WHITEFLY-PARASITOID-INSECTICIDE INTERACTIONS: A CASE STUDY OF BEMISIA TABACI GENN, 1889 (HEMIPTERA: ALEYRODIDAE), ENCARSIA HITAM HAYAT, 2011 (HYMENOPTERA: APHELINIDAE) AND SELECTED INSECTICIDES ON BRINJAL PLANT HOSTS (SOLANUM MELONGENA L.) (FAMILY: SOLANACEAE) IN THE FIELD

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2013

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By

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science (Applied Entomology)

September 2013

ACKNOWLEDGEMENTS

Alhamdulillah, praises to Allah for His blessing and kindness I have finished this study. My sincere gratitude goes to my supervisor, Professor Che Salmah Md Rawi for the continuous support of my study and research, on her encouragement, motivation and immense knowledge. Her guidance have made me a better person and improved my research as well as my thesis.

I thank Universiti Sains Malaysia for the Research University Grant awarded to my supervisor, which support me financially during the study.

My sincere thanks also goes to my co-supervisor, Dr. Hamdan Ahmad for all his support and assistance. I am also indebted to Dr. Mohd Rasdi Zaini, Prof. Abu Hassan Ahmad, Assoc. Prof. Dr. Hamady Dieng, Dr. Suhaila Ab Hamid and Dr. Salman Abdo Ali AlShami for their useful comments, helps and supports.

My sincere gratitude also goes to Tuan Hj. Hedzir Elyas and laboratory assistant; Puan Siti Khatijah Ghazali for all the helps they provided throughout the sampling activities.

I thank my family, for all that you've done and sacrificed for me. All of you are an irreplaceable gift in my life. My dear father, Askarali bin Patai Mahamad and my mother, Nor Muliani bt Bakar, I owe you so much in life. My dear grandmother, Timah bt Matt, who look after me since the day I was born to this world, no word can describe my love to you. To my one and only sibling, my sister Noradila bt Askarali, thank you for your supports and understanding. For all my family members, thank you so much for always being with me and brighten my life.

I also thank my comrades: Dr. Nur Aida Hashim, Dr. Nurita Abu Tahir, Nor Shazuani Mohd Sobri, Dhiya Shafiqah Ridzuan, Nur Adibah Mohd Ishadi, Wan Nur Asiah Wan Mohd Adnan, Siti Mariam Zhafarina Rusli, Nurul Huda Abdul, Soleh Musa, Mohd Shafiq Zakeyuddin, Aiman Hanis Jasmi, Marcela Pimid, Sudha Rajen and Wan Mohd Hafezul Wan Abd Ghani for the support, stimulating discussions and for all the fun we have during our study.

Last but not least, I thank those who are always being with me through my thick and thin during this study: Abdullah bin Abd Razak, Mariani Mohd Zain, Nor'ain Hassan Basri, Aqilah Adnan, Siti Hajar Sungit, Nurul Haslinda Noordin, Rahimah Hassan, Ainul Farhana Abd Razak, Nurul Nadiah Md Salleh, Farah Adibah Ismail, Nur Sakinah Suardi and many more that I could not mention here. Wherever you are, I thank you with my warmest heart for your unconditional support you have given me.

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2. University Level. Colloquium of the 6th Annual PPSKH Postgraduate 2012, USM, Penang. Attended and Presented. Proceeding “Effect of selected insecticides and parasitization of *Encarsia hitam* (Hymenoptera: Aphelinidae) on whitefly (*Bemisia tabaci*) (Hemiptera: Aleyrodidae), a pest of brinjal (*Solanum melongena*)”. Session 3 (Agrobiology). 14th February 2012. Venue PPSKH-room101, School of Biological Sciences, USM, Penang. (Presenter / Author)

3. University Level. Colloquium of the 7th Annual PPSKH Postgraduate 2012. USM, Penang. Attended and Presented. Proceeding “Effect of selected insecticides on *Encarsia hitam* (Hymenoptera: Aphelinidae), parasitoid of sweet potato whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae) infesting brinjal plant (*Solanum melongena* L.)”. Session 5 (Agrobiology). 8th November 2012. Venue PPSKH-room101, School of Biological Sciences, USM, Penang. (Presenter / Author)

LIST OF ABBREVIATIONS

AI	Active Ingredients
ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
cm	centimeter
cm^2	centimetre squared
CO^2	Carbon dioxide
EC	Emulsifiable Concentrate
ETL	Economic Threshold Level
DOA	Department of Agriculture
g	gram
IPM	Integrated Pest Management
kg	kilogram
L	Litre
LD	Lethal Dose
MARDI	Malaysian Agricultural Research and Development Institute
mg	miligram
ml	milliliter
mm	milimetre
ppm	part per million
RCBD	Randomized Complete Block Design
SE	Standard Error
SC	Suspension Concentrate
SPSS	Statistical Package for Social Science
sp.	Species
var.	variety
WAT	Week after transplanting
WP	Wettable Powder

INTERAKSI LALAT PUTIH-PARASITOID-INSEKTISID: SATU KAJIAN KES *Bemisia tabaci* Genn, 1889 (HEMIPTERA: ALEYRODIDAE), *Encarsia hitam* Hayat, 2011 (HYMENOPTERA: APHELINIDAE) DAN INSEKTISID TERPILIH TERHADAP PERUMAH TERUNG (*Solanum melongena* L.) (FAMILY: SOLANACEAE) DI LAPANGAN

ABSTRAK

Satu kajian lapangan telah dijalankan untuk menilai kesan tiga insektisid (Abamectin, malathion dan diafenthiuron) terhadap interaksi antara perosak terung *Bemisia tabaci* (Homoptera : Aleyrodidae), dan parasitnya *Encarsia hitam* (Hymenoptera : Aphelinidae), serta pertumbuhan pokok dan penghasilan buah terung. Semua pokok terung telah disembur dengan insektisid tertentu pada dos yang disyorkan setiap minggu selama dua tempoh penanaman. Keputusan keseluruhan yang diperolehi menunjukkan jumlah bilangan lalat putih pada pokok yang tidak dirawat adalah sebanyak 14.08 ± 1.44 per daun pada penanaman pertama dan 17.50 ± 4.65 per daun pada penanaman kedua. Ia adalah lebih tinggi berbanding dengan pokok terung yang dirawat dengan tiga insektisid, abamectin (13.88 ± 3.32), malathion (9.80 ± 2.19 per daun) dan diafenthiuron (10.40 ± 2.41 per daun) pada penanaman pertama dan pada penanaman kedua iaitu 15.65 ± 5.42, 8.35 ± 2.79 dan 9.48 ± 2.3 per daun masing-masing. Insektisid yang paling berkesan yang boleh mengurangkan populasi lalat putih di bawah ETL adalah malathion dan diafenthiuron. Selain itu, peratusan parasit pada nimfa lalat putih adalah tinggi pada pokok terung yang tidak dirawat pada tempoh penanaman pertama dan kedua (3.17% - 12.82%) dan (0.52% - 10.00%) masing-masing, berbanding dengan pokok terung yang dirawat dengan insektisid (0.62% - 12.50%) dan (1.01 % - 8.00%) masing-

masing. Penggunaan semua insektisid dalam kajian ini sedikit menjejaskan parasitisme *En. hitam* terhadap lalat putih walaupun tidak ada perbezaan yang signifikan (P > 0.05) diperhatikan di kalangan pokok terung yang dirawat. Berbanding dengan dua insektisid lain, diafenthiuron mengekalkan peratus parasitisme oleh *En. hitam* yang lebih tinggi terhadap *B. tabaci* di lapangan untuk kedua-dua tempoh penanaman pertama dan kedua dengan 12.50% dan 8.00% masing-masing. Kepadatan lalat putih pada daun terung memberi kesan positif kepada ketinggian tumbuhan dan buah terung yang dihasilkan. Ketinggian pokok mencapai 69.67 ± 1.72 cm pada kepadatan lalat putih yang rendah dan ia hanya mencapai 54.31 ± 1.81 cm pada kepadatan lalat putih yang tinggi. Ketinggian pokok menurun dengan peningkatan kepadatan lalat putih. Begitu juga, berat buah-buah terung pada kepadatan lalat putih yang rendah adalah seberat 143.83 ± 12.85 g per pokok dan apabila lalat putih adalah tinggi, berat buah hanya 78.06 ± 16.05 g per pokok. Terdapat perbezaan yang signifikan antara ketinggian pokok dan berat buah yang dihasilkan dengan kepadatan lalat putih (P < 0.05) menunjukkan bahawa ketinggian pokok dan berat buah meningkat apabila ketumpatan lalat putih menurun. Walau bagaimanapun, saiz daun, bilangan daun dan bilangan bunga tidak jauh berbeza pada kepadatan lalat putih yang berbeza. Berdasarkan kajian ini, insektisid terbaik adalah diafenthiuron kerana ia berkesan untuk mengawal lalat putih disamping dapat mengekalkan peratus parasitisme *En. hitam* yang memuaskan dan menyumbang kepada pertumbuhan pokok terung yang sihat dan kualiti buah yang baik.

WHITEFLY-PARASITOID-INSECTICIDE INTERACTIONS: A CASE STUDY OF *Bemisia tabaci* Genn, 1889 (HEMIPTERA: ALEYRODIDAE), *Encarsia hitam* Hayat, 2011 (HYMENOPTERA: APHELINIDAE) AND SELECTED INSECTICIDES ON BRINJAL PLANT HOSTS (*Solanum melongena* L.) (FAMILY: SOLANACEAE) IN THE FIELD

ABSTRACT

A field study was conducted to evaluate the effects of three insecticides (abamectin, malathion and diafenthiuron) on the interactions between *Bemisia tabaci* (Homoptera: Aleyrodidae) the brinjal pest, and the parasitoid *Encarsia hitam* (Hymenoptera: Aphelinidae), as well as on plant performances and fruit production. All insecticides were applied weekly at recommended doses over two brinjal cropping periods. Overall results showed high total numbers of whitefly on untreated plants in the first (14.08 ± 1.44 per leaf) and second (17.50 ± 4.65 per leaf) cropping periods compared to plants that were treated with abamectin (13.88 ± 3.32), malathion (9.80 ± 2.19 per leaf) and diafenthiuron (10.40 ± 2.41 per leaf) in the first crop and in second crop with 15.65 ± 5.42, 8.35 ± 2.79 and 9.48 ± 2.3 per leaf respectively. Malathion and diafenthiuron were the most effective insecticides that reduced whitefly populations below economic threshold level (ETL). Percentages of parasitism was high on whitefly nymphs in untreated control plants in the first and second cropping periods (3.17% - 12.82%) and (0.52% - 10.00%) respectively compared with insecticide-treated plants (0.62% - 12.50%) and (1.01% - 8.00%) respectively. All insecticides affected the parasitization of whitefly although no significance difference was observed among treatments. Among the insecticides, diafenthiuron maintained slightly higher parasitism activity of *En. hitam* in the field during both first and second cropping periods with 12.50% and 8.00% respectively. High whitefly density on brinjal leaves was associated with decreased in plant height and brinjal fruits produced. Plants grow to 69.67 ± 1.72 cm high when the whitefly density was low and it was only 54.31 ± 1.81 cm when whitefly population was high. Similarly, weight of fruits was heavier at low whitefly density (143.83 ± 12.85 g per plant) and lower (78.06 ± 16.05 g per plant) at high whitefly density. The means of plant height and weight of fruits were significantly different on different whitefly density ($P < 0.05$). However, the leaf size, number of leaves and number of flowers were not affected at different whitefly populations densities. Therefore, the result of this study showed that diafenthiuron was the best insecticide in term of its effectiveness against whitefly and it can maintain relatively high parasitization of *En. hitam* which subsequently contributed to healthy growth and good performances of brinjal plants bearing good quality of fruits.

CHAPTER 1

GENERAL INTRODUCTION

Agriculture activity is important to determine the quality of the environment (Hails, 2002). Furthermore, Daily *et al.*, (1996) reported that life on earth related to proper functioning of several ecological processes, which provide humanity with a lot of irreplaceable benefits. In agriculture, brinjal is among one of the most important vegetable crops. It has an important role in everyday diet because of its high nutritive value. Brinjal fruits contain vitamins A, C, E and also a lot of minerals like phosphorus, calcium and iron (Chandrakumar *et al.*, 2008).

Brinjal plants are very much susceptible to insects especially in the rainy season. About 53 species of insect pests has been known to attack brinjal right from seedling to final harvesting stage (Biswas *et al.*, 1992) of which eight are considered as minor pests as they generally cause little damage (Nayer *et al.*, 1995). One of the serious problems in brinjal cultivation is the infestation of pest that causes great losses. The most common pest of brinjal is whitefly.

Whitefly is a serious vegetable pest particularly on family Solanaceae. Its population is currently increasing worldwide (Cote *et al.*, 2002). In Malaysia, a recent survey on vegetables showed that whitefly was found throughout the country. There are different species of whitefly found in the lowland and highland areas. Two species were found in lowland such as *Aleurodicus dispersus* (spiralling whitefly) and *Bemisia tabaci* (sweet potato whitefly). However, only one species, the *Trialeurodus vaporariorum* was found in the highland (Cameron Highland) (Syed Abdul Rahman *et al.*, 2000).

To overcome the problem, chemical control is widely used in managing insect pests on brinjal. Repeated uses of broad spectrum synthetic chemicals also results in environmental contamination, bioaccumulation and biomagnifications of toxic residues and disturbance in ecological balance (Dadmal *et al*., 2004). Chemical control is the primary method to manage whitefly, but it also has two serious drawbacks, rapid development of insecticide resistance and negative effects on natural enemies (Gonzalez-Zamora *et al.*, 2004). Resistant biotypes of whitefly have been described for different classes of insecticides, especially organophosphates, pyrethroids, and cyclodienes, and even for the relatively new group of chloro-nicotinyl insecticides (leading substance imidacloprid) (Prabhaker *et al.,* 1989, Dittrich *et al.*, 1990b; Cahill *et al.*, 1995 and Byrne *et al.*, 2003). In addition, the rapid build-up of insecticide resistance in this pest calls for alternative management solutions for dealing with pest outbreaks (Gerling *et al.*, 2001).

Hence, there is an urgent need to look for an alternate and safer method (Srivastava, 1993). There is a growing interest in searching for more effective control methods for *B. tabaci* other than the use of insecticides, particularly in regions where pesticide usage is less desirable. Biological control agents known as ‘armies’ of different predators and parasitoids in crop ecosystems is receiving considerable interest as a crop protection strategy in a number of crops (Ehler 1992; Murdoch *et al.*, 1985; Riechert and Lawrence, 1997). A control technique using the entire complex of natural enemies that prey upon a pest is often highly effective and very sustainable (David, 2002).

One of the objectives of this study was to determine the efficacy of selected insecticide on whitefly *B. tabaci* population on brinjal plant (*Solanum melongena* L.). Such indiscriminate used of insecticides are reported to cause insecticide resistance in insect pests, resurgence or increased infestation by some insect species due to the destruction of predators and parasitoids (Forrester, 1990). This study was also conducted to determine the effect of insecticide on the parasitization of whitefly by parasitoid, *Encarsia hitam*. *Encarsia* sp. *and Eretmocerus* sp. are known as primary parasitoids of whitefly, and many nominal and undescribed species are known to attack *B. tabaci* (Zolnerowich and Rose, 2008).

In addition, another aim of this study was to compare brinjal fruit production between insecticides-treated plants and non-insecticides treated plants. Non-treated plants depended entirely on natural enemies (parasitoid) to protect them against pest infestations. The comparison would be made to evaluate the effect of whitefly infestations and indirect effect of insecticide applications on quantity and quality of fruits and plants performances. Subsequently, the finding of this research would establish the best insecticide that would maintain very low whitefly density and high parasitism by *En. hitam,* produce high quality yield and good plant performances.

The objectives of this study were summarized as below:

1. To determine the efficacy of selected insecticides on whitefly *B. tabaci* population on brinjal (*Solanum melongena* L.)

2. To determine the effect of selected insecticides on the parasitization of whitefly by parasitoid, *Encarsia hitam* on brinjal (*Solanum melongena* L.)

3. To compare the plant performances and fruit production between insecticides-treated and untreated brinjal plants.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

In Malaysia, vegetable and ornamental growers both in the highlands and lowlands use prophylactic insecticides application to control whitefly (Syed Abdul Rahman *et al.,* 2000). This has led to an increase in the cost of vegetable production and development of insecticide resistance, which lead to failure in the control of whitefly. High infestation of whitefly encourages development and growth of sooty mould on leaves, thus indirectly reducing surface area for photosynthesis and poor growth of plants particularly in brinjal, tomato, capsicum, and cucumber (Spiers *et al*., 2008).

The possible development of insecticide resistance has led many growers to mix several insecticides together and increase frequency of applications resulting in the development of cross resistance phenomena. Furthermore, the application of insecticides can also result in toxicity issues, which may negatively affect plant growth and development. It seems possible that applications of foliar insecticides could adversely affect photosynthesis by clogging, or at least partially blocking, plant stomates which gases are exchanged. Reduced photosynthetic rates can delay production times or reduce plant quality due to chemical toxicity. While visible phytotoxicity and the toxicity to humans and animals are tested prior to registration, subtle impacts such as effects on flower production, stunted growth or longer production times are not often tested (Spiers *et al*., 2008)

To reduce cost and develop a more sustainable control method, other means of control measures such as biological control using predators and parasitoids, cultural control and biological insecticide application as integrated manners need to be evaluated and implemented (Syed Abdul Rahman *et al.,* 2000). For biological control purpose, other than predators and parasitoids, whiteflies are naturally attacked by insect pathogens. These entomopathogenic fungi, which are also known as mycopesticides or mycopathogens, are fungi that prey on insects. Entomopathogenic fungi are one of the useful components of an Integrated Pest Management (IPM) programme because they are relatively host specific, inexpensive to produce, able to function in a wide range of greenhouse environments, and safe to humans (McDonough *et al.,* 2003). *Beauveria bassiana* and *Verticillium lecanii* are two fungal pathogens that attack *B. tabaci* and reduce its population. *B. bassiana* spores cause white muscardine diseases in insects, have been formulated into insecticidal products (McDonough *et al.*, 2003).

2.2 Whitefly

The common name “whiteflies” refers to the tiny insects in the family Aleyrodidae. The wings and bodies of the adults are covered with a fine, powdery or flour-like white wax (Hodges and Evans, 2005). Aleyrodidae is a single family within the Sternorrhyncha, one of three suborders of the Hemiptera, and includes around 1,500 currently valid species and subspecies names (Martin, 2005).

The sweet potato whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) have been recorded since 18th century and it is a pest to more than 500 plant species (Gennadius, 1889). *Bemisia tabaci* has been recorded in Turkey causing serious damage to vegetables in 1974 (Horowitz, 1986). Other than Hawaii, *B. tabaci* has been reported as a serious pest of cultivated crops in tropical and subtropical areas including Africa, Asia, Central America, South America, and the West Indies where it is also known as the tobacco whitefly and cotton whitefly. In North America, it has been reported from Maryland, Texas and Mexico, Arizona, California, District of Columbia, Florida and Georgia (Cock, 1986).

The adults of *B. tabaci* lay eggs on the undersurfaces of young leaves. It is also reported that an additional difficulty for chemical control was caused by the behaviour of this insect since adult feeding, mating and oviposition and larval development occurred on the lower surfaces of leaves. Over the years, a number of insecticides have shown effective control against whitefly but resistance has developed rapidly (Palumbo *et al.*, 2001).

The size of an egg is about 0.2 mm long, pear shaped and stands vertically on the leaf surface. The eggs are attached to the leaf by tiny pedicel or "stalk" at their bases (McAuslane, 1995). The mean wingspans of female and male whitefly are 2.13 mm and 1.81 mm, respectively (Byrne and Bellows, 1991). Female longevity ranges from 10 to 24 days during which it can lay from 66 to 300 eggs (Bogran and Heinz, 2000). On leucaena [*Leucaena leucocephala* (Lam.) de Wit] plant, *B. tabaci* longevity is 13.50 ± 0.12 days for male and 16.50 ± 0.12 days for female. The fecundity of *B. tabaci* on leucaena is 62.60 ± 61.53 eggs per female (Thomas *et al.*, 2011). However, McAuslane (1995) reported that each female whitefly may lay more than 400 eggs and live about two months. The developmental period of *B. tabaci* from egg to adult is significantly different on different host plants.

Coudriet *et al.* (1985) showed that the average period from egg to adult was about 23.6 days at 25°C, and 17.8 days at 27.5°C and eggs failed to hatch at 36.0°C or higher temperature. On leucaena, the developmental periods of the egg, the first to fourth instars to adults were 6.7 ± 0.18, 4.2 ± 0.18, 3.8 ± 0.14, 3.0 ± 0.0 and 5.2 ± 0.18 days, respectively, with a total life-cycle duration of 22.9 ± 0.58 days (Thomas *et al.*, 2011). The life cycle of whitefly is shown in Figure 2.1.

Figure 2.1: **Life cycle of whitefly (*Bemisia tabaci*)**

Source: http://www2.dpi.qld.gov.au/horticulture/18512.html

Whitefly population is increasing worldwide, thus enabling some viruses to infest plant species previously unaffected by whitefly-transmitted viruses (McAuslane, 1995). The whitefly was found to attack crops such as poinsettia that it had not infested previously (McAuslane, 1995). The whiteflies are now globally distributed and found on all continents except Antartica (Oliveira *et al.*, 2001). It's causing damage to a wide range of horticultural crops both in the field and under protected cultivation (Cock, 1986).

Three types of damage caused by the whitefly were direct damage, indirect damage and transmission of viruses (Berlinger, 1986). Direct damage is caused by piercing and sucking of sap from the foliage of plants. Heavy infestations of adult and their progeny can cause the death of seedling and reduce the plant growth rate and yield due to sap removal (McAuslane, 1995). Indirect damage caused by whitefly results in the accumulation of honeydew, which serves as a substrate for growth of black sooty mould on leaves and fruits. The mould reduces photosynthesis and adversely affects the value of the plant or yields rendering them unmarketable (Berlinger, 1986). The third type of damage is caused by vectoring of plant viruses by the whitefly with various biotypes. A low whitefly population is sufficient to cause significant damage to the plants (Berlinger, 1986).

The *B. tabaci* B-biotype is the newly proposed species *B. argentifolii* which has caused serious problem and transmitted many plant viruses. Other than B-biotype, there are other *B. tabaci* biotypes such as A biotype which transmit geminiviruses and lettuce infectious yellow viruses (LIYV) (Costa and Brown, 1991), the Asystasia biotype (E) colonizes only Asystasia species and exclusively vectors the Asystasia golden mosaic virus (AGMV), the Nigerian sweet potato (H) biotype which has a narrow host range, transmits tomato yellow leaf curl virus (TYLCV) (Brown *et al.*, 1994), and the sida biotype, which could colonize numerous plant species (including cultivated beans, okra, and tobacco, as well as many weed species) and act as excellent vector of whitefly transmitted geminiviruses found in bean, tobacco, and several indigenous weeds (Bird and Maramorosch, 1975; 1978).

2.3 Parasitoids of *B. tabaci*

Biological control of whitefly is the manipulation of natural enemies of whitefly to prevent or suppress whitefly populations below the economic threshold level (ETL) (McAuslane, 1995). Some effective predators of *B. tabaci* are identified from nineteen species of insects in four families (Chrysopidae, Miridae, Anthocoridae and Coccinellidae) and eleven species of mites from two families, Phytoseiidae and Stigmaeidae (Gerling, 1990b).

Parasitoids of whitefly include the minute wasp, *Encarsia* sp. and *Eretmocerus* sp. Each of the parasitoids is about one millimetre long and either yellow, dark brown or bicolour (brown head and yellow body), depending on the species. Females of tiny parasitic wasps lay their eggs inside whitefly nymphs. When the wasp eggs hatch, the larvae feed internally on the whitefly nymphs, eventually killing the host (Bogran and Heinz, 2000).

Several biological control strategies such as the use of Hymenopteran parasitoids, either native or exotic (Goolsby *et al.*, 1998, Ardeh *et al.*, 2005) have been evaluated as an attractive management alternaltive for whiteflies (Gerling *et al.*, 2001). There are large amount of listed fauna of *B. tabaci* parasitoids, but comparatively a few have been studied and intentionally used for pest control. This is partly due to poor knowledge of their taxonomy, biology or ecology (Gerling *et al.*, 2001).

During 1980s and 1990s, when there are rapid increase of *B. tabaci* population in the southern United States, numerous populations of exotic parasitic Hymenoptera, primarily in the genera *Encarsia* and *Eretmocerus* (Hymenoptera: Chalcidoidea: Aphelinidae), were introduced (Zolnerowich and Rose, 2004) as biological control agents (Goolsby *et al.*, 2000). *Encarsia* and *Eretmocerus* prefer to attack on the second to fourth host instars with the latter preferring to oviposit under younger whitefly nymphs. Females of tiny parasitic wasps lay their eggs inside whitefly nymphs. When the wasp eggs hatch, the larvae feed internally on the whitefly nymphs, thus killing the host (Bogran and Heinz, 2000).

Parasitic wasp requires a protein meal and often host-feed in order to mature a full complement of eggs (Gerling, 1990b). Experiments have shown that parasitoids cannot identify whitefly infested plants when presented in a mixture of infested and uninfested ones. Host-finding is achieved following a random search on the leaf and visual location of hosts from a very short (about 1 mm.) distance (van Lenteren and Martin, 1999; Gerling *et al.,* 2001). Sense of smell plays a role in host finding and parasitoid females show arrestment responses once they encounter honeydew contaminated leaves (Shimron *et al.*,1992). The time spent searching upon a leaf is also depend on previous searching results and is greatly extended once the hosts are found and successfully parasitized (Shimron *et al.*,1992; van Lenteren and Martin, 1999).

Several parasitoid species are being released against *B. tabaci* such as *En. formosa*, the best known parasitoid which is routinely used against the greenhouse whitefly in greenhouses (van Lenteren and Martin, 1999). Other species that have been released for *B. tabaci* control include *En. nigricephala*, *En. pergandiella, En. Sophia*, *Er. mundus*, *Er. emiratus*, *Er. eremicus* and *Er. hayati* (Hoelmer, 1995; DeBarro *et al.,* 2000; Goolsby *et al.,* 2000; Gerling *et al.,* 2001). Thus, according to Gerling (1996), the classical concept pointing to the ‘‘original home country’’ of the pest as the source for its most effective natural enemies may not hold for *B. tabaci*, and its natural enemies should be sought throughout the range of the pest’s occurrence.

Other than parasitoids, there are several predators that are important in the biological control of whitefly. Predator plays an important role in controlling whitefly, but understanding how it influences whitefly densities in the field is still undeveloped and its contribution has often been undervalued (Naranjo, 2001). *B. tabaci* predators include arthropods in 9 orders and 31 families (Gerling *et al.*, 2001). This is based on an update of previous lists (Gerling, 1986; Lopez-Avila, 1986; Cock, 1993; Nordlund and Legaspi; 1996) and accounts for synonymies of major predator groups.

Most *B. tabaci* predators are beetles (Coccinellidae), lacewings (Chrysopidae, Coniop terygidae), true bugs (Miridae, Anthocoridae), mites (Phytoseiidae) and spiders (Araneae). Only few natural enemy species have been studied in detail, and for many of them, their records are only limited to laboratory observations or qualitative field records (Gerling, 2001).

2.3.1 *Eretmocerus* sp.

The genus *Eretmocerus* includes 65 nominal species; undoubtedly there are many undescribed species as well. All *Eretmocerus* species known are primary parasites of whitefly, and many undescribed species are known to attack *B. tabaci* (Zolnerowich and Rose, 2008). *Eretmocerus* sp. occurs worldwide and is distinct from *Encarsia* both biologically and taxonomically. They oviposit under the host and develop in a vital capsule inside the host (Gerling *et al.*, 1991). The adult has a large-clubbed, 3-segmented antenna that sets them apart from confamilial species (Rose *et al.*, 1996). Recent contributions added to the understanding of *Eretmocerus* through morphological analyses of North American species, and by examined their courtship behavior, reproductive relationships and allozyme patterns (Hunter *et al.*, 1996; Rose *et al.*, 1996; Rose and Zolnerowich, 1997).

Except for some *Eretmocerus* species, many whitefly parasitoids are oligophagous, facilitating exploitation of new, introduced whitefly species by indigenous parasitoids. This has caused the establishment of new faunal complexes of *B. tabaci* parasitoids following the pest's spread into new regions, resulting in the broad list of parasitoids (Gerling *et al.*, 2001). However, oligophagy is usually coupled with differential host preferences that affect their efficacy as natural enemies (DeBach and Rosen, 1991).

2.3.2 *Encarsia* sp. (*Encarsia hitam* Hayat)

This genus, *Encarsia*, is of considerable interest to taxonomists and biocontrol workers as its species are parasitoids of pest species belonging to the Aleyrodidae and Diaspididae, and of hormaphidine aphids. This interest in *Encarsia* systematics in the past three decades led to the publication of several papers including revisions, and resulted in increase in the number of described (and currently valid) species from 146 of 1980 to 384 species by 2009 (Hayat, 2011).

Female *Encarsia* wasps live 15–39 days and lay 50–300 eggs, depending on conditions. Male *Encarsia* are very rare, and make up less than 1% of the population. Optimum temperature for *Encarsia* development is 23–27˚C, with humidity from 50 to 70% and lighting at least 10 hours'light per day to favour *Encarsia* development. The development period from egg to a new adult wasp varies from 31 days at 18˚C to 10 days at 30˚C. The lowest temperature it can survive is 13˚C. Lower temperatures will reduce the effectiveness of *Encarsia*. *Encarsia* effectiveness is also reduced at relative humidity above 75%; and heavy deposits of honeydew and plants with very hairy leaf surfaces will reduce its searching ability (Llewellyn, 2002)

One of the most common *Encarsia* species, *En. Formosa*, is used globally for controlling *T. vaporariorum* in greenhouses grown with vegetable and ornamental crops. It is a solitary endoparasitoids and thelytokous (unfertilised eggs produce female offspring). Females prefer to deposit single eggs in third and fourth instar whitefly nymphs. The adult *E. formosa* obtains energy and nutrients by piercing the integument of nymphs with the ovipositor and feeds on hemolymph that seeps from the wound (Hoddle, 1999). *Encarsia formosa* parasitised the second, third and fourth (pupal) nymphal stages of the whitefly. The pupa turns black within 10 days after being parasitized (Figure 2.2). It is effective against *T. vaporariorum* but not *B. tabaci* (Sanderson, 1996). Feeding with *B. tabaci,* the parasitoid development is slow, and the adults are less fertile in comparison to wasp reared on *T. vaporariorum* on the same host plant. *Encarsia formosa*, a well known parasitoid of *T. vaporariorum,* is more efficient controlling this species than *B. tabaci* (Brasch *et al.*, 1994).

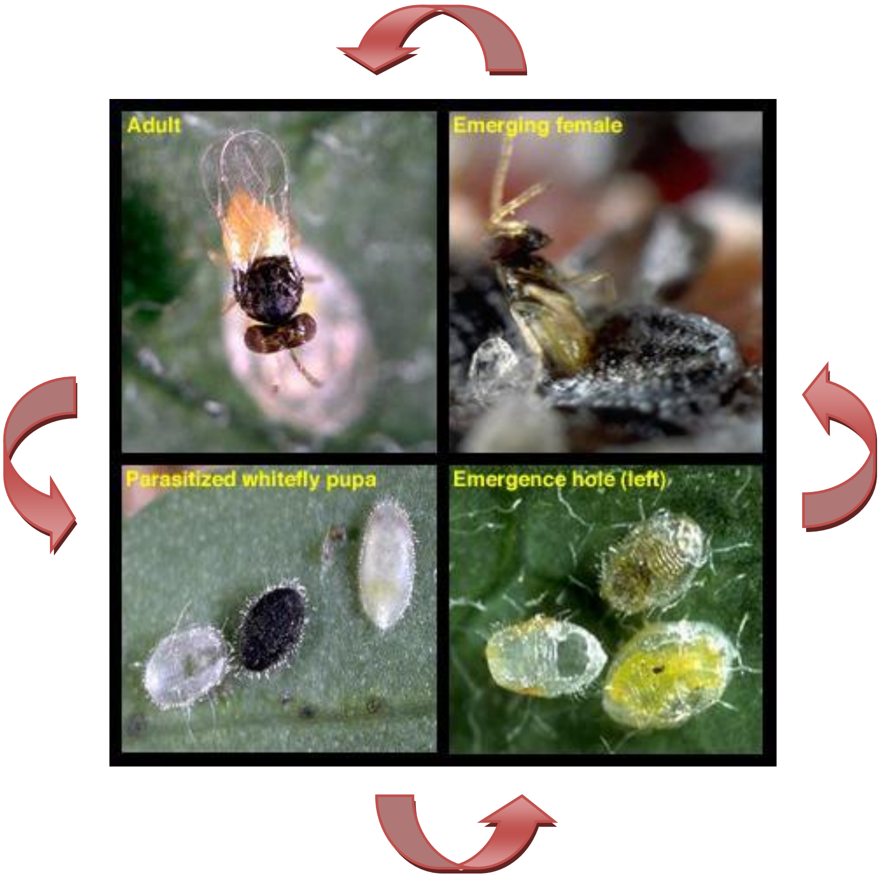
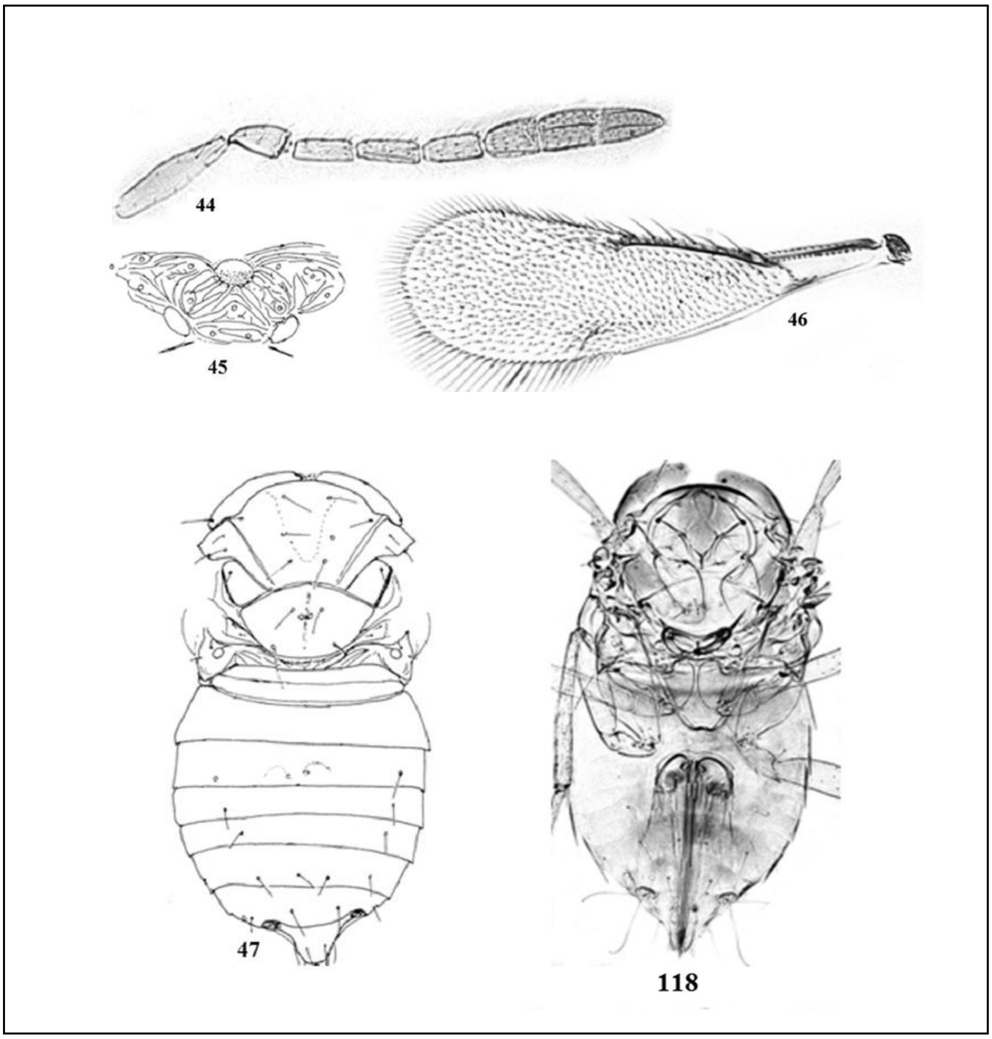


Figure 2.2: **Life cycle of parasitoid** (*En. formosa*)

Source: http://www.organicgardeninfo.com/encarsia-formosa.html

Encarsia sp. that was identified in this study is *Encarsia hitam*. The species name 'hitam' is from a Sanskrit word which means beneficial. The confirmation of species name was done by Dr. Mohammad Hayat (Aligarh Muslim University) and it is a new species described in India. The length of the female is between 0.49 - 0.74 mm. The colour of the body is yellow to pale yellow. Its antenna is yellow to yellowish brown especially on clava. The legs are pale yellow in colour and it has mandible with two pointed teeth and two rounded, blunt teeth. The antennal formula is 1133 (Figure 2.3). *Encarsia hitam* was first reported in India (Assam; Meghalaya; Uttarakhand; Uttar Pradesh) (Hayat, 2011).



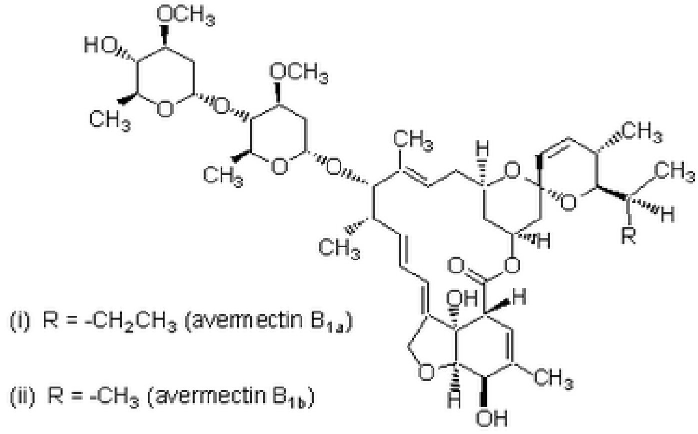
Figures 2.3: *En. hitam*., female: 44, antenna; 45, ocellar triangle; 46, fore wing; 47 and 118, mesosoma and metasoma (Source: Hayat, 2011).

2.4 Insecticides used for brinjal pest management

Chemical control is the primary method to manage whitefly, but it has two serious effects; rapid development of insecticide resistance and negative impact on natural enemies (Gonzalez-Zamora *et al.,* 2004). Resistant biotypes of whiteflies have been described for different classes of insecticides, especially organophosphates, pyrethroids, and cyclodienes and relatively new group of chloro-nicotinyl insecticides (leading substance imidacloprid) (Prabhaker *et al.,* 1989; Dittrich *et al.,* 1990b; *Cahill et al.,* 1995; Byrne *et al.,* 2003).

Due to indiscriminate use of insecticides and development of resistance, whitefly has changed its status from incidental to primary pest in field and vegetable crops (Cahill *et al.,* 1995). Some workers have reported a distinct resistant biotype known as B - biotype having distinct biochemical characteristics, a wide host range, increase in fecundity and are frequently considered prone to developing resistance to insecticides (Costa and Brown, 1991; Cohen *et al.,* 1992). Among various kinds of insecticides, three insecticides have been selected in this study. They are abamectin, malathion and diafenthiuron insecticides.

2.4.1 Abamectin



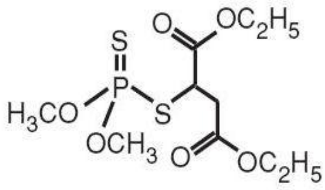
Abamectin is a broad spectrum insecticide and acaricide with high pesticidal activity. It is a natural product of the soil microorganism *Streptomyces avermitilis* which is produced through microbiological synthesis in biotechnological industry. It belongs to the family of macrocyclic lactones called avermectins and originally isolated as antiparasitic agents whose chemical structure, mode of toxic action and high potencies for a broad spectrum of invertebrate pests have been thoroughly studied (Putter *et al.,* 1981; Roslavtzeva, 1987; Bloomquist, 1993). They bind with high affinity to sites in the head and muscle neuronal membranes of various insect species (Deng and Casida, 1992; Rohrer *et al.,* 1995), thereby acting as agonists (chemical that binds to some receptor of a cell and triggers a response by that cell) for GABA-gated chloride channels (Mellin *et al*., 1983; Albrecht and Sherman, 1987). They affect the insects nervous system by increasing chloride ion flux at the neuromuscular junction, resulting in irreversible paralysis (Ishaaya, 2001; Horowitz and Ishaaya, 2004).

Abamectin has been found to be active against the greenhouse whitefly *Trialeurodes vaporariorum* Westwood in highland area, Malaysia (Mohd Rasdi, 2005) and it is also believed to be efficient in controlling *B. tabaci* (Bacci *et al.,* 2007).

Other than whitefly, another insect pest that also become resistance to abamectin are flower thrips, *Frankliniella occidentalis* (Chen *et al.,* 2011a), tomato leaf miner *Tuta absoluta* (Siqueira *et al.,* 2001), and diamondback moth *Plutella xylostella* (Pu *et al.,* 2010). Abamectin is currently used in Brazil to control insects, like *Alabama argillacea* (Hübner), *Liriomyza huidobrensis* (Blanchard), *Phyllocnistis citrella* Stainton, *Tuta absoluta* (Meyrick) and mites, such as *T. urticae*, *Tetranychus ludeni* Zacher, *Polyphagotarsonemus latus* (Banks), *Panonychus ulmi* (Koch), *Aculops lycopersici* (Massee) in several crops (e.g. cotton, citrus, apple, water melon, strawberry, cucumber, potatoes, tomatoes, and ornamental plants) (Andrei, 2005).

Abamectin was also generally toxic to many macrophytes, non-target organisms such as fish. Fish generally accumulate contaminants from aquatic environments. Study by Al-Kahtani (2011) clearly indicates the toxic nature of the insecticide abamectin on the oxygen consumption and the biochemical constituents of the tilapia fish (*Oreochromis niloticus*). The changes in proteins, carbohydrates and lipid in the fishes that were contaminated with abamectin will naturally affect its nutritive value.

2.4.2 Malathion

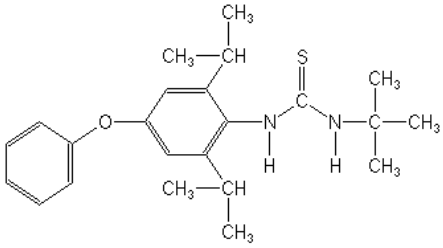


Malathion

Malathion is a broad-spectrum organophosphate insecticide that is widely used (Aspelin and Grube, 1999; Gratz and Jany, 1994; Walker, 2000). In the United States, 0.9 to 1.4 million kg of malathion are applied annually to more than 800,000 ha of cropland (Aspelin and Grube, 1999). Malathion is commonly used to control vegetable pest in Malaysia and it is suggest by MARDI as one of the insecticide can be use to control Whitefly, *B. tabaci* (Ithnin *et al.,* 2009).

Malathion has also been used for mosquito control in many countries including Malaysia. In Malaysia, few studies on malathion was conducted to control mosquito population, such as *Aedes albopictus* (Selvi *et al.,* 2010) and *Aedes aegypti* (Vythilingam and Panart, 1991). Azmi *et al*. (1988), Guneidy *et al.* (1989), Kawakami (1989) and Wen-Mei (1990) have reported resistance against malathion in controlling mosquitoes. From 1994 to 1998 and in 2000, no resistance was detected to malathion in the field populations of *B. tabaci* and in the years 1999 and 2001–2007, a very low level of malathion resistance was found (Mushtaq *et al.,* 2010). One of the malathion resistance by *B. tabaci* is reported by Ram and Jaglan (2005).

2.4.3 Diafenthiuron



Diafenthiuron is an effective compound that has been used in some parts of the world, particularly in Israel, where it has been used as an alternative to pyriproxyfen for *B. tabaci* control in cotton since 1998 (Horowitz *et al.,* 1999). It is a new type of thiourea derivative which specifically acts on phytophagous mites, whiteflies and aphids which was launched in 1991, and the only modern representative of compounds that interrupt oxidative phosphorylation by inhibition of the mitochondrial ATP synthase. Diafenthiuron is a pro-acaricide, its carbodiimide metabolite inhibits the enzyme. It is effective against motile stages of spider mites and also provides good eriophyoid control. Diafenthiuron has low mammalian toxicity and short environmental persistence (Josef Ehrenfreund, 2007; van Leeuwen *et al.,* 2010).

It has a favourable acute mammalian toxicity, the LD50 for acute oral and dermal toxicity in the rat being > 2000 mg/kg (Hollingworth, 2001) coupled with low toxicity to beneficial insects and predatory mites (Streibert *et al.,* 1988). Under field conditions, diafenthiuron is phytochemically converted to a carbodiimide derivative in the presence of sunlight, resulting in insecticidal activity greater than the parent compound (Steinemann *et al.,* 1990). It has a mode of action unique from any other chemistry used for *B. tabaci* control. It directly effects insect respiration through the inhibition of oxidative phosphorylation and disruption of mitochondrial ATP synthesis (Ruder and Kayser, 1993). The compound has very low mammalian toxicity with little toxicity to natural enemies and pollinators (Streibert *et al.,* 1988; De Clercq *et al.,* 1995; De Cock *et al.,* 1996).

Study on effect of diafenthiuron to different stages of *B. tabaci* nymph has been conducted previously by Ishaaya *et al.,* (1993). Diafenthiuron was sprayed prior to a 48-h infestation by adult females of the sweet potato whitefly *B. tabaci* Gennadius, on cotton seedlings under greenhouse conditions. When the different development stages were separately sprayed directly, the nymphal stage was the most susceptible. It was the most effective against the nymphal stage, resulting in 54% and 100% suppression of progeny formation at concentrations of 5 and 25 mg *a.i./l,* respectively but reduction of egg hatch obtained was mild (30-35%).

2.5 Brinjal as a host plant

Brinjal (*Solanum melongena*) or also known as eggplant is a common and very popular crop. The name brinjal is popular in India and is derived from Arabic and Sanskrit word whereas the name eggplant has been derived from the shape of the fruit of some varieties, which are white and resemble in shape to chicken eggs. It is also called aubergine (French word) in Europe.

Brinjal is grown extensively in India, Bangladesh, Pakistan, China and the Philippines. It is also popular in Egypt, France, Italy and United States (Chen and Li, 1997). Brinjal is originated from India but now planted in both tropical and sub tropical countries. It is the most-consumed vegetable in India and grown on more than 500 000 hectares, making it one of the main sources of cash for many farmers (Daniel Miller, 2007).

Brinjal belongs to the family Solanaceae with the botanical name *Solanum melongena* L. (Table 2.1). The family contains 75 genera and over 2000 species (Department of Biotechnology India, 2012). There are three main botanical varieties under the species *melongena.* The common brinjal, to which large, round or egg-shaped fruited forms belong under var. *esculentum*. The long, slender types are classified under var. *serpentinum* and the dwarf brinjal plants are placed under var. *depressum* (Choudhary, 1976).