidoptera: Psychidae). Bagworm is referred to as a larva which hides in a built protective bag like a cocoon. Numerous bagworm species commonly found in Malaysia are based on cocoon size and shape identified in the field. The shapes and sizes of cocoons have variation from a narrow hose to an expansive sac (Cheong and Tey, 2012). Wood (1968) has reported that three major species of bagworms in South-east Asia caused oil palm damage namely, Metisa plana Walker, Pteroma pendula Joannis and Mahasena corbetti Tams. These three psyched species have commonly reached outbreak status (Wood, 1968; Basri et al., 1988; Hoong and Ho, 1992). Several studies have reported that Metisa plana is a significantly key pest of oil palm plantations in Malaysia. Basri et al. (1988) reported that the study in 1929 has identified Metisa plana as the first among other pests. Meanwhile, Wood and Nesbit (1969) has reported the most common incidence of bagworm attack in Eastern Sabah was Mahasena corbetti. Moreover, Norman and Basri (2007) reported that the infestation of Metisa plana was identified as the most widely affecting oil palm in Peninsular Malaysia. Ho et al. (2011) has analysed the historical records of bagworms infestation in Peninsular Malaysia. The analysis showed that the total 69 estates in Peninsular Malaysia about 63 955 ha were attacked by Metisa plana and Pteroma pendula as a primary pest. The oil palm was damaged due to the bagworms feed behaviour, specifically on the...
leaflets. Besides, it is using small pieces of leaflets and small twigs embedded by tough silk as the materials to build the caterpillar casing as a cocoon to develop the larvae into pupae and later adults (Barlow, 1982).

Norman and Basri (2007) have revealed the bagworm outbreak, mainly of *Metisa plana* and *Pretoma pendula* incidence, occurred about 16% of the total area of 1.9 hectares throughout Malaysia in 2000 to 2005. Meanwhile, approximately 32,475 ha estate and 5100 smallholder land in central Johor was infected by bagworms (Mazmira et al., 2015). Earlier, Wood et al. (1973) reported that a damage of 50% will cause the oil palm yield decline to 43%. The study by Cheong et al. (2010) has reported the biological control agents such as predators, parasitoids and pathogens significantly associated with the bagworm mortality about 37%, 35.9% and 27.2% respectively with naturally controlling bagworm populations in oil palm plantations. According to Hajek (2004) and Norris et al. (2003), biocontrol is an eco-friendly and sustainable mechanism to reduce pest population by using natural enemies when the number of pests is below economic level. In addition, Sethi and Gupta (2015) have mentioned that the biological control application in agriculture relies on natural agents rather than chemicals.

Integrated pest management (IPM) is the best mechanism to control the outbreaks of bagworm population in oil plantations (Ramlah et al., 2013; Mohd Mazmira et al., 2010; Najib et al., 2013). According to Wood and Norman (2019), further study on the relationship between current regular treatments and continuing infestation have to be done. These reviews focus on the importance of various mechanisms of bagworm controls and recognising the possible ecological factors in pest control. The application of selective biopesticides, chemicals, mass-trapping by pheromone to complement on-going biological agents contributed to the developing science that became known as integrated pest management (IPM). There has been a gradual increase in bagworm infestation widespread and intensive in many places since 1990. The need of pesticide application besides the existence of biological control in the affected areas without much appreciation of selectivity. In many years, extensive research work has been conducted wherever the existence of bagworm infestation has been outstanding. The continuity of study would improve the current knowledge of bagworm control for minimizing the threats of outbreaks and crop losses. The review finding summarized the application of biopesticides as well as chemicals to control the outbreaks; usage of mass-trapping by pheromone attractant in sticky traps has been discussed as an alternative for continuous male bagworm moth trapping in the field and the establishment of beneficial plants for natural pest control such as predators and parasitoids due to the existence of nectar producing flowers.

**Biopesticides**

Biopesticides are derived from microbes and plants are known as biological natural agents. The application of biopesticides can target the specific pests and save the environment from any chemical pollution. Application of *Bacillus thuringiensis* (Bt) is not affecting the non-target organisms including the oil palm pollination weevil, *Elaeidobius kamerunicus* (Najib et al., 2015). Furthermore, Najib et al. (2014) reported that Bt is an environmentally friendly microbial insecticide that is not toxic to freshwater fish, human, domestic animals and vertebrates (Najib et al., 2015). Bt has produced crystalline protein inclusion during sporulations as it has become insecticidal actions against bagworms (Nester et al., 2002). In addition, the proteins are highly specific against certain insect orders (Hofte and Whitely, 1989). Mazmira et al. (2011) has reported that bagworm has been controlled effectively in several oil palm plantations in Malaysia using *Bacillus thuringiensis* (Bt) via aerial spraying. According to Basri (1993) and Chong et al. (2010) that the reduction of bagworm population was not only caused by Bt product application but also the biotic and abiotic factors have the important roles in reducing the population and regulating the larval community.

In addition, Hasber et al. (2015) reported that single treatment using bioinsecticide (Btk) have controlled *Metisa plana* larvae satisfactorily compared to the synthetic insecticides such as trichlorfon, cypermethrin and lambda-cyhalothrin. However, the application of Btk was not efficient to reduce the larval population below ETL when the population of *Metisa plana* larvae was high-density (>50 larvae/foot). It was suggested that regular application of Btk is recommended to reduce the population below ETL. According to Tan et al. (2008), application of Btk with concentration between 20 to 100 ppm under laboratory conditions resulted in 70% - 100% of larval mortalities. Meanwhile, Kok et al. (2012) found that Btk 324 ppm in laboratory conditions was the slowest-acting insecticides to control *Metisa plana*. Hasber et al. (2015) suggested that further studies needed to optimise the application Bt conditions for effective control of bagworm larvae in oil palm plantations.

**Chemicals**

Malaysian Agriculture Digest (2013) has reported that the usage of agrichemicals in Malaysia in 2005 was RM 328 million. Meanwhile in 2012 the increment figure of agrichemical usage to RM 563 million was reported. The usage of pesticides in Malaysia showed a similar trend where there was a significant increase of about 28% since 2008. Application of chemical control, methamidophos through trunk injection and cypermethrin through spraying to infected oil palm by bagworms have shown positive results where live larval numbers fell below the threshold level of 10 LPF (Norman and Basri, 2010). In young oil palm, a knapsack sprayer is used to control identified bagworm population (Basi et al., 1988; Sudarsono et al., 2011) Based on reports by Yap (2000) the bagworm outbreaks have suppressed and maintained the infestation below the action threshold by using chemical control. According to Salim et al. (2015) that the fastest acting of chemical insecticides can be seen 30 days after a single application of chemical insecticides where the larval population dropped below economic threshold level (ETL).

Soil chemical drenching with organophosphate insecticides trichlorfon and chlorpyrifos and the pyrethroid insecticides cypermethrin and lambda-cyhalothrin have been used to control the bagworms population (Basi et al., 1988; Chung, 1988; Yap, 2005). Rhaids et al. (2009) found that chlorantraniliprole showed the effective control of bagworm populations where the chemical had a residual effect for 10-day thus providing effective control to protect oil palm over the sustained period of bagworms. Chemical controls are the main mechanism in most oil palm plantations to control the outbreaks of bagworms (Hasber, 2010). Based on further study, Hasber et al. (2015) reported the application of synthetic insecticides such as trichlorfon, cypermethrin and lambda-cyhalothrin in oil palm has effectively controlled the population of bagworms after 30 DAT.
Ground spraying was done in a field with a single round of treatment and reduced the bagworm populations below the ETL at 30 DAT (<5 larvae/frond). These findings were consistent with Chung (1998) who reported the efficiency of trichlorfon and cypermethrin have reduced the bagworm population below the ETL at 30 DAT. The similar findings also discovered by Syed and Salleh (1991) that the application of trichlorfon was very effective to control larvae of Metisa plana with a dosage at 1 kg (95%) per hectare in a single treatment. Similarly, Kok et al. (2012) demonstrated pesticides application under laboratory conditions control against bagworms. The application of trichlorfon (1900.0 ppm), chlorantraniliprole (50.0) and cypermethrin (75.0 ppm) showed effective control of bagworms and it is a potential for Metisa plana management.

Trunk injection (TI) has been chosen as a treatment to control bagworm population since the mid-1970s. (Khoo et al., 1983). The correct chemical application time is extremely important for effectiveness of treatment. After full emergence of larva is the right time for optimum chemical application. The chemical residue remains in leaves for certain periods have killed the subsequent pest generations (Wood, 1976; Wood, 1988). Reliable census would determine the correct time for chemical treatment thus achieving good results in bagworms population control (Chung and Sim, 1993). Wood (1987) reported that there is no significant damage against oil palm due to drilling the holes in the palm trunk. In addition, pesticides residues have not remained in the edible products (Yap, 2005).

**Mass Trapping by Pheromone**

Mass trapping using pheromone-baited has been achieved to directly control the insect pest (Smit et al., 2001; Alpizar et al., 2002; Norman and Othman, 2006; Norman et al., 2010). However, the effectiveness of pheromone traps is influenced by several factors such as distance of insects to trap (Byers, 1999), the trap design (Valles et al., 1991) and pheromone plume characteristics (Ali Niaze, 1983). In addition, Witzgall et al. (2010) have reported that trap maintenance, cropping system, residue management and environmental conditions were postulated to have affected pheromone efficacy. The usage of pheromone traps is cost-effective compared to mating disruption due to a smaller number of pheromones required as well as crop contamination (Witzgall et al., 2010).

The application of live virgin females’ bagworms (Metisa plana) as pheromones to trap the male bagworms (Norman and Othman, 2006; Normal et al., 2008; Norman et al., 2010). Norman et al. (2010) found that the synthetic female sex pheromone has a potential to be developed as for mass trapping of male bagworms. In addition, Norman et al. (2010) reported that the number of live larvae per frond reduced based on the number of female bags with eggs in the trapping plot thus reducing the frond damage. Further studies by Norman et al. (2012) resulted in the confirmation that chances of successfully mating was reduced by trapping the male moth. It was reported that the percentage of female bags with eggs in the trapping plot was about 20% lower than the control plot hence lowering the population of the subsequent bagworm’s generation.

**BIOLICAL AGENTS**

Enhancing the biocontrol agent management in oil palm plantations is an important approach to reducing pest populations. The losses of biodiversity in a wide range of organisms as well as biocontrol agents due to the conversion of natural habitat to oil palm plantations (Bernes et al., 2014; Fitsherbert et al., 2008). As suggested by Gray and Lewis (2014) the landscape heterogeneity in oil palm plantations is a potential mechanism to diversify the biodiversity especially the population of native biocontrol agents through the protection of riparian buffers. This is supported by Foster et al. (2011) and Koh et al. (2009) that protection of natural habitat surrounding the oil palm plantations can promote the predation rates as a biological agent. Maintaining diverse habitats inside and surrounding oil palm plantations support the movement of predatory insects and the potential for predators to control crop pests bridging biodiversity conservation and function (Lucey et al., 2014; Senior et al., 2013; Tschamke et al., 2007). In addition, planting and maintaining flowering plants in oil palm plantations is necessary to improve the ability of natural enemies to control pest populations as part of integrated management programs (Mathew et al., 2007). Kamarudin and Wahid (2010) have reported that planting Cassia cebunensis within the vicinity of oil palm plantations can promote bagworms’ parasitoids.

**Parasitoids**

Parasitoids can be described as living things or organisms that live in or inside the host or predators to control pests. Parasitoids are the extremely effective natural enemies in controlling pest populations on farms (Hawkins et al., 1997). Parasitoids can be described as living things or organisms that live in or inside the host organism and eventually kill the host. In other terms, parasitoids are parasitic insects that grow from larvae found on or in an individual host of eggs laid either in or near the host (Cheong and Tey, 2013). Since 1967, there have been several parasitoids that were identified that are parasitoids against M. plana and P. pendula (Brian and Norman, 2019). According to Wood (1968), he described and first described some of the parasitoids including Dolichogenidea (Apanteles) mesetae. As stated from Brian and Norman (2019), around 10% of all insect species labeled as parasitoids found in the Order Hymenoptera are one of many insect parasitoids with several Diptera (flies) mainly from individual species of larger size as shown in Table 1.

There are two types of parasitoids which are primary parasitoids and secondary parasitoids or other names referred to as hyperparasitoids. According to Basti et al. (1995), study from PORIM Kluang, Johor, revealed that the primary parasitoid contains six species and secondary or hyperparasitoid is another six species as shown in Table 1. This study was supported (Basti and Kevan, 1995; Norman and Basti, 2010; Jamian, 2017) where the records showed hemipteran species attacked bagworms along with six primary parasitoids and predators against M. plana. Hyperparasitoids were attacking other parasitoids that are related to bagworms as a family of Hymenoptera is commonly found for the main oil palm bagworms. This shows that the hymenopteran family may function as primary or secondary parasitoids (Brian and Kamarudin, 2019), of which several of the highly ordinary are the family Eulophidae, Eurytomidae, and Ceraphronidae. Further research from the field collection is from Tiong (1979), Basti et al. (1995), Teh (1996), and a comprehensive account by Norman et al. (1996). Coincidentally, the life cycles of pests and parasitoids can be associated, or pests can be changed by parasitoids to accommodate their growth (Debach, 1974; Debach and Rosen, 1991).
A major parasitoid in oil palm plantations in Peninsular Malaysia, *D. metesae* were found to attack another species of bagworm, *Pteroma pendula*. (Norman et al., 1998; Cheong et al., 2010; Mahadi et al., 2012; Halim M. et al., 2018). Prior studies from Hanysyam et al., (2013) identified that parasitoids of the family Ichneumonidae (*G. bunoh and B. oxymora*) which are closely associated, act as main parasitoids, also has a large and high presence in oil palm plantations attacked by bagworms. There is another species from the family Chalcididae (*B. carinata*) which is the main parasitoid has also been identified as one of the most plentiful hymenopteran parasitoids of bagworms in Peninsular Malaysia (Yusdayati et al., 2014; Halim M. et al., 2018). Among the control effects performed by primary parasitoids where this species will interfere with or slow down the formation of natural balance (Brian and Kamarudin, 2019). This indicates the specific importance of these species in regulating the population of pests.

### Table 1: Classification of parasitoid against bagworms in oil palm plantation from 1970 to 2002

<table>
<thead>
<tr>
<th>Types of Parasitoid</th>
<th>Super Family</th>
<th>Family</th>
<th>Species</th>
<th>Bagworms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Hymenoptera</td>
<td>Braconidae</td>
<td>Dolicoegenidea (Apanteles) metesae, Aulosaphes psychidivorus</td>
<td>Metisa plana</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ichneumonidae</td>
<td>Goryphas bunoh, G. inferus, Fislistina sp., B. oxymora</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chalcididae</td>
<td>Brachymeria spp., B. carinata</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eulophidae</td>
<td>Tetrastichus sp., Pediobius sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elasmidae</td>
<td>Elasmus sp.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Braconidae</td>
<td>D. metesae, A. psychidivorus</td>
<td>Pterona pendula</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chalcididae</td>
<td>Brachymeria spp.</td>
<td></td>
</tr>
<tr>
<td>Secondary (Hyperparasitoid)</td>
<td>Hymenoptera</td>
<td>Eulophidae</td>
<td>Pediobius sp., P. imbreus</td>
<td>Mahasena corbetti</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ichneumonidae</td>
<td>Echthromorpha agrestoria, G. bunoh</td>
<td></td>
</tr>
<tr>
<td>Diptera</td>
<td>Tachinidae</td>
<td>Eozennia equatorialis, Palexorista solennis, Thrycola psychidarium, Exorista quadrimaculata</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


### Predators

In Malaysia, bagworms are one of the common and severe pests of oil palm (Basri et al., 1988). Pests on crops can be handled through two main methods through chemical input with the use of pesticides or biocontrol (Wood, 2004). Controlling this pest by using chemicals continuously will affect the natural enemies of pests and indirectly to beneficial insects such as oil palm insect pollinators. Thus, successful integrated pest management requires biological control that has been the core of the program (Zulkifli et al., 2004). Jamian et al. (2017) states that an alternative to chemical dependence in agricultural systems using predatory insects has proven to be an effective biological control agent. Predatory insects are species that live freely by catching and eating bagworms in general, where most frequent are the bugs and beetles (Brian & Norman, 2019). According to Cheong and Tey (2013), whether larvae or nymphs, it takes several to many individuals to reach maturity indicating predatory insects differ from parasitoids. The predators are generalist feeders (wide host range) and will build up when an outbreak is already occurring.

### Table 2: Natural predator associated with a population of bagworms.

<table>
<thead>
<tr>
<th>Types of Insects</th>
<th>Super Family</th>
<th>Family</th>
<th>Species</th>
<th>Mode of Attack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bugs</td>
<td>Hemiptera</td>
<td>Reduviidae</td>
<td>Sycanus dichotomus</td>
<td>Sharp proboscis found in these predatory insects can penetrate and suck body fluids with reudvii which is incredibly capable for eating bagworms.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cosmolestes picticeps</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pentatomidae</td>
<td>Cantheconidia furcellata</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Platynopus melacanthus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beetle</td>
<td>Coleoptera</td>
<td>Cleridae</td>
<td>Callimerus arcafer</td>
<td>Grubs reside in the bagworm cocoon and feed the inside.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Control at pupal stages</td>
<td></td>
</tr>
</tbody>
</table>

Source: Jamian et al., (2010); Cheong and Tey, (2011); Jamian (2017); Norman et al., (2019); Brian & Norman (2019); Ahmad et al., (2020).

Predatory species from Hemipterans are an important group of predators found in oil palm plantations (De Chenon et al., 1989), which are *Cantheconidea furcellata* and *Platynopus melacanthus* (Pentatomidae) as well as killer bugs, *Sycanus dichotomus* and *Cosmolestes picticeps* (Reduviidae) have predatory abilities against worm caterpillars (Azlina, 2011; Siti Nurulhidayah et al., 2011, Norman et al., 2019). Prior studies (Schaefer and Ahmad, 1987; Zulkifli et al., 2004; Siti Nurulhidayah and Norman, 2016; Jamian et al., 2017; Siti Nurulhidayah et al., 2020), had proven that applicable biological control for nymphs and larvae of insect pests are reduviid predators. However, previous study from Azlina (2011) has shown that *C. picticeps* often show cannibalism to their own
population where it can thwart its role as an efficient biocontrol agent for bagworms causing it to become a less specific predator. Other predator agents such as species from Coleoptera that is chequered beetle *Callimera arcader* (Cleridae) have shown the ability to control the stages of bagworms even though this species is less well known (Cheong and Tey, 2011). Among the species, the most common Reduvuid bug that feeds on nellite caterpillars such as *Darna sp.* and *Setotheosa assigna* is *Sycanus dichotomus* Stål. (Singh, 1992; De Chenon et al., 2017); and bagworms such as *M. plana* and *P. pendula* (Jamian et al., 2010; Norman et al., 2017; Siti Nurulhidayah et al., 2020). The study from De Chenon et al. (1989) showed the effective way of *S. dichotomus* as a biocontrol agent for *M. plana*. Overall, *C. furcellata*, *P. melacanthus* and *S. dichotomus* are the most potential predators to control *M. plana* (Azlina, 2011; Jamian et al., 2017).

**Beneficial Plants**

The basis of the success of biological pest control programs is observed from the capability of assassin insects targeted to find their prey effectively to survive in the environment. The development of beneficial plants from ground vegetation flowers was an important element to ensure accomplishment in implementation of Integrated Pest Management (IPM) towards bagworms. Various types of plants have been correlated with the stimulation of the activity from natural enemies for the biological control of bagworms (Nor Sarashimatun et al., 2011). The performance of insect predators can be improved by introducing flowering plants that are usually grown on the edge of oil palm plantations (Jamian, 2017). Thus, there is some previous research done on the suitability of numerous species of flowers that can be planted in the oil palm environment to support natural enemies.

Plant species would produce nectar and flowers that consist of an open structure allowing easy access to the pollen. The vital role of parasitoids in regulating the number of bagworms reported by Basri et al. (1995), its population depends on the availability of sanctuary and food resources, such as nectar supplied by plants is advantageous in the oil palm ecosystem, while Basri et al. (1999) declared that these plants was discovered to extend the life of adult parasitoids. Jamian and Nur Azura (2018) report that the combination of flowering plants (*T. subulata*) and its prey (*M. plana*) will maintain the longevity and fertility of predatory insects. Longevity and fertility of predatory insects can be maintained by a combination of flowering plants (*T. subulata*) and its prey (*M. plana*) (Jamian and Nur Azura, 2018). However, the observations from Syed and Shah (1977), Brown and Norman (2019) show that shortage of food and shelter for adult parasitoids due to the devastation of soil vegetation can be the cause of leaf-eating caterpillar outbreaks. Norman and Basri 2010 reported that four species of plants are beneficial for bagworms and leaf eating insects which are *Cassia cobanensis*, *Asystasia gangetica*, *Crotalaria usaramoensis* and *Euphorbia heterophylla*. Meanwhile, *Cassia cobanensis*, *Asystasia gangetica*, *Euphorbia heterophylla* and *Turnera subulata* are four species of nectar-producing plants that beneficial to the biocontrol agent of bagworms (Basri et al., 2001; Ho et al., 2003; Norman et al., 2019).

The occurrence of *P. pendula* in oil palm cultivation has been assessed by the presence of parasitoids on *C. cobanensis* (Norman and Ohman, 2016). Insect predatory activity is seen to be more noticeable on farms meanwhile parasitoids prefer to live on plants that have nectar sources which are *C. cobanensis* and *Asystasia gangetica* (Norman et al., 2019). Basri et al. (1999) and Yusdayati et al. (2014) suggested that *Turnera spp.* better preferred than *C. cobanensis*, due to *Turnera spp.* flowering is continuous, whereas *C. cobanensis* flowers seasonally, once in a year that might require replanting if its growth is inhibited during the dry season. Factors of difficulty in establishing and having a short life cycle, *E. heterophylla* is not recommended for cultivation (Ho et al., 2003)

Basri et al. (1999) reported *C. cobanensis*, *Crotalaria usaramoensis*, *Asystasia gangetica* and *Euphorbia heterophylla* are flowering plants containing nectar consisting of sucrose, fructose and glucose. While nectar whose composition includes sugar, protein, phenolic, hydrogen peroxide and aromatic compounds produced from *Mucuna sempervirens* flowers (Liu et al., 2012). Carboxylic acids, lipids and other organic compounds are also found in flower nectar that could attract predatory insects due to volatile compounds from host plants (Baker and Baker, 1975; Buchmann and Buchmann, 1981). A comprehensive experiment was conducted by Ho et al. (2005) to evaluate the effectiveness of various types of beneficial plants and the results show three plant species namely *T. subulata*, *A. leptopus* and *C. cobanensis* become the most effective to attract natural enemies. Schlindwein and Medeiros (2006) have reported that *Turnera subulata* flowers can attract 28 species of insects. The results of previous studies from Jamian et al. (2020) showed that a strong attraction to beneficial plant for *T. subulata* against tested predators due to allelochemistry when released into the environment where these findings are in line with Yusdayati (2008), who reported that *Turnera sp.*, *A. leptopus* and *C. cobanensis* were preferred by natural enemy. Thus, these observations show the importance of cultivating beneficial crops such as *C. cobanensis* around oil palm plantations to maintain natural enemy populations for long-term bagworm control.

**CONCLUSION**

The sustainability of bagworm infestation outbreaks control measures has been investigated intensively in Malaysia. It is important to integrate various mechanisms in bagworm population control measures based on the current knowledge and operational practices. The prominent plantation companies have the research unit to study threats and opportunities regarding the issues of bagworm infestation in oil palm estate. Beside that, the researchers of government agencies and higher institutions have the same interest to collaborate for the sustainability of bagworm control measures needs and opportunities for field experimentation and knowledgeable investigation. Integrated pest management (IPM) is widely recognised and accepted in implementation of bagworms control in oil palm plantation. It is suggested that establishment of biological control would ensure the existence of biological agents to continuously control the population of bagworms as it is still under EDL. However, the incidence of bagworms more than EDL should be controlled with chemical application since the biological agents have been shown to be inefficient in controlling the bagworms population. The integration of several approaches and mechanisms such as biopesticides, chemicals and mass-trapping by pheromone are applicable whenever the infestation of bagworm exceeds the threshold level of 10 LPF. It is to be a complement for the establishment of biological controls agents as a preventive measure by attracting the parasitoids and
predators. The predators and parasitoids are the natural agents to control the bagworm population in the estate. The potential of treatment application would reduce the incidence of bagworms attack as to increase oil palm yield in plantations. Continuous monitoring of pest incidence through census programs to detect the early stage of infestation for immediate actions. Overall, the sustainability of bagworm control should be continuously investigated through intensive field work study. This is important to be referenced in estate operational activities especially for pest and disease management. The precise methods, sufficient knowledge and technical support will contribute to the optimum of oil palm plantations management. This review paper has highlighted the possible approach of sustainable control of bagworm in oil palm plantations. The findings of the paper have summarized from related literature specifically about the recommended measures for both chemical and biological controls in pest infestation controls. This is significant input to the practitioner in industry for the alternative solution in improving sustainability of bagworm control in oil palm plantations.

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