ESTABLISHMENT OF THE BIOLOGICAL CONTROL SYSTEM BY BLACK ANT, *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) AND MEALYBUG, *Cataenococcus hispidus* (Morrison) (Homoptera: Pseudococcidae) AGAINST THE COCOA POD BORER, *Conopomorpha cramerella* (Snellen) (Lepidoptera: Gracillariidae) IN NORTH SUMATERA, INDONESIA

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UNIVERSITI SAINS MALAYSIA

2011

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by

AHMAD SALEH

Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

JULY 2011

ACKNOWLEDGEMENTS

Praise be to Allah, the most Gracious and the most Merciful, who had blessed me with His Mercy to accomplish this research and completed writing this thesis.

Special thank to a wise and generous Prof Abu Hassan Ahmad, my advisor as well as supervisor, who always give provide confidence to me in my hard times, advice to my research progress, discuss and visit to field trials and lastly he has thoroughly read my thesis since the first draft until final. I am grateful that he suggested to PT. Lonsum and ensure that I can continue from Master to PhD programs. Equally important, Prof. Che Salmah Md Rawi, my co-supervisor, who always give suggestions that are important in implementing the experiments, analyzing the research results and in correcting this thesis.

I would like to thank Dr. S. Nelson, Director of Research, Bah Lias Research Station and the board of PT.PP London Sumatra Indonesia Tbk for the financial support and permission to pursue my PhD program.

I owe my deepest gratitude to the late Datuk Dr. R. A. Syed (Entomology consultant) and Mr. Harold Speldewinde (Planter) who introduced me to Prof Abu Hassan Ahmad for starting the Master program at Universiti Sains Malaysia, Penang in 1997. In addition, my thanks to Dr. H. L Foster (the previous Director of Research) who proposed and supported my postgraduate proposal to the board of Lonsum. I would like to thank Prof Arshad Ali and Dr. Hamady Dieng, who discuss some parts of my thesis and advice.

I am grateful to many of my colleagues; General manager, manager and staff of Lonsum cocoa estates, Crop protection staff and statistician to support and help program. Besides that thank for my conductors, Alik Latif, Misno, Yatno, Tetti Nurleni Siregar and M. Ali Nasution who conduct and recording my trials honestly. Lastly I would like to show my deepest gratitude and love to my wife, Sri Benty and my children Shofa Nurhadiasty and Adril Syafri for their moral support and love and understanding.

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PEWUJUDAN SISTEM KAWALAN BIOLOGI OLEH SEMUT HITAM, *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) DAN KUTU PUTIH *Cataenococcus hispidus* (Morrison) (Homoptera: Pseudococcidae) TERHADAP PENGOREK BUAH KOKO, *Conopomorpha cramerella* (Snellen) (Lepidoptera: Gracillariidae) DI SUMATERA UTARA, INDONESIA

Abstrak

Satu kajian untuk pewujudan *Dolichoderus thoracicus* (semut hitam) dan kutu putih (*Cataenococcus hispidus*) sebagai agen kawalan biologi untuk mengawal Pengorek Buah Koko (PBK) (*Canopomorpha cramerella*) dilakukan di ladang koko Bah Lias LONSUM di Sumatera Utara. *Canopomorpha cramerella* dewasa betina lebih suka bertelur di buah koko peringkat 4 (yang berumur 14-16 minggu, panjang buah 15 – 20 cm). Jumlah telur and larva tertinggi dijumpai di awal dan akhir tahun atau selepas berakhirnya puncak penunaian. Sebahagian besar telur dan larva ditemui pada buah daripada kanopi bahagian atas, dan kurang pada buah di kanopi yang lebih rendah dan terendah pada buah di batang pokok. Bilangan paling tinggi lubang masuk dan keluar larva PBK terdapat pada buah koko peringkat 5 (berumur 18-20 minggu, panjang buah 15 – 20 cm) sementara lubang keluar tidak dijumpai pada buah peringkat 1 (berumur 1 – 4 minggu, panjang buah 1 – 4 cm) dan peringkat 2 (berumur 5 dan 8 minggu, panjang buah 5 – 10 cm). Tujuh puluh peratus larva PBK keluar dari buah koko di antara jam 2100 - 0400 dan tertinggi pada jam 0200. Meskipun demikian, 5% dari larva keluar pada hari pertama atau kurang daripada 46% keluar dalam 3 hari setelah buah dituai. Larva PBK mengambil masa kurang dari satu jam untuk membuat kepompong yang melindungi mereka. Tidak ada telur diserang parasitoid yang ditemui pada buah yang diperiksa, sementara 92- 98% kematian larva secara semula jadi didalam buah koko. Selain itu, kematian semula jadi pupa di tanah lebih tinggi dibandingkan di kanopi. Lebih 30 peratus pupa PBK yang dikumpulkan dari lapangan mati disebabkan oleh

kematian semula jadi. Madu yang dihasilkan oleh kutu putih adalah makanan untuk semut hitam dan honeydew ini tidak memanjangkan umur kupu – kupu dewasa PBK (8.29 ± 0.24 hari).

Populasi semut hitam pada sarang yang diperbuat dari pada daun koko kering meningkat pada bulan seterusnya dan sarang tahan hingga 14 bulan. Sarang buatan perlu digantung selama 3 bulan pada pokok koko yang mempunyai populasi semut hitam yang tinggi sebelum dipindahkan ke kebun koko yang baru. Gabungan daun koko kering dengan bahan sintetik (beg poliester) memanjangkan masa manfaat sarang buatan lebih dari 4 tahun, seterusnya populasi semut hitam 2.2 kali lebih tinggi berbanding dengan populasi semut pada sarang buatan yang dibuat dari pada daun koko kering. Tujuh puluh lapan peratus daripada populasi kutu putih pada irisan kulit koko adalah nimfa dan selebihnya dewasa. Nimfa menunjukkan kemampuan pergerakan lebih besar dari pada dewasa. Kehadiran kutu putih pada bunga koko tidak memberi kesan terhadap pembentukan buah muda. Untuk membangun populasi semut hitam di ladang koko yang baru, pertama kawasan tersebut perlu bebas dari semut antagonis. Pengawalan semut antagonis dilakukan dengan menggunakan insektisida. Pengumpanan adalah kaedah umum yang digunakan untuk mengawal semut, namun, apabila menggunakan kaedah ini, pertimbangan mesti diberi kerana umpan beracun mungkin disukai oleh semut hitam. Kedua, pemindahan sarang buatan yang mempunyai semut hitam dan memberikan iris tipis kulit koko yang memiliki kutu putih perlu dilakukan di ladang baru. Bila 70% dari pada buah koko yang dituai telah mempunyai kutu putih pada buah, ini menunjukkan bahawa populasi kutu putih sudah cukup untuk mempertahankan populasi semut hitam yang tinggi di kebun koko. Keputusan kajian PBK ini boleh digunakan untuk membangunkan satu program Pengawalan Perosak Bersepadu dengan memberi penekanan kepada kawalan biologi.

ESTABLISHMENT OF THE BIOLOGICAL CONTROL SYSTEM BY BLACK ANT, *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) AND MEALYBUG, *Cataenococcus hispidus* (Morrison) (Homoptera: Pseudococcidae) AGAINST THE COCOA POD BORER, *Conopomorpha cramerella* (Snellen) (Lepidoptera: Gracillariidae) IN NORTH SUMATERA, INDONESIA

Abstract

A study on the establishment of *Dolichoderus thoracicus* (black ant) and *Cataenococcus hispidus* (mealybug) to be used as biological agents for *Conopomorpha cramerella*, cocoa pod borer (CPB) was carried out in LONSUM cocoa estates in Bah Lias, North Sumatera. *Conopomorpha cramerella* moths prefer to lay their eggs on cocoa pods stage 4 (age 13 – 16 weeks old; 15 to 20 cm length). High population of eggs and larvae were found in the beginning and the end of the year or after the end of cocoa peak crop. Most of the eggs and the larvae on pods were found from upper canopy, less on pods from lower canopy and lowest on pods from the trunk. The highest number of entry and exit holes of CPB larvae was on pods stage 5 (age 17 – 20 weeks old; 15 to 20 cm length) while the exit holes were not found on pods stages 1 (age 1 – 4 weeks old; 1 to 4 cm length) and 2 (age 5 – 8 weeks old; 5 to 10 cm length). Seventy percent of larvae exited from cocoa pods between 2100 - 0400 hr and the peak was at 0200 hr. In spite of this, 5 % of larvae emerged in the first day or less than 46 % emerged from harvested pods within 3 days. Within less than one hour the emerging larvae formed cocoons. Sixty seven eggs were laid by one female. Parasitized eggs were not found on the examined pods, while 92 - 98 % natural mortality of larvae was obseved in cocoa pods. In addition, the proportion of natural mortality of pupae was higher on the ground compared to in the canopy. More than 30 % of the pupae collected from the field were dead probably due to natural mortality. Honeydew produced by the

mealybugs becomes the food for the black ants but this honeydew did not prolong the longevity of CPB moths (8.29± 0.24 days).

The population of black ants in nests made from dry cocoa leaves increased in following months and the nests can be maintained up 14 months. For the stability of the ant population in an artificial nest, three months is needed for the nests to be hung on cocoa trees, before they could be transferred to new cocoa areas. The combination of dry cocoa leaves with synthetic material (polyester beg) prolonged the functional of the artificial nest for more than 4 years. Moreover, the population of black ant was 2.2 times higher in such nests when compared to the population found in artificial nests made from dry cocoa leaves. Seventy eight percent of mealybug populations on the slices of cocoa husk were nymphs and the remaining were adults (22 %). The nymphal stage showed greater dispersal ability (57 cm in 4.5 hours) while the adult only 10 cm in 4.5 hours. The presence of mealybugs on cocao flowers did not affect the formation of young pods. To establish black ant population in new cocoa areas, first, the area should be free of antagonistic ants. The suppression of antagonistic ants was through application of insecticides. Baiting is a common method used to control ants, however; when this method is used, consideration needs to be taken because the poison bait may be favored by the black ant. Second, transferring of one pair of artificial nests occupied by black ant and two thin slices of cocoa husk with mealybugs to new areas was done. When 70 % the harvested pod have mealybugs, it was an indication that population of mealybugs was sufficient to maintain high population of black ant in cocoa plantations. The results of this study can be integrated for developing an efficient control method of Integrated Pest Management of CPB which emphasizes biological control.

CHAPTER 1

GENERAL INTRODUCTION

The cocoa pod borer is a serious pest of cocoa which is difficult to control because of its behavior that protects it from enemies or control techniques (Wardojo, 1980a; Wardojo, 1984; Lim *et al.* 1987; Sidhu *et al.* 1987; Wessel, 1993). Its life cycle was approximately 30 days and the population can be built in a short time. The larval stage is the most active and damaging stage in the CPB life cycle. It is comparatively long, spending 70% (18-21 days) of its total life cycle. It lives inside the cocoa pod thus difficult to kill or control using conventional sprays of insecticides (Wardojo,1980b; 1984; Lim *et al.* 1982).

The larvae of CPB drill cocoa pods and penetrate into the pods where they feed on the pulp at the funicle and central placenta. The beans from damaged pods are normally small-sized and they are difficult to extract from the pods. The beans from the damaged pods are sunken and their quality is poor (Wessel, 1993). Attacking of CPB on younger pods may result in malformed and clumping of beans making them non-extractable during harvest (Wardojo, 1984; Azhar (1995); Azhar & Long, 1995). The yield loss caused by CPB can reach up to 80% if the pest is not controlled (Wardojo, 1980a). In Lonsum cocoa plantations, the reduction of cocoa yield approached 50% in some fields (Saleh & Abu Hassan, 2001; Saleh, 2003a).

Various cultural techniques are presently practiced to control the population of CPB. The widely used **'rampasan'** removes all pods from cocoa trees (force removal), thus eliminating oviposition sites for the females of CPB (Wardojo, 1980a; Wessel, 1993; Azhar *et al.* 2000). **The regular complete harvesting of ripe pods**, has its own drawback. Some pods on the upper canopy of cocoa trees are unreachable and are left unharvested on the trees (Wood *et al.* 1992; Day *et al.* 1994).

Chemical control of CPB using insecticides has been known for its effectiveness and fast action. However, the timing of application that reaches the targeted life stages of CPB is extremely important for effective control of this pest (Sidhu *et al.* 1987). **Sleeving** is a control method by which the cocoa pods are covered with plastic bag to prevent the female moths from laying their eggs on the pods (Wardojo & Moersamdono, 1984; Azhar *et al.* 2000). A biological control method by using an **egg parasitoid**, *Trichogramma* sp. to control CPB population has been practiced with satisfactory results (Tay, 1987; Alias *et al.* 1999). **Sex pheromone traps** have been tested; around 70 – 80% of the available male moths could be caught (Anon, 1986; Alias *et al.* 1999, 2004). Some biological control agents such as **biopesticides** *Beauveria bassiana*, *Paecilomyces fumosoroseus* fungus (Lim *et al.* 1988) and nematode *Steinernema carpocapsae* (Rosmana *et al.* 2001) were tried at small scales, but not widely practiced due to less attractive results. **Cocoa clones resistant** to CPB, such as KW 514, 571 and ARDACIAR 10, are recommended by Indonesia Cocoa Coffee Research for the farmers (Susilo *et al.* 2004; Anon. 2009d). Lim & Phua (1986) observed that clones PA7, UA30, UA12, UA9 and NA34 are tolerant to CPB and Teh *et al*. (2005) reported that clone PBC 123 was a popular commercial clone in Sabah, as they are tolerant to CPB.

The latest development in biological control method of CPB is the use of other biological agents of the CPB, the black ant, *D. thoracicus* (Azhar, 1992; Ho, 1994; See & Khoo, 1996; Azhar *et al.* 2000; Saleh, 2003a). In 1995, the black ant was strongly considered for use against CPB after the discovery of this pest in Lonsum cocoa estates (Saleh, 2003a). The results of several trials indicated that the CPB infestation can be eliminated by high black ant population (Saleh & Abu Hassan, 2002b; Saleh *et al.* 2007b).

Unfortunately in some cocoa fields, it is difficult to maintain high populations of black ant due to unsuitable conditions of the cocoa canopy (Saleh, 2003a; Saleh *et al.* 2006b). Understanding the biology of the CPB and its biological control agents is of prime importance in formulating an IPM programme for this pest. Therefore, this study examines the population of CPB and biological control agent, the black ant, *D. thoracicus,* together with its symbiont, the mealybug *C. hi*sp*idus*. This study also involves examining the role of coexisting antagonist ants in the ecosystem. The results of these studies are expanded to form the basis for developing an IPM strategy in controlling CPB by using the black ant.

This study aims at: 1) studying biology and ecology of the cocoa pod borer, *C. cramerella* controlled by black ant, *D. thoracicus*, and its symbiotic mealybug, *C. hi*sp*idus* 2) developing the methods of suppressing antagonist ants in cocoa field. 3) developing a suitable artificial nest for the black ants. 3). developing suitable methods to the establishment of black ant population. 4) and formulating an IPM programme for controlling CPB using black ant.

CHAPTER 2

LITERATURE REVIEW

2.1. History of cocoa cultivation in Indonesia

Theobromae cocoa Linnaeus (Family: Sterculiaceae) is a neotropical species originating from the Amazon basin and it grows under forest trees in South America. *Theobromae cocoa* is one out of 20 species of *Theobromae* and it has three varieties: Criollo, Forestero and Trinitario. The Trinitario is a natural hybrid between Criollo and Amelonado (selected from high productive Forestero variety) (Wood & Lass, 1985; Sutanto, 1994). The cocoa tree was introduced to Minahassa, Northern Sulawesi, Indonesia, between 1750 and 1780. The original plant was assumed to be brought into Indonesia from the Philippines and spread to other areas in the country. It was reported that cocoa was planted before 1778 in Java Island. From then on more cocoa were planted and many estates were established in Java and cocoa was subsequently exported in 1880. The main problems in producing cocoa (cocoa beans) were its serious pests: mosquito bug, *Helopeltis* sp. and cocoa pod borer (CPB), *Conopomorpha cramerella*. Since 1880, cocoa could have become an important crop in Java if not for the outbreaks of these two pests (Wardojo, 1980a; Atmawinata, 1993; Toxopeus & Giesberger, 1993). Consequently most of cocoa planters converted their cocoa plantations to rubber and coffee estates, which were more profitable in the 1920's. However, some planters in central Java continued to grow cocoa using the Trinitario variety, which was more vigorous than Criollo variety. These planters had successfully adopted more effective control methods to suppress the cocoa pests (Toxopeus & Giesberger, 1993).

The changing size of cocoa planting areas in Indonesia is mainly due to the price of the commodity. Azhar (2009) reported that the price of cocoa beans or cocoa products which plays a key part in determining the eventual income of cocoa farmers.

This income or profit of the cocoa planters is very much dependent on the production and price of cocoa while the decrease in cocoa production may be related to pests and diseases outbreaks (Azhar & Lee, 2004; Azhar, 2009). In 2006, Indonesia was the third largest cocoa producer in the world, producing about 14 % out of total world production of 3,731,000 tons (Sutanto, 1994; Wahyudi & Abdoellah, 2008; Anon. 2009d; 2009f). Table 2.1 shows cocoa production by various countries in the world from 2005 to 2006.

Table 2.1. Major cocoa producers in the world in 2005-2006.

Country	**Tons ('000)**
Cote d'Ivoire	1,519
Ghana	740
Indonesia	520
Nigeria	190
Cameroon	170

Sources: ICCO, USDA, FAO, LMC (Anon. 2009f)

Cocoa was first planted in Lonsum plantations (PT. PP. London Sumatra Indonesia Tbk, North Sumatra, Indonesia) in 1973. In the beginning, 61 ha of plantation areas were planted with this crop. Cocoa planting areas increased gradually to 4600 ha in 1995 in several estates across the country; seven estates in North Sumatra, one in East Java and one in North Sulawesi. Due to decreasing yield of cocoa, cocoa areas in Lonsum plantations were gradually converted to oil palm. Presently (in 2005) only 2631.00 ha plantation located in three Estates, North Sumatera, East Java and North Sulawesi maintains cocoa as a crop (Anon. 2005).

2.2. History of cocoa pod borer (CPB), *Conopomorpha cramerella* (Snellen) in Indonesia

Cocoa pod borer (CPB), *C. cramerella* damages on cocoa pods in Indonesia was discovered for the first time in 1895, and thereafter, most of cocoa plantations were badly attacked by the CPB (Wessel, 1993). Saleh (2003a; 2003b) reported that the first CPB was spotted in Lonsum cocoa plantations in September 1994. From then on it spread to all Lonsum cocoa areas in North Sumatra Estate, and in East Java estate, this pest was only found after year 2000. In Lonsum estates, the CPB were controlled using Integrated Pest Management (IPM) techniques where by the black ant (*D. thoracicus*) was used as a biological control agent. This biological control technique was combined with two cultural practices of complete harvesting and burying of cocoa husks (Saleh & Abu Hassan, 2002b; Saleh, 2003a; Saleh *et al.* 2006b).

2.3 Biology and ecology of the cocoa pod borer, *Conopomorpha cramerella* (Snellen) (Lepidoptera: Gracillariidae)

Conopomorpha cramerella (Snellen) is known as cocoa pod borer (CPB); cocoa moth and penggerek buah kakao in Indonesia and pengorek buah koko in Malaysia (Wardojo, 1980b; Azhar, 1986a). The change of the generic name for the cocoa pod borer, *Acrocercops cramerella* (Snellen), to *Conopomorpha cramerella* (Snellen) was made by Bradley in 1985 (Lim, 1987; 1992).

The CPB is widely distributed in the line and apparently in South-East Asia and the Western Pacific (Lim, 1987). Some studies on the biology and control of this pest was done by Mumford (1986); Lim (1987) and Posda (2011). Lim *et al.* (1982) and Lim (1987) the life cycle of the CPB consists of egg, larva, pupae, adult stage and sexual dimorphism by Posda, 2010 (Figure 2.1). The duration of life history and longevity are shown in Table 2.2

Female Male

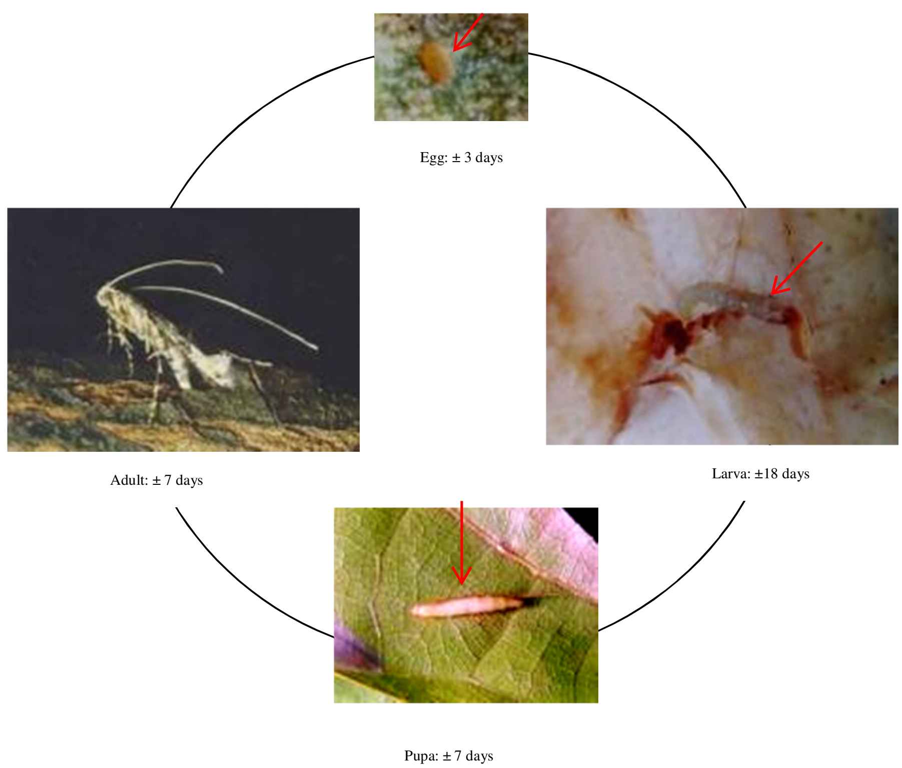

Figure 2.1. Life cycle of the cocoa pod borer, *C. cramerella*

Table.2.2. Some developmental stages of *C. cramerella* (means in brackets)

Reference	Duration of stage (days)				Adult longevity (days)		
	Eggs	Larvae	Pupae	Total	Adults (♂)	Adult (♂)	Total
Roepke (1912)	-	-	-	-	-	-	< 8
Dammermen (1929)	-	-	-	28	-	-	< 7
Van Hall (1932)	-	-	-	30	-	-	-
Wardojo (1980a)	7	16	7	30	-	-	7
Vaniangan *et al*. (1981)	3 - 6	15-17	6 – 7	24 – 32	-	-	7
Lim *et al*. (1982)	2 – 7 (3.3)	14 – 20 (17.6)	6 – 7 (6.7)	22 – 34 (28.6)	1 – 6 (3.2)	1 – 9 (5.1) (under starvation)	1 – 10 (4.5)
Day (1985)	2 - 4	15-27 (x = 19.1)	6 – 9 (x = 7.0)	23 - 40	-	-	8 – 9 (fed with water) 3 – 4 (under starvation)

(Lim, 1987; 1992)

2.3.1. Eggs

The egg is normally laid on the pod surface particularly in the furrow of the middle and top portion of the pod (Lim *et al.* 1982; Azhar, 1990a). Most of eggs are laid singly (37%), but also in pair (27%) or in triplet (10%) (Lim, 1987; Lim, 1992). The eggs are very small (0.45 ± 0.01 mm in length and 0.25 - 0.30 mm wide) and have an elliptical shape, with numerous longitudinal and transverse ribs on the shell. They are transparent and orange-yellow in colour and very difficult to recognise with naked eyes (Wessel, 1993) (Figure 2.1). The stage of pod which is at risk to egg-laying by adults of CPB is when the pods are more than 7 cm in length (pods more than 10 weeks old) (Azhar & Long, 1993; Teh *et al.* 2005) and the females preferred to lay eggs at 4-6 weeks before pods ripen (Lim *et al.* 1982; Day, 1983; Day, 1986).

2.3.2. Larvae

After hatching, the first instar larvae penetrate directly into the epidermis of cocoa pod and bored through the mesocarp and subsequently feed on mucilage or placenta of cocoa until full-grown in the cocoa pods (Lim, 1987; 1992).

Azhar (1995) reported that the larvae bore straight down towards the sclerotic layer. Some larvae penetrate directly through the sclerotic layer, while others may turn and drill horizontally up to several centimetres along the outer surface of sclerotic layer before eventually penetrating the sclerotic layer at a point remote from the surface site of the egg shell. Once inside the pod, the larva completed its development (Fig. 2.1). The larva eats and its way making winding tunnels filled with brown excrements just beneath the pod wall and between the beans. The beans were left untouched (Wessel, 1993). The larvae feed on placental and pulp tissues, leaving behind galleries filled with brownish faeces. The developed larva is reported to have three to five instars. Upon completion of the larval stage (range at 14-20 days, average of 18 days), the final instar, about 10-12 mm, long greenish in colour, burrows through an exit hole of about 1 mm in diameter to pupate (Wessel, 1993; Azhar, 1995).

After about 14 days, when the caterpillar is full-grown, it bores through the pod wall to outside, preferably through the thinnest part of the pod wall, i.e. the grooves at night (Wessel, 1993).

2.3.3. Pupae

Upon emergence from the pod, the mature larva actively seeks a suitable pupation site by crawling or lowering itself by a silk thread. The pupation site could be a furrow of the pod, or on green and dried leaves and other debris on the ground (Wessel, 1993; Azhar, 1995). The pupa spins and develops a cocoon within 24 hours. The mature larvae cast their skins, and through the membranous wall of the cocoons, very lively pupae of a pale yellow-grey colour can be seen (length of 7-8 mm, and width approximately 1 mm) (Fig. 2.1) (Wessel, 1993). Lim *et al*. (1982) reported that the average length of the pupa is 12.30 ± 0.19 and the width 7.70 ± 0.05 mm. After about 6-8 days the pupae turn dark-grey, and 1-2 days later they slide forward, break through the cocoon and the moths emerge (Lim, 1987; Wessel, 1993; Azhar, 1995).

2.3.4 Adult

Cocoa Pod Borer is a nocturnal insect. The average duration taken for the emergence of adult moths was observed to be 1 minute. A majority of the moths emerge between 6 p.m. and 9 p.m. No emergence was observed before 6 p.m. (Lim, 1987). The moth is very delicate; the body is 7 mm long and 2 mm broad, with a wing span of 12 mm (Fig 2.1) (Wessel, 1993). Lim *et al.* (1982) reported that the mean female body length is 5.87 ± 0.41 mm and wing span (12.41 ± 0.76 mm); the male body length and wing span are 5.65 ± 0.33 mm and 12.61 ± 0.76 mm, respectively. The forewings are decorated with many white cross lines and yellow spots at the tip, which is fringed. The hind wings have a crown of long and fine hairs. They start to fly at sunset, and then lay their eggs singly, normally on the pod surface, particularly in the furrow (Azhar, 1990b; Wessel, 1993) and the eggs are not laid on other parts of tree (Wardojo & Moersamdono, 1984).

Egg production varies considerably depending on the longevity of the moth, and the potential fecundity of CPB is over 200 eggs per female (Lim, 1992). The duration of the life cycle from oviposition until the emergence of the moth takes about a month and adults do not survive for more than a week (Wessel, 1993).

In the laboratory, moths emerge from cocoons in the evening. In the day time they perch quietly in the cages, and do not become restless even when disturbed. Within a room they do not fly towards a lighted window, but float gradually and slowly towards the ceiling and rest in a dark corner. When the moths are released outside, they fly upwards and disappear into the top of trees (Wessel, 1993). Apart from that, the flight of the moths is slow and unsteady; they often float up and down on the same spot. Furthermore, the moths give the impression that they are unable to fly great distances. However, they can be easily transported by a strong wind (Wardojo, 1980c; Lim *et al.* 1982; Wessel, 1993; Azhar, 1995). A single male was observed to cover a distance of 153 metres in one flight in open area (Lim *et al.* 1982).

2.3.5. Population build-up

As soon as the moth has established itself in a cocoa plantation of reasonable size, the conditions of life are such that all offspring of a sequence of generation can reach the adult stage (Wessel, 1993).

The ovary of a female contains 40-50 eggs (Wessel, 1993); however, Day (1985) and Azhar & Long (1996) estimated that the number of eggs laid on the surface of cocoa pods by individual moth is between 60–150 eggs. The assumption is that one female lays only 20 eggs, and half of the offspring are females; thus, after 5 generations (in 5 months time) one female can produce 200,000 progenies (Table 2.3) (Wessel, 1993).

Table 2.3. Estimation of population size (*C. cramerella* female) after 5 generation

Generation	Female	Eggs	Female
1st	1	20	10
2nd	10	200	100
3rd	100	2,000	1,000
4th	1,000	20,000	10,000
5th	10,000	200,000	200,000 (larvae)

(Roepke, 1912; as quoted in Wessel (1993).

2.4. Biology of the black ant, *D. thoracicus* (Smith) (Hymenoptera: Formicidae)

The cocoa black ant is a very common tree dwelling species; workers are 3.6-4.1 mm long with brown legs and antennae; the female is 4.9 mm long (Kalshoven, 1981). The cocoa black ant is arboreal (Holldobler & Wilson, 1990) and ubiquitous in cocoa-coconut ecosystem (Azhar, 1994a).

Previously, the black ant was known as *Dolichoderus bituberculatus* (Mayr) (Giesberger, 1983). Lastly, it was identified by Bolton as *Dolichoderus thoracicus* (Smith) (Khoo & Chung, 1989). The head (frontal), the dorsal and lateral view of the workers are shown in Plates 2.1, 2.2 and 2.3.

Plate 2.1. Head (frontal) of *D. thoracicus* worker (Anon. 2009b)

Plate 2.2. Dorsal view of *D. thoracicus* worker (Anon. 2009b)

Plate 2.3. The lateral view of *D. thoracicus* worker (Anon. 2009b)

The ants are usually found in shaded places in the cultivated areas. The nests are found in sheaths of bamboo, under folded palm leaves and also in the crown of coconut trees. They sometimes cover their nest entrances with a thin layer of papery material (Kalshoven, 1981). Where cocoa in grown under coconut, the black ant can be found nesting in a variety of places including the cocoa leaf litter, the cocoa canopy, within the laterally curled leaflets of dried coconut fronds, underneath the dried sheath that once served to protect the coconut inflorescence, under the proximal ends of live coconut leaflets, and in holes and crevices of both living and dead trunks and branches (Khoo & Chung, 1989).

Colonies of black ants normally contain 20,000–50,000 individuals, one female (4.9 mm long) occurs among every 100-200 worker ants (Kalshoven, 1981) and many queens are present in a nest (polygyny) so that when the new nest is formed, it very unlikely that the nest would be without at least a queen (Khoo & Chung, 1989). See and Khoo (1996) reported that *D. thoracicus* is highly polygynous species of ant, without well defined territorial boundaries.

In Central Java, the reproductive generation appears at the end of the rainy season and at the beginning of the dry season swarming does not occur (Kalshoven, 1981). Mating takes place inside the nest 5-7 days after the reproductive adults emerge. Egg production commences 10-20 days later and continues for an extended period, at an estimated rate of 1300-1700 eggs per year. The workers develop in 37-52 days and, like the females, live for at least one year. New nests are formed close to the original colony under favourable conditions; but under adverse circumstances emigration soon occurs (Kalshoven, 1981).

Food of black cocoa ant is largely derived from the honeydew of its mutualism, the mealybug, *C. his*p*idus* (Ho & Khoo, 1997). Species of mealybugs attended by *D. thoracicus* include: *C. his*p*idus, Planococcus lilacinus, Pseudococcus elisae,* and *Maconellicoccus hirsutus* (Khoo & Chung, 1989). The black ant also regularly tend the long-tailed mealybug of cocoa (*Planococcus lilacicus*), the green scale (*Coccus viridis*), the white fly of jambu (*Psidium guajava*), some small tree hoppers (Membracidae) and Psyllidae (Kalshoven, 1981; Azhar, 1986b, 1988b). Kalshoven (1981) added that besides attending the mealybugs, black ants also feed on nectar which produced by flower resinous secretion of bamboo, pollen and fungal fructification. It has been observed that when the mealybug of cocoa is scarce, the black ants also feed on the peel of the fruits of a small weed, wellcresses (*Paperomia pellucida*) (Kalshoven, 1981).

It is known that the presence of the ants favours the development of white cocoa mealybugs (the survival of these coccids may depend on the ants) and that of green coccid. The mealybugs (which cover the colonies with papery material) are protected by ants (Khoo & Ho, 1992; Azhar, 1994a).

The black ant did not increase the development of the coffee root mealybug (*Planococcus citri)* (Kalshoven, 1981).

In times of starvation, ants regularly eat their brood and numbers of ant species are known to produce non-viable eggs for food. Brood and egg composition may serve to explain why only adults of black ant could be found at the end of the two month period when black ant was isolated from any obvious food source (Ho & Khoo, 1997).

Black ant is normally found and become a dominant species where there are coconut palms intercropped with the cocoa trees (Azhar, 1995; Azhar *et al.* 2000). The ants are nuisance in the plantations during the harvest of the pods. However, the mealybug colonies maintained by the ants are considered to be relatively harmless. Furthermore, it has been proved that the ants are of great use in the cocoa plantation to control one of the most feared pests of cocoa, the *Helopeltis* bug, which attacks the pods in all stages by stinging and sucking (Khoo & Chung, 1989; Azhar, 1995).

The black ants, however, prevent this damage since the bugs are deterred from attacking the crop by the great numbers of ants. This was already noted by the cocoa growers in Kediri, Java, as early as 1908 and led to the practice of transferring ant nests to their crops. The validity of this practice was later confirmed by the now classic experiments and the slogan "without black ant no cacao"' was publicised in cocoa plantations in 1950 (Kalshoven, 1981). Making 'leaf-nests' as ant-dwellings refined the technique of transferring ant colonies to the plantation. It was also found necessary to control the long legged ant (yellow crazy ant) *A. gracilipes* as this species drives away the black ants and preventing its establishment in the cocoa. Several behavioural and biological characteristics of the black ants favour the use of this species for controlling cocoa pest.

The black ant does not sting and is not particularly aggressive. However the dense population of workers usually turn to aggressive and likely to bites when disturbed in their nest (Khoo & Chung, 1989).

In contrast to some species of ants, a solitary queen is the only individual in the colony that reproduces. When ‘harvesting nests of black ant, the polygynous habit makes it very unlikely that a nest would be without at least a queen. The black ant readily colonises suitable sites. There are no behavioural boundaries between colonies and it is possible to get a large nearby population of black ant in a farm. In contrast, many ants maintain ‘no-man’s land’ between colonies even though they are of the same species. This results in patchy distribution of the population. The ant has a propensity to spread rapidly within the crop. Black ant eats the honeydew produced by mealybugs, and they protect the mealybugs from predators. Black ants and mealybugs are in a symbiotic-mutualism relationship (Azhar, 1994a; Ho & Khoo, 1997; Khoo, 2009).

2.5. Biology of the mealybug, *Cataenococcus hispidus* (Morrison) (Homoptera: Pseudococcidae)

Cataenococcus hispidus is a common mealybug and a polyphagous species in Indonesia. However, the damage done to cocoa by this species is negligible. This mealybug is even useful in the cocoa plantations. The species is widely spread throughout South India, Malaysia, Java, Bali, Lombok, Sulawesi, Taiwan and the Philippines, and is not found above 1000 m sea level. It probably originated from Java (Kalshoven, 1981).

The adults are oval to roundish and covered with a thin layer of wax (Plate 2.4 A). A dorsal line and some narrow cross lines (edges of segments) have somewhat a thinner wax cover. The waxy projections of the marginal fringes are short and broad and adjacent to each other. The body fluid and the translucent areas are brownish-red in colour. The main host plant of *C. hispidus* is cocoa, but *Annona muracata* (soursop, sirsak), *Ceiba pentandra* (kapuk tree), *Erythrina* sp. (coral tree, dedap), *Nephelium lappaceum* (Hairy Lychee, rambutan) and *Psidium guajava* (guava, jambu batu/biji) as well as several fruit trees also are host plants of the mealybugs. In Indonesia this species is rarely found on coffee and citrus, but it is a major pest of Arabica coffee in South India. Their preferred sites are cocoa pods and petioles while on rambutan and soursop, they are found on the fruits (Kalshoven, 1981; Azhar, 1994a).

The young nymphs of mealybug are very mobile and gregarious during the first 4 weeks (Plate 2.4 B). They become adults in 37-50 days. About 270 embryos develop inside the parent insect, of which no more than 30 become adults. Nevertheless, a 300-fold increase has been noted within 3 months. Very few males have been observed. Reproduction is generally parthenogenetic. Oviposition time takes 4-5 weeks. Dispersal is mainly through migration of the young nymphs (Kalshoven, 1981).

Plate 2.4. A. Adults of mealybug B. Nymphs of mealybug

The prime importance of the mealybug in cocoa culture relates to the fact that it attracts the useful black ant, which in turn leads to the deterrence of *Helopeltis* bugs. The species sometimes causes sooty mould on citrus (Kalshoven, 1981).

The mealybugs feed by sucking sap from pod peduncles, pods and other parts of the cocoa tree, but no damage is apparent to the pod (Azhar, 1988b; Khoo & Chung, 1989; Graham, 1991; Khoo & Ho, 1992).

The abundance of the mealybug is greater in shaded areas which correlates with a surplus build up of nitrogen because of its slow utilisation by plants under this condition (Azhar *et al.* 2000). In this mutual relationship, the benefits are reciprocated, where the mealybug offers honeydew as an important food source to the black ant, which in return provides protection from predation and parasitism, and colony hygiene to the mealybug. The mealybugs are often completely dependent (obligate symbiotic) on the black ants whose removal of accumulated honeydew prevents the build-up of fungal disease (sooty mold) that is often destructive to the mealybug colonies (Graham, 1991; Azhar *et al.* 2000). A colony of black ants can live off food provided by the mealybugs without other sources of nutrition for at least eight weeks (Ho & Khoo, 1997).

2.6. Biology and ecology of antagonistic ants for *D. thoracicus*

Ants are one of the dominant communities of cocoa fauna (Azhar, 1985). They have been reported to influence the cocoa fauna structure and can be used as control agent for some of cocoa pests (Entwistle, 1972; Azhar, 1985). However, four of them in Lonsum cocoa areas are common as antagonist ants in establishment of black ant (*D. thoracicus*) in cocoa areas are Weaver ant, (*Oecophylla smaragdina*), Yellow crazy (long legged) ant, (*Anoplolepis gracilipes*) and Acrobat ant, (*Crematogaster* sp), White-footed ant, *Technomyrmex* sp (Khoo & Chung, 1989; Saleh *et al.* 2007a). These antagonist ants compete for the foods and aggressive to drive out black ant from their territories (Entwistle, 1972).

2.6.1. The weaver ant, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae)

Oecophylla smaragdina, a large, reddish-brown biting species at which nest between spun-up leaves. It is called rangrang, rerangga, or kerengga in west Indonesia (Kalshoven, 1981; Van Male & Cuc, 2007). The Australia species of this genus is known as the green tree or weaver ant. The species is common in the lowlands, especially near the coast and in drier areas and occurs throughout much of Asia, Australia and New Britain. The nests are often found high in trees and in the crown of coconut palms. The large females (15–16 mm long; olive green) start a new colonies after they are fertilised during nuptial flights. The workers occur in two sizes; 5 mm and 8-10 mm (Kalshoven, 1981; Azhar, 1985). The front view of head, dorsal and lateral view of *O. smaragdina* worker are shown in Plates 2.5, 2.6. and 2.7, respectively.

Plate 2.5. The front view of head of *O. smaragdina* worker (Anon. 2009e)