EFFECT OF NUTRIENT, COMPETITOR PESTS AND EARLY INFESTATION ON THE POPULATION ABUNDANCE OF WHITEFLY (*Bemisia tabaci* Gennadius) ON BRINJAL (*Solanum melongena* L.)

By

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LIST OF ABBREVIATION AND SYMBOLS

IPM	Integrated Pest Management
mm	millimeter
PLRV	Potato Leaf Roll Virus
PVY	Potato Virus Y
ETL	Economic Threshold Level
IGR	Insect Growth Regulator
UV	Ultra Violet
MARDI	Malaysian Agriculture Research and Development Institute
g	gram
N	Nutrient level
TC	Non-pre-infestation on plant
TW	Pre-infestation by whitefly on plant
TA	Pre-infestation by aphid on plant
DOA	Department of Agriculture
L	liter
ppm	part per million
RCBD	Randomized Complete Block Design
ANOVA	Analysis of Variance
SPSS	Statistical Package for Social Science
S.E	Standard error (±)
df	Degree of freedom
MRT	Multiple Range Test

SS	Sum of square
°C	Celcius
r	Pearson correlation value
MANOVA	Multiple Analysis of Variance
DNA	Deoxinucleic Acid
RNA	Rebonucleic Acid
ml	milliliter
Na2CO3	Disodium carbonate
µL	micro liter
nm	nanometer
mg	milligram
$NaNO_2$	Sodium nitrite
NaOH	Sodium hydroxide
$AlCl_3$	Aluminum Chloride
ANCOVA	Analysis of Covariance
PVPP	Polyvinyl polypyrrolidone
DNS	Dinitrosalicyclic Acid
GCS	β-1, 3-glucanase
M	Mean light absorbance
DF	Dilution Factor
SSC	Slope of Standard Curve
RMW	Relative Molecular Weight
TRV	Total Reaction Value
TRT	Total Reaction Time
EEV	Enzyme Extraction Volume

EDTA	Ethylenediamine Tetra Acetia acid
ε	Absilon
POD	Peroxidase
RDA	Redundancy Analysis

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JOURNALS

1. **Mohd Rasdi Zaini**, Che Salmah Md Rawi, Abu Hassan. Effect of nutrient and pre-infested brinjal, *Solanum melongena* by whitefly and aphid on population dynamics of whitefly, *Bemisia tabaci*. 2013. **Agriculture, Forestry and Fisheries.** Science Publishing Group. Vol. 2, No. 1. 1-10.

SEMINAR AND CONFERENCES PROCEEDINGS

1. **Mohd Rasdi, Z.** and Che Salmah, M. R. (2011). Multitrophic system: Effect of different concentrationS of nutrient and pre-infested brinjal (*Solanum melongena*) on whitefly (*Bemisia tabaci*) population. Proceeding of 3rd International Symposium & Exhibition in Sustainable Energy & Environment. 1-3 June 2011, Melaka, Malaysia. (SCOPUS)

2. **Mohd Rasdi, Z.** and Che Salmah, M. R. (2011). Effect of nutrient concentration and pre-infested brinjal, *Solanum melongena* (by whitefly and aphid) on population dynamic of whitefly, *Bemisia tabaci* planted under rainshelter. Proceeding of Global Conference on Entomology (GCE). 5-9 March, 2011, Chiang Mai, Thailand.

3. **Mohd Rasdi, Z.** and Che Salmah, M. R. (2011). Ecology of Whitefly in Multitrophic System. Proceeding of Colloquium of the 5th Annual PPSKH Postgraduate, USM, Penang. Session 3 (Agrobiology). 22nd June 2011. Venue PPSKH-room101, School Biology, USM, Penang.

4. Mohd Rasdi, Z. and Che Salmah, M. R. (2011). Composition of Insects in a Tritrophic System of Brinjal. Seminar of Entomological Society of Malaysia (ENTOMA). Venue: at G148, Biology Building, Universiti Kebangsaan Malaysia, Bangi Seloangor. 30th November 2011. Organizer ENTOMA.

5. **Mohd Rasdi Z**., Che Salmah M.R., and Abu Hassan A. (2012). Effect of Nutrient and Pre-Infested Brinjal Plants, *Solanum melongena* on the Population and Interaction between Whitefly and Competitor Pest in a Multitrophic System.International Congress of Entomology (ICE 2012) in Daegu, Korea. 19-25th August 2012. EXCO Exhibition Centre, Daegu, Korea. Poster Presentation.

6. **Mohd Rasdi, Z.** and Che Salmah, M. R. (2012) First paper: Multitrophic system: Effect of different concentration of nutrient and pre-infested brinjal (*Solanum melongena*) on whitefly (*Bemisia tabaci*) population. Second Paper: Asymmetrical Effect of Nutrients Levels and Pre-infestation on Brinjal Plants against Parasitism Activity on Whitefly by Parasitoid (*Encarsia hitam*). Colloquium of the 7th Annual PPSKH Postgraduate 2012. USM,

Penang. Attended and Presented. Session 5 (Agrobiology). 7-8th November 2012. Venue PPSKH-room101, School Biology, USM, Penang.

7. **Mohd Rasdi, Z.** and Che Salmah, M. R. Effect of pre-infested brinjal plants, Solanum melongena on composition and interaction of key insect pest communitiesin multitrophic systems. Proceeding of Biodiversity and Integrated Pest Management: Working together for a sustainable future. 4th 7th July 2013. Manado, North Sulawesi, Indonesia.

8. Che Salmah M. R., **Mohd Rasdi, Z.**, Abu Hassan, Hamady, D. (2013) Whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae) parasitism by *Encarsia hitam* (Hymenoptera: Chalcididae) in eggplant: Effect of nutrient supplements and pre-infestation treatments. Proceeding of Biodiversity and Integrated Pest Management: Working together for a sustainable future. 4th 7th July 2013. Manado, North Sulawesi, Indonesia.

KESAN NUTRIEN, PEROSAK PESAING DAN INFESTASI AWAL TERHADAP KELIMPAHAN POPULASI LALAT PUTIH (*Bemisia tabaci* Gennadius) KE ATAS TERUNG (*Solanum melongena* L.)

ABSTRAK

Himpunan spesies artropod (lalat putih *Bemisia tabaci* Gennadius, afid *Myzus persicae* Sulzer, kutu hitam *Thrips* sp., hamama labah-labah merah *Tetranychus* sp., and pemangsa hamama *Phytoseiulus* sp.) pada tanaman terung (*Solanum melongena* L.) yang dijangkiti awal (pra-jangkitan) telah dibajai dengan tiga tahap kepekatan nutrien, iaitu N1 (50 ppm = 0.05g/L), N2 (150 ppm = 0.15g/L), dan N3 (300 ppm = 0.3g/L) telah dikaji dan penilaian telah dibuat ke atas interaksi di semua peringkat trofik (di antara perosak, serangga pemusuh semulajadi dan tumbuhan perumah).

Tambahan lagi, serangan lalat putih juga berkait rapat dengan fenologi perumah iaitu pada peringkat vegetatif dan peringkat buah. Serangan lalat putih lebih tinggi dicatatkan pada (kawalan) pokok bukan awal-serangan (pra-jangkitan) yang menerima kepekatan nutrien yang tinggi. Walau bagaimanapun, pada pokok yang dirawat dengan awal-serangan oleh lalat putih, populasi lalat putih adalah lebih rendah tanpa mengira kepekatan nutrien yang dibekalkan kepada tanaman. Tahap serangan yang paling rendah dapat diperhatikan pada tanaman yang menerima kepekatan nutrien 150 ppm, iaitu kadar yang disyorkan kepada penanam oleh Jabatan Pertanian, Malaysia. Berdasarkan keputusan ini, kepekatan 150 ppm boleh diterima sebagai kepekatan nutrient yang optima untuk mengawal serangan lalat putih pada tanaman terung. Tambahan lagi, penghasilan pertahanan kimia oleh pokok telah dikesan pada kadar populasi lalat putih yang rendah , dimana kesimpulannya bahawa

kesan serangan yang utama (lebih toksik) keatas tanaman (seperti lalat putih) berupaya merangsang sistem pertahanan yang berkesan.

Pemerhatian dari dua tempoh tanaman menunjukkan trend kelimpahan pesaing perosak yang agak tinggi (afid, thrips dan hama labah-labah merah) di dalam semua rawatan kecuali atas pokok-pokok yang dirawat dengan awal-serangan oleh lalat putih. Walau bagaimanapun, kelimpahan lalat putih dan thrips sangat dipengaruhi oleh serangan awal dan aplikasi nutrien terutamanya dalam tempoh penanaman pada kali pertama. Semua populasi artropod berubah dengan ketara bagi setiap dua minggu pensampelan yang berhubung kait ketika peringkat pertumbuhan awal tanaman dengan tahap toleransi yang berbeza-beza terhadap serangan perosak. Lalat putih dapat mengekalkan populasi yang agak tinggi sungguhpun perlu bersaing dengan perosak lain bagi mendapatkan makanan dan ruang. Lalat putih memanfaatkan kewujudan bersama dengan lain-lain serangga kerana parasitoid juga menyerang mangsa yang ada apabila populasi parasitoid tinggi. Tanaman awal-serangan (oleh lalat putih dan afid) tidak mempengaruhi kadar parasit pada pupa lalat putih tetapi kepekatan nutrien yang berbeza dan peringkat umur memberi kesan yang signifikan terhadap parasitisma keatas perosak. Parasitisma yang tinggi pada lalat putih pada tanaman kali kedua apabila populasi parasitoid tinggi.

Serangan awal tanaman (pra-jangkitan) oleh lalat putih dan afid membangkitkan mekanisme pertahanan kimia dan Jumlah Kandungan Flavonoid TFC) yang lebih tinggi di dalam tanaman awal-serangan oleh lalat putih dan afid. Walau bagaimanapun, pengeluaran TPC (Jumlah Kandungan Phenolic) menurun iaitu berkait rapat dengan tahap serangan perosak.

Kedua-dua rawatan yang diberikan kepada tanaman dan fenologi tanaman yang mengalami serangan perosak pada tahap yang berbeza mempengaruhi aktiviti enzim peroxidase dan β-1,3-glucanase. Tahap nutrien yang rendah (50 ppm) boleh meningkatkan β-1,3-glucanase terutamanya di peringkat awal tanaman tetapi tiada hubungan seumpama itu ke atas peroxidase. Walau bagaimanapun, peningkatan nutrient pada peringkat berbuah (8 WAT) dapat meningkatkan aktiviti β-1,3-glucanase (sebagai sistem pertahanan) di dalam pokok terung yang mana menghasilkan kadar kelimpahan kutu hitam yang tinggi. Pokok awal-serangan oleh lalat putih menghasilkan pertahanan kimia lebih awal dengan ketara dan populasi perosak menurun ke tahap yang sangat rendah sebelum peringkat berbuah (8 WAT).

Afid dan thrips boleh menjadi peramal yang baik kepada populasi lalat putih apabila mereka hidup bersama pada pokok terung. Kelimpahan afid menurun dengan ketara secara negatif dengan kenaikan aktiviti peroxidase (POD) dan ß-1-3 glucanase (GCS) sementara populasi lalat putih dan thrips pula mempunyai hubungan positif yang kuat dengan aktiviti POD.

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ABSTRACT

The assemblage of these arthropods species (whitefly *Bemisia tabaci* Gennadius, aphids *Myzus persicae* Sulzer, thrips *Thrips* sp., red spider mites *Tetranychus* sp., and predatory mite *Phytoseiulus* sp.) on early infested (pre-infested) brinjal plants (*Solanum melongena* L.) that were fertilized with three levels of nutrients concentrations, N1 (50ppm=0.05g/L), N2 (150ppm=0.15g/L) and N3 (300ppm=0.3g/L) were investigated and the interactions of all trophic levels (pests, natural enemy and host plant) were evaluated.

In addition, the infestation of whitefly was also closely associated with host plant phenology; vegetative and fruiting stages. Much higher whitefly infestation was recorded on non early-infestation (control) plants receiving high nutrient concentrations. However, on whitefly pre-infested plants, whitefly populations were lower regardless of the concentrations of nutrients supplied to the plants. The lowest infestation was observed on plants receiving 150 ppm nutrients, a rate recommended to the growers by the Department of Agriculture, Malaysia. Thus nutrient level was considered as the optimum nutrient concentration for sustaining whitefly infestation on brinjal plants. Furthermore, higher induction of plant chemical defence was detected at low whitefly population level which led to the conclusion that a more potent pest (whitefly) was able to stimulate the production of effective chemical defence.

Observation from two cropping periods showed trends of relatively high abundances of competitor pests (aphids, thrips and red spider mites) in all treatments except on plants pre-infested by whitefly. However, only population of whiteflies and thrips were significantly influenced by early-infestation and nutrient applications especially in the first cropping period. Populations of all arthropods varied significantly in biweekly collections corresponding to plant's growth stages with different levels of tolerance against pest attacks. Whitefly maintained relatively high population despite having to compete for food and space with other pests. Whitefly benefited from its co-existence with other arthropods because its parasitoids, *Encarsia hitam* also attacked other pests especially aphids when their populations were high. Pre-infested plants (by whitefly and aphids) did not influence parasitism intensity on whitefly pupae but varying levels of nutrient and age of the plant showed significant effects on parasitisation of the pest. Higher parasitisation of whitefly was observed during the second cropping period when initial population of the parasitoid was high.

Early infestation of the plants by whitefly and aphids aggravated plant chemical defence and higher TFC production was recorded in plants pre-infested with whitefly and aphids. However, as plants grew to maturity, the TPC production decreased correspondingly with severity of pest attacks.

The two treatments given to the plants and phenology of the plants which suffered different severity of pest infestations influenced the activities of the enzymes peroxidase and β-1,3-glucanase. Higher activity of β-1,3-glucanase was recorded in plants receiving low nutrient concentration (50 ppm) particularly at the early stage of plant growth but there was no such relationship in activity of peroxidase. However, increased nutrient levels at the fruiting stage (8 WAT), increased the activity of β-1,3-glucanase in brinjal plants which concluded with higher thrips abundance. Plants pre-infested by whitefly produced defence enzymes significantly earlier and pest populations decreased to very low level before the fruiting stage (8 WAT).

Aphids and thrips can be good predictors of whitefly population when they co-existed on brinjal plants. Aphid abundance was negatively affected by peroxidase (POD) and ß-1-3 glucanase (GCS) activities in the leaves while whitefly and thrips populations were positively correlated the POD activities.

CHAPTER 1

INTRODUCTION

1.1 Background

Whitefly (*Bemisia tabaci* G.) in the family Aleyrodidae has been recorded to infest a wide range of crops all over the world such as in the Philippines, Indonesia, El Salvador, Mexico, Brazil, Turkey, Thailand, Arizona and California (Nicolas, 2000). Whitefly was detected late 1800's (McAuslane, 1995) and first observed as a pest affecting tomatoes in America in 1870. Presently, whitefly is one of the most predominant insect pests in many ornamental and vegetable crops grown in greenhouses or under rain shelter all over the world. More than 500 plants species from 74 plant families are infested by whitefly (B. *tabaci*) (Mound and Halsey, 1978; Greathead, 1986; and Johnson *et al*., 1992). Apart from its threat as one of the global agricultural pests, whitefly is also a vector of plant viruses (Jones, 2003).

Whitefly is known to attack vegetable plants primarily brinjal , tomato and cucumber (Kenneth *et al*., 2002; Johnson *et al*, 1992) especially in the lowlands and highlands of Malaysia (Syed Abdul Rahman *et al*. 2000; Mohd Rasdi, 2005). A survey conducted recently on vegetables in Malaysia showed that whitefly was found throughout the country. Initial studies show that the whitefly species found in the highland and lowland areas are different (Syed Abdul Rahman *et al*., 2000). Two species are regularly encountered in the lowlands. They are *Aleurodicus dispersus* (spiralling whitefly) and *Bemisia tabaci* (sweet potato whitefly). In the Cameron Highlands, only one species was found namely, *Trialeurodus vaporariorum* (Syed Abdul Rahman *et al*., 2000). *Bemisia tabaci* causes serious economic threat to crop yields around the world (Brown *et al*., 1995 and Oliveira *et al*., 2000). Consequently, insecticides application is becoming a major tool and widely used by farmers to control whitefly and other pests (Palumbo *et al*., 2001). Most farmers resort to using insecticides because the availability of various insecticides in the market and their continuous efficacy (Li *et al*., 2001). However, Horowitz and Ishaaya (1996) who reported that a long-term controlling program on whitefly has become difficult due to reducing effectiveness in both the fields and glasshouses. For instance, insecticide such as imidacloprid is previously very effective against whitefly (Sharaf, 1986 and Palumbo *et al*., 2001), but intensive use of the insecticide has rendered it less effective due to rapid development of resistance (Denholm, *et al*., 1995; Dittrich and Ernst, 1990; and Palumbo *et al*., 2001). The use of excessive amount of fertilizers also contributes to severity of infestation of whitefly. Simmons and Abd-Rabou (2009) reported increasing threat of whitefly infestation after high application of fertilizers in the field which increased the abundance of whitefly.

Usually pests are attracted or repelled to host plant due to several reasons (Walling, 2000). Fertilizer applications attract pest infestations by providing good host plant quality for growth and reproduction (Lin *et al*., 1999; Nevo and Coll, 2001; and Zurina *et al*, 2010). Whitefly for example, has a strong preference for Solanaceae plants such as brinjal, tomato and chilli (Prabhu *et al*., 2009; Syed Abdul Rahman *et al*., 2000; and Mohd Rasdi, 2005) that are supplied with high amount and concentrations of nutrients (fertilizer) (Zurina *et al*., 2010).

On the other hand, plants are able to defend themselves against certain degree of pest infestation by initiating productions of protective compounds. Secondary metabolites are produced as plant defense mechanism after plants are infested by pests especially during the early stages of growth (Bell, 1980 and Lattanzio, 2006).

Different amount and concentrations of nutrients applied to the plants could influence physiological performance of the plants (Nevo and Coll, 2001 and William *et al*., 2002) which subsequently affect the insect-pest populations infesting them (Stamp and Yang, 1996; Simmonds, 2003; and Lattanzio, 2006). Both high nutrient and variations of plant variety were found to alter plant-pest relationship and pest abundance on them such as infestations of whitefly and other herbivorous insect-pests on highly fertilized Solanaceae plants (Teja and Bradford, 2000 and Zurina *et al*., 2010). In contrast, low nitrogen and water contents in the plant often connected with reduced preference and insect performance (Stamp and Casey, 1993 and Suwarno, 2009).

Competition among pests usually occurs in most crops in which many pests of different categories coexist simultaneously (Vandermeer, 2006). Many empirical and theoretical studies relate pest species composition (Aquilino *et al*., 2005) on host plants in various trophic levels as affecting pest populations (sizes) on the plants. Understanding the pest species population and their relationships are important for development of a good strategy in controlling important pests especially the whitefly (Li *et al*., 2011 and Nomikou *et al*., 2001). However, in addition to competition, interaction among various pests on brinjal plants such as whitefly and other pests is also regulated by other factors (Horowitz *et al*., 1984; Gerling *et al*., 1986; and Mohd Rasdi *et al*., 2009a) such as plant defence system.

Naturally plants protect themselves from pest attack through various techniques. Plants protect themselves either through morphological-mechanical mean such as having thorns, hairs, waxes and structural fibres or via chemical mean by producing secondary plant compounds or metabolites (Dicke *et al.,* 1990a and

1990b; Takabayashi *et al.,* 1991; Dicke and van Loon, 2000; and Potting *et al.,* 1995).

Swain (1977) reported that some plants produce different chemical defenses to combat different species of pests. They react differently to infestation by different species of insects and different types of mode of feeding (chewing, sucking and piercing) (Walling, 2000), consequently compounds that are produced as the result of plant mechanical damage and the compounds that are generated due to pest attack are discernible (Dicke *et al.,* 1990b and Turling *et al.,* 1990).

Most plants produce a broad range of secondary metabolites in response to biotic stress (Lattanzio and Cardinalli, 2006) that are toxic to herbivores such as flavonoid and phenolic compounds. Some plants, however, could produce specific secondary metabolites that are consistently different in volatile components corresponding to attack by specific insect pest species (Dicke and van Loon, 2000). Many plants respond to pest infestation by activating their transduction pathways (Dempsey *et al.,* 1999 and Ryan, 2000) and producing specific enzymes (peroxidase, polyphenol oxydases, ß-1-3-glucanse) to fight against the pests as well as to attract natural enemies. Considering these facts, plants defence mechanism could reduce the population size of pests on specific hosts.

Apart from chemical defense induced by host plants, natural enemies are highly responsible in suppressing pest populations. In general, natural enemy responses to the stress signal from the plants through production of plant attractants (Takabayashi and Dicke, 1996 and Dicke and van Loon, 2000). Twenty eight species of parasitoids and nineteen species of predatory insects recorded as being effective against whitefly (Lopez-Avila, 1986 and Gerling, 1990a). They include parasitoids Aphelinidae (*Aphelosoma*: 1 species, *Encarsia*: 20 species, *Eretmocerus*: 6 species), and Platygasteridae (*Amitus*: 1 species), four families (Chrysopidae, Miridae, Anthocoridae and Coccinellidae) and eleven species of mites from two families (Phytoseiidae and Stigmaeidae) (Gerling, 1990a). Although the general perception indicates that the predators and parasitoids are less effective control agents (Coudriet *et al*., 1986; Gerling and Horowitz, 1984; Gerling, 1986; and Gerling, 1990a), the effects of natural enemies on various key pests entail serious investigation (Naranjo, 2001; Nell *et al*., 1976) for sustainable and long term population regulation.

In agro-ecology, it is presumed that multi-trophic interactions exist among plants, pest and natural enemies during each cropping period (McCann and Yodzis, 1997). However, there is an interesting argument why herbivorous insect populations are more abundant in agro ecology (agricultural habitats) but less attack in indigenous habitats (Chen and Welter, 2005). The main reason is due to ample provision of suitable food resources at one or more stages of the pests' life cycles in agricultural system that has restricted plant and animal diversity. Dominant herbivorous pests proliferate to their fullest potential in the presence of fewer population regulating agents (natural enemies), competition and effective control practices (Pedigo, 1999).

The major problem of agro-ecology is the existence of poor plant and animal diversity in the system. Polis and Strong (1996) stressed on the need of increasing the diversity of insects which can affect trophic levels, due to increases or decreases in interference competition (including intraguild predation), diet shifts, omnivory, and other buffering mechanisms. Therefore, the problems on poor diversity of plants and insects, and changing of trophic behaviour will lead to significant domination of key pest on plant that required comprehensive study. Hence, details analysis on all variables set to investigate the trophic relationship and behavior of pest abundance on multitrophic system in agro-ecology (Vandermeer, 2006 and Behmer, 2008).

Changes in basic concept of trophic relationship, for instance, irregular feeding behaviour (e.g. from herbivory pest change to predator) was reported in some events due to specific reasons (limited food sources and insect diversity sizes) (Vandermeer, 2006). As the feeding behaviour is becoming more complex, therefore, upcoming study should look into the basic concept of omnivory (Vandermeer, 2006) that involves feeding behaviour at more than a single trophic level (omnivory) (McCann and Yodzis, 1997). The need for more research in this area is really important (Norris *et al*., 2003).

1.2 Objectives of the Study

At present, there is not much detail information on whitefly and other insect-pests associated with their host plants in a multitrophic perspective (Mohd Rasdi, 2005). The limited documentation and understanding of multispecies interaction on respective host plants is a limitation or constraint to the adoption of the IPM concept. Therefore, the present study was undertaken with the following objectives;

a. To determine the effect of various nutrient levels and early pest infestation of host plants (brinjal) on composition and interactions of whitefly and competitor pest populations infesting them as well as parasitism activity.

b. To identify and quantify the non protenaceous (Total Flavonoid Content and Total Phenolic Content) and protenaceous (peroxidase and ß-1-3-glucanse) produced by host plants receiving various nutrient levels and suffering from early pest infestations by whitefly, competitor pests and natural enemies in the field.

c. To investigate multitrophic interactions among pest (whitefly), parasitoid (*Encarsia hitam*) and host plants (brinjal plants) in an agriculture ecosystem.

The outcomes of this study would presumably generate comprehensive information on the interaction among trophic levels (plants, pests, parasitoids), which could be manipulated for the development of a sound pest management program of the pests and crop improvement strategies in the future. This information would extremely benefit growers, researchers, and students of agriculturally related fields for a thorough understanding of pest-plant community interactions which are vital for development of good management tactic of both the plant and pests.

CHAPTER 2

LITERATURE REVIEW

2.1 Background on whitefly

Whitefly is one of most important insect pests attacking vegetables particularly those from the family of Solanaceae such as brinjal (*Solanum melongena*) and tomato (*Lycopersicon esculentum*). This pest belongs to the Aleyrodidae family and has been recorded to infest a wide range of crops in Malaysia (Syed Abdul Rahman, 2000) as well as in other countries such as such as Philippines, Indonesia, El Salvador, Mexico, Brazil, Turkey, Israel, Thailand and the USA (Cock, 1986; Horowitz, 1986; Kogan and Turnipseed, 1987; Samudra and Naito, 1991 and De Barro, 1995). Generally, whitefly has the potential to infest different crops and may cause severe damage to these crops. For instance, whitefly was recorded to damage wide range of crops in Philippines including those from Cucurbitaceae [cucumber (*Cucumis sativus*), melon (*Cucumis melo*), and squash (*Cucurbita muscharta*)]; Fabaceae (mungbean and string beans); Caricaceae [papaya (*Carica papaya*)]; Musaceae [banana (*Musa* spp.)]; Solanaceae [brinjal (*Solanum melongena*), chilli (*Capsicum annuum*), tomato (*Lycopersicon esculentum*)]; Euphorbiaceae (*Euphorbia pulcherrima* and ornamentals), and fruit trees such as guava (*Psidium guajava*) (Nicolas, 2000 and Li *et al*., 2011). The crops are directly damaged by this insect through its feeding habits and indirectly through production of honeydew on which sooty mould grows. Whitefly also facilitates viral infection to the crops (Markham *et al*., 1994).

There are more than 1,000 whitefly species from 120 genera that have been documented in the world (Mound and Halsey, 1978). The sweet potato whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) was described more than 100 years ago as a substantial pest of tobacco in Greece (Oliveira *et al*., 2000). This species commonly known as the sweet potato whitefly strain B, belongs to the family Aleyrodidae and classified under the sub-order Sternorrhyncha (Mound and Halsey, 1978; Gill, 1990; Campbell *et al.,* 1994; Campbell *et al.,* 199; and Martin, 1999). It feeds on its host plant by sucking the fluid in the leaf and other parts of the host plant. Severe infestation of whitefly particularly on brinjal plant brings ghastly mind set to farmers and consequently it no longer becomes a good crop to grow.

In the highlands such as Cameron Highlands, Malaysia, whiteflies are more aggressive on crops grown in the rain shelters compared to those grown in the open field (Mohd Rasdi, 2005). Brinjal, cucumber, chilli, capsicum and tomatoes were seriously infested by the whiteflies resulting in a substantial loss (up to 50%) (Syed Abdul Rahman *et al*., 2000 and Zurina *et al*., 2010). Based on a survey conducted in Malaysia in 2000, whitefly was found spread ubiquitously in the entire country. Initial studies noted that two whitefly species are regularly encountered in the lowlands namely; *Aleurodicus dispersus* (spiralling whitefly) and *Bemisia tabaci* (sweet potato whitefly). However, only one species of *Trialeurodus vaporariorum* is widely distributed in the Cameron Highlands (Syed Abdul Rahman *et al*., 2000).

Once whitefly species infests the crops, it will cause serious economic loss up to million dollars (Costa and Brown*,* 1993). Phenotypes and way of communications with their host plants significantly influence whitefly infestation and the dynamics of virus-vector host interactions. Those interactions will determine whether infestations are likely to reach or surpass economic thresholds, and whether vector populations will disperse the transmission of plant viruses (Brown *et al.,* 1995).

The whitefly adults have the ability to fly. The flying activity enhances their dispersal and, hence, they become a good and quick plant feeder. The immature stages are not mobile, typically oval in shape and can be very flat to somewhat convex. While *B. tabaci* starts to infest the plant, it quickly spreads viruses through its feeding habits which will eventually result in severe damage to the plants (Jones, 2003).

According to available reports from Malaysia, whitefly population infested a wide range of plants, causing serious damage to different vegetables such as brinjal, cucumber, chilli, capsicum and tomato (Syed Abdul Rahman *et al*., 2000 and Mohd Rasdi, 2005). Whitefly-related problems happened after abusive used of pesticides and high inputs of fertilizers in the field. Thus, severe infestation of whiteflies and the associated viral diseases led to poor productions of brinjal in Malaysia (Syed Abdul Rahman *et al*., 2000). Consequently, various insecticides such as imidacloprid, buprofezin, formetanate and avermectin are widely used to control whitefly (Syed Abdul Rahman *et al*., 2000). High chemical usages build up whitefly resistance rapidly, while higher quantities of nutrients may increase the abundance of whitefly (Simmons and Abd-Rabou, 2009). Nowadays, many insecticides have become less effective against whitefly as the consequence of insect pest resistance. Rapid development of resistance on B-biotype whiteflies causes a major problem in controlling whiteflies with conventional insecticides such as organophosporus and pyrethroids (Markham *et al*., 1994). Due to the adverse effects of chemical control, other control practices need to be enhanced with more emphasis on the proper application techniques and non-chemical control methods to reduce whitefly populations such as by using natural enemies. Although several studies have been carried out by Malaysian Agricultural Research and Development Institute (MARDI) in both highlands and lowlands areas, the information on population dynamic and control of this pest is still incomplete.

The whiteflies are often present in high numbers on the underside of leaves of several host plants such as brinjal (*Solanum melongena*). As a sap-sucking insect (Pollard, 1955), its stylets in the rostrum pass between host-plant cells until they penetrate the phloem (Janssen *et al.,* 1989) on the undersides of plant leaves. Other insects that have similar feeding mechanism are aphids, mealy bugs and thrips. All of these pests have a specialized piercing and sucking type of mouthparts (Gill, 1990 and Byrne and Bellows, 1991). Large amounts of sap can be removed by this mode of feeding (sucking) and heavily infested plants can be seriously weakened. Leaves often turn to yellow, appear dry and drop prematurely (Bográn and Heinz, 2000).

Both immature and adult whiteflies feed on the plant sap. They also produce a sticky substance called honeydew on the host plant. Honeydew can induce the growth of sooty moulds, which can then reduce the plants ability to absorb light (Naranjo *et al*., 2003). Both the removal of plant juices and the presence of the black, sooty mouth growing on the honeydew can interfere with photosynthesis in the leaves. This results in weak growth, lower yield, and poor function of the plants.

2.2 Biology of whitefly *Bemisia tabaci* (Gennadius)

There are two distinct biotypes of *B. tabaci* namely; Biotype A and B which are sexually incompatible (Bellows *et al.,* 1994) with one another. Infestation of biotype B has higher ability to transmit begomoviruses due to rapid development and wide host range of this biotype.

2.2.1 Life cycle

There are six stages in the whitefly life cycle; egg, first, second, third and fourth larval stages and adult (Malaise and Ravensberg, 1991; Kenneth *et al*., 2002 and Mohd Rasdi, 2005). According to available literature, duration of whitefly life cycle varies due to the variation in host crop (e.g cotton, poinsettia, tomato and other host crops) and temperature (Avidov, 1956; Azab *et al*., 1971; Coudriet *et al*., 1985; Malaise and Ravensberg, 1991 and Sparks *et al*., 2002).

a) Eggs

Mohd Rasdi (2005) reported that whitefly lays its eggs within 48 hours after the mating process and the eggs hatches within six to nine days. Individually deposited eggs are laid vertically and fastened to the undersides of leaves of the host plant. The eggs are white and oval in shape with 0.25 mm long. After 48 hours, the colour of the eggs changes to pale yellow, brownish and finally light black before hatching (Malaise and Ravensberg, 1991).

b) Larvae and Pupae

The whitefly larvae develop to its full size through four stages (McDonough *et al*., 2003). Early larval instar is about 0.3 mm long and has 6 legs and a pair of antennae. The larva is about 0.38 mm long in the second larval stage, 0.51 mm in subsequent stage and the final stage (fourth larval) is about 0.73 mm long (Mohd Rasdi, 2005). The pupa is opaque and white in colour with numerous fringes along its sides. When viewed from the side, the pupa appears block shaped (Kenneth *et al*., 2002).

c) Adults

The adult of whitefly is minute with about 0.9 to 1.2 mm in length (McDonough *et al*., 2003 and Mohd Rasdi, 2005). The duration of life cycle depends on environmental conditions. For example, it can last for 18 days under warm conditions. However, it will spend up to two months under cool conditions (Drees, 2000).

2.2.2 Fecundity and Longevity

The number of eggs laid by whitefly female is influenced by the types of host plant and the environmental temperature (Malaise and Ravensberg, 1991). Whitefly female lays between 30 and 300 eggs on host plants such as poinsettia, *Euphorbia pulcherrima* and its longevity ranges from 10 to 24 days (Hoddle, 1999 and Mohd Rasdi, 2005).

2.3 Ecology of whitefly

2.3.1 Influence of environmental factors on the whitefly population dynamics

Generally, environmental factors are well-known key factors structuring the whitefly community. Horowitz *et al*. (1984) studied the population dynamics of *B. tabaci* in cotton fields in Israel using life table analysis. In the study, the population of whitefly (mortality) was remarkably affected by climatic factors such as humidity and temperature in the open field but parasitism was not a decisive mortality factor. In Sudan, heavy rain was usually followed by obvious decline in the whitefly population (Horowitz, 1986 and Gerling *et al*., 1986).

Bemisia tabaci has a wide range of hosts and it attacks more than 500 species of plants (Greathead, 1986) from 63 plant families (Mound and Halsey, 1978). In Hawai and the United States, many crops such as brinjal, tomato, chrysanthemum, pepper, cabbage, cucumber, avocado, green bean, broccoli, cauliflower, Chinese waxgourd, *Dendrobium* (flowers), hibiscus, gourds, guava, lettuce, luffa, pumpkin, rose, soy bean, squash, sweet potato, poinsettia, bitter melon, pea and watermelon are infested by *B. tabaci* (Mau and Dicke, 1991). Weeds a non-crop host including *Asystasia* sp., *Coccinia* sp., castor bean, *Euphorbia* sp., *Ipomoea* sp., *Malva* sp., *Momordica* sp., and *Xanthium* sp. often serve as alternate hosts of this pest although no evidence suggests that *B. tabaci* can reproduce on weed hosts (Mau and Dicke, 1991). In relation to physical characteristics of its host plant, whitefly is significantly influenced by the leaf surface such as leaf shape, stickiness, and hairiness (Butler and Wilson, 1984). Chemical characteristics of the leaf such as the pH of the leaf sap (Berlinger, 1986) also affect whitefly preference on the host plant.

Bemisia tabaci actively flies early in the morning up to midday (Byrne and Bellows, 1991) but limited ability to direct their flight (Byrne *et al*., 1990). Two types of flight patterns of whitefly are documented in the literature; short-distance and long distance flights (Berlinger, 1986). For long distance, *B. tabaci* adult flies from it host plants to a distance up to 7 km (Cohen, 1990) but short distance flight only occurs under the plant canopy and between cultivated host plants (Lenteren *et al*., 1990). The latter flying pattern is the most common. The direction of flight is primarily dictated by the wind direction (Cohen, 1990). They land on particular plants mostly by chance and tend to stay on suitable hosts.

Variations in the agronomic practices are of growing interest as they may enhance insecticides resistance in the *B. tabaci* community (De Barro, 1995). In addition, Brown *et al*. (1995) reported that agricultural practices of irrigated monoculture system with continuous planting may influence the whitefly population.

It is known that several factors influence the efficiency of whitefly control. These factors include fertilizer application (Nevo and Coll, 2001 and Zurina *et al*, 2010), chemical resistance (Markham *et al*., 1994), planting system, and spatio-temporal factors (Hirano *et al*., 1993). Basically, the spatio-temporal variations could also promote the population density of *B. tabaci* (Hirano *et al*., 1993). Furthermore, whiteflies have the ability to migrate and dispersed by wind for short and long distances (Blackmer and Byrne, 1999).

2.3.2 Biotic interaction

It is an acceptable fact that plant nutrition regime would influence the sap-sucking pests. Thus, changes in fertilization frequency and dosages directed towards increasing the nitrogen in plants have been found to enhance the population growth rate of many pest species (Bi *et al.*, 2001; Nevo and Coll, 2001 and Hogendorp *et al*., 2006). According to Salvucci *et al*. (1998), whiteflies are responsive to proteins levels and the free amino acids from the phloem. Therefore, the effect of higher nitrogen fertilization to the plants may raise the availability of the proteins and amino acids for phloem-feeding pests including whitefly (Godfrey *et al.*, 1999 and Jauset *et al*., 2000).

Several researchers stated that whiteflies feed, oviposit and develop more quickly on plants with higher nitrogen concentrations (Bentz *et al*., 1995; Simmons *et al*., 2000; and Inbar *et al*., 2001). As reported by Zurina *et al*. (2010), the populations of whitefly were found higher on the chilli plants (*Capsicum annum*) after the plants were supplemented with high nitrogen. Additionally, the population of whitefly was also higher on cotton treated with high nitrogen compared to plants supplied with low dosage of nitrogen (Lin *et al*., 1999). Similar study by Jauset *et al*. (1998) reported that the preference of the greenhouse whitefly (*Trialeurodes vaporariorum*) on the leaf was positively related to fertilizer rate, specifically nitrogen.

2.4 Brinjal as host plant

2.4.1 Brinjal cultivation and environment in Malaysia

Brinjal is a very famous fruit vegetable grown throughout Malaysia on more than 1,000 hectare. The other common names of brinjal are eggplant, aubergine, terong, oriental eggplant, garden eggplant, Italian eggplant, berenjena, nasu, ngagwa and gunea squash. crop originated from India and available in both tropical and sub tropical countries. There are two types of brinjal in Malaysia namely; *S. melongena* (terong panjang/elongated brinjal) and *S. macrocarpon* (terong engkol/ santan/ bulat/ round brinjal). All varieties of brinjal are hardy and can easily be cultivated in many types of soil in Malaysia (Lee, 1979).

Brinjal grows well in the environments where the temperature ranges from 25°C to 35°C. It also requires from 340 to 515 mm of rainfall (Lee, 1979) and can grow well on various types of soil such as peat, marine sands, and ex-mining soils with a pH range from 5.5 to 6.8 (Lee, 1979; Department of Agriculture, 1997). Several activities are involved in brinjal planting such as bed preparation, sowing, seed treatment, liming, manuring, transplanting, irrigating, pest and disease control, prunning, and harvesting.

2.4.2 Brinjal as host plant for whitefly

Although several studies reported infestation of whiteflies on various host plants in Malaysia, few studies demonstrated the infestation of whitefly on brinjal. Brinjal is the most preferred host plants followed by tobacco (*Nicotiana tabacum*) and tomato (*Lycopersicon esculentum*) for feeding and oviposition as either individually plants or multi plants (no choice test or choice test) (Mohd Rasdi, 2005; Mohd Rasdi *et al*., 2009a; and Syed Abdul Rahman, 2000). There was significant association between biochemical constituents in brinjal [e.g. glycoalkaloid (solasodine), phenols and phenolic oxidase enzymes (poly phenol oxidase and peroxidase)] and pest infestation (Kallo, 1988 and Prabhu *et al.*, 2009).

2.4.3 Other brinjal pests and diseases

Besides whitefly, other insect pests including aphids and thrips which have similar feeding mechanism may attack brinjal. For example, leaf feeding ladybird beetle (*Epilachna indica*), fruit and shoot borer (*Leucinodes orbonalis*), green peach aphid (*Myzus persicae*), red spider mite (*Tetranychus cinnabarinus*) thrips (*Thrips palmi*) and mealybugs are reported to attack brinjal (Lee, 1979; Gill, 1990; and Byrne and Bellows, 1991). The summary of biology and ecology of some brinjal pest are briefly described.

a) Green Peach Aphid (*Myzus persicae*)

The green peach aphid, *Myzus persicae* (Hemiptera: Aphididae), known also as peach potato aphid, is a European native species but currently it has worldwide distribution (Hogmire and Polk, 2003). Young nymphs are yellowish green in colour and have three darker green lines at the back of the abdomen (Hogmire and Polk, 2003). Although it has many host plants such as broccoli, cabbage, brinjal, sweet potato and tomato, it also attacks many ornamental crops such as carnation, chrysanthemum, flowering white cabbage, poinsettia and rose. It has a very complex life cycle and has been found on more than 800 plant species (Ronald, 2000). The winged aphid has a black spot in the middle of its abdomen. Adult females fly for far distances and do not lay eggs, but instead give birth to wingless nymphs. Each female produces about 50 nymphs; hence aphid populations can grow very rapidly. Nymphs shed their skins several times as they develop into adults. The aphids can complete one generation from new born nymphs to adults from 6 to 15 days. After several generations without wings, eventually adults with wings are produced (Hogmire and Polk, 2003). *Myzus persicae* feeds primarily on the undersides of leaves, which cause them to curl, distorted and yellow. Consequently, the leaves drop prematurely from the plant. Feeding may also take place on flowers and fruits resulting in flowers abortion and fruits fall. When abundant, aphid feeding results in excretion of large amounts of honeydew which would support the growth of a black sooty mould that causes spotting of leaves and fruits (Hogmire and Polk, 2003). Injury caused by this species is mainly through their ability to transmit a number of destructive viruses such as Potato Leaf Roll Virus (PLRV) and Potato Virus Y (PVY) (Godfrey *et al*., 2002).

b) Thrips

Thrips is one of the major insect pests which threaten production of vegetables and fruits. Thrips is very tiny insect which has piercing mouth parts that cause destructive damage to the plants. They are about 0.2 cm long and narrow-bodied insects commonly found feeding on leaves and stems (Lewis, 1973). The duration of life stages of thrips from eggs to adult ranges from 8 to 14 days (McDonald *et al*., 1999). The duration of eggs ranges from two to four days, first instar is from one to two days, the second instar is between two to four days, prepupa from one to two days, pupa from one to three days and adult is between 30 to 45 days (Greer and Diver, 2000). The adult has two pairs of fringed wing, which normally are held back over and parallel to the body. Only the two larval stages and the adult are active feeders as they rest during the prepupal and pupal stages. Thrips apparently can rely entirely on parthenogenetic reproduction, in which the female produces young without mating. Temperature and rate for development of *Thrips palmi* from egg to adult ranges between 15 to 30^{o}C (McDonald *et al*., 1999).

2.5 Control of whitefly

There are several techniques to control whitefly infestation including biological, cultural and chemical methods. Integrated Pest Management (IPM) is a decision support system for the selection and use of pest control tactics singly or harmoniously coordinated into a management strategy, based on cost-benefit analyses which considered the effects and impacts on environment, society and growers (Norris *et al*., 2003). The IPM concept, explained the expression of "integrated control" was originally described the use of insecticides in a way that was compatible with the biological control of insects. There are several specific components in IPM such as population monitoring, utilization of thresholds, use of biological control agents, cultural practices and pesticides are applied only when it is necessary.

The success of IPM is still doubtful due to many reasons particularly in implementation of this concept. Some previous experiences noted that the failure of IPM or difficult to practice by farmers to determine the Economic Threshold Level (ETL) due to several reasons such as different types of crops, geographical factors, biological control effectiveness and climatic factors. Thus, in order to develop more effective control strategies, it is important to study the chemical ecology and insect behaviour (Ahuja *et al*., 2011). Many previous studies elucidated that the plant volatiles have promising prospects for the future of the IPM.

2.5.1 Biological control

Biological control in the classical sense means the importation of parasitoids, predators, and pathogens for the control of introduced (exotic) pests. This method keeps whitefly population below the economic injury level (McAuslane, 1995). Nineteen species of insects belonging to four families (Chrysopidae, Miridae, Anthocoridae and Coccinellidae) and eleven species of mites from two families (Phytoseiidae and Stigmaeidae) are recorded as effective predators to *B. tabaci* (Gerling, 1990a). The predators of whitefly include assassin bug (*M. caliginosus*), lady beetles (*Delphastus* and *Nephaspis*), green lacewings (*Chrysopa* and *Chrysoperla*), minute pirate bugs (*Orius*), big-eyed bugs (*Geocoris*), and damsel bugs (*Nabis*). However, parasitoids of whitefly include minute wasps, *Encarsia* sp. and *Eretmocerus* sp., each measuring 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 pupa and after the eclosion of wasp's eggs, the larvae feed internally on the whitefly nymphs and eventually kill the host (Bogran and Heinz, 2000). A total of 28 species were recorded as parasitoids of *B. tabaci* including Aphelinidae (*Aphelosoma*: 1 species, *Encarsia*: 20 species, *Eretmocerus*: 6 species), and Platygasteridae (*Amitus*: 1 species) (Lopez-Avila, 1986; Gerling, 1990a).

Predators and parasitoids do not seem to be effective agents in reducing *B. tabaci* populations under field conditions (Horowitz, 1984; Coudriet *et al.*, 1986; Gerling and Gerling, 1986; Gerling, 1990b). However, the effects of several parasitoids are better in the glasshouses. In combination with other control methods, parasitoids have been proposed as potentially useful biological control agents. Some of these agents have given considerably good results such as *Eretmocerus haldemani*

(Family: Aphelinidae) in cotton fields of California (Gerling, 1967) and *Eretmocerus mundus* in cassava fields of Zimbabwe (Gerling, 1985).

In addition to predators and parasitoids, whiteflies are naturally attacked by insect pathogens especially fungus. These entomopathogenic fungi are also known as mycopesticides or mycopathogens which prey on insects. The entomopathogenic fungi are also useful components of IPM programme as 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. The spores from the fungal pathogens *B. bassiana*, which cause white muscardine diseases in insects, have been formulated into insecticidal products (McDonough *et al*., 2003). Classical biological control programmes using insect predators have been conducted against several whitefly species such as the silverleaf whitefly, citrus whitefly, and giant whitefly (Bogran and Heinz, 2000). Nevertheless, the potential of predator species against whiteflies has been examined in only a few species such as *Delphastus catalinae* and *Serangium parcesetosum* (Coccinellidae), *Macrolophus caliginosus* (Miridae), *Chrysopela carnea* and *C. rufilabris* (Chrysopidea) (Gerling *et al*., 2001).

2.5.2 Cultural control

Cultural control is aimed at avoiding or preventing whitefly infestations, eliminating sources of whitefly and keeping it out of planted areas. There are several cultural practices such as sanitation, distances between plants and row spacing and types and amount of fertilizer. One of the common control methods is sanitation (McAuslane, 1995). Good crop sanitation involves inspecting the presence of whitefly, followed by routine inspection or monitoring. Routine inspection allows detection of early infestation and implementation of appropriate action (McDonough *et al*., 2003). During the growing season, geminivirus infected plants can be rogue out and destroyed. After harvest, crop residues should be removed leaving no plant material for large numbers of whitefly during crop free period (McAuslane, 1995).

The barriers have been used, successful in keeping whitefly from invading greenhouses. Greenhouses are screened with very fine mesh plastic screen. Ventilation must be increased, however, to reduce the likelihood of infection by plant pathogens. UV absorbing greenhouse plastic films also reduces whitefly infestation. Whiteflies do not enter greenhouse or areas covered with this type of plastic as frequently as they do when the greenhouses are covered with non UV absorbing material (McAuslane, 1995). Coloured plastic mulches are effective in reducing whitefly populations and Gemini virus incidence. In Florida, tomato plants covered with yellow or aluminium plastic mulches produces more yield with less incidence of tomato mottle virus infection than those covered with white or black plastic mulches (McAuslane, 1995).

The use of resistant host plants has potential as an IPM component for suppression of *B. tabaci* populations (Berlinger, 1986). A trial was conducted in Sudan on the susceptibility of eight tomato varieties for *B. tabaci* strain B infestation. Low numbers of whitefly eggs, nymphs and adults occurred on a more resistant variety, Red Cloud (Kisha, 1984). Nevertheless, resistant host plant offers limited hope for whitefly management. At present, no variety of host plant is highly resistant to whitefly. Nonetheless, smooth leaf varieties of cotton and soybean are less preferred by ovipositing female whitefly than those hairy leaved varieties (McAuslane, 1995).

2.5.3 Chemical control

Chemical control is the most common method to control whitefly population. However, this mean of control is difficult to achieve consistently good results due to rapid development of resistance of the pests against the insecticides (Palumbo *et al.*, 2001) and the habitat of immature forms primarily concentrate on the undersides of the leaves while older larvae and pupae are distributed at lower canopy of the plant (Mohd Rasdi *et al.*, 2009a). Furthermore, Coudriet *et al.* (1985) reported that the larval development, adult feeding, mating and oviposition also occur at the lower surfaces of leaves.

In the last decades, some insecticides have provided effective control against whitefly, yet resistance has developed rapidly (Palumbo *et al.*, 2001). For instance, whitefly was reported to develop resistance to several new chemical compounds, including new insecticides (pyrethroid) and insect growth regulators (IGRs) (Palumbo *et al.*, 2001). The unique strategy and behaviour of this insect such as having their life cycles completed on the lower surfaces of leaves provides good protection for them (Coudriet *et al.*, 1985).

Organic and inorganic compounds with completely different modes of action have been identified as effective agents against the whitefly (Mau and Dick, 1991). Neem oil has been used as insecticides, acaricides or as an additive in chemical application. It acts as physical poisons that interfere with respiration in arthropods, although some of the plant oils may contain toxicants. Insecticidal soaps and oils, and pesticides containing neem are few compounds that are less toxic to some parasites and predators in the field. Both petroleum based and plant derived oils have been reported efficacious against all stages of whitefly (Johnson *et al.*, 1992). Soaps and detergents, either synthetic or naturally derived are active against all life stages except for eggs. Botanical extracts such as Margosan-O (Azidirachtin) and glandular secretions from *Nicotiana tabacum* (tobacco) are highly toxic to nymphs. Repellence such as *N. tabacum* extracts can also be used for whitefly control (Johnson *et al*., 1992). Alternative controls other than using pesticides particularly cultural control such as considering optimum nutrient levels and plants chemical defence should be considered for a satisfactory IPM program.

2.6 Plant response and defence system

2.6.1 Secondary metabolites

Secondary metabolites (natural product) are defined as chemical compounds produced by plants as a protection against pests. Secondary metabolism are performed by specialized cells that are important for plants survival in the environment (Lattanzio, 2006). Plants are able to synthesize higher amounts of secondary compounds than other organism (animals) as they have low mobility to escape from their natural enemies (Bell, 1980).

In general, secondary metabolites are not directly involved in growth (replication, translocation and differentiation proceses), respiratory, metabolism, reproduction and photosynthesis of plant (Hartmann, 1991). These chemical compounds are diverse and thus being classified into different categories. Meanwhile, secondary metabolites can be used to identify the taxonomy of certain pests (Frisvad and Filtenborg, 2007). Secondary metabolites are categorised into three chemically distinct groups; terpenes, phenolics and nitrogen (N) and sulphur (S) containing compounds. Terpenes are composed of 5-C isopentanoid units, known as feeding deterrents and toxic to pathogen mostly herbivores. Meanwhile, primarily phenolics synthesized from products of the shikimic acid pathways have several