IDENTIFICATION AND MANAGEMENT OF THRIPS ON SOLANACEOUS PLANTS IN CAMERON HIGHLANDS

By

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ABSTRACT

IDENTIFICATION AND MANAGEMENT OF THRIPS ON SOLANACEOUS PLANTS IN CAMERON HIGHLANDS

TAN JIUNN LUH

Pest management is one of the major challenges for farmers who cultivate vegetables. Therefore, it is vital to understand the farmers' approaches and pest problems in order to provide the necessary assistance for farmers to sustain their productivity. A survey on the farming practices of eggplant, chilli and bell pepper growers was carried out in Cameron Highlands to understand the pest problem and management approaches of farmers. It was found that most of the farmers were still practicing conventional farming methods, namely, most of them are still planting on soil beds, dependent on chemical-based fertilisers and pesticides, and dependent on middle person to market their farms product. However, new technologies such as fertigation and foliar fertilisers, have been adopted by farmers to improve their productions. Thrips were confirmed as one of the most persistent pest problems by eggplant, bell pepper and chilli farmers. Ninety percent of the farmers depended solely on insecticides, namely, abamectin, imidacloprid and spinetoram, to reduce the damages caused by thrips, thus, increasing their production cost. Identification of thrips was carried out to determine the species that were damaging these crops. Four species of thrips, namely *Thrips palmi* Karny, *Thrips parvispinus* Karny, *Frankliniella occidentalis* Pergande and *Megalurothrips usitatus* Bagnall were identified based on their morphological characteristics. A leaf-dip bioassay was carried out to study the insecticide resistance level of *T. palmi* against spinetoram. *Thrips palmi* was used in the test because it was found to be the most abundant among the four species of thrips while spinetoram was named as the most effective insecticide in reducing thrips population in Cameron Highlands. The resistant ratio of *T. palmi* population against spinetoram was found to be 1.69. The resistant ratio is very low, but it does indicate that the resistance against spinetoram was developing among the *T. palmi* population. The susceptible thrips used in the test were collected from organic farm in Cameron Highlands which might contain thrips migrated from nearby conventional farms and that might contribute to the very low resistant ratio.

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APPROVAL SHEET

This dissertation entitled "**IDENTIFICATION AND MANAGEMENT OF THRIPS ON SOLANACEOUS PLANTS IN CAMERON HIGHLANDS**" was prepared by TAN JIUNN LUH and submitted as partial fulfilment of the requirements for the degree Master of Science in Agricultural Science at Universiti Tunku Abdul Rahman.

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20th November 2017

SUBMISSION OF DISSERTATION

It is hereby certified that **TAN JIUNN LUH** (ID No.: **14ADM06097**) has completed this dissertation entitiled "**IDENTIFICATION AND MANAGEMENT OF THRIPS ON SOLANACEOUS PLANTS IN CAMERON HIGHLANDS**" under the supervision of Prof. Dr. Ooi Aun Chuan from the Department of Agricultural and Food Science, Faculty of Science, and Dr. Gideon Khoo from the Department of Biological Sciences, Faculty of Science.

I understand that the University will upload softcopy of my dissertation in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

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TAN JIUNN LUH

DECLARATION

I, Tan Jiunn Luh, hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Tunku Abdul Rahman or other institutions.

(TAN JIUNN LUH)

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LIST OF ABBREVIATIONS

°C	Degree Celsius
AAA solution	Acetic Acid-Alcohol solution
CIS	The Centre for Insect Systematics
cm	centimetre
DDT	Dichloro-diphenyl-trichloroethane
DoA	Department of Agriculture
E	East
E. coli	*Escherichia coli*
FFS	Farmer Field Schools
g	gram
g/l	gram per litre
GAP	Good Agricultural Practice
GDP	Gross domestic product
GMO	Genetically modified organisms
ha	Hectare
IFS	Integrated farming system
IPM	Integrated Pest Management
kg	kilogram
LD_{50}	Lethal Dosage at 50% mortality
m	metre
MARDI	Malaysian Agricultural Research and Development Institute

mg/L	Milligram per litre
mm	millimetre
mt	Metric tons
MYR	Malaysian Ringgit
N	North
NGO	Non-Government Organisation
NPK	Nitrogen-Phosphorus-Potassium
OF	Organic farming
PAN	Pesticide Action Network
RR	Resistance ratio
S/B	Sendirian Berhad
SC	Suspended concentrate
sp.	species
SPM	Sijil Pelajaran Malaysia
TOL	Temporary Ownership of Land/ Temporary Occupational License
TSWV	*Tomato spotted wilt virus*
UKM	Universiti Kebangsaan Malaysia
USD	United States Dollars
UTAR	Universiti Tunku Abdul Rahman

CHAPTER ONE

INTRODUCTION

Vegetables have played a big part of our daily meals. The World Health Organization (2003) stated that sufficient daily consumption of fruits and vegetables, which is approximately 400g of fruits and vegetables per day, could help in the prevention of chronic diseases, for example, cardiovascular diseases, diabetes, obesity and certain cancers. Approximately 31% of ischaemic heart disease and 11% of stroke cases around the world are caused by low intake of fruits and vegetables. Despite the vital role of vegetables in our daily meals, the production of vegetables is not well-known by many.

Vegetable crops are classified as Angiospermae and divided into two main classes, namely, Monocotyledoneae and Dicotyledoneae. Most of the vegetable crops are classified in the family under the class Dicotyledoneae, for instance, the family Cruciferae, the family Cucurbitaceae and the family Solanaceae. The family Gramineae, Alliaceae, Liliaceae, Araceae and Dioscoreaceae are the only ones belonging to the class Monocotyledoneae (Dhaliwal, 2012). The production of these vegetable crops is susceptible to their respective pest damage and pest management is one of the major challenges for farmers. According to Oerke (2006), the potential loss of yield to weeds is approximately 34%, and the potential losses to animal pests and pathogens are approximately 18 and 16% respectively. However, with proper pest management, farmers are still able to sustain the productivity (Oerke, 2006). The most popular pest management approach used by farmers is chemical pesticide, but it is not sustainable (Kabir and Rainis, 2014). Therefore, cultural practice, namely, crop rotation, is practiced to prevent the build-up of various pest populations (Little and Frost, 2008; Mandiriza-Mukwirimba, Kritzinger and Aveling, 2016). In addition, integrated pest management (IPM) approaches have been introduced to the farmers in recent years to overcome unsustainability of conventional approaches (Kabir and Rainis, 2014). The findings of Mandiriza-Mukwirimba, Kritzinger and Aveling (2016) showed that the pest management approaches which combined crop rotation and chemical pesticides are common as farmers are reducing the usage of pesticides due to its adverse effects.

Chemical pesticide is one of the agriculture technologies introduced to improve food productivity in the agriculture sector in Asia during the Green Revolution in the late 1960s to 1980s (Watts, 2010). Insecticides were the first pesticides introduced to the farmers due to the availability of cheap chemical pesticides after the World War II and also pests were the constant problem faced by Asian farmers (Kaosa-ard and Rerkasem, 1999). The Green Revolution was a success to many people because it increased the production yield in a short amount of time, but according to Watts (2010) the success of Green Revolution might have been overstated because the production was not sustainable. For instance, during the Green Revolution in Bangladesh, only 1 kg of nitrogen was needed to yield 20 kg of grain but now the same amount of nitrogen only produces 8 to 10 kg (Hossain et al., 2007). Besides that, Das and Tripathi (2014) stated that the increased food production by Green Revolution has caused other problems such as the loss of soil health, increasing pest resistance and environmental pollution. For instance, after two decades of Green Revolution the Punjab farmers were left with poor land, highly resistant pests, waterlogged deserts and debts (Shiva, 1991). The negative side effects of synthetic pesticides were raised in the early 1960s when Carson (1962) mentioned that the use of pesticides would eventually kill all the birds due to its high toxicity. After Carson (1962), more of the negative effects of agriculture chemicals were revealed, namely, water pollution due to excessive use of agrochemicals, degraded soils, and increasing incidence of cancers and other relevant diseases. Contradicting the initial benefits of Green Revolution, poor farmers have become even poorer due to the introduction of agricultural technologies. Poor farmers are financially burdened with lower market prices due to high production or sometimes overproduction, and also higher expenditure on seeds, fertilisers and pesticides, and farm machinery (Fresco, 2015).

Regardless of the problems that arise from chemical pest control methods, farmers are still highly dependent on them to manage the pests because farmers do not have the necessary knowledge of alternative pest control methods, such as, integrated pest management (IPM) (Anyanwu, 2012). According to Grube et al. (2011) , the total world pesticide expenditure was more than USD35.8 billion and

USD39.4 billion in 2006 and 2007 respectively, while the usage of pesticides was approximately 2.36 million tons in both 2006 and 2007. Despite the high usage of pesticides, the pest problems have become more severe as more insect pests are becoming resistant to the chemicals. The first insecticide resistance case was reported in 1941 by A. L. Melander, where the San Jose scale, *Quadraspidiotus perniciousus*, was found to be resistant against an inorganic insecticide, lime sulphur, within two weeks of applications in orchards. The number of insecticide resistance cases grew exponentially after the introduction of DDT and other synthetic organic insecticides. Many insects have developed insecticide resistance to major groups of insecticides, and in addition, the insects are also resistant to new insecticides with different modes of action (Karaagac, 2012). The insects that initially develop resistance are usually herbivorous insects, such as the diamondback moth and thrips, because they naturally inherit the higher activity of detoxifying enzymes which allows them to handle plant secondary chemicals in nature. Therefore, the most problematic insects in the world are usually pests, after they have been frequently sprayed with insecticides which free them from their natural enemies (Mallet, 1989). The use of pesticides has not solved the pest problems of farmers but has instead created more severe insect infestations in the long run as well as increased the cost of production.

The Southeast Asian agricultural sector is still backward and stagnant as compared to other sectors which have become modernized. There are several factors that stagnate the growth of the agricultural sector in Southeast Asia and one of them is related to the Green Revolution (Daquila, 2007). According to Barnett et al. (2009), small-scale farmers produce most of the food consumed worldwide and 87% of the small farms are located in Asia. Approximately 70% of Asians live in the rural areas and the majority are farmers who depend on agriculture for survival (Ooi, Canillas and Yambao, 2007). These small-scale farmers are the ones most affected by the Green Revolution and become victims of its negative effects. The financial burden of the small farmers increased with the use of chemical fertilisers, high-yielding varieties of seeds and pesticides. According to Watts (2010), the purchase of these chemicals has made poor farming communities poorer and through the Green Revolution, the poverty level of these farmers has worsened. Therefore, it is necessary to understand the needs of these small holding farmers before providing them with non-sustainable solutions, such as chemical pesticides.

The farming practices of farmers need to be investigated in order to provide the farmers with the necessary support. In this study, Solanaceae crops were the focus because they belong to one of the world's most economically important plant families which includes many agriculturally important species, such as potato, tomato, eggplant, chilli, and tobacco (Olmstead et al., 2008). The Solanaceae crops are also considered as the most valuable vegetable crops in the world, with several members of the family being selected as food sources (potato, chilli pepper, eggplant and tomato), ornamentals (petunia and *Datura*) and medicine (tobacco, *Hyoscyamus* and *Mandragora*) to human civilisation (Gebhardi, 2016; Jagatheeswari, 2014). Similar to other vegetable crops, the Solanaceae crops are also susceptible to pest attack and proper pest management should be carried out to ensure the yield of these crops are able to meet the market demand. Due to the great diversity of Solanaceae crops in terms of habitat, morphology and ecology (Yadav et al., 2016), the pests are variable from one Solanaceae species to another. However, there are several pests that are considered as important among the Solanaceae crops, namely, whiteflies, aphids, leafminers, thrips and spider mites. The most recommended method to control these pests are no longer chemical methods but IPM strategies which focus on the use of biological control agents (Perdikis, Kapaxidi and Papadoulis, 2008).

According to Rebek et al. (2012), IPM strategies which involve biological control agents, such as parasitoids and predators, are becoming popular because it is environmentally friendly and less or non-toxic compared to chemical controls which have caused multiple environmental and health hazards to consumers. Biological control methods have proven effective and reliable in managing the population of insect and mite pests in Solanaceae crops as compared to chemical controls in addition to benefits such as zero resistance development, no environmental pollution and zero pesticide residue in the farm produce (Perdikis, Kapaxidi and Papadoulis, 2008). The IPM strategies have been successfully implemented in Asia and Africa with increased yields and reduction in the usage of pesticide. The Asian countries that have participated in introducing IPM to their farmers include, Bangladesh, Cambodia, China, India, Indonesia, Japan, Laos, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam, while the African countries include, Burkina Faso, Egypt, Ghana, Kenya, Mali, Malawi, Niger, Senegal, Tanzania, Uganda and Zimbabwe (Pretty and Bharucha, 2015).

Unfortunately, Malaysia is not among the Asian countries which have introduced and implemented IPM strategies in pest management. Most of the farmers in Malaysia are still very much dependent on chemical pesticides as the sole pest management strategy (Halimatunsadiah et al., 2016). Studies by Kabir and Rainis (2015) found that farmers lack knowledge and information about IPM, thus discouraging them from adopting IPM strategies. In addition, the farmers' traditional assumption that the higher the usage of pesticide, the better the yield, have generated some negative perception on IPM strategies (Kabir and Rainis, 2013; Pretty and Bharucha, 2015). However, the conventional assumption of the farmers is inaccurate, because the findings of Alam et al. (2016) showed that the plots which adopt IPM strategies have better yield compared to plots which practice conventional farming methods. Therefore, educating the farmers on new farming practices, especially pest management method, is vital to improve the quality as well as the quantities of our local vegetable production.

Educating the farmers is necessary and it has been carried out in many Southeast Asian countries, such as, Cambodia, Laos and Vietnam. The researchers form teams to undergo "needs-based" research on vegetables to address the actual needs of the rural farmers and educate them on methods for planting better crops

(Ooi, Canillas and Yambao, 2007). “Needs-based” research is carried out based on the needs of the farmers and the outcome of such research will be used to support the farmers’ activities, for instance, providing solutions to their farming activities and improving the quality of their crops by providing proper education in the field or farm. The establishment of the Farmer Field Schools (FFS) in many Southeast Asian countries, namely, Cambodia, Indonesia, Laos, Philippines, Thailand and Vietnam, is one of the efforts by the Food and Agriculture Organization to help farmers to act on their own initiative and analyze and solve problems by themselves in the way that promotes sustainable agriculture (Watts and Williamson, 2015b; Pontius, Dilts and Bartlett, 2002). Through the FFS, farmers are able to achieve greater control over their fields by learning and selecting agriculture technologies that benefit them and contribute to better food production (Pontius, Dilts and Bartlett, 2002). Such activities are also necessary in Malaysia in order to determine the actual needs of the Malaysian farmers. Needs-based research is required to identify the actual problems faced by farmers in Malaysia and to assist the farmers in identifying the potential solutions. This cooperation between agricultural scientists and farmers will result in better agricultural practices which promote sustainable agriculture.

This study was part of the initiative for “needs-based” approach to address the needs of Malaysian vegetable farmers. The focus of this study was on the Solanaceae crops, particularly, eggplant (*Solanum melongena* L.), bell pepper and chilli pepper (*Capsicum annuum* L.), cultivated in the Cameron Highlands, because the Solanaceae are economically important globally and they are some of the most valuable vegetable crops (Jagatheeswari, 2014; Samuels, 2015). *S. melongena* (eggplant) and *C. annuum* (chilli pepper and bell pepper) were chosen as the focus among the Solanaceae crops because of their economic importance among the fruit-bearing vegetables (Jagatheeswari, 2014). *S. melongena* is cultivated mostly as a food crop but it also possesses several medicinal uses, thus making it one of the important Solanaceae food crops cultivated globally. *C. annuum* is important among the Solanaceae crops because of its diverse uses, such as being consumed as a raw food, dried into flakes or powders, made into sauces, and is one of the ingredients used by Native Americans as well as in some modern tropical medicines (Shah, Shah and Patrekar, 2013). The management of thrips on these crops was investigated because of the severe infestation of thrips in various Southeast Asian countries, such as Malaysia and Indonesia (Fauziah and Saharan, 1991; Hirose, 1991; Sastrosiswojo, 1991). Cameron Highlands was chosen as the target research area because it is the major region for vegetable production in Malaysia (Aminuddin et al., 2005). The objectives of this research were to:

a) investigate the farming practices of the Solanaceae crops growers, such as, the pest management practices.
b) identify the thrips problems faced by the Solanaceae crops growers, for instance, the damages on the crops.
c) identify the main species of thrips that infest Solanaceae crops, namely, eggplant, bell pepper and chilli.

d) evaluate the effects of the main pesticide on the major thrips species of Solanaceae crops.

CHAPTER TWO

LITERATURE REVIEW

2.1 Farming Practices

In general, there are two agriculture practices that are commonly known, which are conventional farming and organic farming. Conventional farming or conventional agriculture, is the standard dominant farming practice of most farmers around the world (Kristiansen and Merfield, 2006). Conventional farming practices in agriculture usually relate to intensive cropping system with high input of chemical fertilisers, herbicides and pesticides (Beus and Dunlap, 1990). On the other hand, organic farming practices in agriculture emphasizes on the ecology of the natural environment, such as, natural pest control using natural enemies, absence of man-made genetically modified organisms (GMO) crops and no chemical fertilisers and pesticides (Francis and Wart, 2009). Intensive agriculture or conventional farming is practised by most farmers in Southeast Asia due to the rapid population growth as well as the impact of Green Revolution. In household farming, traditional agriculture is still being practised but in commercial farming systems such as those in Cameron Highlands, Malaysia, usually operate in an intensive manner, for example, planting five to ten crops per year, time interval between each harvest and next crop is only a week or less, usually monoculture, continuous weeding, irrigated and with a large amount of chemical input (Capistrano and Marter, 1986).

Since the Green Revolution, agriculture chemicals are popular among commercial or conventional farming systems (Zakaria, 2006) and according to Tiraieyari et al. (2013), more than 90% of fertilisers used by all farming systems in Malaysia are chemical fertilisers. However, organic farming system is gaining popularity over conventional farming system recently due to the increasing demand for chemical-free food products as well as growing environmental awareness among the public (Chin et al., 2010). According to Diepeningen et al. (2006), organically managed soils are healthier as they contain higher biodiversity and lower leaching of nutrients as compared to conventionally managed soils. In addition, organic farming practices also lead to less erosion as compared to conventional farming practices (Auerswald, Kainz and Fiener, 2003). Hence, organic farming practices not only produce chemical-free food, it is also proven to conserve the environment better than conventional farming practices.

Despite the advantages of organic farming practices, most commercial or conventional farmers in Malaysia are still reluctant to convert to organic farming. This is due to the farmers’ limited knowledge and experience in organic farming practices, especially on pest and disease management, and thus, they resort to the use of pesticides to manage their crops (Assis and Mohd Ismail, 2011). In addition, food security is also one of the major concerns. To produce sufficient food, conventional farming, which will eventually degrade the environment, is widely practised (Barrow, Weng and Masron, 2009). However, some conventional farmers are now using more organic matter, such as, animal manure, plant compost and kitchen waste, as fertilisers and reducing the usage of chemical fertilisers (Assis and Mohd Ismail, 2011).

The Department of Agriculture (DoA) Malaysia has been vigorously promoting sustainable farming practices such as Integrated Farming System (IFS), Good Agricultural Practice (GAP) and Organic Farming (OF) practices in order to reduce the usage of agriculture chemicals in crop production due to the environmental problems that result from using these chemicals (Tiraieyari and Uli, 2011). For instance, the DoA of Malaysia has emphasized the use of Korean Natural Farming technique as a soil enhancer to reduce the usage of chemical fertilisers and as an effort to popularise organic farming practices (Zakaria, 2006). Despite the government's effort to promote sustainable farming practices, the farmers play the most important role in adapting those practices and according to Assis and Mohd Ismail (2011), the farmers' attitude towards organic farming system is still negative. Hence, more effort should be placed on disseminating information and providing support as well as education to farmers on organic farming systems in order to convert farmers from conventional practices to sustainable practices.

2.1.1 Agriculture in Cameron Highlands

Cameron Highlands (4°28'N, 101°23'E), which is located in the state of Pahang, is one of the most important regions for vegetable production in Malaysia, where vegetable farming occupy 50% of the total of 5500 hectares agricultural land in the region (Aminuddin et al., 2005). The agriculture activity in Cameron Highlands started since 1930s and was adapted for the planting of introduced vegetables and fruits, like different varieties of cabbages, radishes, asparagus and strawberries (Hecke and Linde, 2011). According to Shirasaka (1988), 50% of the households in Cameron Highlands are involved in vegetable farming and the largest area for vegetable farms are located at Tringkap, Kampung Raja and Bertam Valley (Figure 2.1), due to the comparatively flat land. In addition to these three areas, vegetables are also grown in Kuala Terla, Kea Farm, Mensun Valley and Ringlet (Ooi, 1979).

The average size of each farm is 0.77 hectares (Lim, 1972) and about 90% of the farmers possessed lands that are 0.81 hectares or less (Shirasaka, 1988). Cameron Highlands is suitable for planting a wide range of vegetable crops due to the favourable climate which has a mean annual temperature of approximately 18°C and annual precipitation of more than 2800 mm (Hamdan et al., 2014). According to Kunasekaran et al. (2011), approximately 72.2% of farmers have been farming under a Temporary Ownership of Land (TOL) also known as the

Temporary Occupational License, which require annual renewal. This has been a major barrier for farmers to invest on their land which is under TOL, especially to start organic farming or development for agritourism (Kunasekaran et al., 2011; Tiraieyari, Hamzah and Samah, 2014). Farmers who farm under TOL are not motivated in land conservation as they claim that the government could reclaim the land and therefore they opt for high yield production which involves high chemical inputs (Tiraieyari, Hamzah and Samah, 2014).

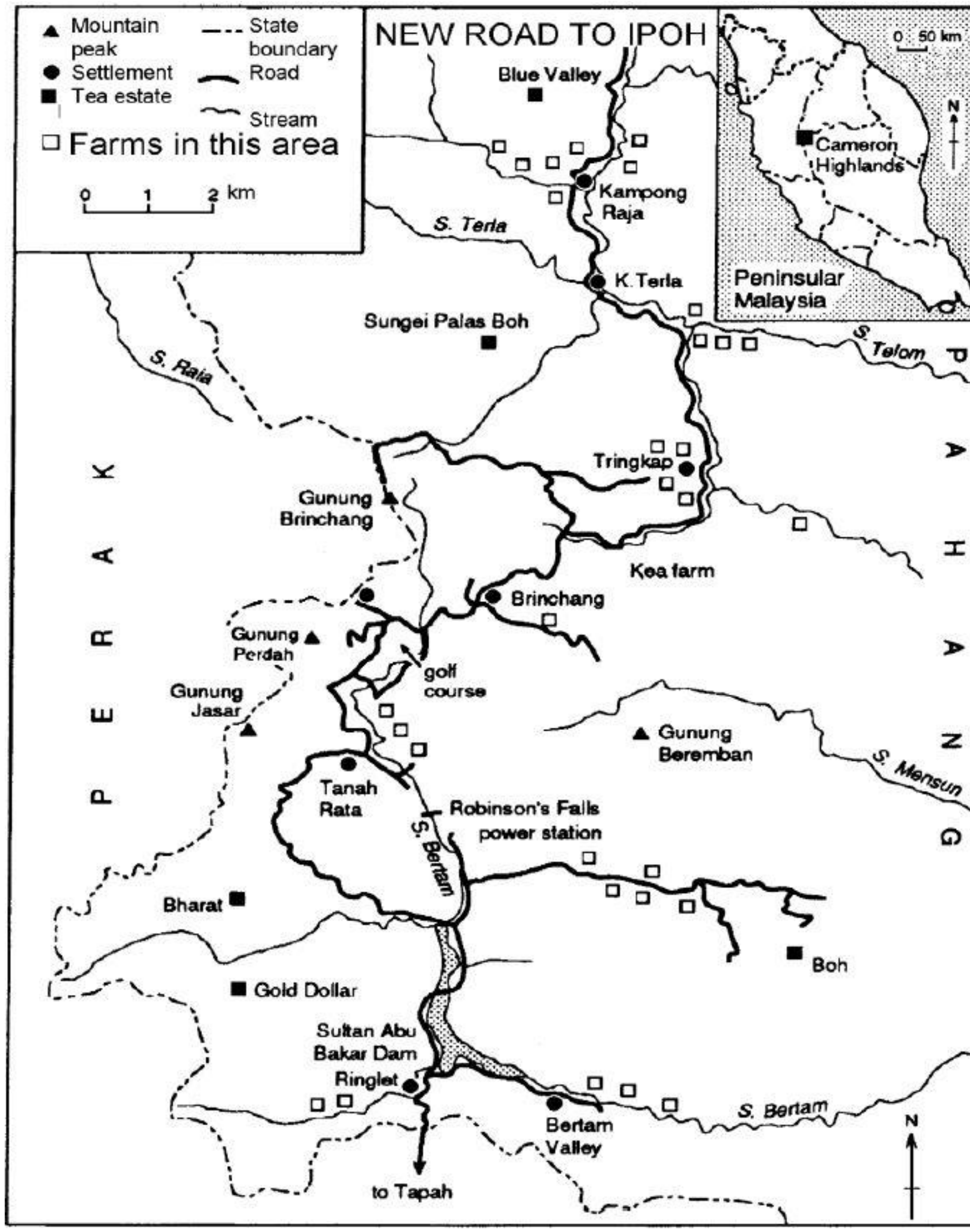

Figure 2.1: The map of Cameron Highlands (Barrow et al., 2005).

2.1.2 Major Vegetable Crops in Cameron Highlands

In spite of the favourable climate in Cameron Highlands, only certain crops are preferred by farmers due to better profit over other crops (Lim, 1972) and the price variation could be as much as 1.5 times (Shirasaka, 1988). The most popular vegetables that are cultivated in Cameron Highlands are English cabbage, Chinese cabbage and tomato (Aminuddin et al., 2005). Besides that, other vegetables, such as lettuce, celery, water cress, spring onions, spinach, French beans and chilli are also cultivated by farmers in Cameron Highlands (Shirasaka, 1988) and Chinese spinach and potato are found to be more profitable than more popular crops (Lim, 1972). English cabbage is popular because it is relatively easy to grow and farmers have more experience in planting cabbages (Chan, 2002). Half of the vegetable cultivation area in Cameron Highlands is for planting cabbages, followed by other temperate vegetables such as, tomato, bell pepper, lettuce, shallots and sweet pea. Approximately USD 15 million worth of vegetables, namely cabbages, tomato and chilli are exported annually to Singapore (Razak and Roff, 2007). According to Kamil, Alwi and Singh (2000), chilli is one among the major vegetables grown in Malaysia and the cultivation of the major vegetables occupy about two-thirds of total vegetable cultivation area in Malaysia.

According to the report from the Department of Agriculture (DoA) Malaysia (2012b), eggplant has also been recently classified under major vegetables in Malaysia. The main production area of eggplant in Malaysia is in Cameron Highlands (Department of Agriculture, 2013). In 2011, the production of eggplant was the sixth highest in Cameron Highlands, which was 10,401.40 metric tons (mt) and English cabbage was the highest (168,283.22 mt), followed by lettuce (29,705.49 mt), leaf mustard (21,888.03 mt), Chinese cabbage (15,922.44 mt) and tomatoes (114,603.12 mt) (Department of Agriculture, 2012b). According to the statistics of Department of Agriculture Malaysia, eggplant has gained popularity in Malaysia, from 2007 to 2011. The area planted with eggplant has increased from 1,295 ha to 1,763 ha and the production has increased from 20,706 mt to 33,887 mt (Department of Agriculture, 2012a).

2.1.3 Major Agriculture Problems in Cameron Highlands

According to the farmers, the major factors that affect profitability and vegetable production are the fertilisers that are not effective on the selected crops and ineffective pest control methods (Lim, 1972). According to Aminuddin et al. (2001), high amounts of fertilisers are used by farmers to overcome the infertile soil due to erosion when opening farming areas. Pesticides are used extensively to manage pests and diseases and as a consequence, large amounts of these chemicals are leached during heavy rainfall. These run-off agro-chemicals have caused several environmental hazards, namely water pollution and soil contamination. Insecticides have been detected on the surface river water in Cameron Highlands, for instance, high concentrations of Cypermethrin (synthetic pyrethroid) and Chlorpyrifos (organophosphate) are present in river water during both dry and wet seasons (Haron et al., 2015). Organochlorine pesticides, such as, aldrin, endrin ketone, heptachlor epoxide, methoxychlor and endosulfan, have also been detected in Bertam and Terla river in Cameron Highlands (Abdullah et al., 2015).

According to Eisakhani et al. (2011), agriculture activity is one of the major causes of water pollution in Cameron Highlands. The excessive use of nitrogen-based fertilisers in agricultural areas has caused the accumulation of nitrates in the soil. These nitrates are washed by water and enter the streams and ground water. Besides that, the uncontrolled opening of land areas for agriculture activities have increased the incidence of soil erosion. Soil erosion carries large amounts of phosphate that are also used as fertilisers into the streams. These phosphates are immobile in the soil and hence leads to water pollution. Tan and Mokhtar (2010) concluded that water pollution in Cameron Highlands can be associated with several major factors, for example, illegal waste disposal, poor community awareness on pollution and waste management, rapid development, land clearing activities and water borne diseases caused by *E. coli* contamination. Three out of four of these factors are associated with agriculture activities in Cameron Highlands.

Besides the negative effects of agro-chemicals on the soil and water, the effectiveness of these chemicals degenerate over time. Liu et al. (2010)

demonstrated that long term usage of inorganic chemical fertilisers will decrease the soil pH value and thus affect the microbial biomass and activity in the soil leading to a decrease in crop yields. Sole dependence on inorganic chemical fertilisers will eventually result in lower crop yields due to the degrading soil organic matter, but the condition will improve with the addition of organic fertilisers. The use of chemical or inorganic fertilisers during conventional farming is not sustainable as they will pollute the environment as well as decrease long term crop yields (Abedi, Alemzadeh and Kazemeini, 2010; Brar et al., 2015). According to Uka, Chukwuka and Iwuagwu (2013), the growth performance of okra (*Abelmoschus esculentus* (L.) Moench) was better when fertilised with organic fertilisers as compared to NPK chemical fertilisers, and the best organic fertiliser was poultry droppings followed by cow dung. Besides providing plants with nutrients, organic manure also helps to enhance soil aggregation, soil aeration and water holding capacity. Furthermore, organic manure helps in creating a better root system by slow release of nutrients and thus create a favourable condition for plant growth (Kandil and Gad, 2009). Organic manure as fertilisers are able to provide better soil fertility and improve soil condition for plant growth which will produce higher yields in the long term compared to inorganic mineral fertilisers (NPK). According to Auerswald, Kainz and Fiener (2003), the organic farming approach which uses organic manure as fertilisers will cause less erosion as compared to conventional farming which uses inorganic fertilisers. Therefore, it is able to help in reducing water pollution by decreasing soil erosion and leaching of nutrients into streams.

Zuriana et al. (2015) found that the intention of Cameron Highlands farmers to use insecticide on their crops depend largely on the decision made by themselves and not due to peer influence. Farmers have the perception that insecticides are easily obtained and also, they possess the skill and ability to use them on their crops. Therefore, this is one of the reasons for the intensive use of chemical pesticides for pest management because the farmers are in control of their farms and they make the final decision on the pest management methods to be used throughout the crop production cycle. Farmers have become very dependent on the use of pesticide to control pest and diseases problems in their farms. Despite being unsure about the pests and diseases, farmers still spray pesticides that they perceive as effective and generic pesticides that are less effective, are used by the small-scale farmers who cannot afford expensive chemicals. These pesticides are sprayed in large amounts for pest control but the necessity of such heavy application is doubtful (Mispan et al., 2015).

The intensive usage of agro-chemicals on pest, diseases and weeds causes environmental pollution and leads to the development of resistance in the pest, diseases or weeds. For instance, redflower ragleaf (*Crassocephalum crepidioides*) a common broadleaf weed in tomato and potato fields was found be to very resistant to paraquat in Cameron Highlands (Ismail, Chuah and Khatijah, 2004). In addition to the herbicide resistance, it is also reported by Ooi (1985), that the diamondback moth (*Plutella xylostella* L.) a serious cabbage pest, has a very high resistant factor to multiple insecticides, for instance, the resistance factor to malathion was found to be 2096. Farmers still continue using insecticides to control this pest regardless of the resistance by either increasing the dosage beyond the recommended rate or using a “cocktail” insecticide where a mixture of two or more insecticides are sprayed or both (Ooi, 1985). This practice may result in long-term harm to both the environment and human health (Watts, 2010). Ooi (1990) demonstrated that chemical pesticides are not the only option to control pest and diseases, since there are natural enemies to assist in the management of pest and diseases. For instance, the diamondback moth can be successfully controlled by three primary parasitoids, namely, *Cotesia plutellae* Kurdjumov, *Diadegma semiclausum* Hellen and *Diadromus collaris* Gravenhorst, when the spraying of chemical insecticides decreases. Reducing the usage of chemical pesticides and employing more natural enemies to control pests and disease not only benefits the environment but also increases the profits since the cost of purchasing insecticides has been reduced (Shamsudin, Amir and Radam, 2010). Besides, reducing the dependency on agro-chemicals will help in solving the major agriculture problems in Cameron Highlands, namely environmental pollution by agro-chemicals, wastes and pesticide resistance.

2.2 Solanaceae Vegetables

The Solanaceae family is one of the economically important plant families which is believed to have originated from South America because of the high diversity of Solanaceae species found there (Samuels, 2015). The Solanaceae are one of the most valuable vegetable crops that have a broad range of uses from medicinal to ornamental as well as daily food crops (Samuels, 2015; Jagatheeswari, 2014). *Solanum* is the most economically important genus in the family of Solanaceae, which includes potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), and eggplant (*Solanum melongena*). The *Capsicum* genus is also important in the Solanaceae family which includes the chilli peppers and bell peppers (Jagatheeswari, 2014). According to Samuels (2015), in 2010, food crops under the family Solanaceae were cultivated globally and the production was approximately 540 million tons, but this figure was focused only on the four staple crop species, namely, potato, tomato, eggplant and capsicums. In this study, only the eggplant (*S. melongena*), chilli and bell pepper (*Capsicum annuum*) would be studied as they are more economically important to Malaysia, for instance, Malaysia was one of the top countries in importing dry chilli, at approximately 111,737 tons (Liu, Kang and Kang, 2013) and the centre of eggplant production is in Asia (Frary and Doganlar, 2013).

2.2.1 Eggplant (*Solanum melongena* L.)

The centre of origin of the eggplants, *Solanum melongena* L., is most probably located at the North East of India and Burma to northern Thailand, Laos, Vietnam and Southwest of China where wild eggplants still thrive. Historical evidence shows that eggplants were popular in ancient India about 2000 years ago and at the same time it was also cultivated in China in the early 5th century (Daunay, Laterrot and Janick, 2008). It is now widely cultivated throughout the tropics, subtropics and warm temperate regions, and in greenhouses in temperate countries (Sutarno, Danimihardja and Grubben, 1993). According to the statistics of the Food and Agriculture Organisation cited by Frary and Doganlar (2013), China was the top producer of eggplants with about 26 million tons production, followed by India which produced 10 million tons in 2009. There were also other large producers of eggplants, such as Egypt (1.2 million tons), Turkey (820,000 tons), Indonesia (450,000 tons), Iraq (369,000 tons), Japan (349,000 tons), Italy (245,000 tons), Spain (205,000 tons) and the Philippines (201,000 tons).

According to Daunay, Laterrot and Janick (2008) and Sutarno, Danimihardja and Grubben (1993), eggplants are used for medicinal and ornamental purposes, whereas the young and almost mature fruits are eaten daily as vegetables. The fruits of eggplant are rich in certain minerals and antioxidants (Frary and Doganlar, 2013). The eggplant life cycle begins with seed germination which takes about 2 weeks and can be transplanted to the planting field at approximately 4 to 6 weeks after sowing. After transplanting, flowering will begin 6-8 weeks later and the fruits can be harvested 5 weeks after flowering (Sutarno, Danimihardja and Grubben, 1993).

2.2.2 Chilli and Bell Pepper (*Capsicum annuum* L.)

According to Liu, Kang and Kang (2013), *Capsicum* species is believed to originate from South America, and according to Poulos (1993), the origin of *Capsicum annuum* is believed to be Mexico. Historical evidence shows that *Capsicum* pepper were consumed in northern Peru 9,000 years ago, thus confirming the origin of *Capsicum* plants (Daunay, Laterrot and Janick, 2008). The genus *Capsicum* consists of about 30 species and *C. annuum* has the highest morphological diversity. It is also the most economically important *Capsicum* species as compared to others (Oyama et al., 2006). *C. annuum* is believed to be widely cultivated throughout the world and the capsicum peppers are a key ingredient of the cuisine in tropical countries such as Thailand, Korea and India (Daunay, Laterrot and Janick, 2008; Liu, Kang and Kang, 2013). The capsicum peppers are used for medicinal purpose, flavouring, dyes and food (Daunay, Laterrot and Janick, 2008). Chilli is vital in both food and pharmaceutical industries, where the fruits are used as food and spices while the active ingredients are used in the production of medicines and other pharmaceutical products (Rejab, 2008; Liu, Kang and Kang, 2013).

According to Rejab (2008), chillies are able to fetch a higher price as compared to the other locally grown vegetables in Malaysia. The chillies or peppers are known to be vegetables which contain a high nutritional value and diverse antioxidant compounds (Liu, Kang and Kang, 2013). According to Poulos (1993), Asia produces approximately 8 million tons of capsicum peppers in which India, China, Indonesia and Korea are the biggest producers with the largest land areas. Malaysia produces 21,000 tons and is the second largest producer in Southeast Asia. The life cycle of the *Capsicum* species begins with the germination of seeds which takes about 6-21 days and the continuous flowering will begin around 60-90 days after sowing. Flowers will typically open for 2 to 3 days and approximately 40 to 50% of the flowers will form fruits. Fruits will start maturing around 4 to 5 weeks after flowering and are harvested at an interval of 5 to 7 days. The peak harvesting period is at 4 to 7 months after sowing (Poulos, 1993).

2.3 Thrips

Thrips belongs to the order of Thysanoptera, where “thysano” means fringed and “ptera” means wings because the wings of the adult thrips carry a maginal fringe of cilia (Mound, 2005). Adult thrips are very small in size, usually less than 2.5 mm long, and they may be winged or wingless (van Emden, 2013). According to Triplehorn and Johnson (2005), some tropical species of thrips may grow up to 5.0 mm to 13 mm long. The colour of adult thrips are usually pale yellow to dark brown, but there are some thrips which are black or white in colour (Robinson, 2005; van Emden, 2013). The thrips have elongated slender bodies or slightly compressed bodies with short four-to-nine segmented antennae on the head and asymmetrical sectorial mouthparts (Robinson, 2005; Gillott, 2005). Thrips are divided into two suborders, namely, Terebrantia and Tubulifera, which share one unique morphological structure, i.e., only the left mandible is fully developed while the right mandible is resorbed by the embryo (Mound, 2005). The thrips have rasping and sucking mouthparts which allow the herbivorous thrips to feed on plant juices and fungi, while the predatory thrips feed on the body fluids of prey, such as mites and other small insects (Gillott, 2005; Cote, 2015).

The thrips go through metamorphosis which are intermediate between simple and complete, where the first and second instars, which are called larvae, have no external wings. In the suborder Terebrantia, the third and fourth instars are called the prepupa and pupa respectively, which are inactive or do not feed. Conversely, in the suborder Tubulifera, the third instar is called prepupa, and has no external wings, while the fourth and fifth instars are inactive pupal stages (Triplehorn and Johnson, 2005). According to Robinson (2005) and van Emden (2013), the family Thripidae comprised many economically important thrips species as most of the species are plant feeders and some are agricultural pests.

These herbivorous thrips are commonly found in the flowers and leaves of host plants. Although most of the Thripidae are plant feeders, there are also some predatory thrips and fungus-feeding thrips (Gillott, 2005). Therefore, precise identification on the thrips species is vital to develop an effective solution to solve agricultural pest problems which are associated with thrips.

2.3.1 Life Cycle of Terebrantia Thrips

The general life cycle of Terebrantia thrips consists of 6 stages (Figure 2.2), which begin with the eggs followed by two active feeding larval stages and two inactive stages, the prepupal and pupal stages, and finally the adult stage (Sueo, 1993). In the suborder Terebrantia, the eggs are laid by female thrips into the host plant tissues using a saw-like ovipositor (Richards and Davies, 1977). According to Robinson (2005), the eggs are usually inserted into the tissues on the leaves of the host plant. The development of the thrips are dependent on the temperature, for instance, *Thrips palmi* has a mean generation time of 20.5 days at 30°C whereas the mean generation time at 15°C is 80.2 days (Murai, 2002). The average duration for the development of thrips from eggs to adult is the longest at 16°C and the shortest at 31°C. In addition, the percentage of thrips which successfully develop into adult from eggs is only 57.5% at 19°C and the highest percentage of successful development occurs at 25°C, which has 78.8% individuals developing into adults from eggs (Yadav and Chang, 2014).

According to Reitz (2009), the average duration of the egg stage is about 2 – 4 days at approximately 25 – 30°C. The two larval stages will take approximately 4 to 14 days depending on the temperature, for instance the larval stage is completed within 4 days at 32°C (Capinera, 2008). After the larvae stop feeding, the thrips will proceed into two inactive stages, the prepupa and pupa, which will usually take place in the soil or leaf litter on the ground (Reitz, 2009). These two stages usually take approximately 3 to 12 days depending on the temperature, and the adult stage begins after emergence from the pupa (Capinera, 2008). According to Yadav and Chang (2012), the average pre-adult and adult developmental periods for the male thrips are faster than the female thrips but there is no difference in the developmental time for other stages in the life cycle. The female thrips have a longer life span as compared to the male thrips. According to Capinera (2008), the longevity of adult female thrips is approximately 10 to 30 days, and 7 to 20 days in the males. According to Fauziah and Saharan (1991), the adult thrips of both sexes possess wings and fly readily. In addition, the adult thrips will appear paler in colour and smaller in size when they occupy habitats that are warmer in temperature (Sueo, 1993).

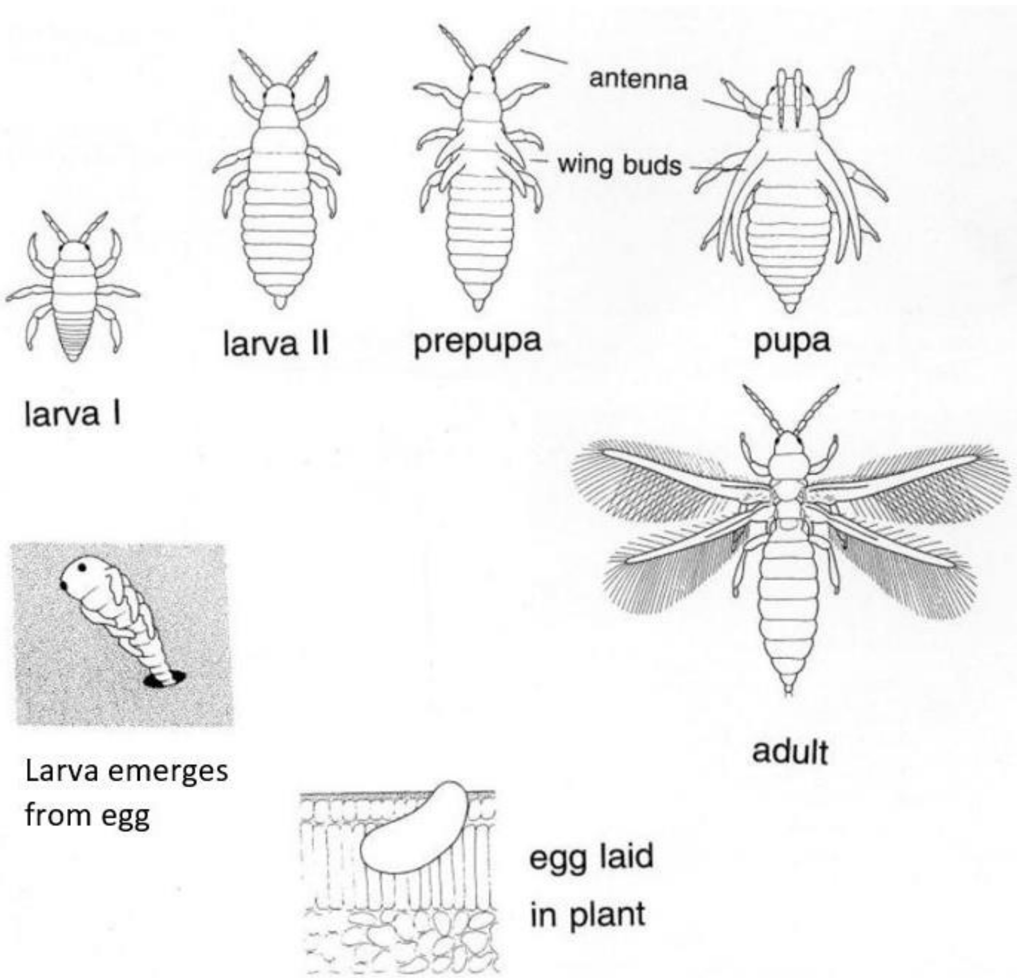

Figure 2.2: The typical life cycle of Terebrantia thrips (Martin, 2017).

2.3.2 Thrips Damage in Eggplant and Chilli

The damage caused by thrips on cultivated crops can result from direct feeding on the leaves, flowers or fruits, transmission of viruses and product contamination (Mound and Teulon, 1995). In this study, the focus will be on the thrips that damage eggplant and chilli. According to Srinivasan (2009), *Thrips* *palmi* Karny, commonly known as the melon thrips, is the species that cause severe damage to eggplants especially during the dry season and they are widely distributed in three regions, namely, South Asia, Southeast Asia and Oceania. Besides these three regions, Capinera (2008) reported that *T. palmi* is also found in South America (Brazil, Colombia, French Guiana and Venezeula), North America (Florida and Hawaii), Africa (Mauritius, Nigeria, Reunion and Sudan) and throughout the Caribbean. Hirose et al. (1993) reported that *T. palmi* has been one of the most important vegetable pest in Japan since 1978, where the host plant includes eggplant, cucumber, muskmelon, green pepper and watermelon. Moreover, *T. palmi* has also been reported as the most serious pest in both greenhouse and open fields for eggplant, cucumber and sweet pepper cultivation. *T. palmi* does not only damage the crops but also acts as a vector for the tospoviruses (Murai, 2002). Thrips has become one of the most important pests in vegetable cultivation in Malaysia and *T. palmi* is one of the common thrips species found on chilli, cucumber (*Cucumis sativus*) and eggplant (Fauziah and Saharan, 1991). Besides Asia, *T. palmi* has been observed to heavily infest eggplants, bell peppers and other vegetables crops in South Florida (O'Donnell and Parrella, 2005). It was reported by Muniappan et al. (2012) that the most serious damage caused by *Thrips* species on eggplant and chilli was the transmission of tospoviruses and *Capsicum* chlorosis virus. The adult and larvae of *T. palmi* usually feed on the foliage by sucking the plant sap. The damage symptoms of *T. palmi* are leaf crinkling and discoloration. Slightly infested leaves exhibit silvery feeding scars on the abaxial surface, while heavily infested leaves turn brown or yellow and appear dry. Infested fruits become scarred and deformed (Hodges et al., 2009; Srinivasan, 2009).

Besides *T. palmi*, *Scirtothrips dorsalis* Hood, commonly known as the chilli thrips and *Thrips parvispinus* Karny (Taiwanese thrips) have been reported as key pests of chilli plants in Thailand (Bansiddhi and Poonchaisri, 1991). *S. dorsalis* has also been recorded as a chilli pest by Muniappan et al. (2012). *S. dorsalis* is especially problematic during the dry season and the damage is more commonly seen on the young fruits and flowers, in which the fruits are abnormally shaped with marks and scarring on their surfaces (Bansiddhi and Poonchaisri, 1991). Although *T. parvispinus* has been found in Thailand with *S. dorsalis*, it is more commonly observed infesting hot chilli plants in Java, Indonesia, where it is one of the major pests of hot chilli (Vos et al., 1991). According to Sastrosiswojo (1991), *T. parvispinus* has caused up to 22.8% of yield losses to the chilli cultivation in Indonesia and chemical control has been found to be ineffective. The symptoms of damage caused by *T. parvispinus* is similar to the other thrips, i.e., the scarring of the fruits, curling of the leaves, scarring and irregular stains on the underside of the leaves and also premature flower drop (Vos et al., 1991). The three most common thrips in Asia that feed on chillies are *S. dorsalis*, *T. palmi* and *Thrips tabaci* Lindeman (onion thrips) (Talekar, 1991).

The western flower thrips, *Frankliniella occidentalis* Pergande is also one of the key pest of several fruiting vegetables including eggplant and chilli in Florida (Funderburk, 2009). It is an invasive pest species in Malaysia, and is reported to be abundant in highland areas (Mound and Azidah, 2009). According to Azidah (2011), the *F. occidentalis* was found on *C. annuum* plants in Cameron Highlands but was not observed in eggplants. However, according to Papadaki, Harizanova and Bournazakis (2008), eggplants are more attractive to *F.occidentalis* as compared to chilli in Greece. The damage due to *F. occidentalis* is similar to those caused by other thrips, i.e., discoloration of leaves and fruits, necrosis of the damage area and deformation of fruits and leaves (Tommasini and Maini, 2002). Besides that, *F. occidentalis* is also one of the most predominant and effective vectors of *Tomato spotted wilt virus* (TSWV) (Maris et al., 2003). According to Funderburk (2009), adult *F. occidentalis* resides in the flowers of tomato, eggplant and chilli, where they feed on the pollen and the flower tissues. Female *F. occidentalis* lays eggs in the young developing fruits of these plants.

2.3.3 Chemical Control and Resistance of Thrips in Eggplant and Chilli

According to Capinera (2001), chemical control is usually not recommended in the control of *Thrips palmi* as it is ineffective against the eggs which reside in the foliar tissue and the pupae which are in the soil. However, insecticides are still frequently used for suppression of thrips. The use of chemical controls may be due to the farmers' lack of knowledge about the existence of biological control agents, such as predators and parasitoids (Assis and Mohd Ismail, 2011). According to Bao et al. (2014), certain strains of *T. palmi* have been found to be very resistant to spinosad in nature, that is about 1938-fold more resistant as compared to the susceptible strains, and it is noted that resistant strains possess genes that allow them to be insensitive towards the spinosad insecticide. Besides spinosad, *T. palmi* is also resistant to imidacloprid, where certain strains are 12.2-fold more resistant as compared to susceptible strains (Bao et al., 2015). Therefore, it is suggested that chemical control is not a sustainable control method for the suppression of *T. palmi*. The findings of Hirose (1991) show that the increase in the application of insecticides worsens the infestation of *T. palmi* in eggplant. Conversely, eggplants in home gardens which are rarely or never treated with insecticides experience less *T. palmi* damage.

Despite such evidence, the effectiveness of several insecticides was tested and most of them were found to be ineffective against *T. palmi*, causing less than 50% mortality (Murai, 2002). According to Cannon, Matthews and Collins (2007), *T. palmi* is resistant towards many insecticides under the chemical classes of organophosphate, carbamate and pyrethoid. It was reported by Seal et al. (2013) that imidacloprid and certain organophosphates, namely dimethoate, dimethyl phosphate, azinphosmethyl and acephate, and abamectin are able to suppress up to 50% of *T. palmi* populations in the field. Spinosad and carbamates such as formetanate hydrochloride, are most effective in the suppression of 80 to 95% of *T.*

palmi populations. However, the use of organophosphates and carbamate in the commercial farms will also cause high mortality among the natural enemies of *T. palmi*, such as the insidious flower bug (*Orius insidiosus*) (Seal et al., 2013). Therefore, chemical controls are not a sustainable method to suppress *T. palmi*. As mentioned by Bao et al. (2014) and Bao et al. (2015), certain strains of *T. palmi* in Japan possess natural resistance towards spinosad and imidacloprid, which were reported by Seal et al. (2013) to be effective in controlling *T. palmi* in Florida.

The recommended insecticides for the suppression of *Scirtothrips dorsalis* and *Thrips parvispinus* in Thailand are carbaryl, prothiophos, methiocarb, carbosulfan and phosalone. However, poor farming practices during insecticide application, e.g., not following the recommended dosage, continuous routine applications regardless of the presence of the pest and the mixing of several insecticides (cocktail), have caused severe thrips problems as well as environmental problems (Bansiddhi and Poonchaisri, 1991). According to Vos et al. (1991), the use of diafenthiuron has given satisfactory results in the control of *T. parvispinus* but the extensive use of agrochemicals has caused *T. parvispinus* populations to develop resistance to insecticides. On the other hand, *S. dorsalis* populations could be controlled by organophosphates (quinalphos, phosphamidon fenthion and diamethoate), carbamate (carbaryl), permethrin (a synthetic pyrethroid) and imidacloprid (a neonicotinoid class insecticide). In addition, spinetoram and several neonicotinoid class insecticides have been reported to be effective in the reduction of *S. dorsalis* populations on pepper crops (Kumar et al., 2013). According to Seal et al. (2006), the most effective insecticide in reducing the population of adult and larvae *S. dorsalis* in Florida was chlorfenapyr (arylpyrrole class insecticide), followed by spinosad (spinosyn class insecticide) and imidacloprid. It is reported that chemical control is not a sustainable method for suppressing *S. dorsalis* populations because it is costly, pollutes the environment, promotes resistance in pests and harms the natural biological control agents (Arthurs et al., 2009). Excessive reliance on insecticides has placed *S. dorsalis* under intense selection pressure which has led to the development of insecticide resistance. It was noted by Kumar et al. (2013) that *S. dorsalis* had recently developed resistance against monocrotophos, acephate, dimethoate, phosalone, carbaryl and triazophos in Florida.

According to Mound and Azidah (2009) and Azidah (2011), *Frankliniella occidentalis* is an invasive pest species in Malaysia and it infests *C. annuum* plants and other ornamental flowers such as chrysanthemum (*Chrysanthemum indicum* L.) in the highland areas. Fipronil has been found to be most suitable insecticide in controlling *F. occidentalis* (Gholami, Sadeghi and SheikhiGrajan, 2015). Based on the findings of Shan et al. (2012), butylene fipronil, phoxim, chlorfenapyr, chlorpyrifos, spinosad, thiamethoxam, benfuracarb, acetamiprid, carbosulfan, cyhalothrin and bifenthrin are insecticides that are highly effective in controlling both the adult and larval populations of *F. occidentalis*. In another study by Chung, Kang and Kwon (2000), abamectin and imidacloprid were shown to be effective against *F. occidentalis* populations in the greenhouse in Korea. Furthermore, cartap hydrochloride caused the highest mortalities in *F. occidentalis* when tested on pepper leaf as compared to pyraclofos, imidacloprid and abamectin (Cho, Uhm and Lee, 1999). However, similar to the other species of thrips, *F. occidentalis* also developed resistance towards several insecticides when they are used routinely to control their populations. According to Gao, Lei and Reitz (2012), *F. occidentalis* has gained resistance against multiple insecticides, such as, carbosulfan, chlorpyrifos, fipronil, imidacloprid, spinosad and abamectin. These insecticides are effective in controlling *F. occidentalis* populations in some areas but resistance has been noted in other areas. This indicates that the chemical control method is not sustainable. Besides that, the resistance ratio of *F. occidentalis* against spinosad was found to be as high as 13500-fold in Almeria, Spain and up to 3682-fold in Murcia, Spain. According to Gao, Lei and Reitz (2012), the resistance ratios of *F. occidentalis* against carbosulfan, chlorpyrifos, imidacloprid and abamectin were 22.2-, 16-, 14- and 240-fold respectively. Despite being reportedly effective in suppressing *F. occidentalis* during laboratory and field tests, the pest will eventually develop resistance against the chemical if it is consistently applied in the field. Even though insecticides are the fastest way to suppress thrips, it is not sustainable and thus, alternative control methods which are sustainable should be developed and practised.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Survey of the Solanaceae Crops Growers Farming Practices

A survey was carried out in Cameron Highlands among eggplant, bell pepper and chilli pepper growers. The survey was carried out in the form of a verbal interview and the information was collected with the help of a questionnaire shown in Appendix A. Information collected through the survey interview focused on three major parts, namely, the details of the farming operation and farming practices, information on the pests and diseases as well as the management of the pests and diseases and lastly the financial aspect of their farming activities. The general information of the farmers was also compiled for reference on a private and confidential basis. The information would be used for the study of thrips in Solanaceae crops, namely, eggplant, chilli and bell pepper, in Cameron Highlands, for instance, the species of thrips on the crops and the control methods of the thrips. According to Ooi (1979), vegetables are largely grown in seven areas of Cameron Highlands, i.e., Kampong Raja, Kuala Terla, Tringkap, Kea Farm, Mensun Valley (Brinchang), Ringlet and Bertam Valley (Figure 3.1). This is supported by Mazlan and Mumford (2005) who stated that most vegetable cultivation in Cameron Highlands took place between 900 and 1400 m above sea level, which included the seven areas mentioned by Ooi (1979). Based on these references, in order to facilitate the survey, vegetable cultivation areas were divided into three zones based on their respective altitude. The three zones were the northern zone (Blue Valley, Lojing, Kampong Raja and Kuala Terla), the central zone (Tringkap, Kea Farm, Mensun Valley, Brinchang and Tanah Rata) and the southern zone (Ringlet, Boh Road Area and Bertam Valley (Table 3.1). The three zones were divided based on altitude: northern zone was from 1300 to 1500 m above sea level, the central zone ranged from 1400 to 1580 m above sea level, and the southern zone was below 1280 m above sea level (Shirasaka, 1988). The separation was based on the altitude because the altitude would affect the mean temperature in each zone and that, in turn, would influence the growth duration of the plants as well as crops preferences of the farmers, especially for the target plants (eggplant, bell pepper and chilli). In each zone, 10 farmers who planted these selected crops were chosen at random for the interview.

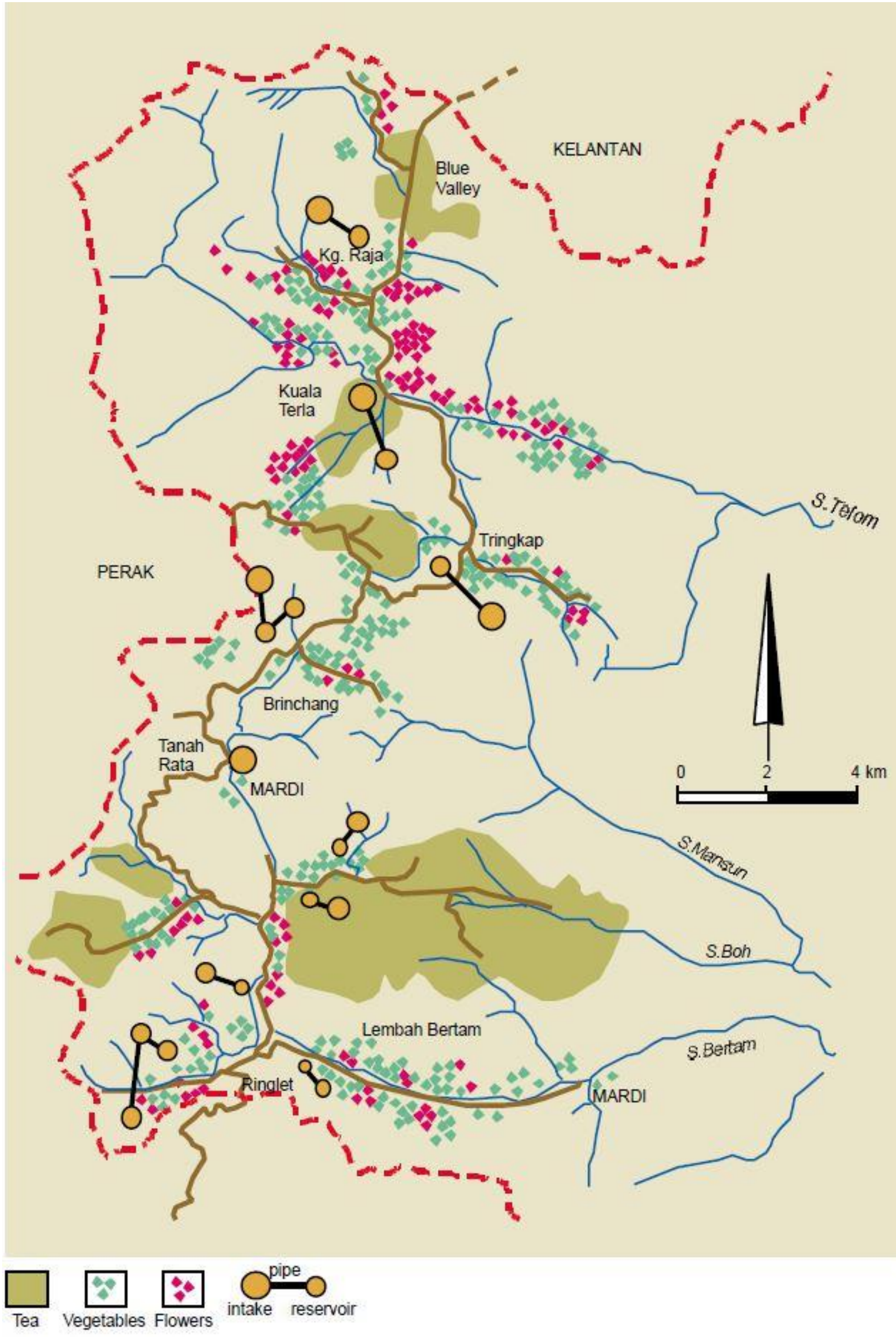

Figure 3.1: Map of Cameron Highlands showing the agriculture landuse (Wan Abdullah et al., 2000).

Table 3.1: The farming areas where the interviews were carried out.

Locations	Estimated Coordinates	
Blue Valley	4°35’06”N	101°25’05”E
Lojing	4°35’32”N	101°25’40”E
Sungai Ikan	4°34’53”N	101°23’12”E
Kampung Raja	4°34’03”N	101°24’06”E
Kuala Terla	4°33’01”N	101°24’41”E
Kea Farm	4°30’08”N	101°24’30”E
Tringkap	4°30’35”N	101°25’30”E
MAFC, Tanah Rata	4°28’02”N	101°23’21”E
MARDI, Tanah Rata	4°28’03”N	101°23’06”E
Taman Sedia, Tanah Rata	4°28’45”N	101°22’46”E
Mensun Valley	4°29’49”N	101°23’45”E
Habu and Boh Road Area	4°27’03”N	101°23’35”E
Batu 33	4°26’54”N	101°22’39”E
Ringlet, Mr Ho’s Farm	4°25’16”N	101°23’18”E
Ringlet Farming Area	4°24’34”N	101°22’13”E
Bertam Valley	4°24’44”N	101°24’35”E

**Note: the coordinates do not show the exact location of each farm but the location of the farming area, which consists of multiple farms.

3.2 Identification of Thrips Species

Thrips were confirmed to be the major pest affecting Solanaceae crops production in Cameron Highlands through the farm surveys and farmers' feedback. All the participating farmers unanimously agreed that thrips were the worst pests in eggplant, bell pepper and chilli. Therefore, thrips species that were present on these three Solanaceae crops were identified.

3.2.1 Sampling of Thrips

Thrips samples were collected at random from eggplant, bell pepper and chilli farms in Cameron Highlands. The thrips samples were stored in 70% ethanol (Astral Scientific, Australia) upon collection until they were ready for mounting. At least a hundred thrips were collected from each zone: northern, central and southern zones.

3.2.2 Mounting of Thrips Sample

The thrips mounting method was modified from Bisevac (1997). Each thrips sample was transferred from 70% ethanol (Astral Scientific, Australia) into

5% sodium hydroxide (LOBA, India) solution and soaked for no more than 12 hours or overnight. The wings, antennae and legs were spread out gently using a paint brush (size: 0/2) and a minutien pin. The positioned thrips was transferred to distilled water for 5 minutes before it was soaked in AAA solution for 30 minutes. AAA solution is a mixture of 20 ml glacial acetic acid (Sigma-Aldrich, USA), 50 ml 95% ethanol (Astral Scientific, Australia) and 45ml distilled water. The thrips was transferred to 95% ethanol (Astral Scientific, Australia) for 5 minutes and to 99.5% absolute ethanol (HmbG, Germany) for 1 to 2 minutes. The sample was transferred to clove oil (Bendosen, Malaysia) for 30 minutes. A drop of Euparal (Bioquip, USA) mounting medium was placed on the cover slip and the thrips was transferred from the clove oil ventrally up into the drop of Euparal. The wings and antennae were positioned with the painting brush or minutien pin if it was not positioned properly. A drop of Euparal was placed on the glass slide with a drop of Euparal essence (Bioquip, USA) to thin the Euparal. Thinning of the mounting medium was only necessary if the mounting medium was too concentrated and would damage the structure of the sample when mounted, otherwise, it was not needed. The glass slide was inverted and gently placed over the cover slip. The glass slide was immediately re-inverted as soon as the two drops of mounting medium merged. The thrips sample could be adjusted by gently moving the cover slip if the sample was not properly positioned. The completed slide was placed into an oven (Memmert GmbH + Co.KG, Germany) at 38°C – 40°C for 2 to 4 weeks until the mounting medium hardened.

3.2.3 Identification of Thrips Sample

The mounted thrips samples were examined under a Motic BA210 compound microscope (Motic Asia, Hong Kong) at 400x and 1000x magnifications. The thrips sample was identified by referring to the morphological characteristics described by Mound and Ng (2009), Mound and Azidah (2009), Sartiami and Mound (2013) and Kirk (1996). In addition, the characteristics given by Hoddle, Mound and Paris (2012) in Thrips of California were also used as a guide to confirm the identity of the species. The morphological characteristics used to differentiate the species of thrips among the samples were the length of the posteroangular seta, presence or absence as well as the length of the pronotal anterior margin setae, presence of the ctenidia, antennae structure which includes the number of segments, the presence of the ocellar seta as well as the comparison of length between the different pairs of the ocellar seta, presence of the posteromarginal comb as well as the shape, the presence of the discal seta from tergite IV to VI, the structure of the first and second vein of the forewings, and the metanotum structure and seta (Figure 3.2). All photographs of the processed and mounted thrips were taken with a Leica ICC50 HD camera attached to a Leica DM500 compound microscope (Leica Microsystems, Germany).

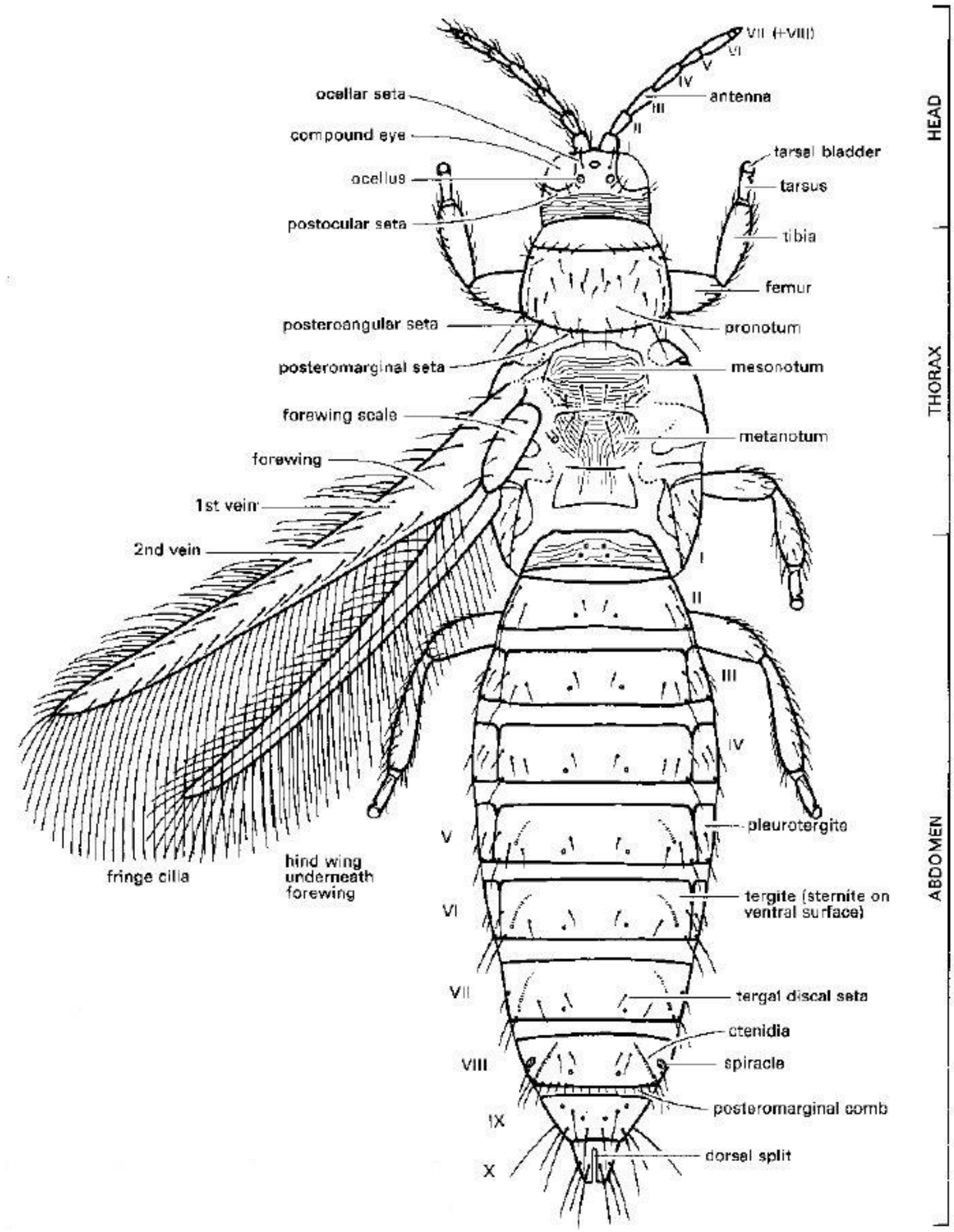

Figure 3.2: The general structure of a Terebrantia thrips which includes the morphological characters used for identification (Mound and Walker, 1982).

3.3 Insecticide Resistance Test

Thrips species that is the most abundant and caused major damage on the crops was chosen for the leaf-dip bioassays test to determine the insecticide resistance of the species.

3.3.1 Thrips Sampling

Thrips samples were collected from both conventional farms and organic farms that planted eggplant, bell pepper and chilli in Cameron Highlands. The thrips from conventional farms represent the test population whereas the thrips from organic farms represent the susceptible population. The thrips were sampled and kept in a 12-litre plastic container (Figure 3.3) with the leaves of the respective plants as food before being tested in the laboratory. Only the most commonly found thrips species among these plants were selected for the test due to the low availability of susceptible thrips samples. Thrips were kept in the plastic containers for not more than 48 hours to ensure that they were suitable for the bioassay test.

Figure 3.3: The 12-litre plastic container.

3.3.2 Leaf-dip Bioassay

Eggplant, *Solanum melongena* L., leaves were used in the leaf-dip bioassay because it is easily available. These eggplant leaves were collected from either home gardens or organic farms to ensure that they were not contaminated with insecticides from the field. The eggplant leaves were washed thoroughly with distilled water and air-dried overnight. The washed eggplant leaves were cut into disc shapes with a diameter of approximately 5 cm (Maharijaya et al., 2011). The leaf-discs were dipped in eight different concentrations (5x serial dilutions) of commercially formulated spinetoram (Endure® 58.7g/l SC; Dow AgroSciences (M)

Sdn Bhd) (Figure 3.4) (Immaraju, Morse and Brawner, 1990). The control leaf-discs were dipped in distilled water only (Santos et al., 2011; Immaraju, Morse and Brawner, 1990). The leaf-discs were air-dried (Jiang et al., 2015) before being placed in petri dishes (10.0 cm diameter; 2.0 cm height) on semi-solid water agar (10g/l agar) with the abaxial (lower) surface of the leaf-disc facing upward (Maharijaya et al., 2011). A minimum of 10 adult thrips were placed on each leaf-disc using a paint brush (size: 0/2) (Jiang et al., 2015; Maharijaya et al., 2011). There were five replicates for each concentration. The mortality of thrips was determined after 48 hours of incubation under room temperature (approximately 25°C) (Herron et al., 2011; Jiang et al., 2015). The adult thrips were considered dead if they did not move after gentle stimulation with the paint brush. The mortality of adult thrips was further confirmed by examining them under 50x magnification with a Motic stereo microscope (Model: SMZ-161, Motic Asia, Hong Kong).

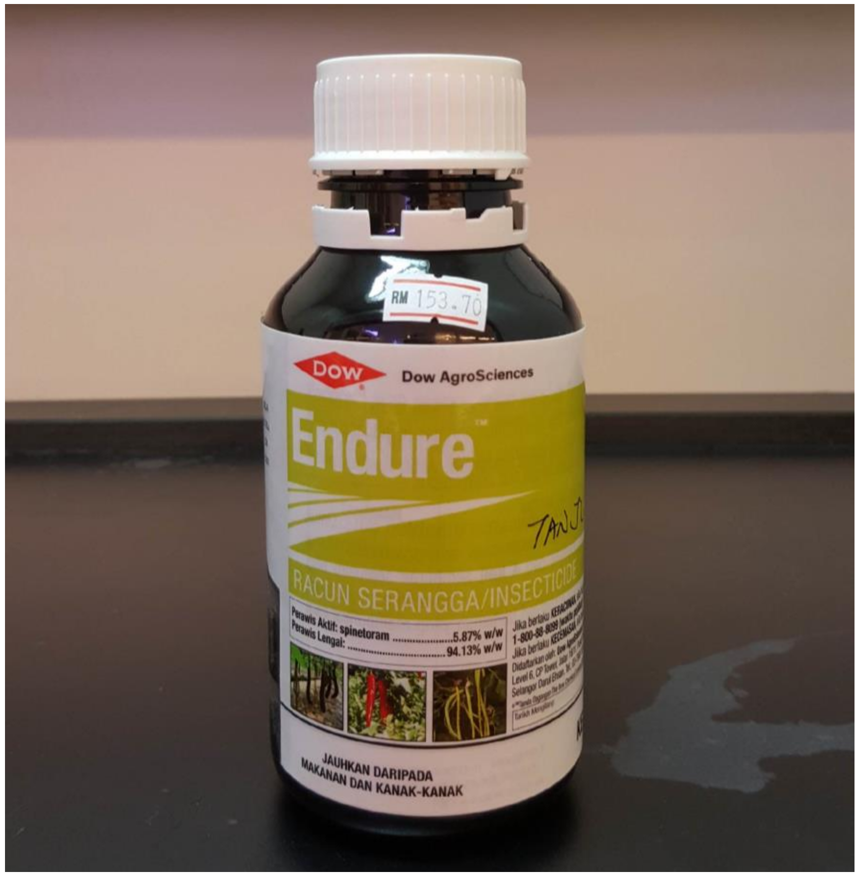

Figure 3.4: The commercially formulated spinetoram insecticide (58.7 g/l) with trade name Endure® SC by Dow AgroSciences (M) Sdn Bhd.

3.3.3 Probit Analysis and Resistance Ratio

In order to obtain the resistance ratio of the thrips, the lethal dosage where 50% mortality was achieved (LD_{50}) had to be determined. The LD_{50} was evaluated using the mortality result obtained from the leaf-dip bioassay test and using the Probit Analysis function in the Statistical Analysis System (SAS) Enterprise Guide 7.11. The LD_{50} values for both susceptible and test populations were assessed. The syntax for performing the probit analysis in SAS is as follows:

```
DATA dosetest;
	INFILE '<File path.txt>' DELIMITER=',' ;
	INPUT Dose N Response;
	Observed= Response/N;
RUN;

PROC probit data=dosetest log10 OPTC;
	model Response/N=Dose / lackfit inversecl itprint;
	output out=B p=Prob std=std xbeta=xbeta;
RUN;
```

The syntax was written based on the guide provided by SAS Institute Inc. (2008), Throne, Weaver and Baker (1995) and Lee (2016, personal communication) and Ng (2016, personal communication). The <File path.txt> was replaced by the actual file path to the data file saved in the personal computer before running the program.

With the LD_{50} value, the resistance ratio was calculated using the formula cited in Gong et al. (2013).

$$Resistance\ Ratio = \frac{LD_{50}\ of\ the\ tested\ population}{LD_{50}\ of\ the\ susceptible\ population}$$

The susceptible population comprised thrips that were collected from organic farms in Cameron Highlands while the tested population consisted of thrips sampled from the conventional farms in Cameron Highlands.

CHAPTER FOUR

RESULTS

4.1 Survey of the Solanaceae Crop Growers Farming Practices

The survey on the farming practices of eggplant, chilli and bell pepper growers was successfully carried out in Cameron Highlands. Cameron Highlands was divided into 3 zones, namely the northern zone, central zone and southern zone, based on the altitude of the areas, and 10 farmers were randomly selected from each zone for the interview. The information collected from the interview focused on the details of the farming operations, farming practices, information on the pests and diseases and their management, and the financial aspect of their farming activities. In addition, demographic information of the farmers, such as age, years of farming experience, the land size, and training received were also recorded in Table 4.1. According to Assis and Mohd Ismail (2011), taking the demographic factors, such as age and gender, into consideration would reduce the response bias of the survey and hence the findings can be generalized.

The demographic information in Table 4.1 show that 96.67% of the farmers were males and 53.33% of them were more than 50 years old. Ninety percent of them were Malaysian, while 10% were foreigners from Bangladesh and Nepal. Most of the farmers only possessed up to secondary education and approximately 23% of them possessed a tertiary certificate, either from a university or college. Sixty percent of the farmers were involved in farming for less than 20 years while 6.67% had been farming for more than 41 years. Most of the farmers were farming in less than 4.05 ha of land that were under Temporary Occupational License (TOL) which required annual renewal. Most of the farmers (66.67%) had not participated in any agriculture-related workshops and seminars, while 30% of them had attended seminar and talks and 3.33% participated in agricultural workshops. Fifty percent of these activities were organised by agro-chemical companies, while the rest were by non-governmental organisation (NGOs) and government agencies, i.e., Pesticide Action Network (PAN), Universiti Tunku Abdul Rahman (UTAR), MARDI and Department of Agriculture. Most of the farmers obtained agriculture-related information from the local licensed pesticides dealers and other farmers, while 19.57% would consult representative NGOs (Pesticide Action Network and CropLife) and agriculture experts (MARDI and university researchers). A few of them (2.17%) would gather information through the mass media, i.e., agriculture magazines, newspapers and online articles.

Table 4.1: Demographic information of the respondents.

		Count	Percentage (%)
Gender	Male	29	96.67
	Female	1	3.33
Age Group	≤ 30 years old	3	10.00
	31 – 40 years old	5	16.67
	41 – 50 years old	6	20.00
	≥ 50 years old	16	53.33
Nationality	Malaysian	27	90.00
	Others	3	10.00
Level of Education	≤ Primary	9	30.00
	Secondary	14	46.67
	≥ Tertiary	7	23.33
Farming Experience	≤ 20 years	18	60.00
	21 – 40 years	10	33.33
	≥ 41 years	2	6.67
Farm Size & Land Tenure	≤ 4.05 ha	29	96.67
	≥ 4.06 ha	1	3.33
	TOL	20	66.67
	Lease	9	30.00
	Others	1	3.33

Note: Land Tenure: TOL, Temporary Occupational License; Others, government-linked land.

Table 4.1 (continued): Demographic information of the respondents.

		Count	Percentage (%)
Attended Training & Organizers	Workshop	1	3.33
	Seminar or Talks	9	30.00
	None	20	66.67
	NGO	2	20.00
	Agro-Chemical Company	5	50.00
	Government Agency	3	30.00
Source of Agriculture Related Information	Licensed Pesticide Dealers	17	36.96
	Sales Representatives	5	10.87
	Mass Media	1	2.17
	Other Farmers (Friends)	14	30.43
	Others	9	19.57

Note: NGO: Non-Governmental Organization; Agro-Chemical Company, including pesticide and fertilisers company; Government Agency: Malaysia Agriculture Research and Development Institute (MARDI) and Department of Agriculture Malaysia (DoA). Others: non-governmental agencies, agriculture experts, foreign and local consultants.

4.1.1 Farm Operations and Farming Practices

The survey on farm operations and farming practices encompassed the planting methods used by the farmers to plant eggplant, bell pepper and chilli, source of the seeds and the criteria for the farmers to choose the variety of the crops, type of fertilisers used and the reasons for the choice of fertilisers, the use of weedicides and types of weedicides used, the main problems faced by the respondents and the average hectarage for eggplant, bell peppers and chilli in each farm.

Approximately 74% of the farmers planted on soil beds while about 25% had adopted the new planting technique, fertigation (Figure 4.1). Ninety-three percent of the farmers used F1 hybrid seeds purchased from local agriculture dealers while 6.67% of them purchased their F1 hybrid seeds from private consultants (Figure 4.2). Processed chicken manure (27.63%) was still the most preferred fertiliser, followed by foliar fertilisers (22.37%) and chemical granular fertilisers (21.05%) (Figure 4.3). Approximately 54% of the farmers chose the fertilisers based on the recommendation of agriculture shop dealers while only 3.23% took the cost into consideration (Figure 4.4). Most of the respondents (66.67%) still depended on herbicides to clear any unwanted vegetations in the farms and the most popular herbicides were paraquat dichloride (45.95%) and glufosinate-ammonium (45.95%) (Figure 4.5 and Figure 4.6). The reason given by most of the farmers for planting eggplant, bell pepper and chilli were good market demand (47.06%), followed by having the experience in planting these crops (20.59%) and the least considered reason was the cost of production (5.88%) (Figure 4.7). Based on Figure 4.8, chillies and bell peppers were most popularly grown in the northern zone (1.18 ha and 3.24 ha respectively) while eggplants were popular in the southern zone (1.94 ha). Pests and diseases were the main problems faced by 46.51% of the farmers, while 4.65% had problems with the soil, such as, non-porous soil (Figure 4.9).

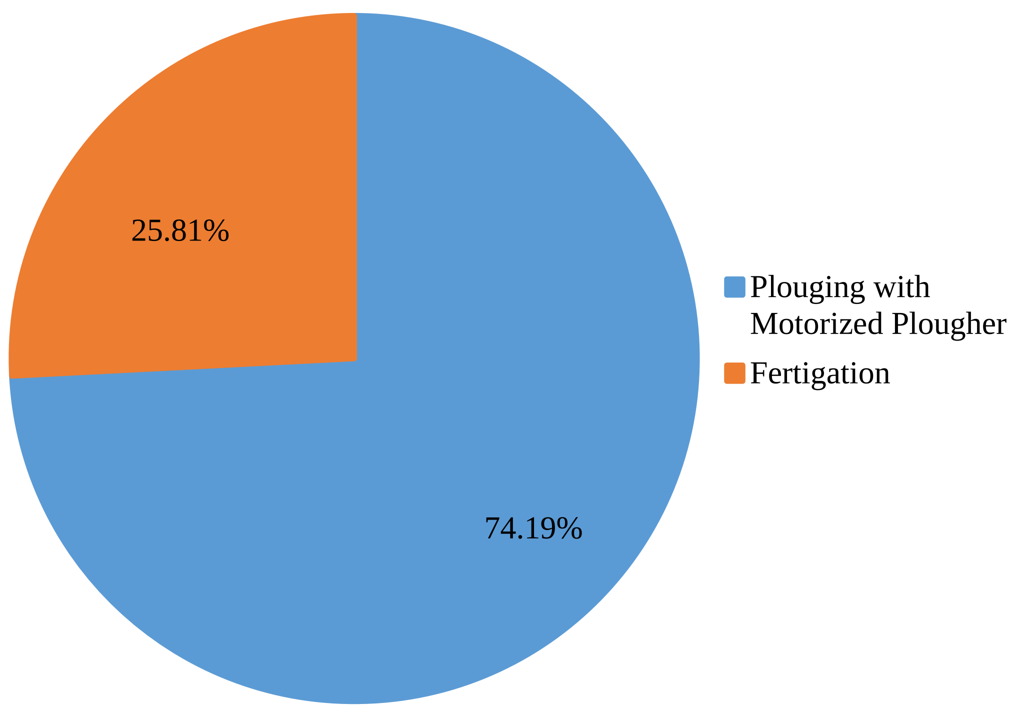

Figure 4.1: Land preparation method used by the respondents prior to the planting of crops.

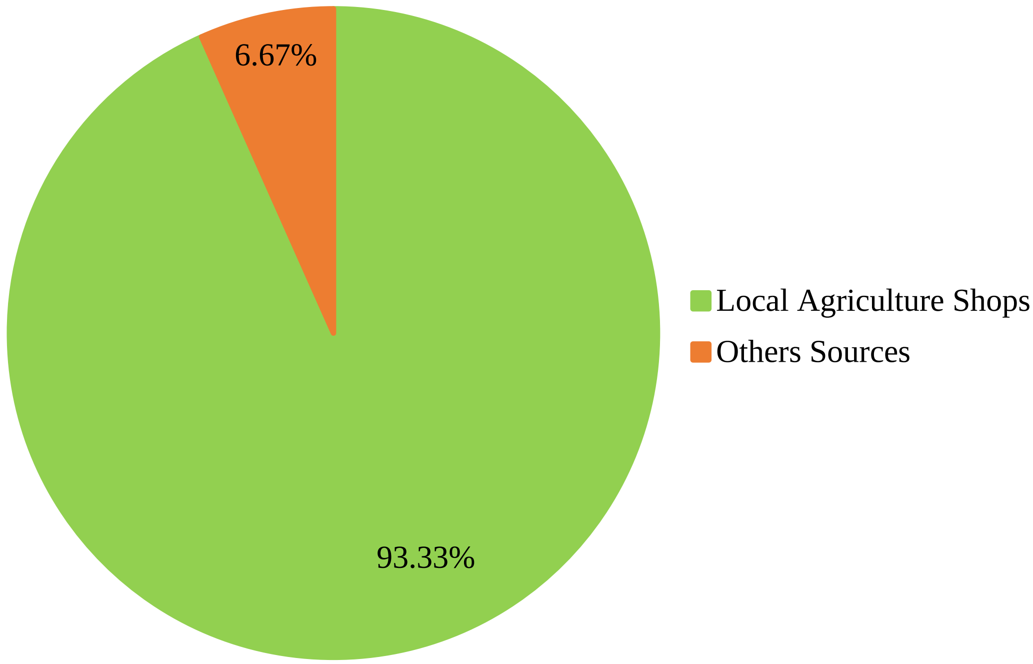

Figure 4.2: Sources of seeds used by the respondents to plant eggplant, bell pepper or chilli.

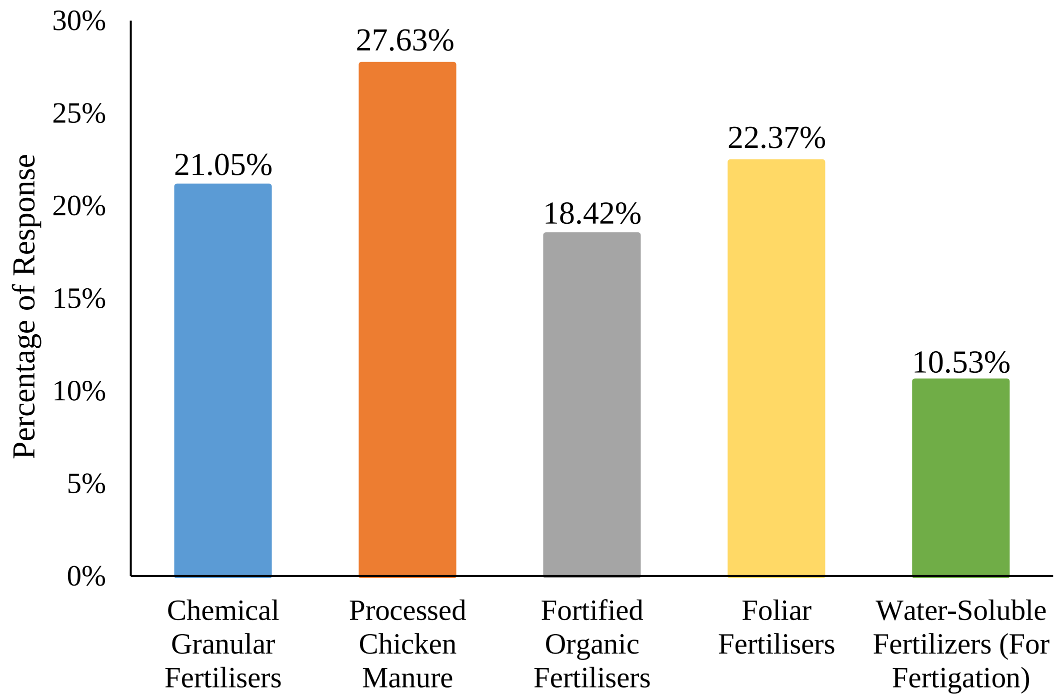

Figure 4.3: Types of fertilisers used by the respondents to plant eggplant, bell pepper or chilli.

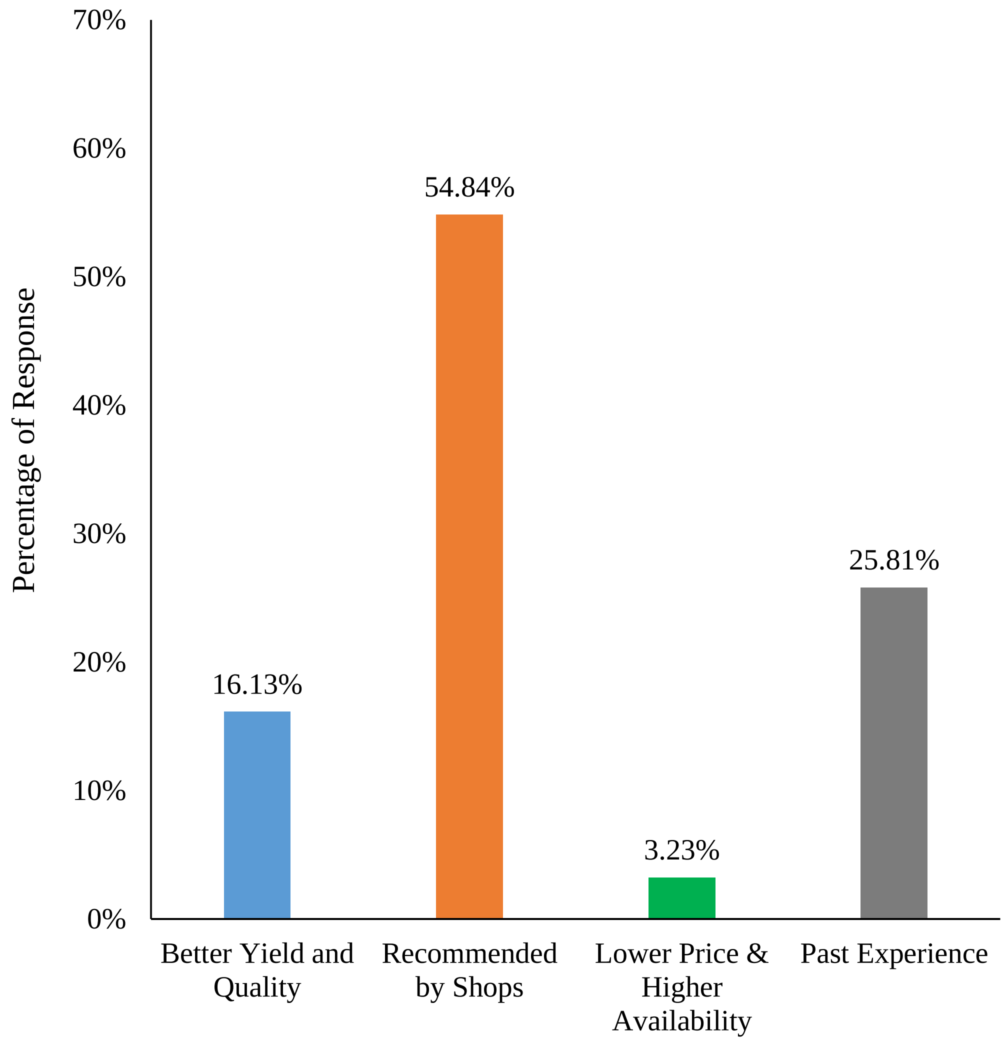

Figure 4.4: Reasons given by the respondents on the usage of the types of fertilisers reported in Figure 4.3.

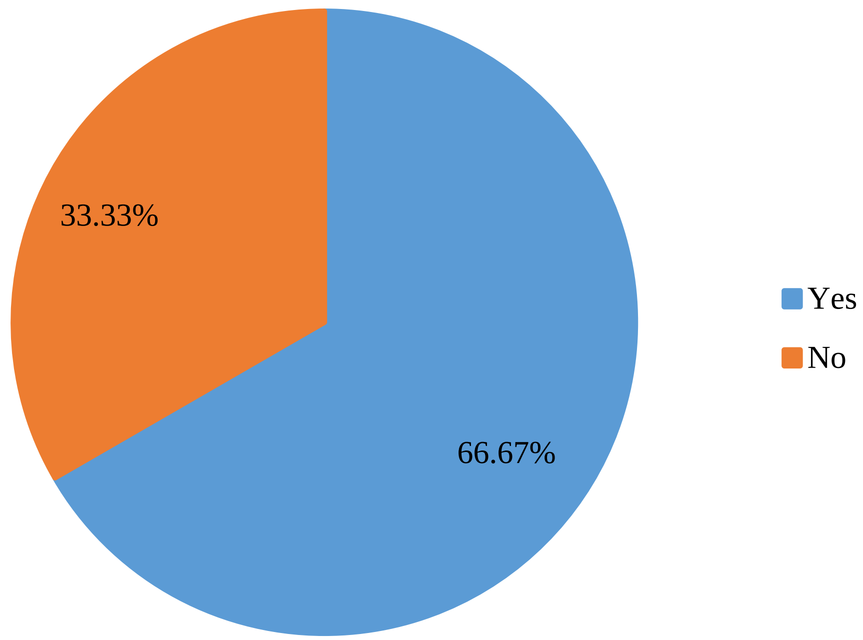

Figure 4.5: Percentage of respondents who reported using weedicides in their farms.

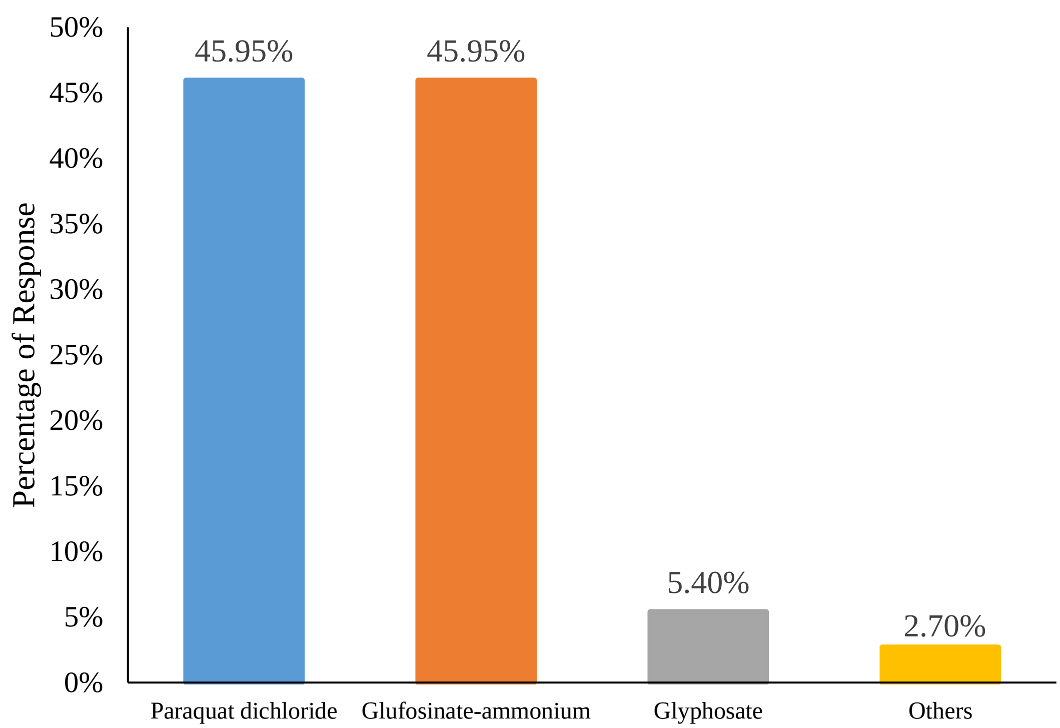

Figure 4.6: Herbicides used by the respondents to clear weeds or any previous vegetation before planting their crops.

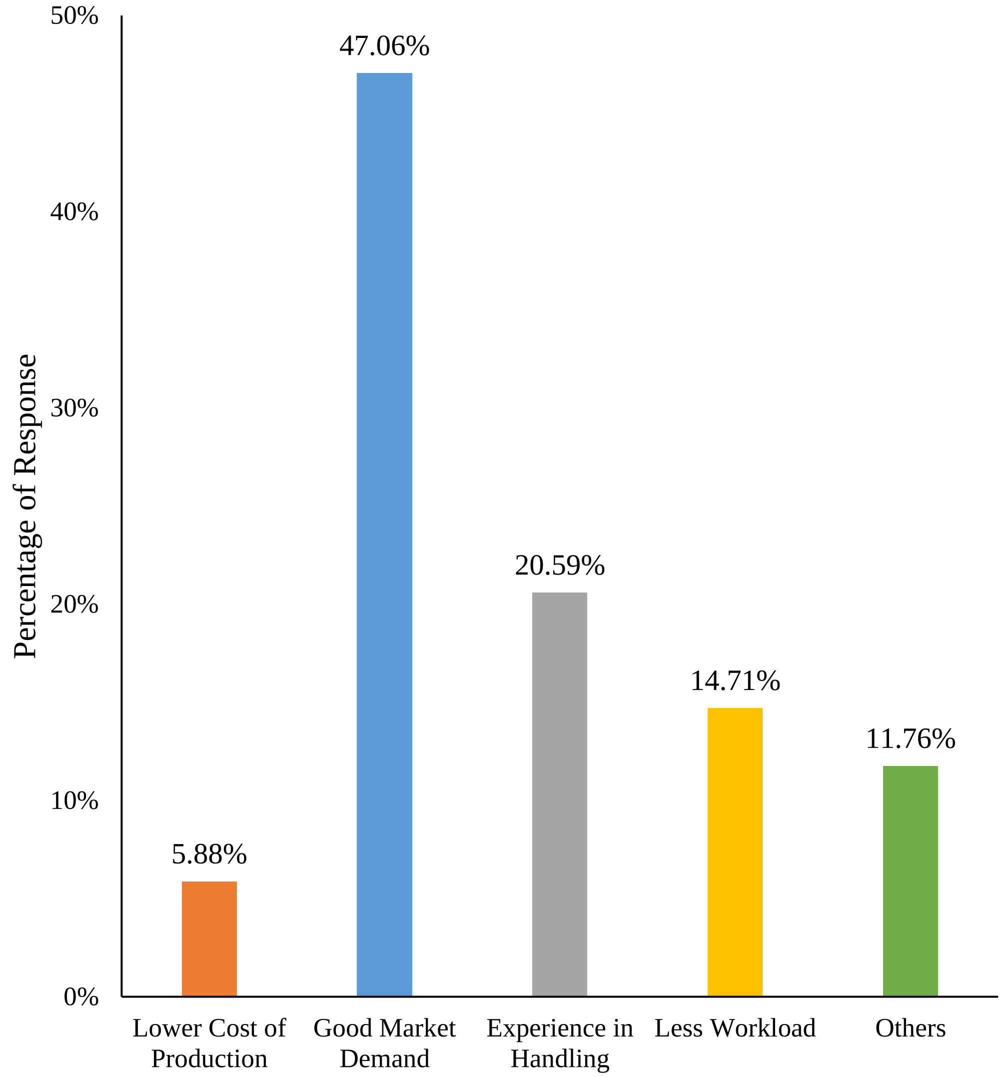

Figure 4.7: Reasons given by the respondents for the planting of eggplant, bell pepper or chilli.

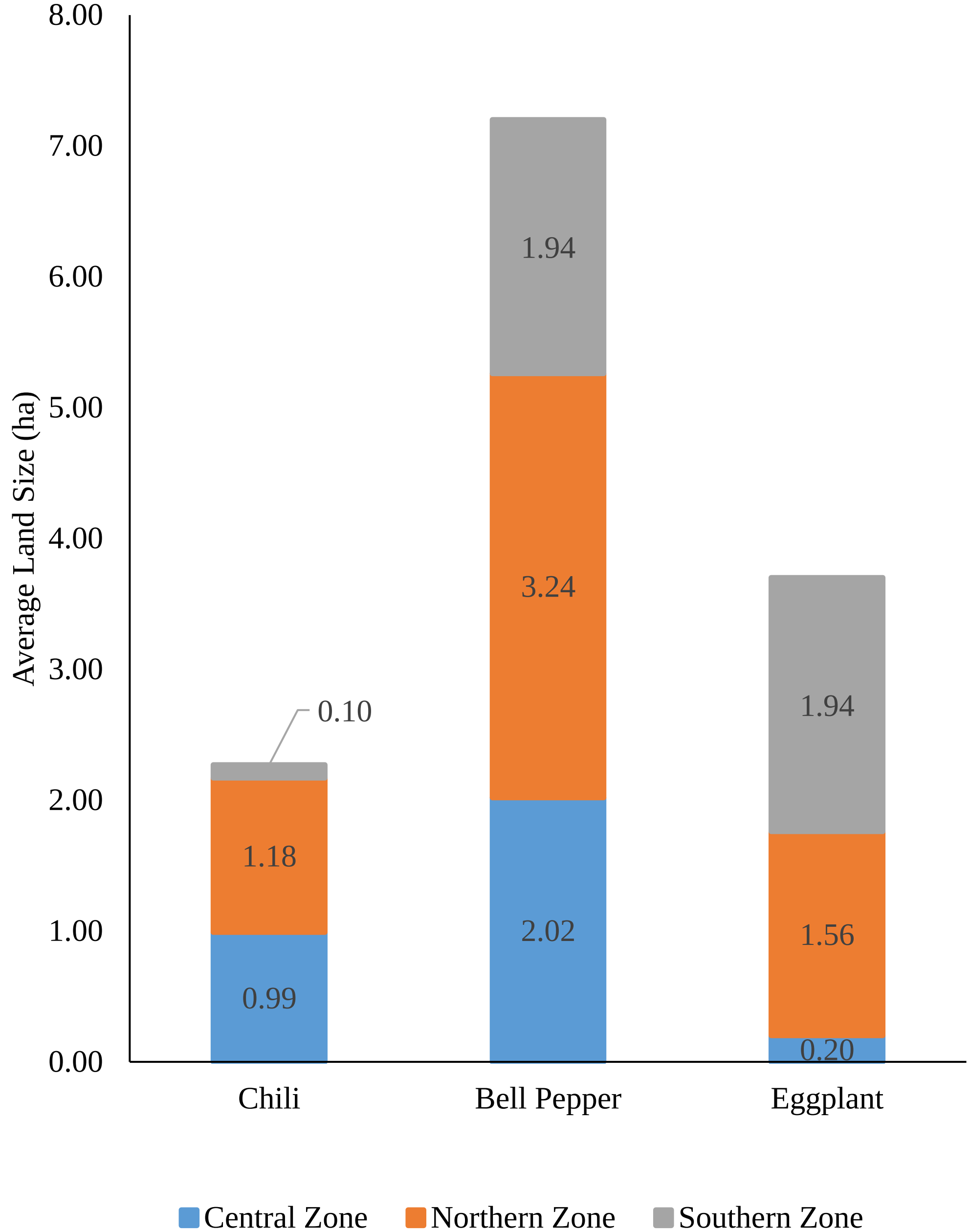

Figure 4.8: Average land size in hectares for chilli, bell pepper and eggplant planted in Cameron Highlands.

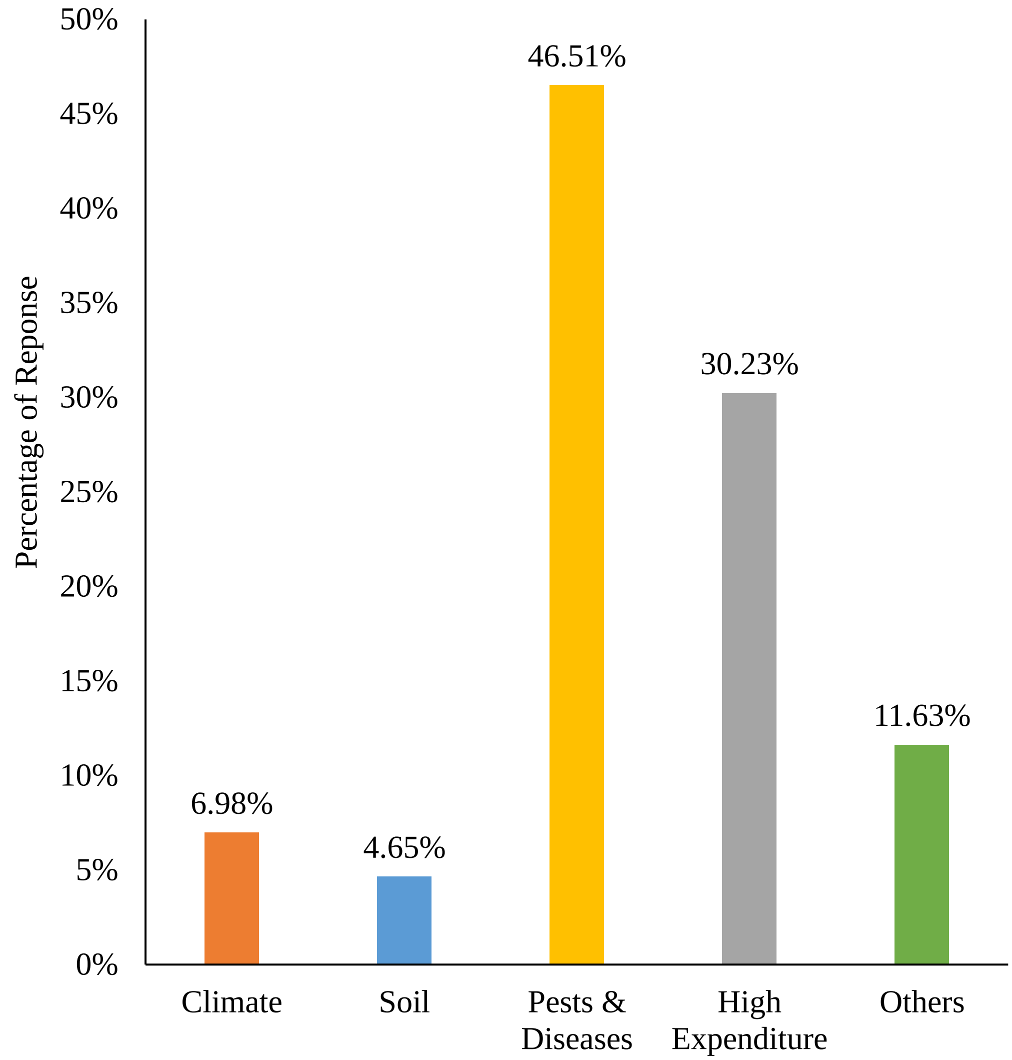

Figure 4.9: Major problems faced by the respondents during the planting of chilli, bell pepper and eggplant.

4.1.2 Information on the Pests and Diseases

This section of the survey was focused mainly on the pests and diseases that caused major damage to the three selected crops, the ability of the respondents to identify and differentiate between the pest insects and non-pest insects, the method to control the pest problems, the possible solutions when facing pest outbreaks and the chemical pesticides (if any) used during the planting of chilli, bell pepper and eggplant.

According to the farmers, thrips (46.77%) were the worst pests of chilli, bell pepper and eggplants, followed by damage caused by unknown pests and diseases (20.97%) and the least were whitefly (1.61%) and bacterial wilt (*Ralstonia solanacearum*) (1.61%) (Figure 4.10). Based on Figure 4.11, 30% of the farmers faced yield losses of less than 5% and 26.67% had yield losses that was between 6 to 10%. Approximately 96% of the farmers could not distinguish between beneficial insects and pest insects (Figure 4.12). Based on Figure 4.13 and Figure 4.14, 90% of the farmers were dependent on chemical pesticides for pest control method and 73.33% of the farmers still practised calendar spraying (at a frequency of once a week). Almost all the farmers (96.55%) were using cocktail pesticides (Figure 4.15). The average spray volume ranged from less than 494 L per hectare to more than 1482 L per hectare (Figure 4.16). The spray volume varies based on the age of the plants and the moisture per leaf. Many farmers (89.66%) purchased and used pesticides that were recommended by the local pesticide dealers. These dealers (68.42%) as well as other farmers (23.68%) were the preferred persons that the farmers consult when they were faced with pest outbreaks (Figure 4.18). Spinetoram, imidacloprid and abamectin were the most popular insecticides to control thrips populations (Figure 4.19). Mancozeb, propineb, cymoxanil and chlorothalonil were the four most popular fungicides used to control fungal diseases on chillies, eggplants and bell pepper (Figure 4.20).

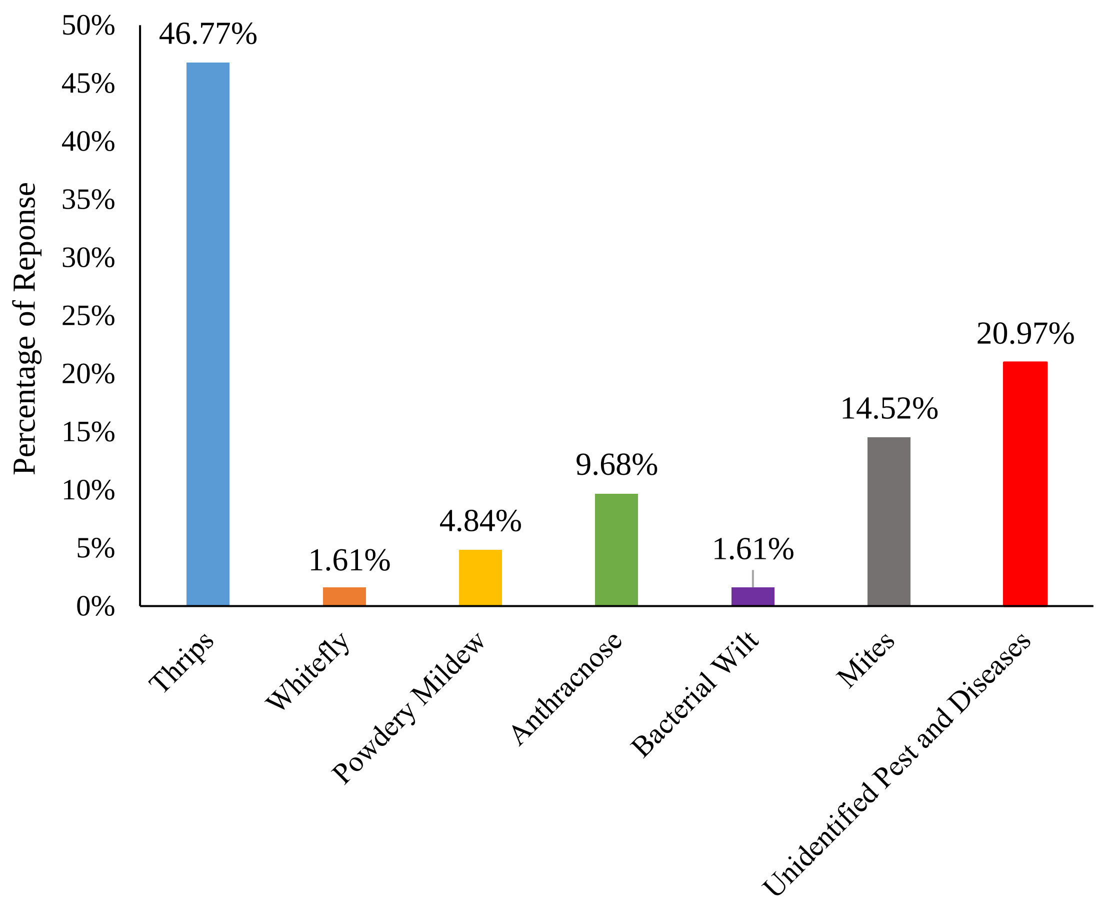

Figure 4.10: Pests and diseases of chilli, bell pepper and eggplant in Cameron Highlands based on the respondents' feedback.

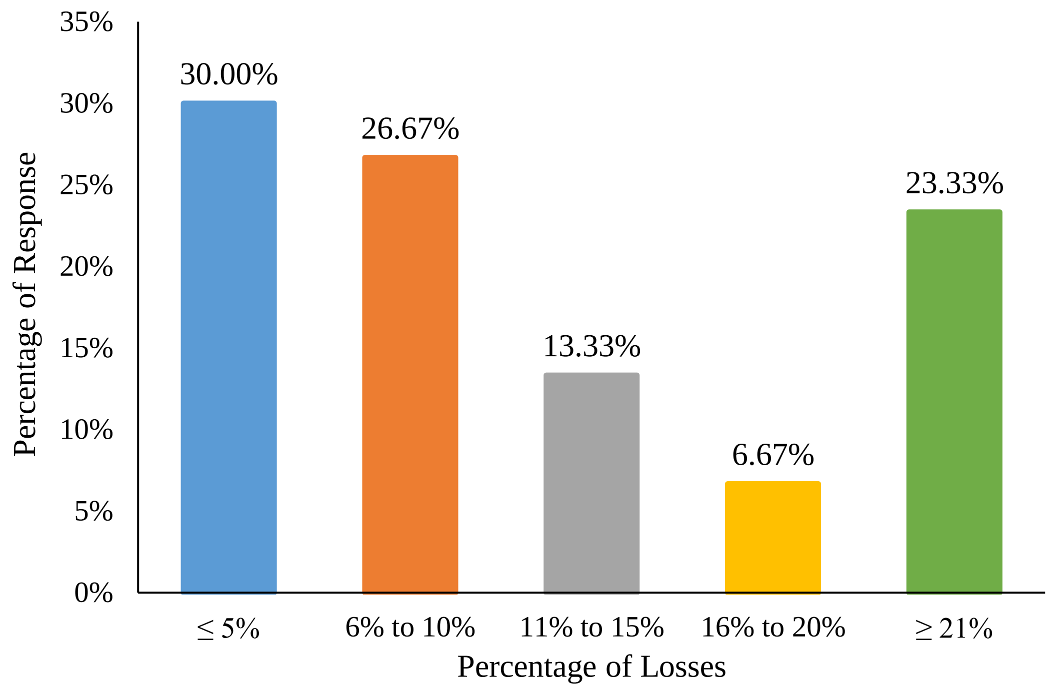

Figure 4.11: Percentage of losses caused by the damage of pests and diseases on chilli, bell pepper and eggplant in Cameron Highlands.

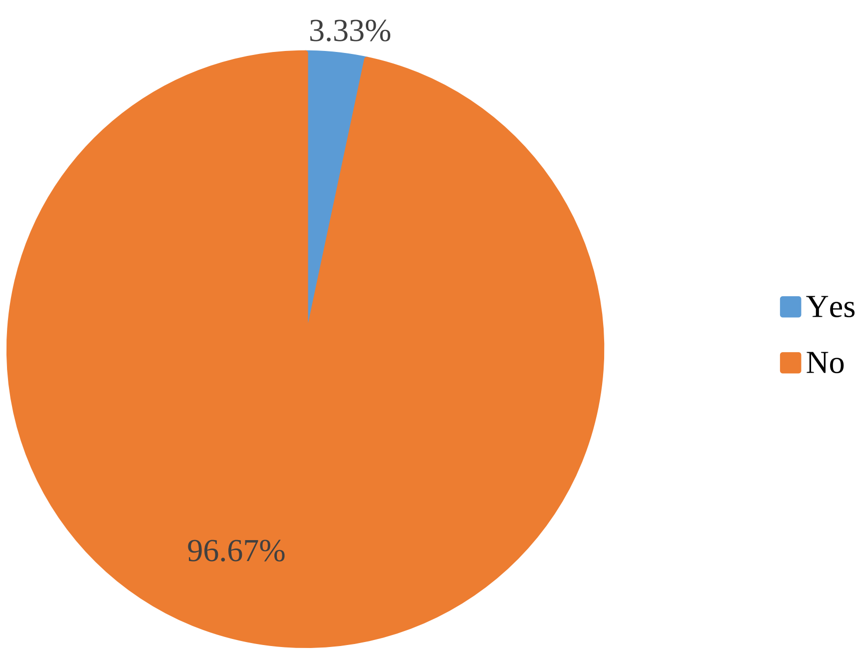

Figure 4.12: Ability of the respondents to identify pest insects and beneficial insects.

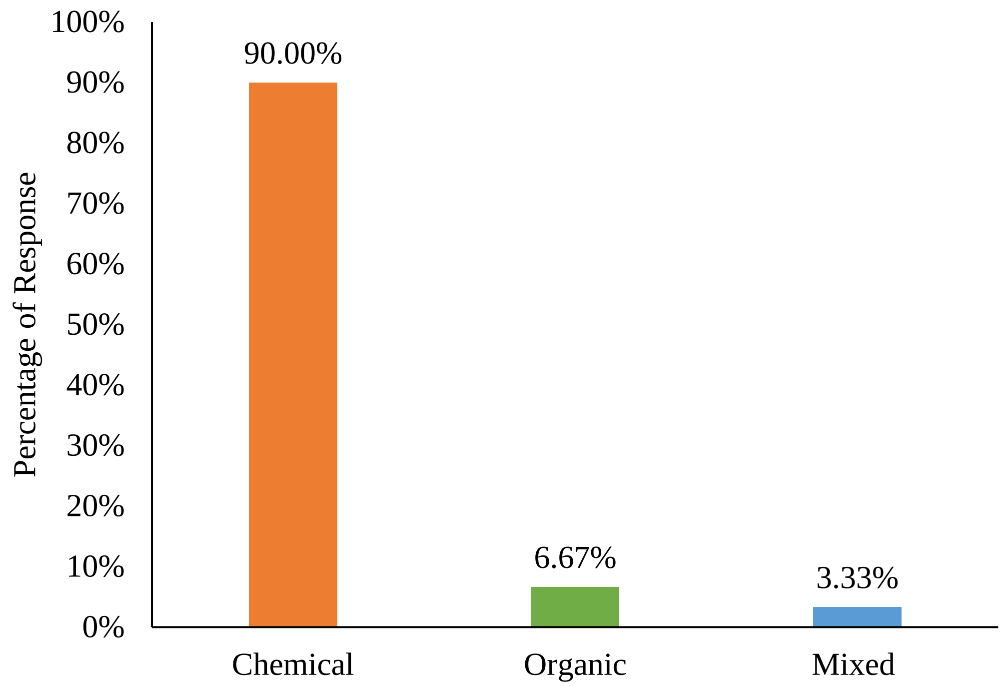

Figure 4.13: Methods used by the respondents to suppress damages caused by pests and diseases. (Note: mixed = using both chemical and organic approaches to control pests and diseases)

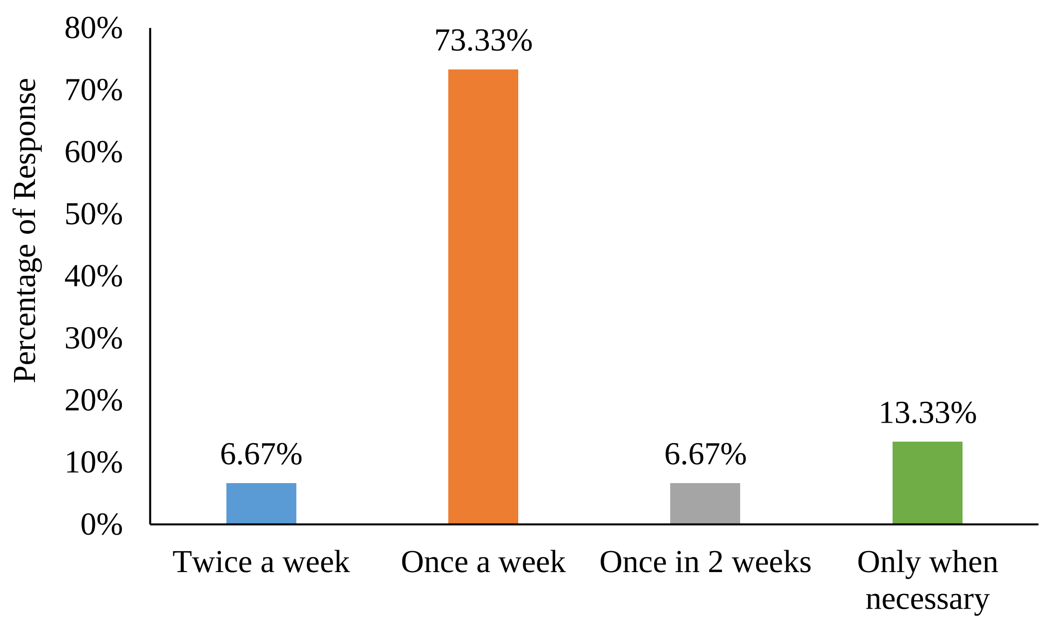

Figure 4.14: Frequency of spraying with chemical pesticides as reported by the respondents.

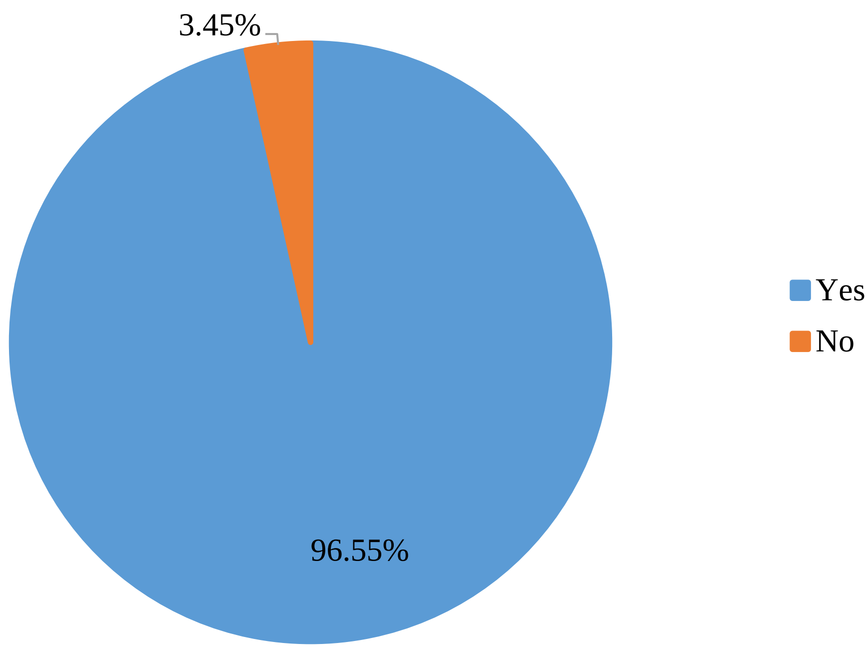

Figure 4.15: Use of cocktail pesticides as reported by the respondents.

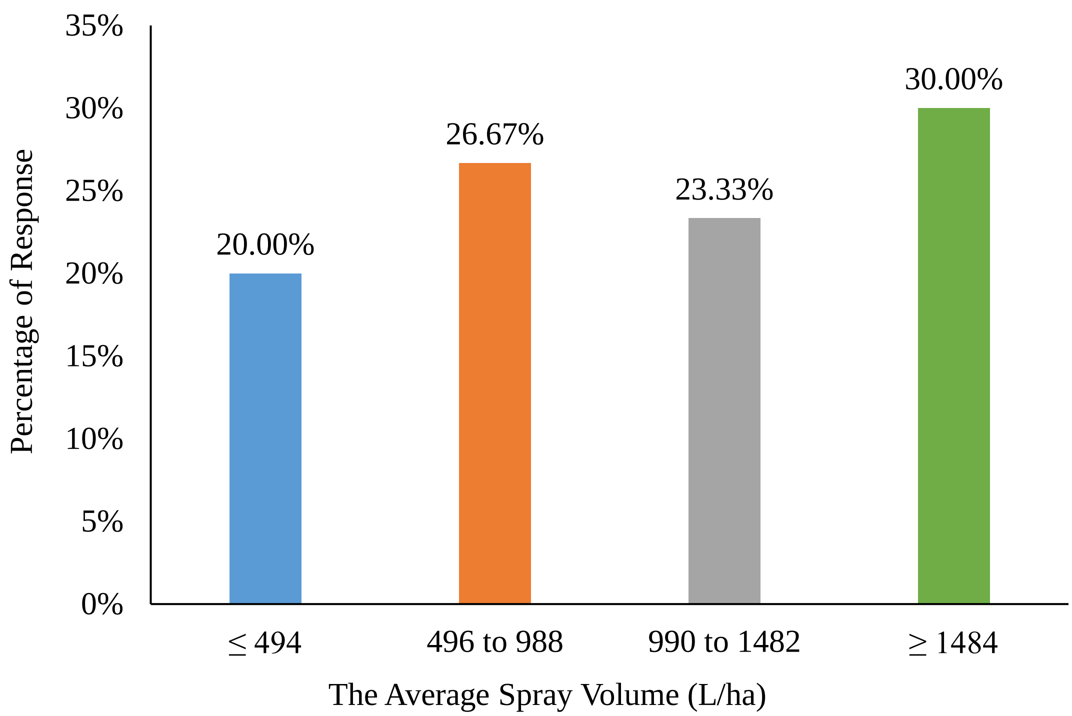

Figure 4.16: Average spray volume per hectare as reported by the respondents.

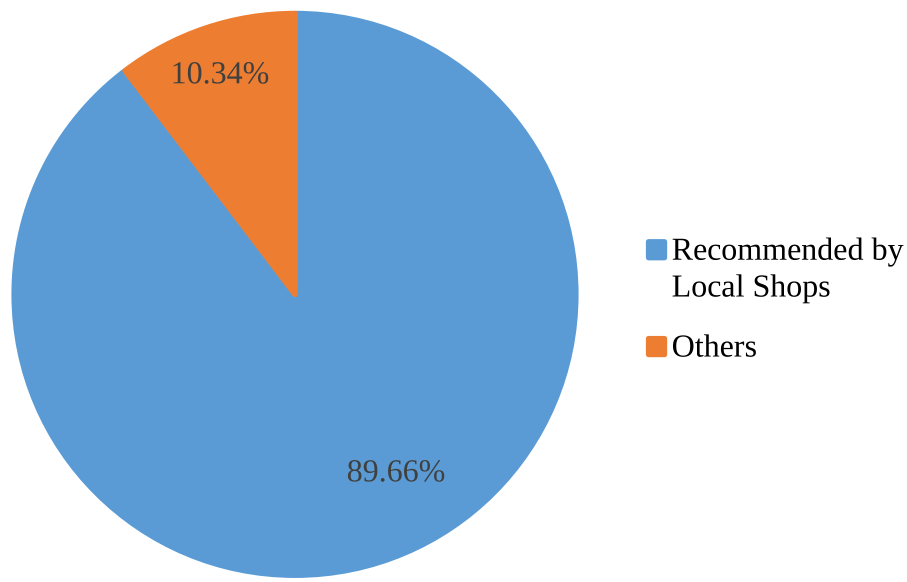

Figure 4.17: Reasons given by the respondents for the purchase and use of pesticides. (Note: Others, includes recommendation from private consultant and the pre-harvest interval)

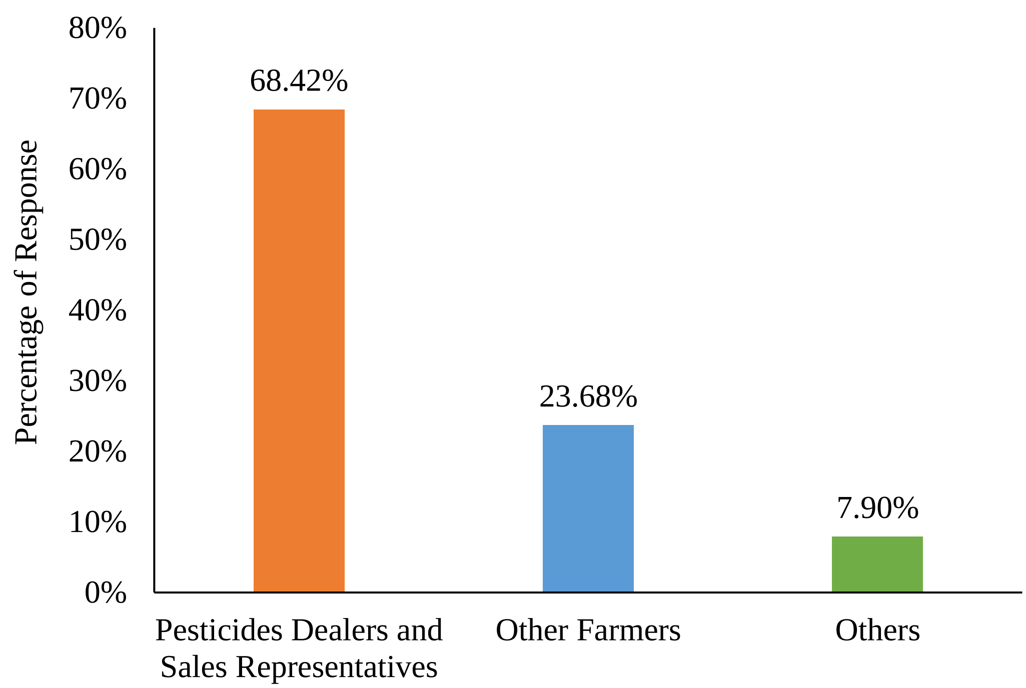

Figure 4.18: The respondents source of solution when facing pest outbreaks. (Note: Others, includes, private consultants and Agro-related officers)

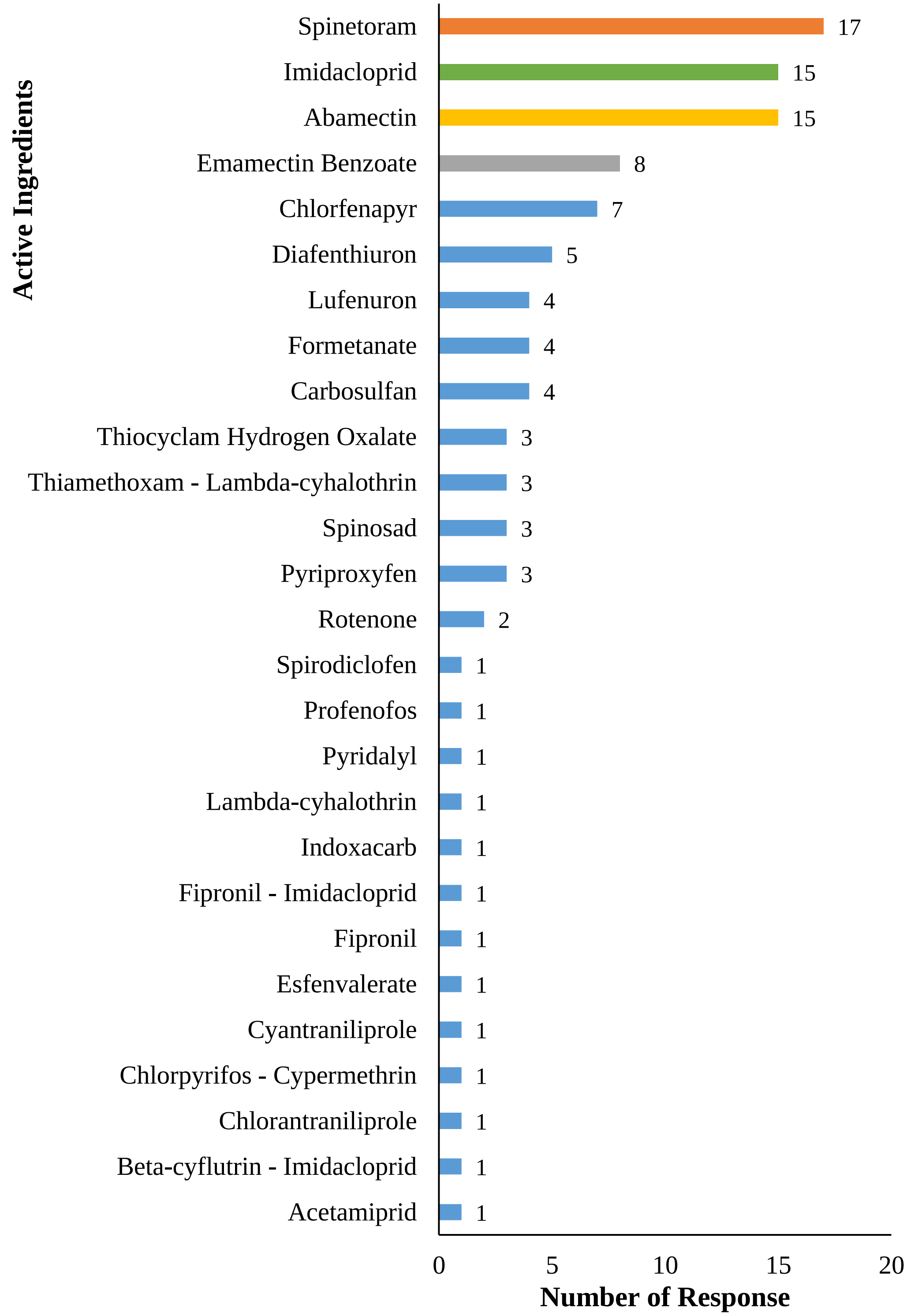

Figure 4.19: Insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Table 4.2: The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	**Trade name(s)**	**Chemical Abstracts name**
Abamectin	Agrimec, Abatin, BrighTin, Vertimec	5-*O*-demethylavermectin A_{1a} (i) mixture with 5-*O*-demethyl-25-de(1-methylpropyl)-25-(1-methylethyl)avermectin A_{1a} (ii)
Acetamiprid	Mospilan	(*E*)-*N*-[(6-chloro-3-pyridinyl)methyl]-*N'*-cyano-*N*-methylethanimidamide
Beta-cyfluthrin-imidacloprid	Solomon	cyano(4-fluoro-3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate and (2*E*)-1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Carbosulfan	Amitage, Marshal, Marsk	2,3-dihydro-2,2-dimethyl-7-benzofuranyl
Chlorfenapyr	Akosu, Kotetsu	4-bromo-2-(4-chlorophenyl)-1-(ethoxymethyl)-5-(trifluoromethyl)-1*H*-pyrrole-3-carbonitrile
Chlorpyrifos-cypermethrin	Nurelle D505	*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridinyl) phosphorothioate and cyano(3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate

Table 4.2 (continued): The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Chlorantraniliprole	Prevathon	3-bromo-*N*-[4-chloro-2-methyl-6-[(methylamino)carbonyl]phenyl]-1-(3-chloro-2-pyridinyl)-1*H*-pyrazole-5-carboxamide
Cyantraniliprole	Benevia	3-bromo-1-(3-chloro-2-pyridinyl)-*N*-[4-cyano-2-methyl-6-[(methylamino)carbonyl]phenyl]-1*H*-pyrazole-5-carboxamide
Diafenthiuron	Pegasus	*N*-[2,6-bis(1-methylethyl)-4-phenoxyphenyl]-*N*'-(1,1-dimethylethyl)thiourea
Emamectin benzoate	Proclaim 019EC	(4''*R*)-5-*O*-demethyl-4''-deoxy-4''-(methylamino)avermectin A_{1a} + (4''*R*)-5-*O*-demethyl-25-de(1-methylpropyl)-4''-deoxy-4''-(methylamino)-25-(1-methylethyl)avermectin A_{1a} (9:1); 4''-deoxy-4''-(methylamino)avermectin B1
Esfenvalerate	Sumi-alpha	[*S*-(*R**,*R**)]-cyano(3-phenoxyphenyl)methyl 4-chloro-2-(1-methylethyl)benzeneacetate
Fipronil	Regent	5-amino-[2,6-dichloro-4-(trifluoromethyl)phenyl]-4-[(1*R*,*S*)-(trifluoromethyl)sulfinyl]-1*H*-pyrazole-3-carbonitrile

Table 4.2 (continued): The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Fipronil-imidacloprid	Lesenta	5-amino-[2,6-dichloro-4-(trifluoromethyl)phenyl]-4-[(1*R*,*S*)-(trifluoromethyl)sulfinyl]-1*H*-pyrazole-3-carbonitrile and (2*E*)-1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Formetanate hydrochloride	Dicarzol	*N*,*N*-dimethyl-*N*'-[3-[[(methylamino)carbonyl]oxy]phenyl]methanimidamide
Imidacloprid	Confidor, Confor, Imida	(2*E*)-1-[(6-chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine
Indoxacarb	Steward	methyl (4a*S*)-7-chloro-2,5-dihydro-2-[[(methoxycarbonyl)[4-(trifluoromethoxy)phenyl]amino]carbonyl]indeno[1,2-*e*][1,3,4]oxadiazine-4a(3*H*)-carboxylate
Lambda-cyhalothrin	Karate	[1α(*S**),3α(*Z*)]-(±)-cyano(3-phenoxyphenyl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Lufenuron	Match	*N*-[[[2,5-dichloro-4-(1,1,2,3,3,3-hexafluoropropoxy)phenyl]amino]carbonyl]-2,6-difluorobenzamide

Table 4.2 (continued): The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Profenofos	Fenop	*O*-(4-bromo-2-chlorophenyl) *O*-ethyl *S*-propyl phosphorothioate
Pyridalyl	Pleo	2-[3-[2,6-dichloro-4-[(3,3-dichloro-2-propenyl)oxy]phenoxy]propoxy]-5-(trifluoromethyl)pyridine
Pyriproxyfen	Amiko	2-[1-methyl-2-(4-phenoxyphenoxy)ethoxy]pyridine
Spinetoram	Endure	a mixture of (2*R*,3a*R*,5a*R*,5b*S*,9*S*,13*S*,14*R*,16a*S*,16b*R*)-2-[(6-deoxy-3-*O*-ethyl-2,4-di-*O*-methyl-α-L-mannopyranosyl)oxy]-13-[[(2*R*,5*S*,6*R*)-5-(dimethylamino)tetrahydro-6-methyl-2*H*-pyran-2-yl]oxy]-9-ethyl-2,3,3a,4,5,5a,5b,6,9,10,11,12,13,14,16a,16b-hexadecahydro-14-methyl-1*H*-as-indaceno[3,2-*d*]oxacyclododecin-7,15-dione (3'-*O*-ethyl 5,6-dihydro spinosyn J, (i)) and (2*S*,3a*R*,5a*S*,5b*S*,9*S*,13*S*,14*R*,16a*S*,16b*S*)-2-[(6-deoxy-3-*O*-ethyl-2,4-di-*O*-methyl-α-L-mannopyranosyl)oxy]-13-[[(2*R*,5*S*,6*R*)-5-(dimethylamino)tetrahydro-6-methyl-2*H*-pyran-2-yl]oxy]-9-ethyl-2,3,3a,5a,5b,6,9,10,11,12,13,14,16a,16b-tetradecahydro-4,14-dimethyl-1*H*-as-indaceno[3,2-*d*]oxacyclododecin-7,15-dione (3'-*O*-ethyl spinosyn L, (ii)) in the proportion 50-90% to 50-10%

Table 4.2 (continued): The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Spinosad	Success	(2*R*,3a*S*,5a*R*,5b*S*,9*S*,13*S*,14*R*,16a*S*,16b*R*)-2-[(6-deoxy-2,3,4-tri-*O*-methyl-α-L-mannopyranosyl)oxy]-13-[[(2*R*,5*S*,6*R*)-5-(dimethylamino)tetrahydro-6-methyl-2*H*-pyran-2-yl]oxy]-9-ethyl-2,3,3a,5a,5b,6,9,10,11,12,13,14,16a,16b-tetradecahydro-14-methyl-1*H*-as-indaceno[3,2-*d*]oxacyclododecin-7,15-dione (spinosyn A), mixture with (2*S*,3a*R*,5a*S*,5b*S*,9*S*,13*S*,14*R*,16a*S*,16b*S*)-2-[(6-deoxy-2,3,4-tri-*O*-methyl-α-L-mannopyranosyl)oxy]-13-[[(2*R*,5*S*,6*R*)-5-(dimethylamino)tetrahydro-6-methyl-2*H*-pyran-2-yl]oxy]-9-ethyl-2,3,3a,5a,5b,6,9,10,11,12,13,14,16a,16b-tetradecahydro-4,14-dimethyl-1*H*-as-indaceno[3,2-*d*]oxacyclododecin-7,15-dione (spinosyn D)
Spirodiclofen	Envidor	3-(2,4-dichlorophenyl)-2-oxo-1-oxaspiro[4.5]dec-3-en-4-yl 2,2-dimethylbutanoate
Rotenone	Rotenone	[2*R*-(2α,6aα,12aα)]-1,2,12,12a-tetrahydro-8,9-dimethoxy-2-(1-methylethenyl)[1]benzopyrano[3,4-*b*]furo[2,3-*h*][1]benzopyran-6(6a*H*)-one

Table 4.2 (continued): The common name, trade names and Chemical Abstracts name of the insecticides used by the respondents to control thrips on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Thiamethoxam and Lambda-cyhalothrin	Alika	3-[(2-chloro-5-thiazolyl)methyl]tetrahydro-5-methyl-*N*-nitro-4*H*-1,3,5-oxadiazin-4-imine and [1α(*S**),3α(*Z*)]-(±)-cyano(3-phenoxyphenyl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate
Thiocyclam hydrogen oxalate	Evisect	*N*,*N*-dimethyl-1,2,3-trithian-5-amine hydrogen oxalate

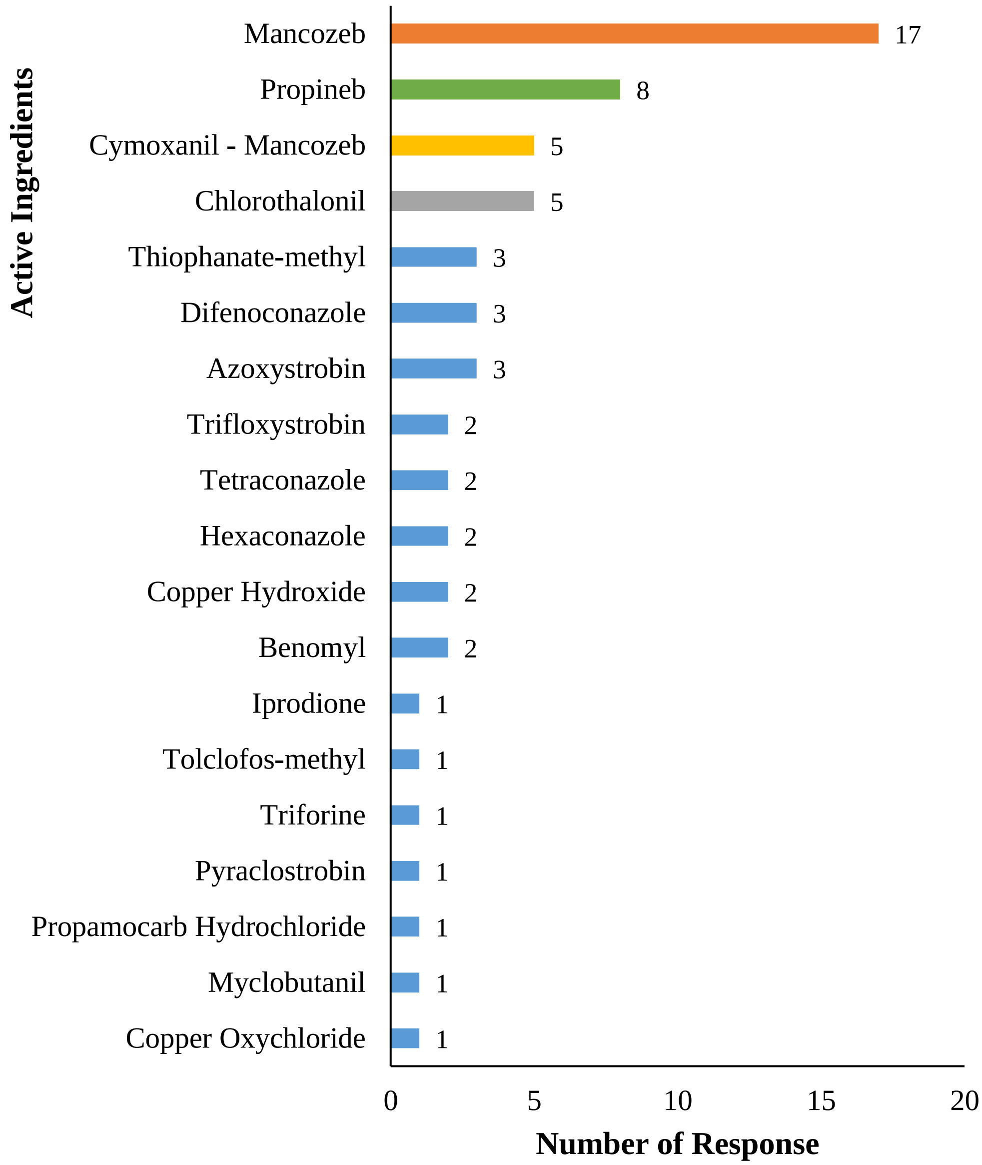

Figure 4.20: Fungicides used by the respondents to control the diseases of chilli, eggplant and bell pepper in Cameron Highlands.

Table 4.3: The common name, trade names and Chemical Abstracts name of the fungicides used by the respondents to control the diseases on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Azoxystrobin	Amistar	methyl (*E*)-2-[[6-(2-cyanophenoxy)-4-pyrimidinyl]oxy]-α-(methoxymethylene)benzeneacetate
Benomyl	Benex	methyl [1-[(butylamino)carbonyl]-1*H*-benzimidazol-2-yl]carbamate
Chlorothalonil	Daconil, Anconil	2,4,5,6-tetrachloro-1,3-benzenedicarbonitrile
Copper hydroxide	Kocide	copper hydroxide ($Cu(OH)_2$)
Copper oxychloride	Pipertox	copper chloride oxide hydrate/ copper chloride hydroxide
Cymoxanil-mancozeb	Curzate	2-cyano-*N*-[(ethylamino)carbonyl]-2-(methoxyimino)acetamide and [[1,2-ethanediylbis[carbamodithioato]](2-)]manganese mixture with [[1,2-ethanediylbis[carbamodithioato]](2-)]zinc
Difenoconazole	Score, Sikop, V-Skop	1-[2-[2-chloro-4-(4-chlorophenoxy)phenyl]-4-methyl-1,3-dioxolan-2-ylmethyl]-1*H*-1,2,4-triazole
Hexaconazole	Anvil, Helix	(±)-α-butyl-α-(2,4-dichlorophenyl)-1*H*-1,2,4-triazole-1-ethanol

Table 4.3 (continued): The common name, trade names and Chemical Abstracts name of the fungicides used by the respondents to control the diseases on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Iprodione	Rovral	3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide
Mancozeb	Dithane M-45, Mancozeb	[[1,2-ethanediylbis[carbamodithioato]](2-)]manganese mixture with [[1,2-ethanediylbis[carbamodithioato]](2-)]zinc
Myclobutanil	Systhane	α-butyl-α-(4-chlorophenyl)-1*H*-1,2,4-triazole-1-propanenitrile
Propamocarb hydrochloride	Previcur	propyl [3-(dimethylamino)propyl]carbamate hydrochloride
Propineb	Antracol	[[(1-methyl-1,2-ethanediyl)bis[carbamodithioato]](2-)]zinc homopolymer
Pyraclostrobin	Cabrio	methyl [2-[[[1-(4-chlorophenyl)-1*H*-pyrazol-3-ly]oxy]methyl]phenyl]methoxycarbamate
Tetraconazole	Domark	(±)-1-[2-(2,4-dichlorophenyl)-3-(1,1,2,2-tetrafluoroethoxy)propyl]-1*H*-1,2,4-triazole

Table 4.3 (continued): The common name, trade names and Chemical Abstracts name of the fungicides used by the respondents to control the diseases on chilli, eggplant and bell pepper in Cameron Highlands.

Common name	Trade name(s)	Chemical Abstracts name
Thiophanate-methyl	Topsin M	dimethyl [1,2-phenylenebis(iminocarbonothioyl)]bis[carbamate]
Tolclofos-methyl	Rizolex	*O*-(2,6-dichloro-4-methylphenyl) *O*,*O*-dimethyl phosphorothioate
Trifloxystrobin	Flint	methyl (α*E*)-α-(methoxyimino)-2-[[[(*E*)-[1-[3-(trifluoromethyl)phenyl]ethylidene]amino]oxy]methyl]benzeneacetate
Triforine	Saprol DC	*N*,*N*’-[1,4-piperazinediylbis(2,2,2-trichloroethylidene)]bisformamide

4.1.3 Financial Aspects of the Farms

The financial information of the farms focused only on the ways the respondents promote or sell their farm products, the average prices of these products, the estimated weight of production per cropping season and the main costs of production.

Many farmers (93.34%) were still dependent on sales agents to market their farm produce, 3.33% sold their products at rented stalls, and 3.33% contracted their produce to hypermarkets and government agencies, such as Federal Agricultural Marketing Authority (FAMA) (Figure 4.21). All the eggplant farmers surveyed (14) sold their produce at an average price of MYR 1.01 to 5.00, while the chilli (9) and bell pepper farmers (5) marketed their products at an average price of MYR 5.01 to 10.00 (Figure 4.22). The eggplant (4) and bell pepper (5) farmers could produce approximately 2472 to 4940kg/ha of produce a month (Figure 4.23), while the chilli (4) farmers produced less than 1235kg/ha per month. Pesticides were considered to be the main production cost for many farmers (58.97%), followed by the cost of fertilisers (23.08%) and wages for labourers (17.95%).

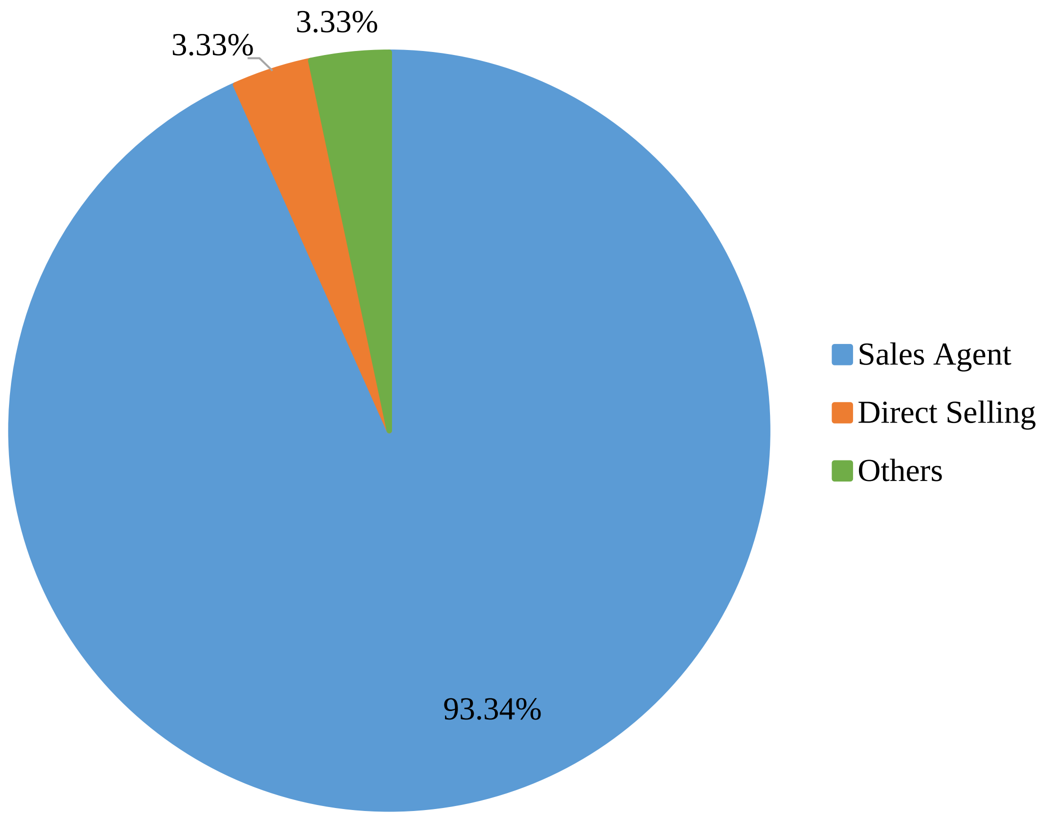

Figure 4.21: Methods used by the respondents to promote or sell their farm products, namely chillies, bell peppers and eggplants.

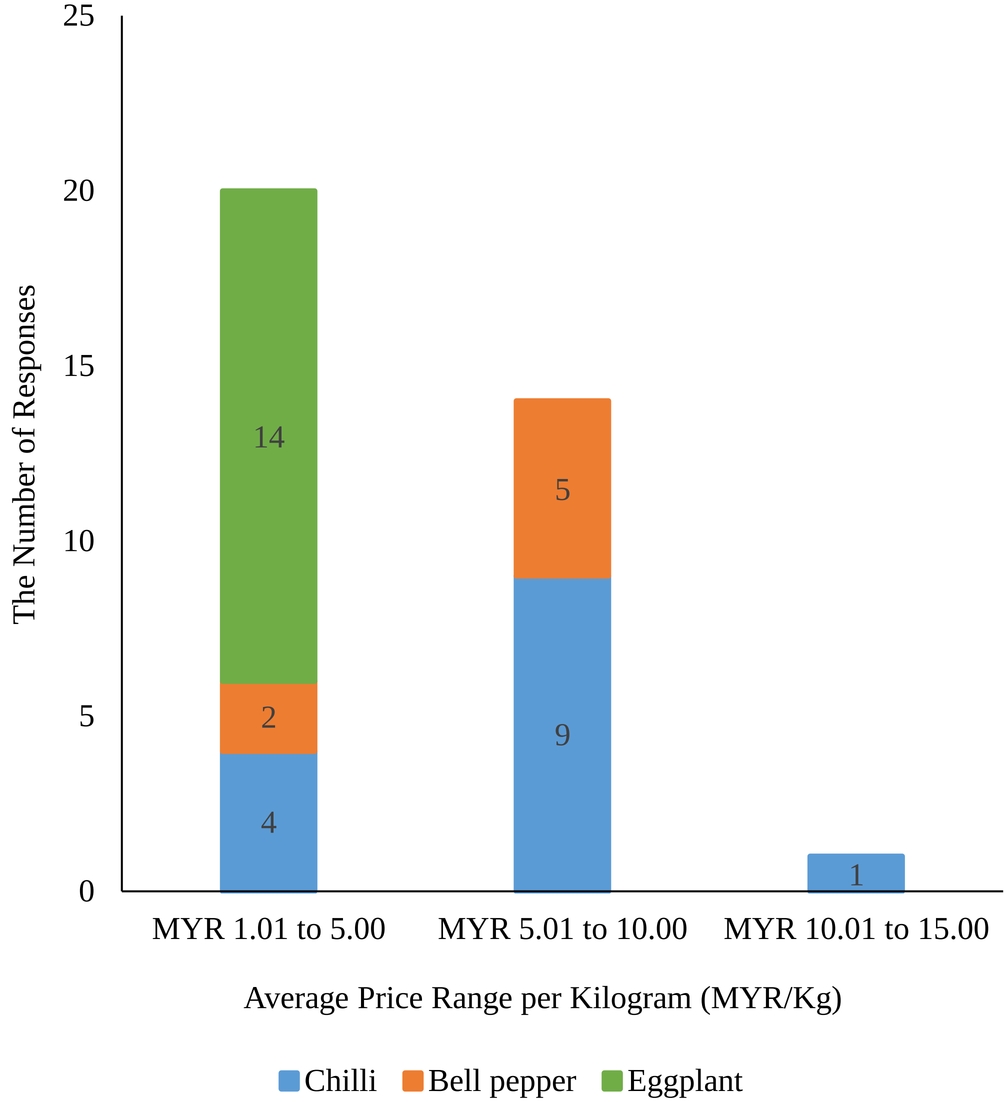

Figure 4.22: Average selling price of the respondents' farm products, such as, chillies, bell peppers and eggplants in Malaysian Ringgit per kilogram (MYR/kg).

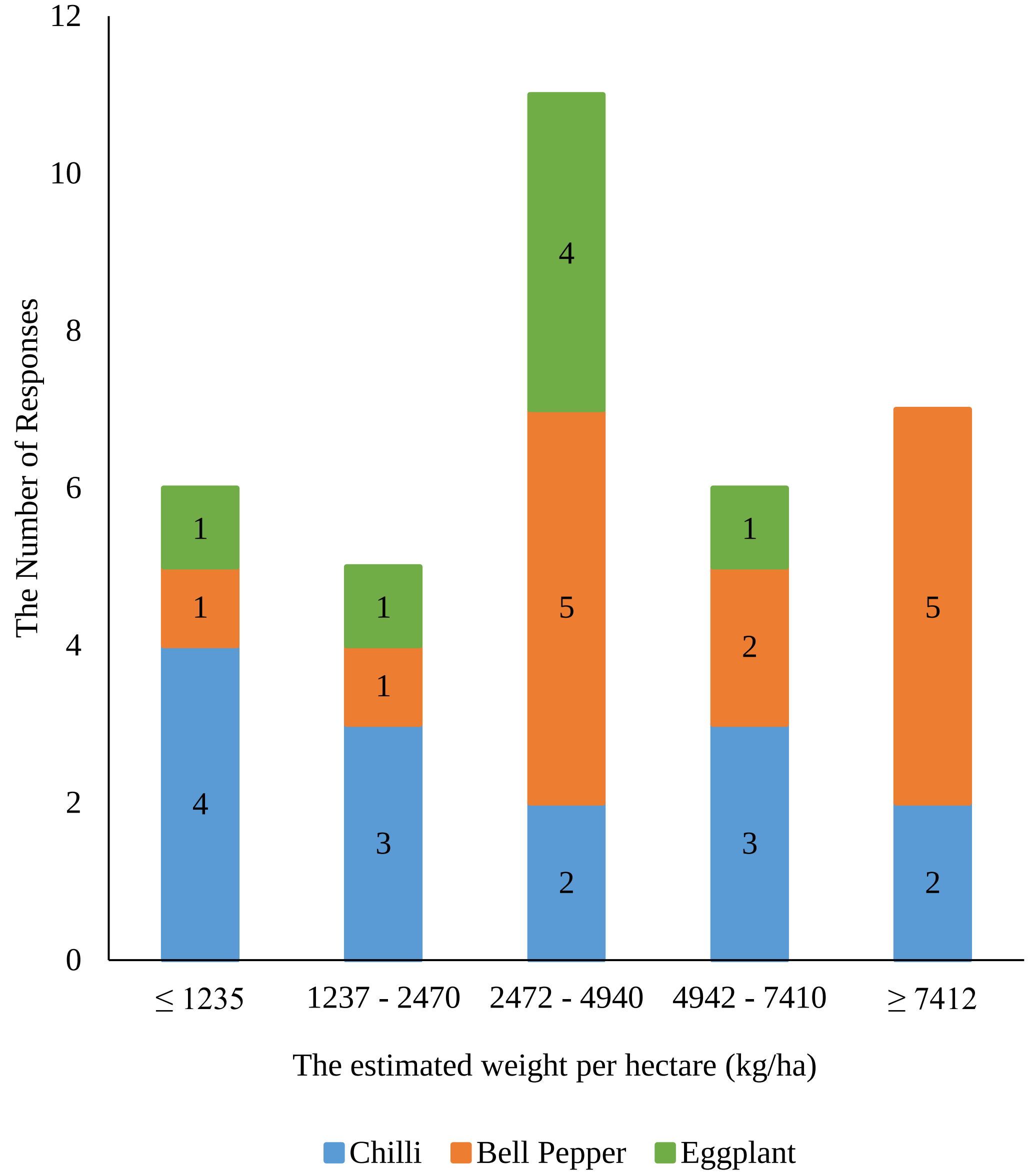

Figure 4.23: Estimated weights of chillies, bell peppers and eggplants produced by the respondents per hectare of land within the period of one month (kg/ha).

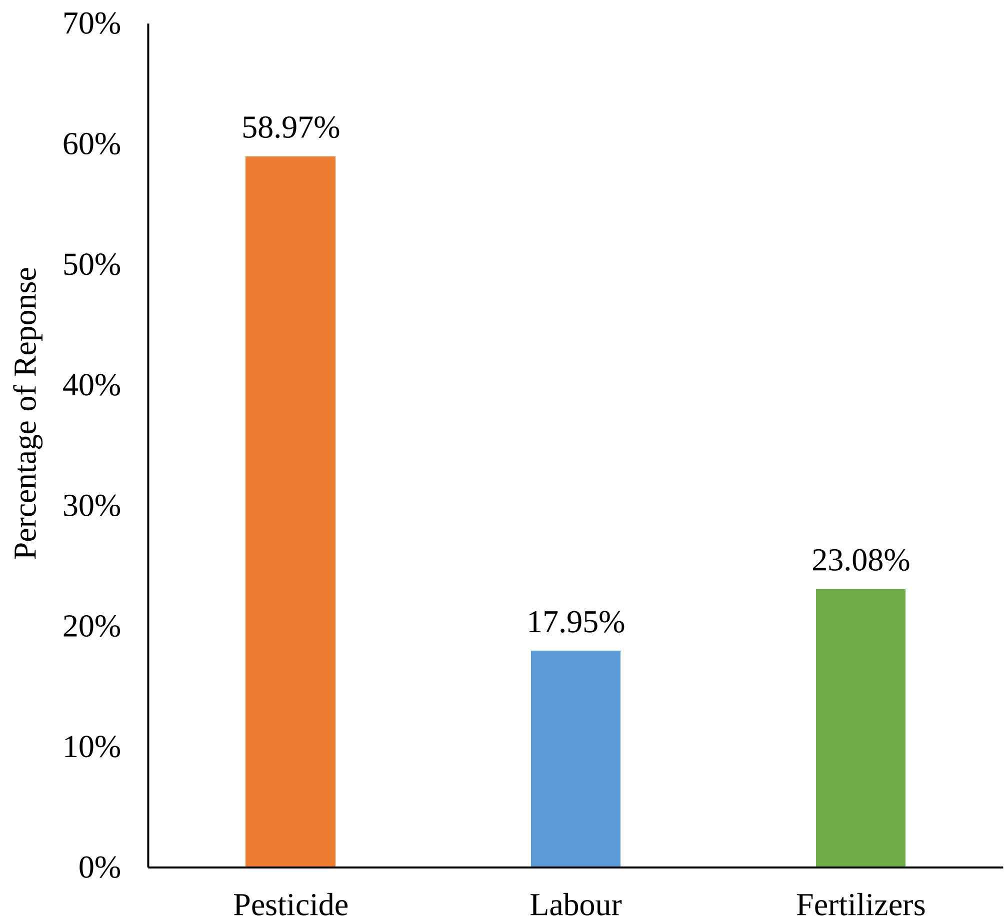

Figure 4.24: Main production costs reported by the respondents for chillies, bell peppers and eggplants in Cameron Highlands, Malaysia.

4.2 Identification of Thrips Species

The thrips samples collected from various chilli, eggplant and bell pepper farms in Cameron Highlands were identified based on the key morphological characteristics described by Mound and Ng (2009), Mound and Azidah (2009), Kirk (1996), Hoddle, Mound and Paris (2012) and Sartiami and Mound (2013). The key morphological characters used for the identification were the posteroangular seta, pronotal anterior margin setae, ctenidia, antennae structure, ocellar setae, posteromarginal comb, discal setae on the tergite IV to VI, the forewings first vein and second vein, and the metanotum structure and setae (Figure 3.2). A total of four species of thrips under the order of Terebrantia and the family of Thripidae were identified. The four species were *Thrips palmi* Karny (melon thrips), *Thrips parvispinus* Karny (Taiwanese thrips), *Frankliniella occidentalis* Pergande (western flower thrips) and *Megalurothrips usitatus* Bagnall (bean blossom thrips). A total of 311 thrips specimens were mounted on microscope slides and examined under a Motic BA210 compound microscope (Motic Asia, Hong Kong) at 400x and 1000x magnifications. *T. palmi* was found to be the most abundant among the four species, followed by *T. parvispinus*, and *F. occidentalis* (Figure 4.25). *M. usitatus* was found to be least abundant, with only one specimen collected. The identified thrips specimens were sent for identification verification at the Centre for Insect Systematics (CIS), Universiti Kebangsaan Malaysia (UKM). The verification was done by Dr. Ng Y.F..

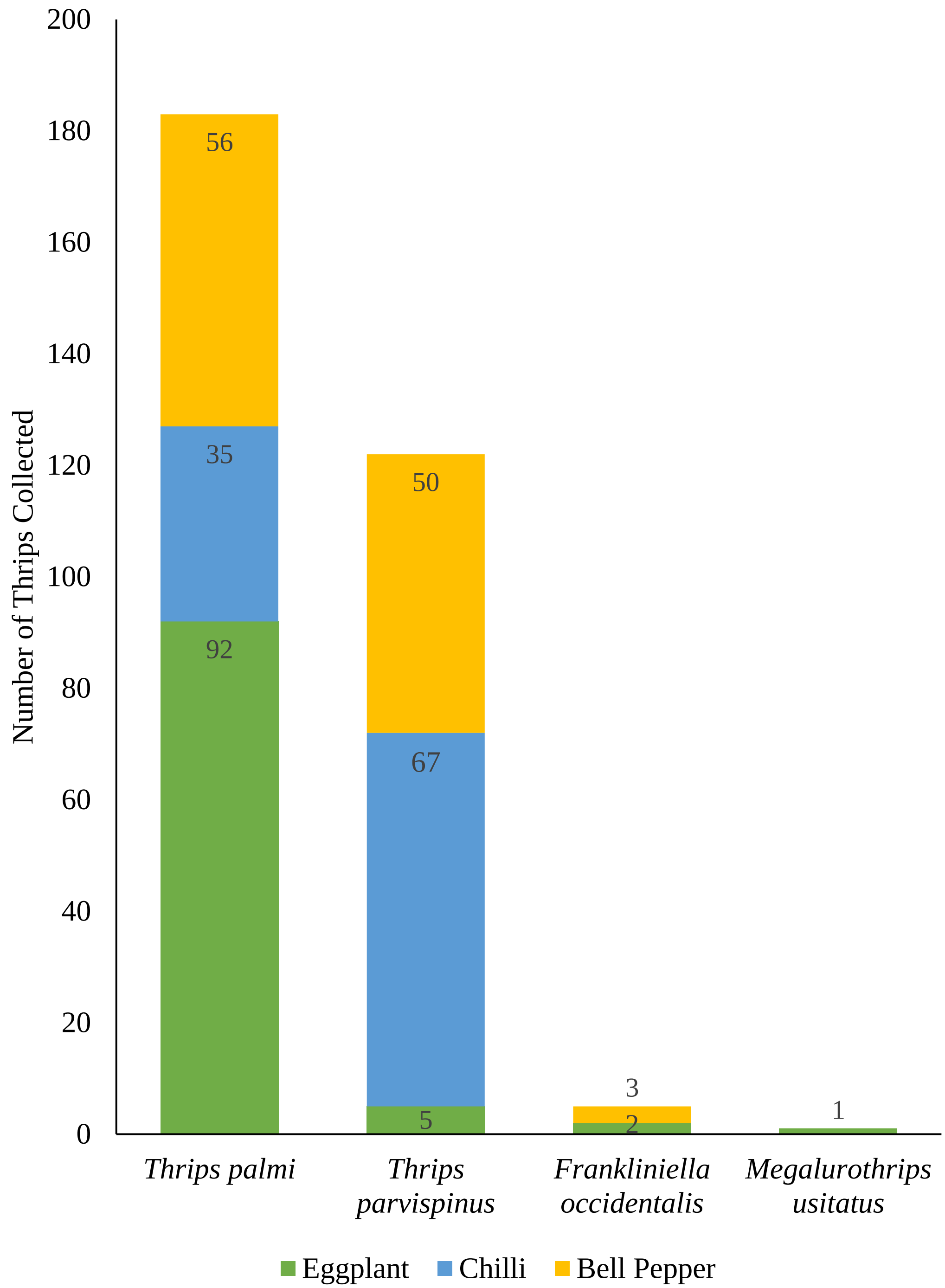

Figure 4.25 (a): Number of thrips specimens collected and sorted by the type of crops.

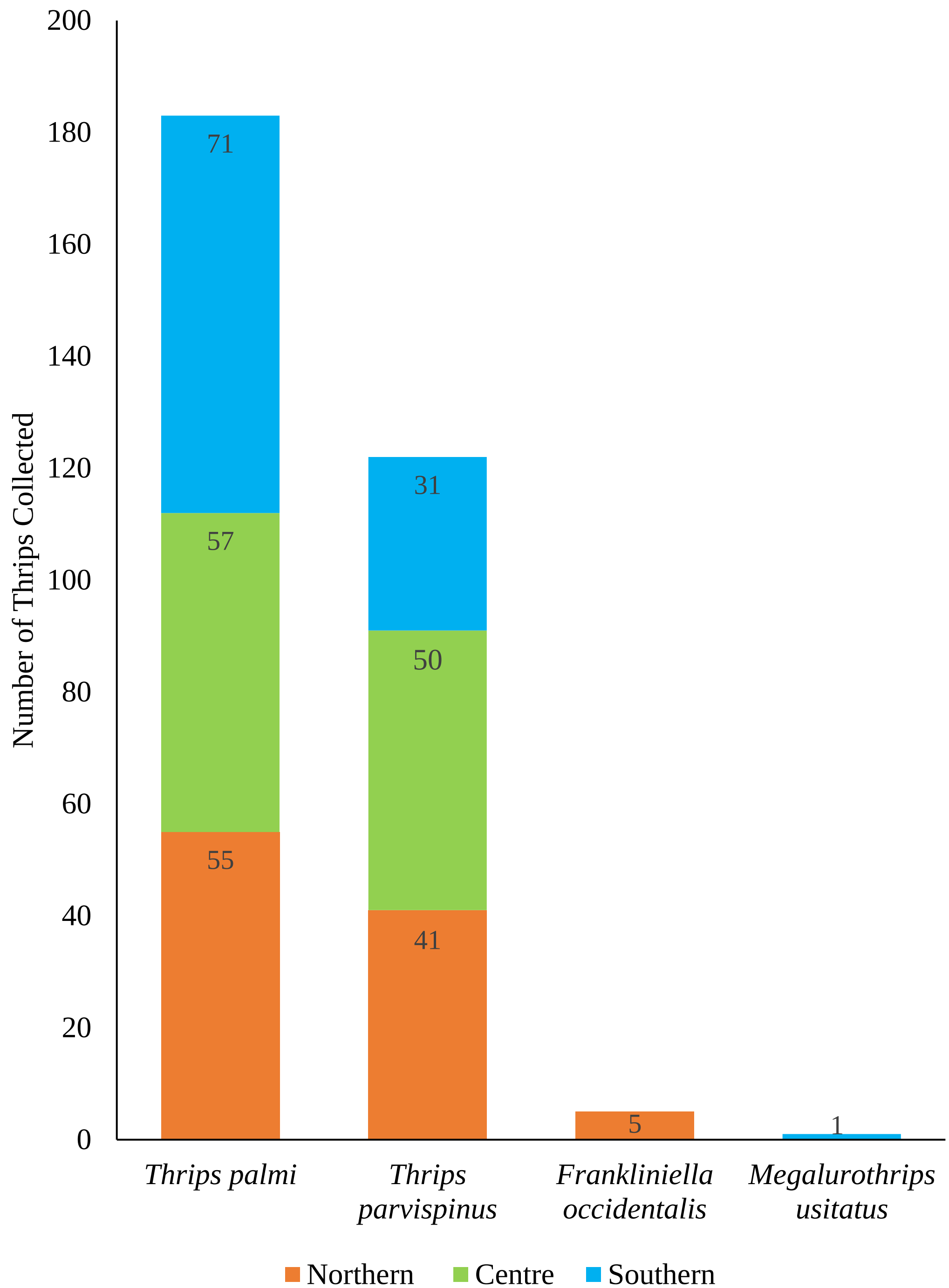

Figure 4.25 (b): Number of thrips specimens collected and sorted by the zone of collection in Cameron Highlands.

4.2.1 Identification of *Thrips palmi* Karny

According to Mound and Ng (2009) and Mound and Azidah (2009), *Thrips palmi* (Figure 4.26) has less than five major pairs of setae on the pronotum (Figure A) and the abdominal tergites near the lateral margin have a few microtrichia. The antennae are 7-segmented where the segment I is not swollen, segment II external margin is not prolonged, the segments III and IV with forked sensorium and the segment VII is short (Figure 4.27 B). The pronotum has 2 pairs of prominent posteroangular setae and the anterior margin bears no long setae (Figure 4.27 A). The abdominal tergites are without craspedum on the posterior margin and tergites V to VIII are with a pair of lateral ctenidia (Figure 4.27 C). In addition, the ctenidia on tergite VIII are posteromesad to spiracle (Figure 4.27 D). The ocellar setae pair I is absent while the pair II setae are shorter than ocellar setae III (Figure 4.28 A). The campaniform sensilla on the antennal segment II (Figure 4.27 B) and mesothoracic sternopleural sutures are present (Figure 4.28 B). The sternites IV to VI bear only posteromarginal setae and without discal setae. The posteromarginal comb on the tergite VIII is complete (Figure 4.27 D). The ocellar setae III is positioned at posterolateral to the fore ocellus (Figure 4.28 A). Metanotal sculpture lines on the metathorax converge near the posterior margin (Figure 4.28 B). The male and female *T. palmi* are both fully winged and the male is usually smaller than female in size. The female possesses an ovipositor which is long and clearly serrated (Figure 4.27 D).

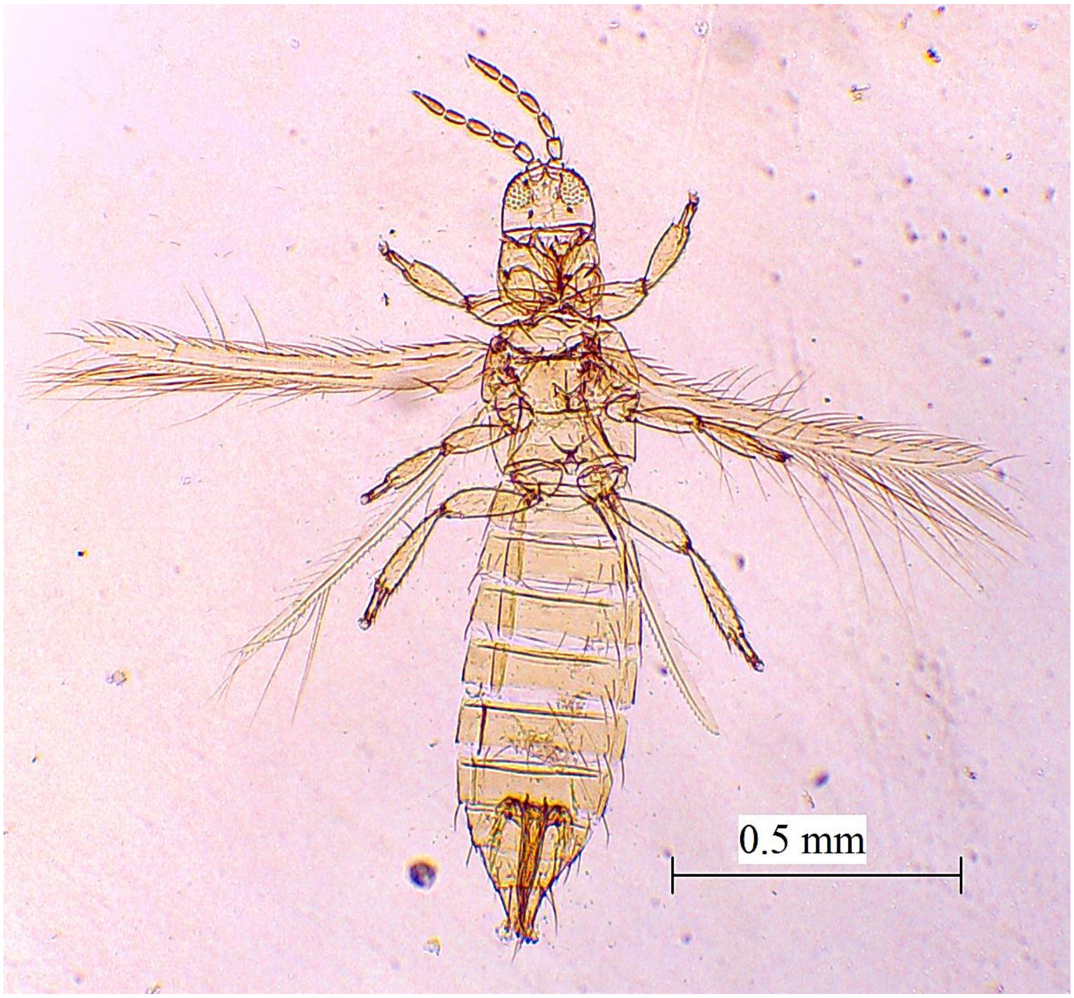

Figure 4.26: ***Thrips palmi*** **Karny under 40x magnification.**

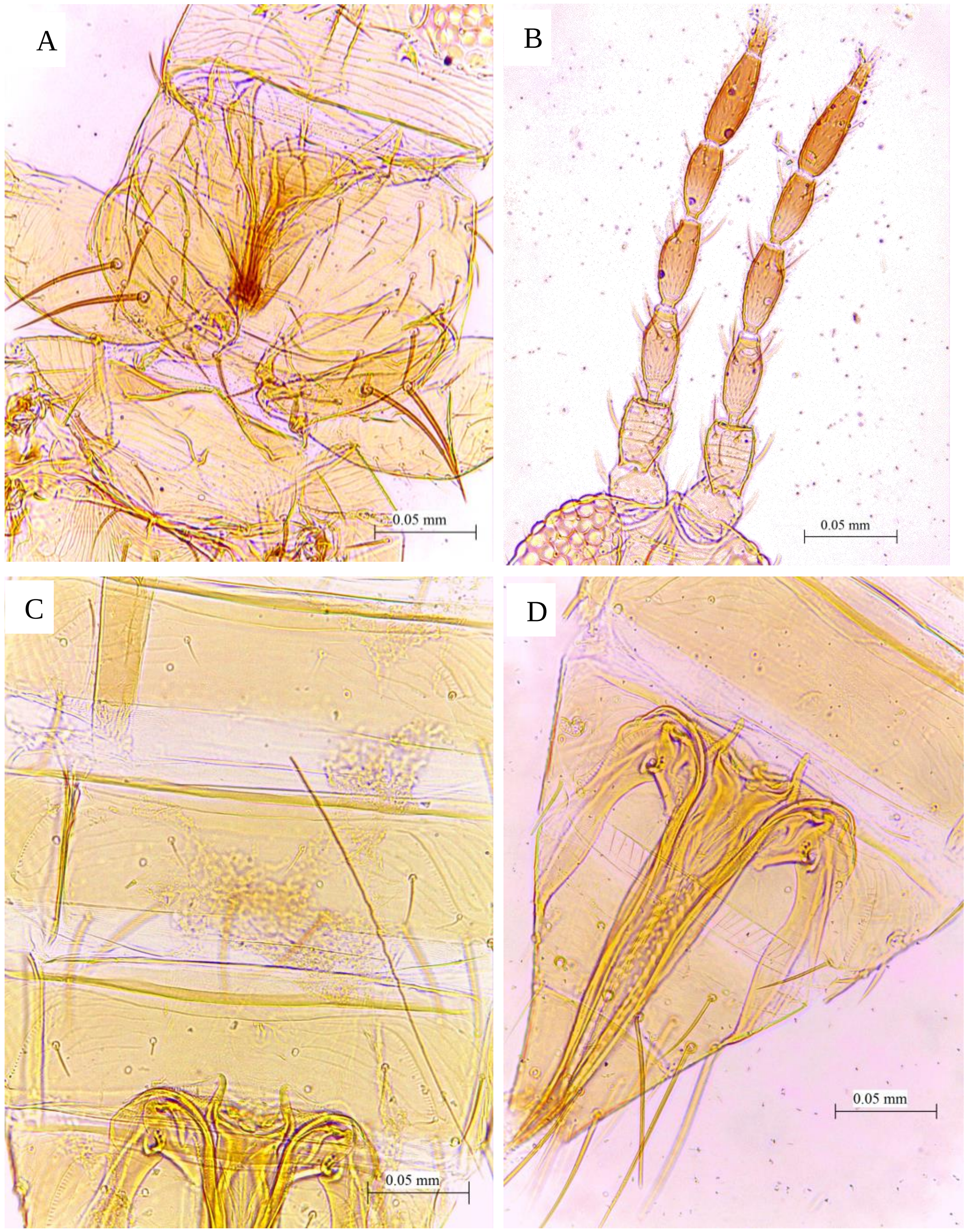

Figure 4.27: Morphological characters of *Thrips palmi* Karny under 400x magnification, (A) pronotum, (B) 7-segmented antennae structure, (C) ctenidia on tergite V-VII and (D) tergite VIII, ctenidia posteromesad and posteromarginal comb complete.

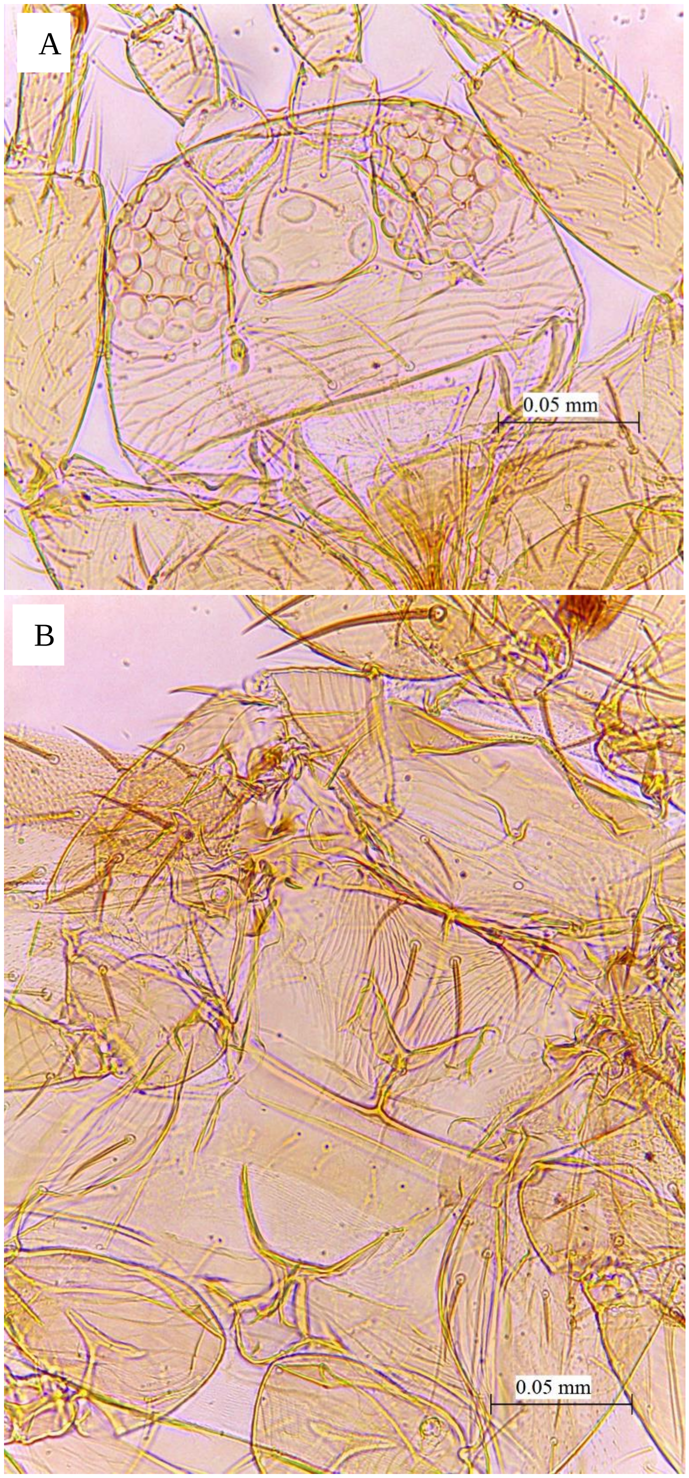

Figure 4.28: Morphological characters of *Thrips palmi* Karny under 400x magnification, (A) head structure and (B) thorax structure.

4.2.2 Identification of *Thrips parvispinus* Karny

According to Mound and Ng (2009) and Mound and Azidah (2009), the pronotum of *Thrips parvispinus* (Figure 4.29) has less than 5 major pairs of setae with 2 pairs of long posteroangular setae and no long setae on the anterior margin (Figure 4.30 A). The antennae of *T. parvispinus* is 7-segmented with forked sensorium on the segments III and IV and the segment VII is short (Figure 4.30 B). The segment I of the antennae is not swollen and the external margin of the segment II is not prolonged. The campaniform sensilla is present on the antennal segment II. Pairs of ctenidia are present on the lateral side of the tergites V to VIII and the ctenidia on tergite VIII is posteromesad (Figure 4.30 C & D). The tergite VIII is without a posteromarginal comb. Ocellar setae I is absent and the setae II is shorter than the setae III (Figure 4.31 A). Craspedum is not present on the posterior margin of the abdominal tergites (Figure 4.31 B). Both discal setae and posteromarginal setae are present on the sternites IV to VI but the sternite VII is without discal setae. The first and second veins of the forewing are with complete rows of setae (Figure 4.31 C). The forewing clavus has an apical seta which is longer than the subapical seta. The metanotal reticles have few internal markings (Figure 4.31 D). The head and thorax are paler than the abdomen and the forewing is paler at the base. The female has a long and clearly serrated ovipositor. Both sexes of *T. parvispinus* are fully winged.

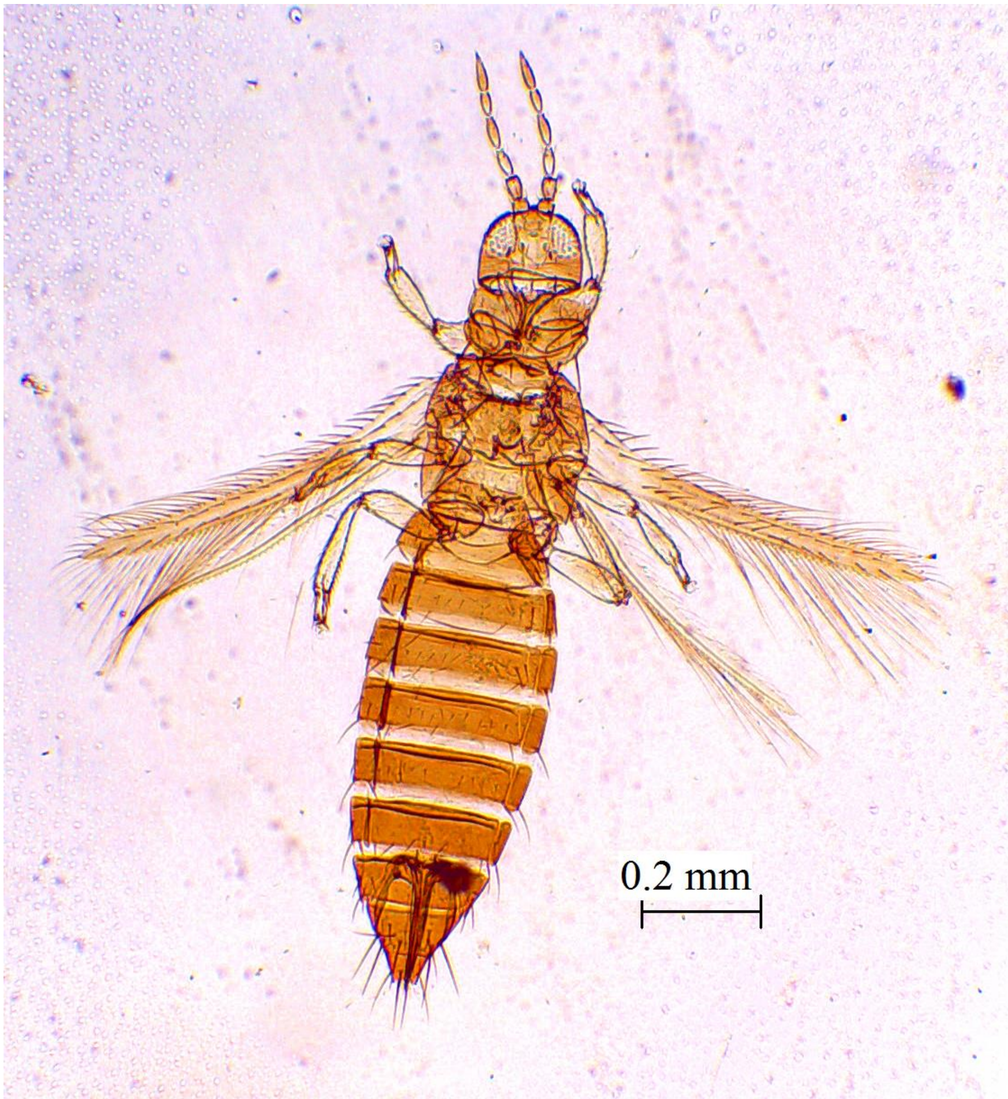

Figure 4.29: ***Thrips parvispinus*** **Karny under 40x magnification.**

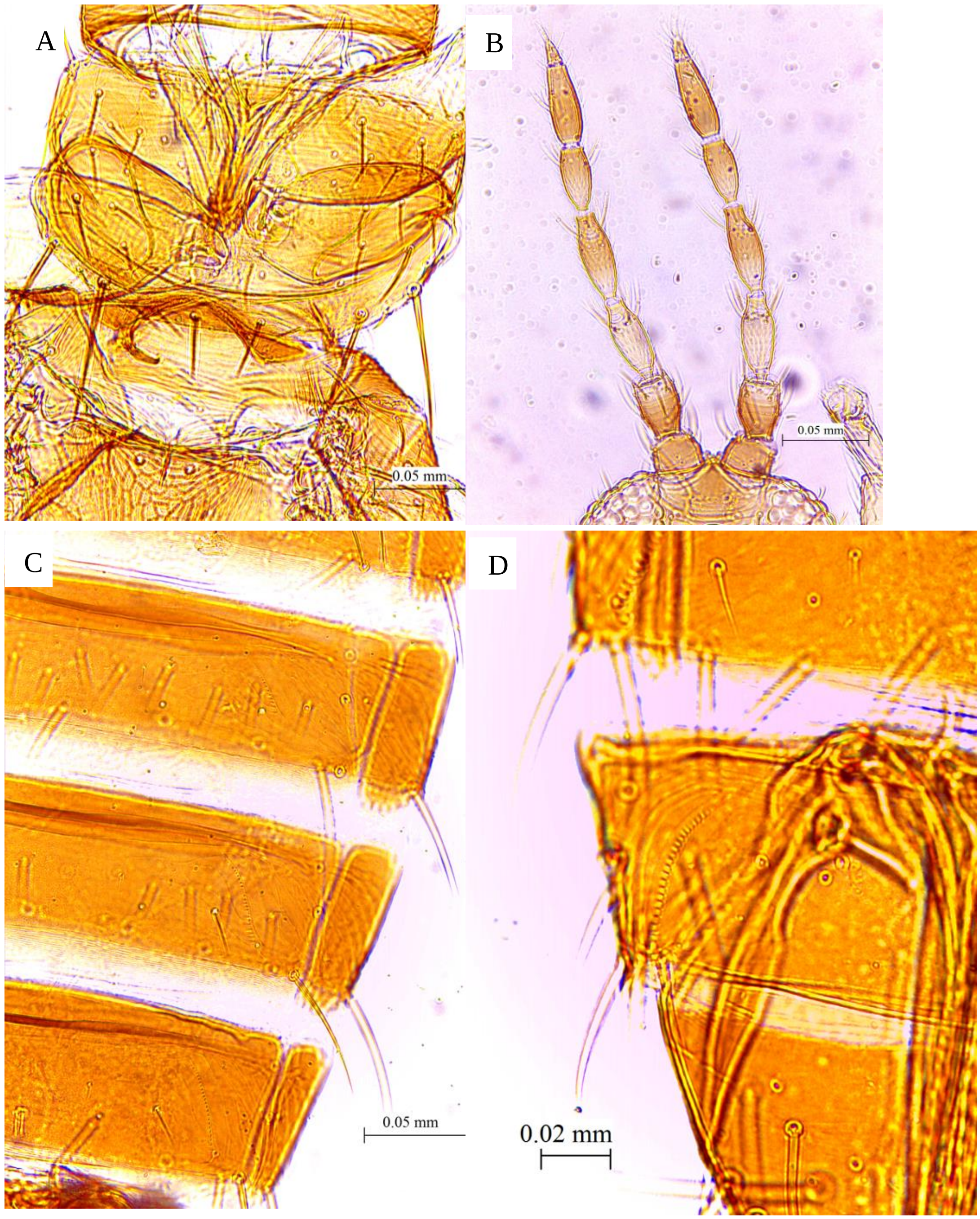

Figure 4.30: Morphological characters of *Thrips parvispinus* Karny under 400x magnification, (A) pronotum, (B) 7-segmented antennae structure, (C) ctenidia on tergite V-VII and (D) tergite VIII, ctenidia posteromesad and posteromarginal comb complete.

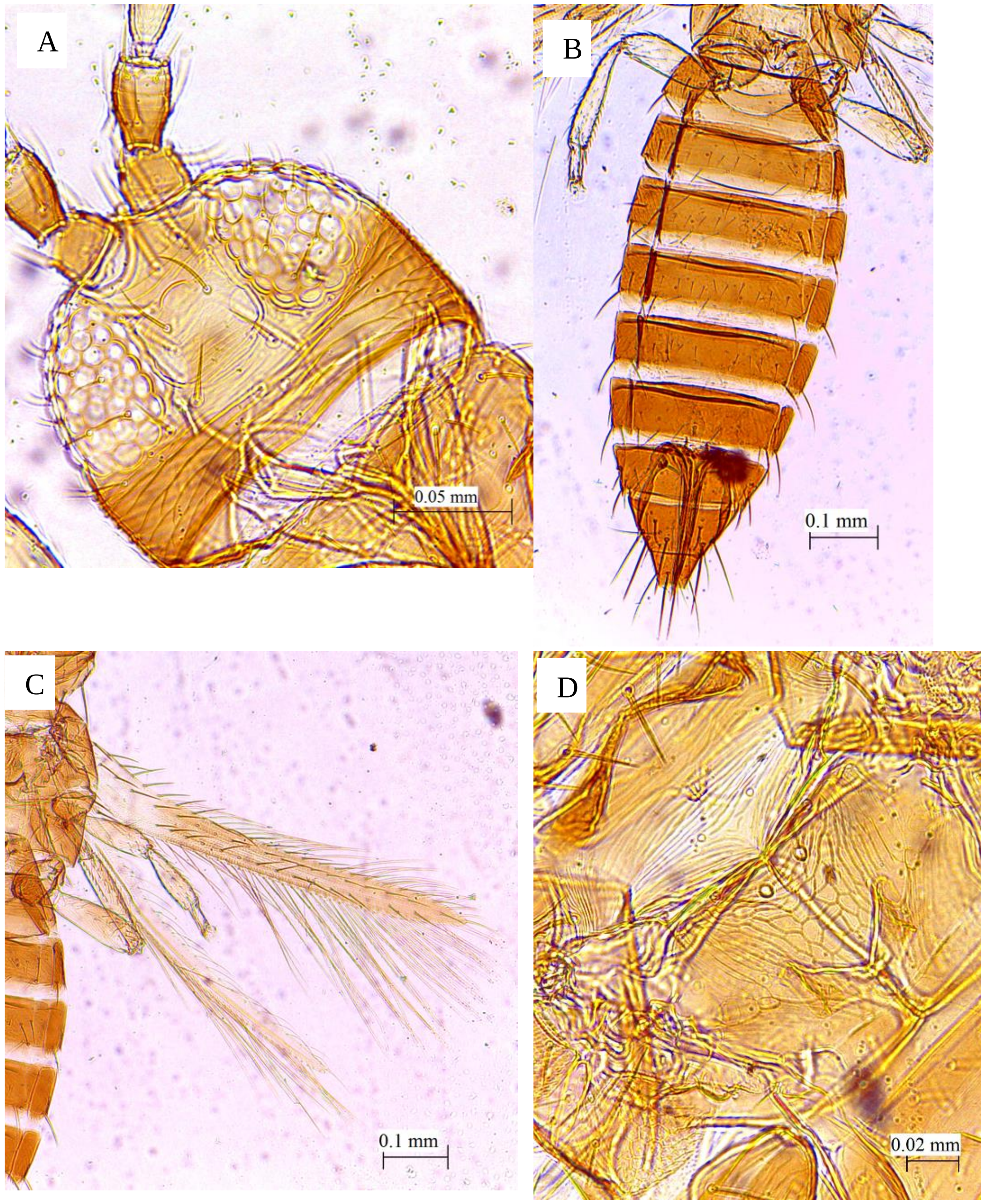

Figure 4.31: Morphological characters of *Thrips parvispinus* Karny under 400x magnification, (A) head ocelli setae, (B) abdomen, (C) wing structure and (D) metanotal structure.

4.2.3 Identification of *Frankliniella occidentalis* Pergande

According to Mound and Ng (2009) and Kirk (1996), the pronotum of *Frankliniella occidentalis* (Figure 4.32) has no more than 5 pairs of major setae and 2 pairs of prominent posteroangular setae. There is 1 pair of setae that is longer than discal setae on the anterior margin of the pronotum (Figure 4.33 A). The antennae are 8-segmented with the segment I not swollen and the external margin of the segment II not prolonged (Figure 4.33 B). The segment VIII of the antennae is neither slender nor long. The row of setae on the first and second veins of the forewings is complete (Figure 4.33 C). The abdominal tergites VI to VII has paired ctenidia which terminate close to tergal seta S3, whereas tergite VIII is with a pair of ctenidia in front of the spiracles (Figure 4.33 D). The metanotum has a pair of middle setae that is more than two-thirds the length of the metanotum (Figure 4.34 A). In addition, there is a pair of small and rounded sense organs on the metanotum. The longest setae are behind the compound eyes where they are at least half of the length of the setae within the three ocelli (Figure 4.34 B). Both sexes of *F. occidentalis* are winged and the male is usually smaller than the female.

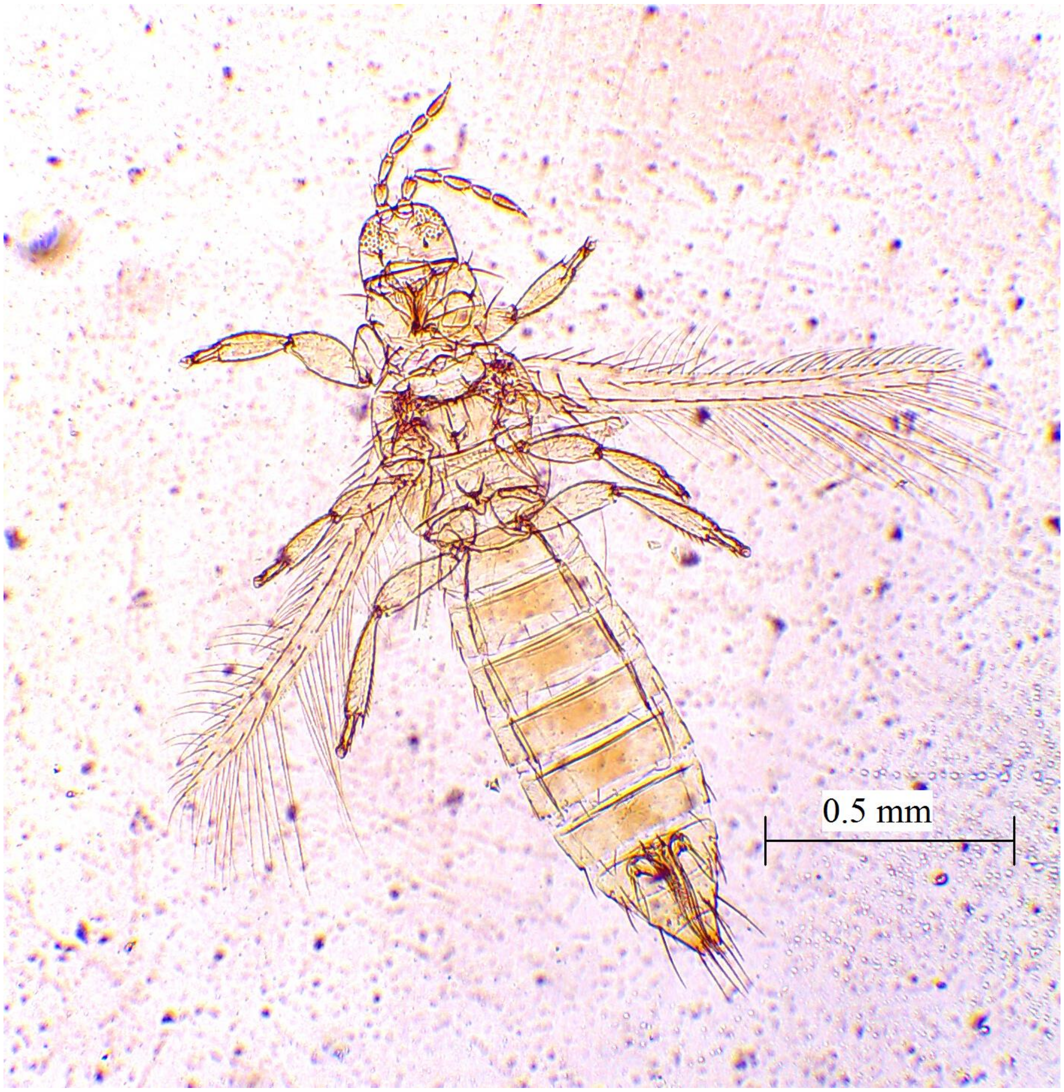

Figure 4.32: ***Frankliniella occidentalis*** **Pergande under 40x magnification.**

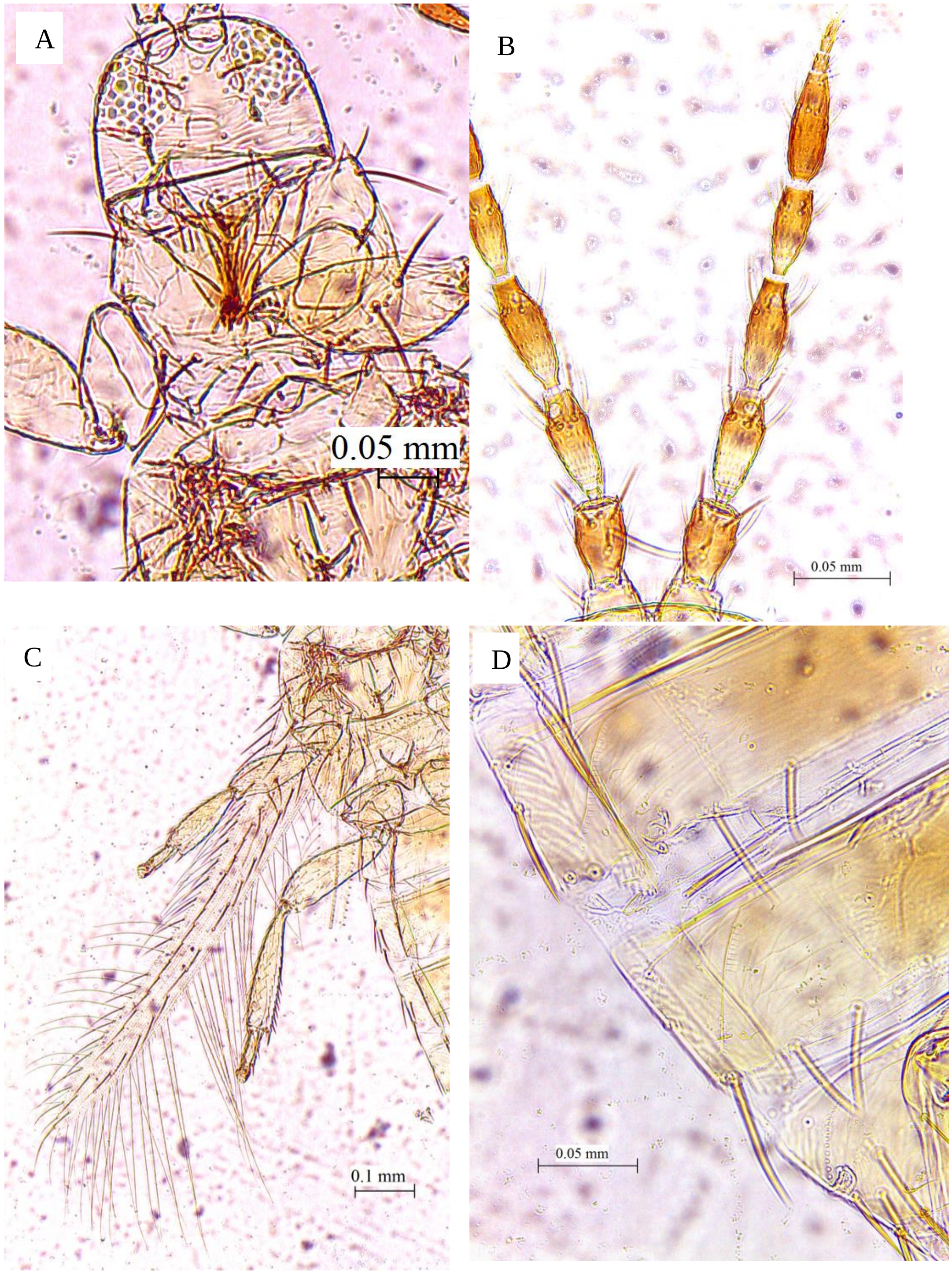

Figure 4.33: Morphological characters of *Frankliniella occidentalis* Pergande, (A) pronotum under 100x magnification, (B) antennae under 400x magnification, (C) wing structure under 400x magnification and (D) ctenidia under 400x magnification.

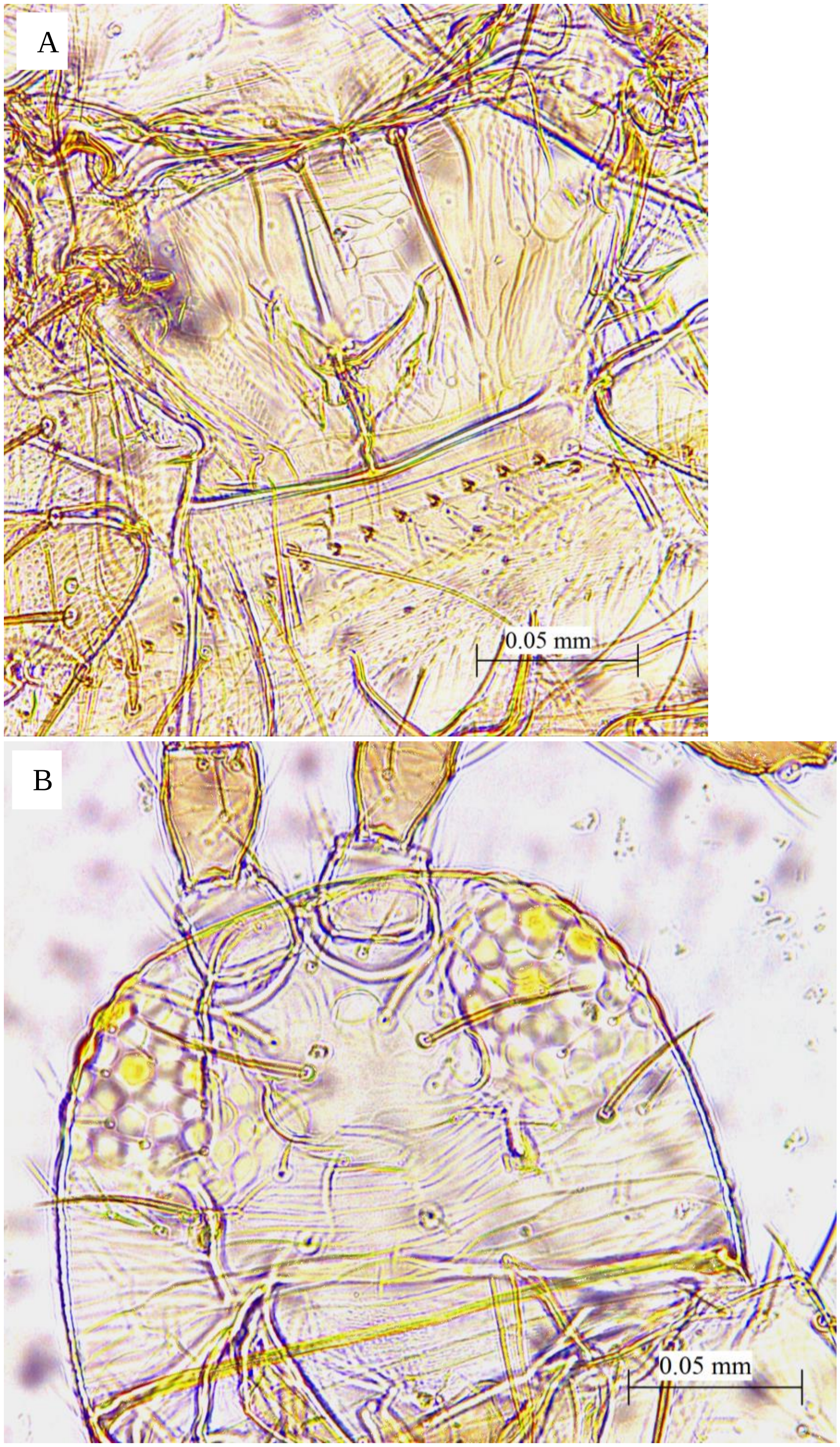

Figure 4.34: Morphological characters of *Frankliniella occidentalis* Pergande under 400x magnification, (A) metanotum and (B) head and ocelli setae.

4.2.4 Identification of *Megalurothrips usitatus* Bagnall

According to Sartiami and Mound (2013), the *Megalurothrips usitatus* (Figure 4.35) has 8-segmented antennae with forked sensoria on segments III and IV (Figure 4.36 A). In addition, the antennal segment III is yellow in colour. The forewings are with cilia on the anterior margin and the setae are not capitate. The first vein on the forewing is distinct from costa vein and both veins on the forewing are with setae (Figure 4.36 B). The reticulation on the head and thorax are usually without any internal markings (Figure 4.37 A). The pronotum is with 2 pairs of prominent posteroangular setae and no long setae on the anterior margin. The ctenidia on the abdominal tergite is absent. The posteromarginal comb on the tergite VIII is present but only laterally (Figure 4.37 C). The ocellar setae III is longer compared to the distance between two ocelli (Figure 4.37 B). Both male and female *M. usitatus* are fully winged but the male is usually smaller and paler than the female.

Figure 4.35: ***Megalurothirps usitatus*** **Bagnall under 40x magnification.**

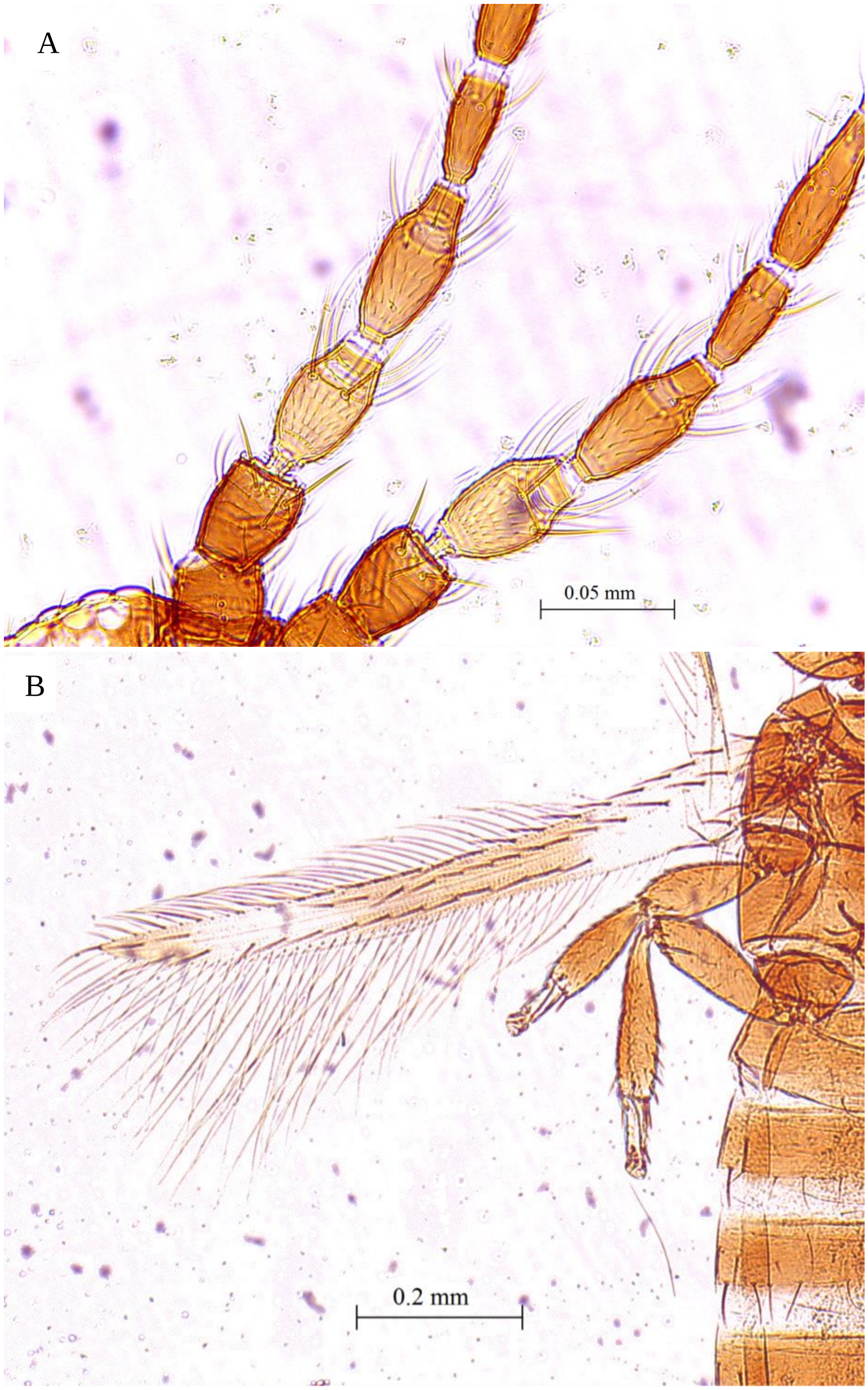

Figure 4.36: Morphological characters of *Megalurothrips usitatus* Bagnall, (A) antennae segments I to V and forked sensoria under 400x magnification, (B) forewing under 100x magnification.

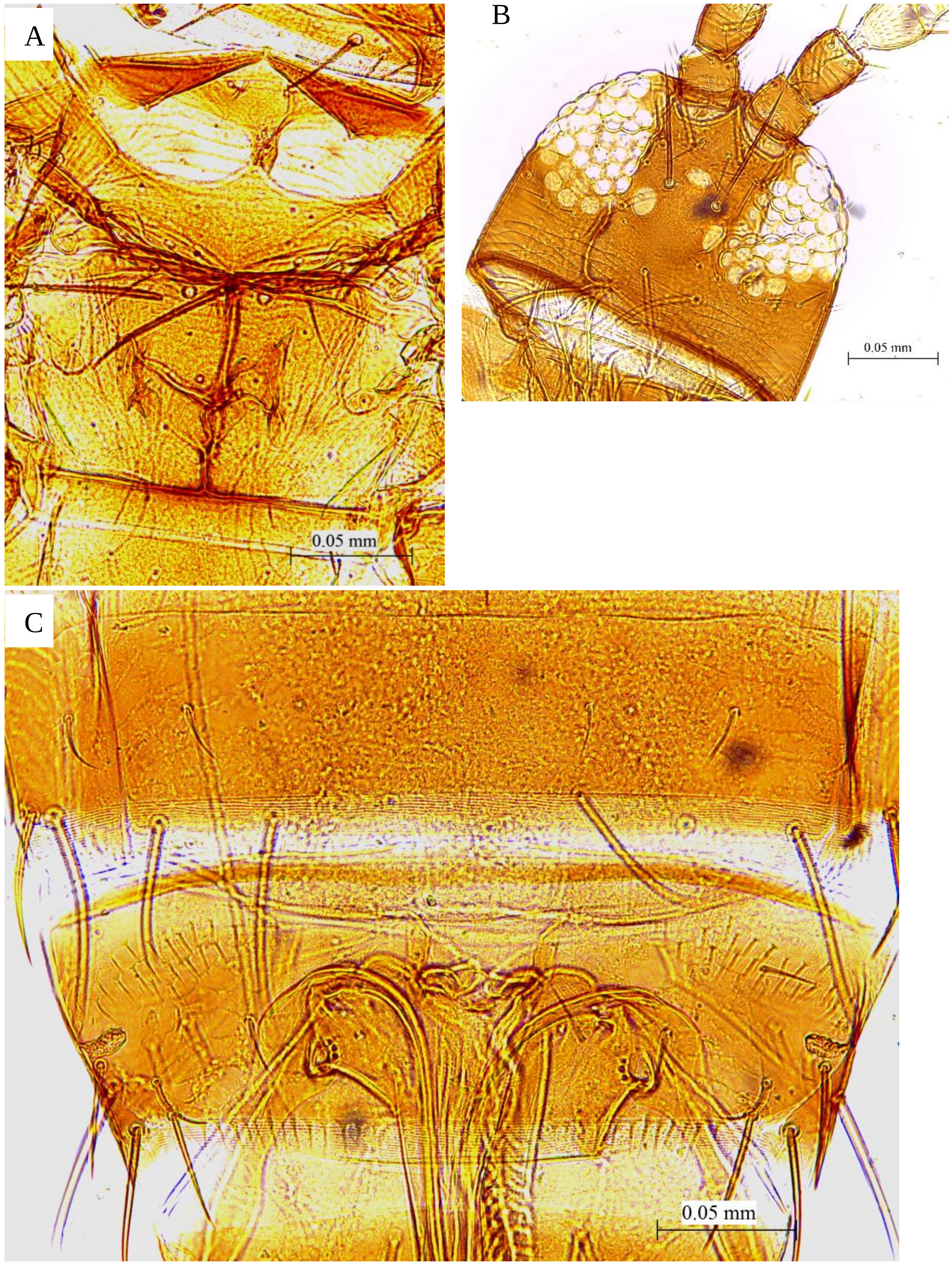

Figure 4.37: Morphological characters of *Megalurothrips usitatus* Bagnall under 400x magnification (A) metanotum, (B) head and (C) tergite VIII.

4.3 Damage Caused by Thrips

The sampled thrips were found in the flowers of eggplants, bell peppers and chillies. The feeding damages caused by these thrips were visible on the fruits as scars (Figure 4.38). In farms with poor control of thrips, damages were also observed on the leaves.

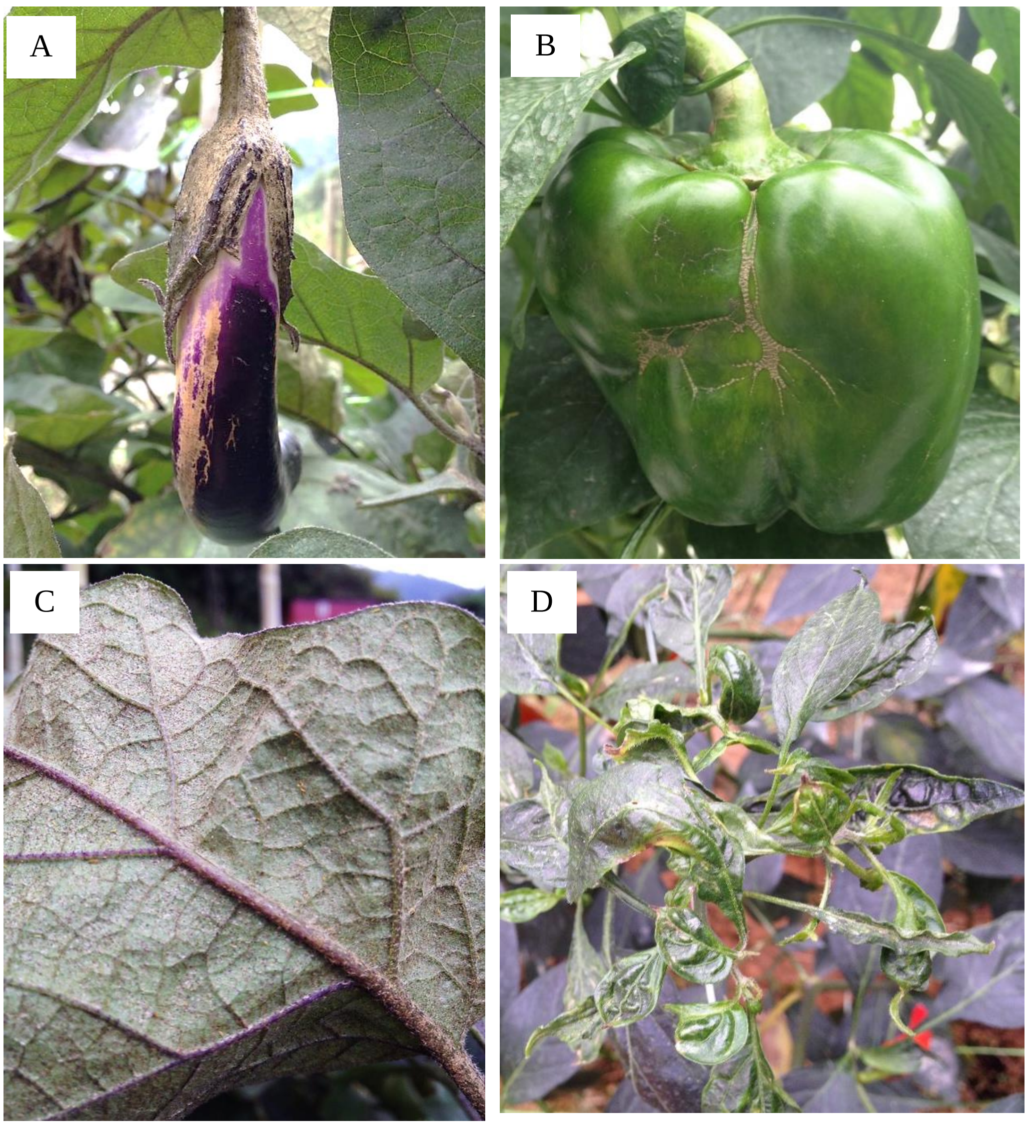

Figure 4.38: Damages caused by thrips on: (A) eggplant fruit; (B) bell pepper fruit; (C) eggplant leaf; and (D) chilli plant (with symptom of viral infection).

4.4 Probit Analysis and Resistance Ratio

The insecticide resistance level of the *Thrips palmi* was analysed using Probit function in Statistical Analysis System (SAS) Entreprise Guide 7.11. The tested populations were collected from farms that practise conventional farming methods, such as, calendar spraying of chemical insecticides. The susceptible populations were collected from farms that practise organic farming methods, which did not apply any chemical pesticides on their crops. Unfortunately, only one organic farm that planted chillies and eggplants was found in Blue Valley, Cameron Highlands. Therefore, all the susceptible populations of *T. palmi* was collected from the same organic farm. *T. palmi* was selected as the species for the insecticide resistance test because it was the most abundant species among the samples collected and it was uniformly present in all three crop species as well as the three sampling zones (Figure 4.26a; Figure 4.26b). Commercially formulated spinetoram (Endure® 58.7g/l SC) was used in this test because, according to the result of the survey (Figure 4.19), this was the most commonly used insecticide to control thrips by farmers.

The results of the leaf-dip bioassay for the tested and the susceptible populations of *T. palmi* are shown in Table 4.4 and 4.5, respectively.

Table 4.4: Mortality of the tested population of *Thrips palmi*, following treatment with different concentrations of commercially formulated spinetoram.

Concentration (mg/L)	Total number of thrips	Mortality
58.700000	60	58
11.740000	60	58
2.3480000	62	49
0.4696000	60	46
0.0939200	60	39
0.0187800	60	36
0.0037570	60	22
0.0007514	60	16
0.0000000	60	12

Table 4.5: Mortality of the susceptible population of *Thrips palmi*, following treatment with different concentrations of commercially formulated spinetoram.

Concentration (mg/L)	Total number of thrips	Mortality
58.700000	62	61
11.740000	60	58
2.3480000	60	54
0.4696000	60	50
0.0939200	63	51
0.0187800	60	37
0.0037570	61	36
0.0007514	60	29
0.0000000	65	25

The result from the leaf-dip bioassay was analysed by using the probit function in the Statistical Analysis System (SAS) Enterprise guide 7.11. The goodness-of-fit of the probit model was assessed by using Pearson's chi-square and likelihood ratio chi-square, where p-values lower than 0.1000 indicate lack of fit and higher than 0.1000 indicate adequate fit ($P < 0.1000$, lack of fit and $P > 0.1000$, adequate fit). The p-values for the goodness-of-fit test for both the tested and the susceptible populations indicate an adequate fit for the probit model (Table 4.6 and Table 4.7).

Table 4.6: Goodness-of-fit test for the tested *Thrips palmi* population.

	Degrees of Freedom	p-value
Pearson Chi-Square	6	0.3664
Likelihood Ratio Chi-Square	6	0.3668

Significance level: $P \leq 0.1000$, $P > 0.1000$

Table 4.7: Goodness-of-fit test for the susceptible *Thrips palmi* population.

	Degrees of Freedom	p-value
Pearson Chi-Square	6	0.9271
Likelihood Ratio Chi-Square	6	0.9247

Significance level: $P \leq 0.1000$, $P > 0.1000$

Table 4.8: Lethal dosage at 50% (LD_{50}) mortality and the resistance ratio of *Thrips palmi* against commercially formulated spinetoram in Cameron Highlands.

	Population of *Thrips palmi*	
	Tested	**Susceptible**
LD_{50} (mg/L)	0.05210	0.03083
95% Fiducial limit	0.01674 – 0.12577	0.00496 – 0.10319
Resistance Ratio	1.69	

With the goodness-of-fit test being insignificant for both the tested and susceptible populations, the lethal dosage at 50% mortaility (LD_{50}) for both populations were determined. The lethal dosages at 50% mortality (LD_{50}) for the tested and susceptible *T. palmi* populations were 0.05120 and 0.03083 mg/L, respectively (Table 4.8). The resistance ratio of the *T. palmi* populations against the insecticide spinetoram was found to be 1.69 (Table 4.8).

CHAPTER FIVE

DISCUSSION

5.1 Demographic Information of the Solanaceae Growers

Cameron Highlands was divided into three zones for the survey based on the difference in altitude between the areas, where the central zone is the highest (averaging 1400m – 1500 m above sea level) and the northern and southern zones are approximately 300 to 500 m less than the altitude of the central zone (Syed et al., 1997). The bias in the data collection through the survey was reduced by taking the zones into consideration, where 10 farmers from each zone were randomly selected to avoid unintentional bias. Demographic information such as gender, age group and level of education, were collected in order to inform readers about the composition of the respondents in the survey and that it represented the selected population involved in the research (Connelly, 2013).

According to Table 4.1, 96.67% of the farmers were males, and 53.33% of the respondents were more than 50 years old. The lack of female respondents in this survey might be due to the lower number of female farmers (3 males: 1 female) in Cameron Highlands (Kunasekaran et al., 2011). In addition, males still dominate the Malaysian agricultural sector (Shaffril, Hassan and Samah, 2009), thus, having a higher number of males in this survey is common in Malaysia. Besides gender, more than half of the respondents are above 50 years old, which concurred with the findings of Shaffril, Hassan and Samah (2009). The latter noted that the average age of the Malaysian farmers was 45.4 years old. Twenty percent of the respondents were between 41 to 50 years old, 16.67% were aged between 31 to 40 years old and only 10% were less than 30 years old. The shortage of young farmers was most probably caused by youths migrating from rural areas to the cities as they are attracted by jobs in factories and commercial sectors (Abdullah and Samah, 2013). The younger generation perceive that their involvement in the agricultural sectors has no promising future and it is a tough job with lower salaries as compared to other sectors. Three major factors, i.e., attitude, acceptance and knowledge, were identified to be the factors that influence the involvement of youths in agriculture (Abdullah, 2013). Besides these factors, the support from family, government and related agencies and authorities are also important in youth involvement in agricultural sectors (Uli et al., 2010; Abdullah, 2013).

Most of the farmers surveyed possessed only secondary education (46.67% of the total respondents), 30% of them had no education or primary education and 23.33% had tertiary education and above (Table 4.1). These findings parallel those of Shaffril, Hassan and Samah (2009), where most of the farmers were found to have Sijil Pelajaran Malaysia (SPM) certificate (Malaysia Education Certification, completion of secondary education), followed by primary education and lastly tertiary education. This is most probably due to tertiary-educated graduates staying away from agricultural sectors because of the traditional thinking that agriculture is a tough job with low salaries and no prospects (Abdullah, 2013). Table 4.1 shows that 60% of the respondents had less than 20 years of experience in farming even though more than half of the farmers were above 50 years old, followed by 33.33% of respondents having 21 to 40 years of experience and lastly 6.67% of respondents had farmed for more than 41 years. This indicates that some of the farmers above 50 years old, most probably did not farm at the start of their careers but ventured into farming only later in life. Thus, this shows the importance of the agriculture sector in Malaysia. The agriculture sector is approximately 11% of Malaysia's gross domestic product (GDP) (Rahman, 2012).

Most of the respondents (96.67%) owned less than 4.05 hectares of farm land and, only 3.33% of respondents owned more than 4.06 hectares (Table 4.1). Furthermore, 66.67% of the respondents' farm lands were under the Temporary Occupational License (TOL) issued by government, followed by leasehold land from private land owners (30%) and, lastly, government-linked land titles (3.33%). The average land size of farmers in Cameron Highlands was approximately 0.81 hectares and 67% of the farmed lands in Cameron Highlands are under Temporary Occupational License (TOL), where a fee will be charged annually by the government to the land holder, i.e. the farmers (Midmore et al., 1996; Shirasaka, 1988; Lim, 1972). Table 4.1 shows that 66.67% of the respondents did not attend any agricultural-based training, followed by 30% and 3.33% who had attended seminars or talks and hands-on workshops, respectively. Fifty percent of the seminars or talks were organised by agro-chemical companies, such as, Bayer, Syngenta and Advansia, followed by local government agencies, e.g., MARDI and Department of Agriculture Cameron Highlands, and lastly non-governmental agencies like Pesticide Action Network (PAN) and CropLife. The high number of respondents who did not attend any agriculture-based training might be due to their education level, where 76.67% of the farmers had only up to secondary school qualification. Although 50% of the talks and seminars were organised by the agro-chemical companies, similar information was easily available to the farmers through licensed agro-chemical dealers in Cameron Highlands.

Approximately 36.96% of the respondents obtained new agriculture-related information from local licensed pesticide dealers, followed by friends who were also farming (30.43%) and others sources (19.57%), such as, non-governmental agencies, local agriculture experts, foreign and local agriculture consultants. Only 2.17% of the respondents used mass media, such as, internet to acquire useful information. This was most likely due to the high number of respondents having an education level of secondary and below. The findings of Shaffril, Hassan and Samah (2009) supported the above findings, that those who had education levels of secondary and below were less internet savvy than those with higher levels of education. Besides that, the older age group was found to surf the internet less than the younger generation.

5.1.1 Farming Practices of the Solanaceae Growers

According to Figure 4.1, 74.19% of the respondents carried out planting using conventional methods for land preparation, which is ploughing soil land with a motorized handheld walking tractor. However, 25.81% of the respondents had adopted a new planting technique, that is fertigation. Fertigation is a modern agriculture technique where fertilisers are supplied together with irrigation water (Kafkafi and Tarchitzky, 2011). Fertigation system is an alternative method for farmers, especially, chilli and tomato, to increase production while reducing the chance infection by soil borne diseases, such as *Pythium* (Yaseer Suhaimi et al., 2012). Besides the benefit of reducing soil-borne diseases, Chow (2016, personal communication) reported that cementing the floor of the fertigation system helped to reduce the population of thrips in the farm. This is most probably due to the disruption of the thrips life cycle because thrips species found on eggplant, chilli and bell pepper needs to pupate in the soils (Kawai, 1990). Therefore, if the ground is cemented for the fertigation system, it will interfere with the pupation of thrips and indirectly kill them. In addition to pest reduction, the yield of chilli cultivation using the fertigation system was higher (27 mt/ha) as compared to conventional methods (18 mt/ha) (Yaseer Suhaimi et al., 2012). Despite these benefits, most of the respondents were still using the conventional method due to the high investment involved in setting up fertigation systems. According to Islam et al. (2012), the cost of setting up a fertigation system was high, for instance, a fertigation system with cemented paved floor costs approximately MYR 160,000 per acre and a system with plastic-covered floor costs approximately MYR 90,000 per acre. Most of the small-scale farmers might have stayed away from this technology due to the large initial investment involved.

Almost all the farmers surveyed (93.33%) obtained their planting seeds from local agriculture shops while 6.67% of the total respondents acquired their seeds from private agriculture consultants (Figure 4.2). Approximately 95% of Malaysian vegetable seeds are imported from overseas whilst local production is only about 13 tonnes per year. These imported seeds are usually sold by various seed companies in Malaysia, such as Leckat Corporation S/B and Sin Seng Huat Seed S/B, that import them from major seed producing companies in China, Taiwan, Japan and Netherlands (Mahmood, 2006). These imported improved quality seeds are hybrid seeds that can only be used for a single generation. Seeds collected from hybrid plants will either exhibit huge variations in plant features, such as uniformity, maturity and characteristics in the next generation or cannot be germinated (sterile) (Sukprakarn, Juntakool and Huang, 2005). Therefore, all respondents purchased their seeds from their respective sources during every planting cycle instead of practicing seed saving.

The respondents used various type of fertilisers and all of them were using more than one type of fertiliser. Figure 4.3 shows the types of fertilisers used by the farmers. Most of the respondents (27.63%) preferred to use processed chicken manure during their planting, followed by the newly introduced foliar fertilisers (22.37%) and chemical granular fertilisers (NPK: 15-15-15 or 12-12-17) (21.05%). Approximately 10.5% of the respondents used water-soluble fertilisers, which were specially designed for fertigation systems. Their usage was the lowest as compared to other fertilisers. The high usage of chicken manure was also noted by Abdullah, Aminuddin and Ghulam (2001), where high nitrogen and potassium were lost through surface runoff due to high input of chicken dung in farmlands. Besides that, the high usage of chicken manure by vegetable farmers in Cameron Highlands, Malaysia was also reported by Lim (1972), where about 2.96 to 7.41 metric tons per hectare per crop of chicken manure were used.

The high usage of chicken manure was probably due to its low cost, high calcium content, and the reduction of unpleasant odours of processed chicken manure (Zakaria, 2006). Calcium is an important nutrient for fruiting vegetables, such as, eggplant, chilli and bell pepper, since it is required for several biochemical processes. Without calcium, the vegetables may undergo severe reduction of fruit formation and stunting (Favaro et al., 2007). Chemical granular fertilisers were reported to be about 5 to 10% of the total amount of chicken manure used (Lim, 1972). The usage of chemical fertilisers is proportional to the crop growing areas in Malaysia (Zakaria, 2006). Foliar fertilisers have been used for about 40 years on many crops but they have become popular due to recent findings that their applications may improve quality and yields (Akanbi et al., 2007). Chaurasia, Singh and Rai (2005) noted that increase in the frequency of foliar spraying resulted in better yields due to higher availability of nutrients. Therefore, many farmers have adopted the use of foliar fertilisers because they are able to increase crop yields and profits.

Most of the farmers surveyed (54.84%) chose fertilisers based on the recommendation of local agriculture shops, followed by their previous experience of using the fertilisers (25.81%) and the performance of the fertilisers, i.e., yield and quality of the crops (16.13%) (Figure 4.4). Price and availability were least considered when choosing fertilisers (3.23%). According to Azman et al. (2013) and Terano et al. (2015), the knowledge and attitude of the farmers had a positive effect towards their behaviour and adoption of farming practices. However, farmers may have insufficient knowledge and training due to the lack of extension services provided by the relevant authorities (Tiraieyari, Hamzah and Samah, 2014). Thus, farmers have to consult local agriculture shops which are always available. Furthermore, farmers are supported by the government in the form of fertiliser subsidies to increase their crop production (Tiraieyari, Hamzah and Samah, 2014). This has caused the farmers to rely on the recommendations by local agriculture shops on fertiliser products which will increase their production regardless of environmental side effects.

Herbicides were used by 67% of the respondents in their farmlands especially when clearing previous vegetation prior to a new planting cycle (Figure

4.5). Paraquat dichloride and glufosinate-ammonium were reportedly used by 91.90 % of the farmers surveyed (Figure 4.6). Many farmers assume that chemical herbicides are more effective and suitable in controlling weeds than other alternative methods (Assis and Mohd Ismail, 2011). This is the major reason for the heavy usage of herbicides to clear any unwanted vegetation. However, dependency on herbicides, such as glufosinate-ammonium, is not a sustainable method because persistent weeds such as goosegrass will eventually build up resistance against the chemical (Jalaludin et al., 2010). It was suggested by Azman et al. (2013) that farmers are willing to change their farming practices, e.g., the use of agro-chemicals to control weeds, if they are able to develop positive attitudes towards environmental conservation. The extension service provided by well-trained extension agents play an important role in providing accurate information and knowledge to farmers through suitable channels, such as workshops, special courses and seminars. Continuous effort in providing support through extension services may result in less dependency of farmers towards the use of agro-chemicals and the recommendations by the local agriculture shops that might not provide accurate and up-to-date information.

The main reason for the farmers to plant eggplant, bell pepper or chilli was good market demand (47.06%), followed by their previous experience with the crops (20.59%) and also the amount of workload (14.71%) (Figure 4.7). Most farmers are focused on short-term cash crops like vegetables and high demand crops due to limited government subsidies and profitability of the crops (Shafiai and Moi, 2015). Thus, it is only natural for farmers to select crops which have better market demand. According to the Department of Statistics Malaysia (2016), the per capita consumption of chilli and eggplant for 2015 was 2.3 kg/year and 1.5 kg/year respectively. Bell pepper and chilli pepper are classified as chilli (*Capsicum annuum*) by the Department of Statistics Malaysia. Chilli and eggplant were among the main vegetables produced by Malaysia in 2014 and the total production was about 40,521 metric tons (2.92%) and 48,702 metric tons (3.52%) respectively. The total area of production for chilli and eggplant was 3,502 hectares (5.34%) and 2,429 hectares (3.62%) respectively. In addition, the total value of the chilli and eggplant produced was MYR 213.1 million (7.40%) and MYR 109.5 million (3.80%), respectively (Department of Agriculture, 2014). These records show the importance of both chilli and eggplant in Malaysia. The respondents chose these crops for planting based on the decent market for chilli and eggplant in Malaysia.

In Figure 4.8, the average land area for the planting of bell pepper was the highest (7.20 ha), followed by eggplant (3.70 ha) and lastly chilli (2.27 ha). According to the respondents, the central zone is more favourable for planting bell pepper as compared to eggplant and chilli, because the higher altitude would lead to slightly lower temperatures throughout the day. According to Shirasaka (1988), the central zone is between 1440 to 1580 m above sea level, while the northern zone and southern zone are between 1000 to 1300 m above sea level, except for Blue Valley, which is 1500 m above sea level. Similarly, most of the eggplants were planted in the southern zone due to the warmer temperatures in Ringlet (1120 m above sea level) and Bertam Valley (1000m above sea level). Based on the findings of Saha et al. (2010), the optimum temperature for the growth of bell pepper is 20-25°C and temperatures above 32°C will result in lower yields.

Pests and diseases are major problems (46.51%, Figure 4.9) encountered by the respondents throughout the process of growing chillies, bell peppers and eggplants, followed by high farm expenditures (30.23%) for the purchase of pesticides, and 11.63% of minor problems like the unpredictable market prices of vegetables. Soil and climate make up the remaining 4.65% and 6.98% of the issues faced by farmers, respectively. Pests and diseases have always been the major factors that influence the quantity and quality of vegetable production which, in turn, affect the income of the farmers (Okunlola and Ofuya, 2010). For instance, the main factor which limits the yield of okra is the insect pests associated with this crop in the tropics (Ewete, 1978). The major contributor to the high farm expenditures is most probably the agrochemicals used in conventional farms, e.g., granular fertilisers, herbicides and pesticides (Yusoff, 2016). In Malaysia, more than 90% of the fertilisers used are mineral fertilisers, and there is an increasing trend for 2002, 2007 and 2008 where the fertiliser consumption was 1.095 million tons, 1.499 million tons and 1.592 million tons, respectively (Othman and Jafari, 2014). Studies by Halimatunsadiah et al. (2016) have shown that higher quantities of pesticides are used by farmers in high-income countries as compared to farmers in low-income countries. This indicates that the commercial prices of pesticides are high and contribute substantially to the costs of running a farm.

5.1.2 Pests and Diseases Management of Solanaceae Growers

Thrips were found to be the worst pest for chilli, bell pepper and eggplants in Cameron Highlands. Among the six categories of pests and diseases in Figure 4.10, thrips hold the largest portion (46.77%), followed by unidentified insect pests and diseases (20.97%), mites (14.52%), anthracnose (9.68%), bacterial wilt (1.61%), powdery mildew (4.84%) and whitefly (1.61%). Based on Figure 4.11, the damages caused by these pests and diseases resulted in farmers losing some of their harvests. The difference in the percentage of losses may be caused by different farm management methods, such as the choice of pesticides for pest control and also the interval periods between each pesticide applications. The tropical climate is favourable for the rapid growth of pest populations which results in severe crop damage and heavy losses in yield (Lim, 1990). The findings of Okunlola and Ofuya (2010) confirmed that farmers who consistently used the same methods and pesticides to control pests and diseases were unable to maintain the quality and quantity of their harvests.

Thrips are not a recent problematic pest in Malaysia. It was reported by Fauziah and Saharan (1991) that *Thrips palmi* was commonly found and caused serious damage to chillies and eggplants. Besides *T. palmi*, it was noted that *Thrips parvispinus* attacked chillies in Thailand (Bansiddhi and Poonchaisri, 1991) and Indonesia (Sastrosiswojo, 1991). *T. palmi* was also found to be an important pest of potato in Indonesia but it was not observed in eggplants and chillies (Sastrosiswojo, 1991; Vos et al., 1991). The increase in insecticide applications has been suggested to cause the outbreaks of thrips in Southeast Asia (Hirose, 1991). However, due to the lack of education, almost all the respondents (96.67%) were unable to differentiate beneficial insects from pest insects (Figure 4.12). Therefore, 90% of farmers surveyed had resorted to using chemicals for pest control (Figure 4.13). Some of the respondents (6.67%) used organic approaches, such as, application of homemade enzymes, rotenone and neem oil, and 3.33% of the respondents employed both organic and chemical methods to overcome their pest problems. More than 60% of the farmers agreed that chemical approaches are faster and more effective to control pests than other alternative methods (Assis and Mohd Ismail, 2011).

Figure 4.14 shows that all the farmers surveyed practised calendar spraying and 73.33% of the respondents sprayed once a week. Calendar spraying of pesticides is a common practice among vegetable farmers (Lim, 1990) and it is also a common practice for most farmers to apply pesticides once a week (Ooi, 1979). Besides calendar spraying, 96.55% of the farmers surveyed mixed two or more pesticides ("cocktail") to spray on their crops. The usual practise of most farmers is to mix only two chemicals together (one insecticide and one fungicide) (Ooi, 1979; Lim, 1990), but some farmers may mix more than two. The farmers' justification for using a "cocktail" is that it would be more effective and less laborious if these chemicals are used together. Similar observations have been made by Ooi (1979) and Lim (1990) that approximately 65% of the farmers used "cocktail" solutions for pest control. Hence, it is presumed that farmers in Malaysia have been employing the same approach to control pests in farms for more than 30 years.

Information on the average spray volume per hectare was also collected from the respondents (Figure 4.6), and it is noted that the spray volume per acre varies among farmers even though the crops might be the same. Figure 4.6 shows that the highest spray volume reported is more than 1484 L per hectare while the lowest is less than 494 L per hectare. This is because the spray volume is highly dependent on the age and size of the crops. If the crops have more leaves and are taller, a heavier spray volume is required. Moreover, the farmers also reported that most of the pesticide applications were performed by foreign workers and some workers might apply the pesticides at a higher level of moisture per leaf than others, thus contributing to the variation in spray volume per acre.

Figure 4.17 shows that 89.66% of the farmers surveyed were using pesticides recommended by local agriculture shops and 10.34% of them were recommended by private consultants, mostly from agrochemical companies, such as Bayer and Syngenta. Better educated farmers would also consider the pre-harvest interval of the pesticide that is recommended by other farmers and pesticide dealers. Regardless of the declining effectiveness of pesticides against resistant pests, e.g., thrips, they still agreed that chemical treatment is more suitable for pest control. This is because its immediate effect on pests favours the purposes of the farmers to maintain a better appearance of the vegetables in order to fetch a higher selling price (Halimatunsadiah et al., 2016). Besides that, more than 60% of the farmers think that using alternative control methods are not beneficial and would inconvenience their farm operations (Assis and Mohd Ismail, 2011). Thus, 68.42% of the farmers surveyed sought the recommendations of pesticide dealers and sales representatives for solutions to pest control and pest outbreaks (Figure 4.18). However, Watts and Williamson (2015a) stated that agroecological methods are more beneficial to farmers because it reduces production costs and exposure to chemical pesticides that will cause adverse health issues. The yield of crops for farmers who employ agroecological methods achieve 20 to 60% increase in production because polyculture helps to reduce losses to weeds, insect pests and diseases (Altieri, Funes-Monzote and Petersen, 2011). Furthermore, the profit of organic farmers are higher than conventional farmers even though there is no difference in yield since organic farmers spend less on pest control (Watts and Williamson, 2015a).

According to Figure 4.19, the top three insecticides used to control thrips populations in eggplant, bell pepper and chilli farms were spinetoram, imidacloprid and abamectin. The top four fungicides (Figure 4.20) that were usually used with these insecticides were mancozeb, propineb, chlorothalonil and cymoxanil plus mancozeb. According to the farmers, spinetoram appears to be the most effective insecticide to control thrips as compared to imidacloprid which has become ineffective despite an increase in spray dosage and frequency. Imidacloprid was one of the most effective insecticides for suppressing the thrips populations (Seal and Baranowski, 1992), but recent studies have shown that imidacloprid has become ineffective in reducing *T. palmi* populations in Florida (Seal, 2005). It is, therefore, possible that *T. palmi* has developed resistance to imidacloprid due to constant exposure to this pesticide in farms. Both imidacloprid and abamectin were marketed earlier as pesticides compared to spinetoram. Imidacloprid was commercially introduced as a pesticide in 1991 while abamectin was introduced in 1985. On the other hand, spinetoram was only commercialised from 2007 and it is the latest insecticide among the top three insecticides named by farmers to control thrips (Tomlin, 2009). It is thus speculated that most thrips species have yet to develop resistance against spinetoram as compared to other insecticides.

5.1.3 Financial Aspects of Solanaceae Growers

Figure 4.21 shows that 93.34% of the respondents promote their farm products, including chillies, bell peppers and eggplants, through sales agents or a “middle person”. The farmers’ dependency on sales agents to promote their products is one of the biggest problems faced by the farmers besides pests and diseases (Shirasaka, 1988). Farmers in Cameron Highlands are highly dependent on farm collectors and lorry operators, also known as sales agents or “middle person” to collect their farm products and sell them to the wholesalers in major towns and cities throughout Peninsular Malaysia, e.g., Ipoh, Kuala Lumpur, Johor Bahru, Kota Bahru as well as neighbouring countries such as Singapore (Shirasaka, 1988). However, based on the survey (Figure 4.21), some of the farmers have begun to use other approaches to promote their farm products instead of being dependent on the "middle person". According to Figure 4.21, 3.33% of the respondents market their own products by selling them directly to customers at the morning or night markets, and 3.33% sell their products through contracts with government agencies and hypermarkets, such as Tesco and AEON.

Figure 4.22 shows that the average selling price for eggplant is in the range of MYR 1.01 to 5.00 per kg, while the average selling price of chilli and bell pepper vary between farmers. During the survey, four chilli growers stated that the average selling price was between MYR 1.01 to 5.00 per kg, nine of them were selling between MYR 5.01 to 10.00 per kg and one of them sold the chillies at more than MYR 10.01. Two bell pepper growers stated that their average selling price was between MYR 1.01 to 5.00 per kg and five of them reported that their average selling price was between MYR 5.01 to 10.00 per kg. This variation in prices is most probably due to the marketing channel used by the farmers and also the market price during the harvesting period. The prices of the vegetables fluctuate throughout the year depending on the supply and demand chain (Lim, 1972). According to Chow (2016, personal communication), the channel to market the farm product is vital in deciding the price. Thus, farmers who are on contracts to sell to hypermarkets like Tesco and AEON, are more likely to get stable prices as minimum prices of the vegetables are set to safeguard the farmers' incomes. Many farmers do not take up contracts as they are not confident of achieving the requirements such as fixed yields, and would incur more losses if they breach the contracts. Farmers who depend on sales agents and "middle persons" are usually forced to sell their vegetables at much lower prices when production is high.

Figure 4.23 shows the estimated yield per hectare in a month. Five eggplant growers surveyed were in the range of 2472 to 4940 kg/ha, whilst five of the bell pepper growers were producing more than 7412 kg/ha. Four of the chilli growers produced less than 1235 kg/ha. Although, most of the chillies growers' yields were less than 1235 kg/ha, there were farmers who obtained yields higher than 1235kg/ha in a month. Two of the growers stated that their yields exceeded 7412 kg/ha. The differences in yields might due to the several factors, e.g., soil condition, presence of beneficial insects such as pollinators, climate, number of farm workers and the input of the farms (Ponisio and Ehrlich, 2016). All of the interviewed farmers practised conventional farming methods where chemical fertilisers and pesticides were used. Thus, the differences in the yields might be due to the selection of fertilisers and the intervals of fertiliser applications as well as the pesticides used for pest control. Farmers who have financial constraints would choose the cheaper insecticides, such as abamectin, which are less effective and thus, result in more losses and lower yields. According to Sudha, Gajanana and Murthy (2006), vegetable production could be enhanced through the adoption of hybrid seeds for planting. Farmers who are less well-off would, therefore, suffer lower yields due to the lack of funds to purchase such seeds.

The main production costs of the farms surveyed were pesticides (58.97%), followed by fertilisers (23.08%) and labour (17.95%) (Figure 4.24). Pesticides, fertilisers and labour costs have been the three main input costs for farms in Cameron Highlands for several decades (Lim, 1972). However, the input cost of fertilisers and pesticides can be reduced if farmers practise composting and biological pest control (Sharifuddin and Rahman, 1991). The main reason farmers are reluctant to adopt biological pest control is because they are unfamiliar with the biological control strategies (Assis and Mohd Ismail, 2011). Hence, biological control training should be provided by government agencies to educate farmers and to reduce the cost of pesticides for vegetable production.

5.2 Identification of Thrips Species in Eggplant, Chilli and Bell Pepper

Four species of thrips has been identified from a total of 311 thrips collected from eggplant, chilli and bell pepper farms in Cameron Highlands. These thrips were identified based on the morphological characteristics described by Mound and Ng (2009), Mound and Azidah (2009), Hoddle, Mound and Paris (2012), Sartiami and Mound (2013) and Kirk (1996). The four species are *Thrips palmi* (Figure 4.26), *Thrips parvispinus* (Figure 4.29), *Frankliniella occidentalis* (Figure 4.32) and

Megalurothrips usitatus (Figure 4.35). *T. palmi* was found to be most abundant among the four species (Figure 4.25a and Figure 4.25b). *T. palmi* and *T. parvispinus* were previously reported on both *Capsicum annuum* (chilli and bell pepper) and *Solanum melongena* (eggplant), while *F. occidentalis* and *M. usitatus* were previously found on *C. annuum* plants in Cameron Highlands (Azidah, 2011). *Thrips hawaiiensis* (Hawaiian flower thrips) and *Scirtothrips dorsalis* (chilli thrips) are among the common thrips observed on eggplants, chillies and bell peppers (Azidah, 2011; Ng, Mound and Azidah, 2014) but these two species were not observed among the collected samples. These species were probably absent due to the constant application of high dosages of insecticides in the farms. Carson (1962) and Isenring (2010) reported that uncontrolled usage of pesticides leads to the reduction of species diversity, such as birds, rodents, bats, bees and butterflies.

The native region of *T. palmi* and *T. parvispinus* is Southeast Asia, while *M. usitatus* is from the Oriental region (Hoddle, Mound and Paris, 2012). Since Malaysia is included in both the Southeast Asian as well as Oriental regions, these three species of thrips can be considered native to Malaysia. Although *T. palmi* is indigenous to Malaysia and western Indonesia, *T. palmi* populations have spread to many tropical regions around the world (Cook, 2003). Conversely, *F. occidentalis*, which originates from western United States of America (Hoddle, Mound and Paris, 2012), is the only non-native thrips found among the collected specimens.

Thrips palmi was evenly distributed among the eggplant, chilli and bell pepper crops, while *T. parvispinus* was found abundantly on chilli and bell pepper but not eggplant (Figure 4.25a). *F. occidentalis* was observed only on eggplant and bell pepper and *M. usitatus* was found only on eggplant (Figure 4.25a). The small number of *F. occidentalis* and *M. usitatus* sampled from these crops shows that these might not be the major species that damage the crops as most of the pest thrips species are polyphagous (Mound, 2005). *T. palmi* and *T. parvispinus* were recorded in all three sampling zones while *F. occidentalis* and *M. usitatus* were found only in the northern and southern zones, respectively (Figure 4.25b).

The infestation of *T. palmi* on chilli and eggplant is not a recent occurrence in Malaysia since *T. palmi* is the most commonly observed thrips species on these crops (Fauziah and Saharan, 1991). Based on the findings of Johari (2015), *T. palmi* is the most abundant in *S. melongena* and *C. annuum* while *T. parvispinus* is fewer in number on eggplant and chilli as compared to *T. palmi*. The results of this study concurred with Johari's (2015) observations (Figure 4.25a) but *T. parvispinus* is more abundant in chilli crops as compared to *T. palmi*. Since 1987, outbreaks of *T. palmi* on eggplant have been observed in Penang, Malaysia (Hirose, 1991). *T. palmi* has also been reported in Southeast Asia, Taiwan, North and South America, Australia, and other tropical and subtropical regions as a serious pest of vegetables, cotton and ornamental flowers (Chang, 1991; Bernardo, 1991; Hirose, 1991; Rachana, Jayasimha and Richa, 2016). *M. usitatus* Bagnall which commonly infests tomato and potato plants, is sometimes found together with *T. palmi*. The two species are easily distinguished through their body colours, i.e., *M. usitatus* is black whereas *T. palmi* is pale brown colour (Bernardo, 1991).

Thrips parvispinus is the most serious chilli pest in Indonesia, where it has caused losses in yield of up to 22.8% (Sastrosiswojo, 1991). According to Vos et al. (1991), Bansiddhi and Poonchaisri (1991) and Azidah (2011), *T. parvispinus* is a very common pest of chilli plants. *F. occidentalis* is a polyphagous species which usually attacks the flowers of 244 host plant species that belong to 62 different families, such as *Capsicum* sp., Cucurbitaceae, tomatoes and roses (European and Mediterranean Plant Protection Organisation, 2004). Based on the results of this study (Figure 4.25), the number of *F. occidentalis* and *M. usitatus* sampled from eggplant, chilli and bell pepper farms in Cameron Highlands may be considered as fewer compared to *T. palmi* and *T. parvispinus*. Therefore, the major damage on eggplant, chilli and bell pepper in Cameron Highlands are primarily caused by *T. palmi* and *T. parvispinus*.

5.3 Evaluation of the Effect of Spinetoram on *Thrips palmi*

The occurrence of insecticide resistance among agricultural pests is common and has been increasing at an alarming rate (Karaagac, 2012). It is important to investigate the development of insecticide resistance in the thrips of Cameron Highlands since most farmers depend solely on the chemical pest control method. The resistance of *Thrips palmi* against commercially formulated spinetoram was investigated because *T. palmi* was found to be the most abundant thrips species on eggplant, chilli and bell pepper in Cameron Highlands. In addition, *T. palmi* was observed to be uniformly distributed among these three crops in the three sampling zones in Cameron Highlands (Figure 4.25a and b). Among the farmers surveyed (Figure 4.19), spinetoram was considered the most popular insecticide for the control of thrips. Furthermore, spinetoram is the latest insecticide used to control thrips as compared to abamectin and imidacloprid. Spinetoram was registered by DowAgroSciences in New Zealand in 2007 while imidacloprid was introduced in 1991 by Bayer AG and Nihon Tokushu Noyaku Seizo K. K. (Tomlin, 2009). Abamectin was commercially introduced in 1985 by Syngenta AG. According to the Pesticide Control Division of Department of Agriculture Malaysia, spinetoram was first registered in Malaysia in 2008.

Imidacloprid was previously one of the most effective insecticides to control *T. palmi*. However, no insecticide has been found to exceed 81.5% effectiveness in thrips control (Centre for Agriculture and Biosciences International, 2016). Imidacloprid was also recommended by Paranjape et al. (2015) as one of the three chemicals to control thrips, of which the other two were abamectin and spinosad. Although imidacloprid was highly recommended, Bao et al. (2015) showed that *T. palmi* populations in Tokushima, Japan had developed resistance to imidacloprid. The highest level of resistance was 12.2-fold more compared to susceptible populations. According to Murai (2002), *T. palmi* from various locations in Japan had developed resistance towards imidacloprid, and samples collected from Nangoku was 16.6-fold more resistant compared to susceptible populations. Seal (2005) also noted that imidacloprid was ineffective against *T. palmi* due to the development of insecticide resistance in Florida. Commercially formulated spinetoram was effective in reducing *T. palmi* populations but Agrimek, the commercially formulated abamectin, was not effective in controlling *T. palmi* even when it was mixed into a cocktail with zeta-cypermethrin and bifenthrin (Seal, Razzak and Sabines, 2014). Hence, it is crucial to determine whether *T. palmi* has started to develop resistance against spinetoram in Malaysia.

The mortality of *T. palmi* from the leaf-dip bioassay with spinetoram is shown in Table 4.2 and Table 4.3. Mortality was analysed using probit analysis to determine the lethal dosage at 50% mortality (LD_{50}) and resistance ratio (Table 4.6). The LD_{50} of the tested *T. palmi* population was 0.05210 mg/L of spinetoram and the LD_{50} of the susceptible *T. palmi* population was 0.03083 mg/L. The resistance ratio (RR) was 1.69 against the commercially formulated spinetoram. The level of insecticide resistance is categorised as susceptible (RR = 1.0), low resistance (RR = 2 – 10), moderate resistance (RR = 11 – 30), high resistance (RR = 31 – 100) and very high resistance (RR > 100) (Santos et al., 2011). Based on the insecticide resistance level, the *T. palmi* in eggplant, chilli and bell pepper farms in Cameron Highlands can still be considered as having very low resistance against spinetoram with an RR of only 1.69. Although the RR is only 1.69, the resistance among *T. palmi* populations against spinetoram seems to be gradually developing. Hirose

(1991) noted that the outbreaks of *T. palmi* was caused by the constant application of insecticides, and gardens or farms that were not or rarely treated with insecticides faced less serious thrips infestation. Furthermore, the farmers surveyed in this study practised calendar spraying and the use of cocktail pesticides (Figure 4.14 and Figure 4.15). Such practices promote the development of insecticide resistance among the thrips population (Bansiddhi and Poonchaisri, 1991). Thus, this will eventually lead to a decrease in the effectiveness of chemical pest control methods. From this study, it can be inferred that *T. palmi* outbreaks is mostly due to the development of insecticide resistance among the thrips populations and the chemical control method is not sustainable.

The "very low resistance" level of the thrips in this study might be due to the susceptible thrips being sampled from among the three crops in organic farms. The susceptible *T. palmi* populations might comprise a mixture of some resistant ones migrated from neighbouring conventional, non-organic farms, which may influence the mortality data of the bioassay. The resistance ratio also suggests that the thrips populations are beginning to develop resistance against spinetoram. Conversely, the development of insecticide resistance might be slowed down by the farmers' practice of rotating the insecticides used to control the thrips (Cheng, Chang and Dai, 2010). Rotation of insecticides with a different mode of action is one of the ways to avoid the quick development of resistance in insect pests whenever pesticides are solely used for pest control (Cheng, Chang and Dai, 2010; Karaagac, 2012). This is, however, not a sustainable solution to overcome insecticide resistance that eventually leads to pest outbreaks. In addition, Murai (2002) stated that malathion, fenthion, ethiofencarb, pyrethrins, propoxur, fenitrothion, trichlorfon, primicarb, acephate, carbaryl, chlorpyrifos, pyridaphenthion, dichlorvos, cyanofenphos, vamidothion, phenthoate, dimethoate-fenvalerate, diazinon, naled, dimethoate, cyanophos, and pirimiphosmethyl appeared to be ineffective in controlling *T. palmi*.

Pest thrips, i.e., *T. palmi* and *F. occidentalis*, possess cytochrome P450-mediated detoxification mechanism and altered nicotinic acetylcholine receptor that allow them to develop resistance against insecticides such as spinosad, imidacloprid, abamectin, bendiocarb, methiocarb, acrinathrin and permethrin (Bao et al., 2015; Bao et al., 2014; Gao, Lei and Reitz, 2012). The altered nicotinic acetylcholine receptor was initially observed in resistant thrips population in southeastern Spain where spinosad was overused to control of thrips. The resistance ratio of these thrips against spinosad was more than 3682-fold (Gao, Lei and Reitz, 2012). Furthermore, the constant application of spinosad to control *F. occidentalis* has led to high resistance among these thrips populations in China, where the highest resistance ratio was determined to be 96.1-fold in 2015 (Li et al., 2016). Resistance against spinosad, the major insecticide used to control thrips was also observed in Israel (Lebedev et al., 2013). Since spinosad and spinetoram belong to the spinosyn class insecticides (Kirst, 2010), thrips that developed high resistance against spinosad will similarly become resistant to spinetoram.

The first detection of insecticide resistance is usually observed as failure in suppressing the pest populations. Through the survey, the farmers seemed to face difficulty in controlling the thrips and most regarded it as the worst pest (Figure 4.10) for eggplant, chilli and bell pepper. Alternative solutions, which are sustainable, such as biological control methods, should be recommended as a replacement to chemical methods in order to keep *T. palmi* populations under control and avoid insecticide resistance. *Ceranisus menes* Walker, an eulophid larval parasitoid and *Orius* spp., a predator of *T. palmi* are among the effective natural enemies to control *T. palmi*. Hirose (1991) found that the population density of *T. palmi* were 10 times higher in sprayed experimental gardens as compared to unsprayed gardens, and this was due to the absence of the predatory *Orius* spp. in sprayed gardens. Several *Orius* spp., e.g., *Orius sauteri*, *Orius minutus* and *Orius nagaii*, are effective predators for controlling *T. palmi* populations (Hirose et al., 1999; Murai, 2002). Thus, indigenous *Orius* spp. present in Cameron Highlands should be studied and information about the presence of natural predators and their effectiveness must be shared with farmers who face *T. palmi* problems.

CHAPTER SIX

CONCLUSIONS

Need-based research is needed to identify the actual problems of the farmers and provide them with sustainable solution, such as, effective pest control methods. A survey to understand the farmers' practices for Solanaceae crops in Cameron Highlands was carried out from July 2014 to March 2015. It is found that many farmers are still practising conventional farming methods. The main challenge faced by Solanaceae crops farmers is pests and diseases and thrips is named as the worst pest. Chemical pesticides are used to control thrips populations in farms and the most popular insecticides are spinetoram, imidacloprid and abamectin.

A total of 311 thrips specimens has been identified based on their morphological characteristics. *Thrips palmi* Karny, *Thrips parvispinus* Karny, *Frankliniella occidentalis* Pergande and *Megalurothrips usitatus* Bagnall are the four species found in eggplant, chilli and bell pepper crops in Cameron Highlands. *T. palmi* is the most abundant among the four species. It is found evenly distributed among the three crops and the three sampling zones.

The resistance ratio (RR) of *T. palmi* is found to be 1.69-fold against commercially formulated spinetoram. The RR value has been classified as very low resistant but continuous dependence on spinetoram or other chemicals is not recommended. This is because thrips will eventually develop resistance against pesticides if it is routinely being exposed to them. Thrips has been found to develop more than 3682-fold resistance against spinosad in southeastern Spain. Resistance against imidacloprid (16.6-fold) was also found in *T. palmi* populations in Japan. Besides that, abamectin was once effective but recently noted ineffective in controlling *T. palmi* population even when it is mixed into cocktail in Malaysia. These evidences supported the fact that dependence on chemical pesticides for pest control will eventually lead to development of resistance. Therefore, spinetoram which is found to be very low resistance may suffer the same fate as the above-mentioned insecticides, which became ineffective after high resistance is developed.

Farmers who try to suppress resistant thrips have been increasing the spray frequency and dosage which leads to environmental pollution as well as affecting the health of the community. Besides that, the production cost also increases as more insecticides are used in each application. Therefore, alternative solutions which are sustainable should be recommended to replace chemical methods. This is to overcome insecticides resistance issue and also to reduce production cost as well as damage towards environment and people. The population of *T. palmi* was 10 times higher in the sprayed experimental gardens as compared to unsprayed gardens in Penang, Malaysia due to the absence of effective natural enemies. Hence, the presence and effectiveness of indigenous natural enemies, such as *Ceranisus menes* Walker (eulophid larval parasitoid) and various *Orius* spp. (predator) should be studied. This information should be shared with the farmers who face *T. palmi* problems.

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APPENDIX A

SURVEY QUESTIONNAIRE

UNIVERSITI TUNKU ABDUL RAHMAN
拉曼大学

Faculty of Science
理科学院

Department of Agricultural and Food Science
农业与食品科学系部门

Survey on the Practices and Problems Faced by Nightshade Vegetable Farmers in Cameron Highlands, Malaysia

金马伦高原茄科蔬菜农民的种植实践和种植问题调查

NOTE:

I. **All information obtained for this survey will be kept private and confidential.**
本次调查所获得的信息与质料将被保密。

II. **The findings of the survey are strictly for the use of vegetable farming research.**
调查结果将严格地用于有关大学农业研究用途。

Part A: Respondent's Particulars or General Information					
Name of Farmer:				**Code[1]:**	
Age:		**Gender (Male/ Female):**			
Nationality:		**Location of Farm:**			
Farmer Contact:					
Education:	**None**	**Primary**	**Secondary**	**College**	**University**
Marital Status:	**Single**	**Married**	**Divorced**		
Number of Children:		**Number of Dependent:**			
How many children are schooling? If any.	**No schooling/Graduated**				
	Kindergarten/ Nursery				
	Primary				
	Secondary				
	College/ University				
Years of Farming Experience:		**Type of Farming:**			
Occupation:	**A.**	**Agriculture is the sole occupation**			
	B.	**Other occupation (Pls specify):**			
Annual Farming Income:	**RM**				

note[1]: Northern Zone (NZ) – include Lodging area, Blue Valley, Kg. Raja, K. Terla
Central Zone (CZ) – include Tringkap, Kea Farm, Menseum Valley, Brinchang and Tanah Rata
Southern Zone (SZ) – include Ringlet, Boh Road Area and Bertam Valley

Estimated Farm Size (acre):		**Estimated Cultivated Area (acre):**	

Land Tenure:	**Freehold**	**Lease**	**TOL**	**Others**

Main Crop(s) & Size:	**I.**
	II.
	III.
	IV.
	V.

Farm Labor:	**Family**	**Hired**	**Mixed[2]**	**Others (Pls specify):**	

If Hired Workers[3]: (Nationality)	**I.**
	II.
	III.
	VI.

Estimated Number of Hired workers:		**Estimated wages[4]:**	

Previous Training:	**A.**	**Agricultural Workshop**
	B.	**Seminars or Talks**
	C.	**Others (Pls specify):**
	D.	**None**

If Yes,	**Organizer**	
	Date/Year	
	Venue	

note[2]: mixed means family and hired workers.
note[3]: farms may employ workers which are from different nationality.
note[4]: wages can be calculated per month or per day.

Information:	**Source of information regarding farming, such as pesticides, fertilisers, seeds, and agriculture news.**
	A. Licensed Pesticide Dealers
	B. Government Officers
	C. Other Farmers (Friends)
	D. Sales Representatives
	E. Mass Media[5]
	F. Others (specify):

note[5]: mass media includes TV, Radio, Magazines, Newspapers and other equivalent.

<table>
<tr><td colspan="5">Part B: Farm Operation and Farming Practices</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="5">1. Land Preparation</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="3">Land Preparation methods:</td><td rowspan="3">Type of Land Preparation Method (can select multiple)</td><td colspan="3">A. Mechanical (pls go to (a))</td></tr>
<tr><td colspan="3">B. Manual (pls go to (b))</td></tr>
<tr><td colspan="3">C. Others (pls go to (c))</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="4"></td><td rowspan="4">(a) Mechanical</td><td colspan="3">A. Motorized Pedestrian Plough</td></tr>
<tr><td colspan="3">B. Rotovate</td></tr>
<tr><td colspan="3">C. Tractor mounted</td></tr>
<tr><td colspan="3">D. Others (specify):</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="2"></td><td rowspan="2">(b) Manual</td><td>A. Hoeing (Cangkul)</td><td colspan="2">B. Others, pls specify:</td></tr>
<tr><td colspan="3">Purpose:</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td>(c) Others land preparation[1]</td><td colspan="2">A. Fertigation in growing bags (pls go to (c1))</td><td>B. Others (pls go to (c2))</td></tr>
<tr><td rowspan="4"></td><td rowspan="4">(c1)</td><td rowspan="4">The Type of Growing Medium[2] in the Bag</td><td colspan="2">I.</td></tr>
<tr><td colspan="2">II.</td></tr>
<tr><td colspan="2">III.</td></tr>
<tr><td colspan="2">IV.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td></td><td colspan="2">The Number of Growing Bag per Acre:</td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">The Estimated Amount of Each Growing Medium per bag</td><td colspan="2">I.</td></tr>
<tr><td colspan="2">II.</td></tr>
<tr><td colspan="2">III.</td></tr>
<tr><td colspan="2">IV.</td></tr>
<tr><td colspan="5"></td></tr>
</table>

note[1]: farms might use pre-mixed planting medium in poly bags, etc. where do need land preparation.

note[2]: Material that placed in the bag, for e.g. coco-peat, loam, compost or etc.

<table>
<tr><td></td><td></td><td>Duration of each Growing Bag[3]</td><td colspan="2"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td></td><td>Estimate Number of Plant(s) per Bag</td><td colspan="2"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td>(c2)</td><td>Please specify the farming system:</td><td colspan="2"></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="11"></td><td colspan="2">Chemical used during preparation (Weedicide)</td><td>Yes</td><td>No</td></tr>
<tr><td colspan="4">If Yes, continue:</td></tr>
<tr><td rowspan="3">Purpose</td><td colspan="3">A) Clear weeds or previous vegetation</td></tr>
<tr><td colspan="3">B) Clear and Prevent disease or pest</td></tr>
<tr><td colspan="3">C) Others, specify:</td></tr>
<tr><td>Specify the product (Brand)[4]:</td><td colspan="3"></td></tr>
<tr><td>Active ingredient:</td><td colspan="3"></td></tr>
<tr><td>Dose/ Concentration[5]:</td><td colspan="3"></td></tr>
<tr><td>Spray Volume:</td><td colspan="3"></td></tr>
<tr><td>Equipment used:</td><td colspan="3"></td></tr>
<tr><td colspan="4"></td></tr>
</table>

note[3]: duration to change the growing bag, how many seasons or how many years change once.

note[4]: if cocktail, list all the herbicides used (the brands, active ingredients and dose for each).

note[5]: get volume of chemical and volume of water added, calculate MV = MV.

2. Seeds and Seeding		
Source of Seeds:	**A. Purchase seeds in shops**	
	B. Developed their own Seeds from previous plants	
	C. Others, specify:	
Choice of Seeds: (can select multiple)	**A. Duration of Growth (shorter)**	
	B. Better resistance towards tough weather, disease & pest	
	C. Better yield in terms of weight and harvest	
	D. Better demand from market	
	E. Others, specify:	
Methods of Seeding:	**A. Broadcast Seeding**	
	B. Drill Seeding	
	C. Others, specify:	
Quantity of seeds used cycle: (Crop: Quantity)	**Crop I:**	
	Crop II:	
	Crop III:	
3. Fertilisers		
Methods for application of fertilisers: (can select multiple)	**A. Broadcasting** *(pls go to (section a))*	
	B. Fertigation *(pls go to (section b))*	
	C. Foliar application *(pls go to (section c))*	
	D. Others, specify:	
Section a: Broadcasting		
Applies chemical fertiliser to crops:	**Yes**	**No**

If Yes:	**I. Type and brands of Fertilisers (For eg, N: P: K?)**	
	Quantity used annually (metric tons):	
	II. Source of Chemical Fertilisers:	
	III. Source of information on Chem Fertilisers:	

Farmers apply organic fertilisers?	**Yes**	**No**

If Yes:	**I. Type of Organic fertilisers:**	**A. Manure; Type:**
		B. Self- made Compost *(proceed to IA)*
		C. Ready-made *(proceed to IB)*
		D. Others, specify:
	IA. List the material for Composting	
	IB. List the Brand and Type of Organic Fertilisers	
	II. Quantity used annually (metric tons):	
	III. Source of Organic Fertilisers:	
	IV. Source of information on Org Fertilisers:	

Farmers applied Fortified Organic Fertilisers?	**Yes**	**No**

<table>
<tr><td rowspan="5">If Yes:</td><td colspan="2">I. Type and brands of Fertilisers
(For eg, N: P: K?)</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Quantity used annually (metric tons):</td><td></td></tr>
<tr><td>II. Source of Chemical Fertilisers:</td><td></td></tr>
<tr><td>III. Source of information on Chem Fertilisers:</td><td></td></tr>
</table>

<table>
<tr><td colspan="2">Section b: Fertigation</td></tr>
<tr><td rowspan="3">Method of Fertigation</td><td>A. Dripping system</td></tr>
<tr><td>B. Spraying</td></tr>
<tr><td>C. Others, pls specify:</td></tr>
</table>

<table>
<tr><td rowspan="8">List the Fertigation Fertilisers and quantity used:</td><td>Fertigation Fertilisers
(Type, i.e., organic, chemical or mixed)</td><td>Quantity
(weight/volume)</td></tr>
<tr><td>I.</td><td></td></tr>
<tr><td>II.</td><td></td></tr>
<tr><td>III.</td><td></td></tr>
<tr><td>IV.</td><td></td></tr>
<tr><td>V.</td><td></td></tr>
<tr><td>VI.</td><td></td></tr>
<tr><td>VII.</td><td></td></tr>
</table>

<table>
<tr><td rowspan="2">Estimate Number of Growing Bag (or plants) per Tank of Mixture</td><td>Volume of Mixture (per Tank):</td><td></td></tr>
<tr><td>Estimate Number Growing Bag/Plants</td><td></td></tr>
</table>

Source of Fertigation Product:	

Source of Information on Fertigation:		
Section c: Foliar application		
List the Foliar Fertilisers and Quantity used:	**Foliar Fertilisers (type, i.e. organic, chemical or mixed):**	**Quantity used per tank (vol/vol)**
	I.	
	II.	
	III.	
	IV.	
	V.	
Estimate quantity per acre (vol/acre)		
Source of Foliar Fertilisers		
Source of Information on Foliar application:		
Frequency of Fertilisers application:		
Reason(s) for the chosen fertilisers:	**A. Better yielding and quality of crops**	
	B. Recommendation from:	
	C. Lower price and high availability	
	D. Others, specify:	

<table>
<tr><td rowspan="4">Reason for fertiliser application methods:</td><td>A. Recommendation from:</td></tr>
<tr><td>B. Result in better yield and crops quality</td></tr>
<tr><td>C. Lower cost and consider efficient</td></tr>
<tr><td>D. Others, specify:</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">4. Choice of Crops</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="4">Type of Crops Planted:</td><td>I.</td></tr>
<tr><td>II.</td></tr>
<tr><td>III.</td></tr>
<tr><td>IV.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="4">Duration for Each Crops:</td><td>Crop I:</td></tr>
<tr><td>Crop II:</td></tr>
<tr><td>Crop III:</td></tr>
<tr><td>Crop IV:</td></tr>
</table>

<table>
<tr><td rowspan="4">Any special condition for the selected crops:</td><td rowspan="3">I. Weather:</td><td>Dry Season:</td></tr>
<tr><td>Rainy Season:</td></tr>
<tr><td>All Season:</td></tr>
<tr><td>II. Others:</td><td></td></tr>
</table>

<table>
<tr><td rowspan="6">Reason for the chosen crops: (can select multiple)</td><td>A. Shorter duration needed to plant</td></tr>
<tr><td>B. The production cost lower</td></tr>
<tr><td>C. Good market demand</td></tr>
<tr><td>D. Less susceptible to pest and diseases.</td></tr>
<tr><td>E. Suitability of weather</td></tr>
<tr><td>F. Others, specify:</td></tr>
</table>

5. Irrigation				
Is the farm irrigated?			**Yes**	**No**
If Yes, State the Type of irrigation system?				
Type of water source?				
6. Pesticide				
Are pesticides used on farm?			**Yes**	**No**
If Yes	**Type of Pesticides Used?**	**I.**		
		II.		
		III.		
		IV.		
		V.		
	Quantity and cost of each pesticide used	**I.**		
		II.		
		III.		
		IV.		
		V.		
7. Main Problems				
What are the main production problems? List in order of priority.		**I)**		
		II)		
		III)		

Part C: Pest and Disease Management, other problems		
Pest Problems:	**Description/ Name of Pest**	**Crop(s) affected**
	I)	**I)**
	II)	**II)**
Insects:	**III)**	**III)**
	IV)	**IV)**
	V)	**V)**
	I)	**I)**
	II)	**II)**
Diseases:	**III)**	**III)**
	IV)	**IV)**
	V)	**V)**
	I)	**I)**
	II)	**II)**
Weeds:	**III)**	**III)**
	IV)	**IV)**
	V)	**V)**
	I)	**I)**
	II)	**II)**
Other pests:	**III)**	**III)**
	IV)	**IV)**
	V)	**V)**

Impact:	**What is the impact of pests and diseases?**	
	Loss of yield (%)	
	Financial loss (RM):	

Methods to overcome problems:

No	**Crop**	**Type of Pest / Type of Disease**	**Control methods**	**Frequency**
1				
2				
3				
4				
5				
6				
7				

When and How farmers indicate needs for pest control? (For eg, by looking at the existence of insects or damage on the crops?)

<table>
<tr><td colspan="4">Who and How farmers decide on when, how often and why selected pest control is done?</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="8">Type of Pesticide</td><td colspan="3">Types of pesticides used and source:</td></tr>
<tr><td>Type/ Mixture</td><td>Pack Size</td><td>Source</td></tr>
<tr><td>I)</td><td></td><td></td></tr>
<tr><td>II)</td><td></td><td></td></tr>
<tr><td>III)</td><td></td><td></td></tr>
<tr><td>IV)</td><td></td><td></td></tr>
<tr><td>V)</td><td></td><td></td></tr>
<tr><td>VI)</td><td></td><td></td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="14">Identification of pest and beneficial insects</td><td colspan="3">Is a farmer able to identify pest from beneficial insects?</td></tr>
<tr><td>Able to identify pest:</td><td>Yes</td><td>No</td></tr>
<tr><td rowspan="4">If Yes, examples of pest identified:</td><td colspan="2">I)</td></tr>
<tr><td colspan="2">II)</td></tr>
<tr><td colspan="2">III)</td></tr>
<tr><td colspan="2">IV)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Able to identify beneficial insects:</td><td>Yes</td><td>No</td></tr>
<tr><td rowspan="4">If Yes, examples of beneficial insects:</td><td colspan="2">I)</td></tr>
<tr><td colspan="2">II)</td></tr>
<tr><td colspan="2">III)</td></tr>
<tr><td colspan="2">IV)</td></tr>
</table>

<table>
<tr><td rowspan="12">Mixing of pesticides:</td><td colspan="6">Pesticide application</td></tr>
<tr><td colspan="2" rowspan="4">Equipment used for spraying</td><td colspan="4">A) CDAs</td></tr>
<tr><td colspan="4">B) Knapsack sprayers</td></tr>
<tr><td colspan="4">C) Motorized Power Sprayers</td></tr>
<tr><td colspan="4">D) Others, specify:</td></tr>
<tr><td colspan="4">Any Mixing of Pesticides? (Cocktails)</td><td>Yes</td><td>No</td></tr>
<tr><td>If Yes, Why?</td><td colspan="5"></td></tr>
<tr><td rowspan="5">If Yes</td><td colspan="5">Mixture of Pesticides</td></tr>
<tr><td>No.</td><td>Pesticide</td><td>Amount (mL)</td><td colspan="2">Crop/ Pest</td></tr>
<tr><td>1</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>2</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>3</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td></td><td></td><td>4</td><td></td><td></td><td colspan="2"></td></tr>
</table>

<table>
<tr><td rowspan="4">Spray volume:</td><td>Crops</td><td>Spray Volume (volume/ area)</td><td>Frequency /per week</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Awareness	**Is farmer aware of the advantages and disadvantages of pesticides?**			
	If Yes, why continue?			
	Is farmer aware of the effect of pesticides on non target organisms?		**Yes**	**No**
	If Yes, why continue?			

How farmers choose type of pesticide and why?	**A) Recommendation from Shops or Sale Representative**
	B) Past experience
	C) Others, specify:
	Reason:

Did farmers fail to control a pest?	**Yes**	**No**
If Yes, Why?		

Help on identifying problems and solution	**Who and where farmers seek aids from when have a problem on pest or disease?**
	A) Pesticides dealers or sales representative
	B) Agricultural Scientist
	C) Other farmers (friends)
	D) Trial and error by increasing dose and frequency of pest control
	E) Others, specify:

Did farmers face other problems, besides pest and disease?			**Yes**	**No**
If Yes	**What kind of problems? (can select multiple)**	**A) Soil fertility problems**		
		B) Natural Disasters and Climate		
		C) Poor Quality Seeds		
		D) Ineffective fertilisers		
		E) Water Pollution		
		F) Others, specify:		
Where the farmers seek help for these problems?	**A) Agriculture Shop dealer or Sale Representative**			
	B) Government officers			
	C) Other farmers			
	D) Others, specify:			

Part D: Financial Aspect			
Market Demand:	**Decision making in planting crops?**		
	A) Sales Agent		
	B) Other farmers (Friends)		
	C) Past experiences		
	D) Others, specify:		
Marketing Vegetables:	**How farmers promote their product?**		
	A) Sales Agent (middleman)		
	B) Friends, Business Partner and networking		
	C) Contact through past experience		
	D) Others, specify:		
Production cost:	**How many seasons of crops per year?**		
	Crops	**Season per annum**	
	I)		
	II)		
	III)		
	IV)		
	V)		
	Average Price of Crops per Kilogram		
	Crops	**Average Price/ kg (RM)**	**Estimate weight per season (kg)**
	I)		
	II)		
	III)		
	IV)		
	V)		

Production cost:	Cost of production per plant?	
	Crops	Cost per plant (RM)
	I)	
	II)	
	III)	
	IV)	
	V)	
	What is the main production cost?	
	Profit / loss? (Estimated value)	

Ways to overcome financial problems?	
	A) Bank Loan
	B) Reduce labor
	C) Personal Savings
	D) Others, specify:

Part E: Additional Question	
What is the main challenge of farming?	

END OF SURVEY

THANK YOU FOR PARTICIPATING

APPENDIX B

Common name	**Chemical Abstracts name**
Acephate	*N*-[methoxy(methylthio)phosphinoyl]acetamide
Carbaryl	1-naphthalenyl methylcarbamate; 1-naphthalenol methylcarbamate
Chlorpyrifos	*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridinyl) phosphorothioate
Cyanofenphos	4-[ethoxy(phenyl)phosphinothioyl]oxybenzonitrile
Cyanophos	*O*-(4-cyanophenyl) *O*,*O*-dimethyl phosphorothioate
Diazinon	*O*,*O*-diethyl *O*-[6-methyl-2-(1-methylethyl)-4-pyrimidinyl] phosphorothioate
Dichlorvos	2,2-dichloroethenyl dimethyl phosphate
Dimethoate	*O*,*O*-dimethyl *S*-[2-(methylamino)-2-oxoethyl] phosphorodithioate
Dimethoate-fenvalerate	*O*,*O*-dimethyl *S*-[2-(methylamino)-2-oxoethyl] phosphorodithioate and cyano(3-phenoxyphenyl)methyl 4-chloro-α-(1-methylethyl)benzeneacetate
Ethiofencarb	2-[(ethylthio)methyl]phenyl methylcarbamate
Fenitrothion	*O*,*O*-dimethyl *O*-(3-methyl-4-nitrophenyl) phosphorothioate
Fenthion	*O*,*O*-dimethyl *O*-[3-methyl-4-(methylthio)phenyl] phosphorothioate

Common name	Chemical Abstracts name
Malathion	diethyl [(dimethoxyphosphinothioyl)thio]butanedioate
Naled	1,2-dibromo-2,2-dichloroethyl dimethyl phosphate
Phenthoate	ethyl α-[(dimethoxyphosphinothioyl)thio]benzeneacetate
Pirimiphosmethyl	4-dimethoxyphosphinothioyloxy-*N*,*N*-diethyl-6-methylpyrimidin-2-amine
Primicarb	2-(dimethylamino)-5,6-dimethyl-4-pyrimidinyl dimethylcarbamate
Propoxur	2-(1-methylethoxy)phenyl methylcarbamate
Pyrethrins	Pyrethrin I, [1*R*-[1α[*S**(*Z*)],3β]]-2-methyl-4-oxo-3-(2,4-pentadienyl)cyclopenten-1-yl 2,2-dimethyl-3-(2-methyl-1-propenyl)cyclopropanecarboxylate; Cinerin I, [1*R*-[1α[*S**(*Z*)],3β]]-3-(2-butenyl)-2-methyl-4-oxo-2-cyclopenten-1-yl 2,2-dimethyl-3-(2-methyl-1-propenyl)cyclopropanecarboxylate; Jasmolin I, [1*R*-[1α[*S**(*Z*)],3β]]-2-methyl-4-oxo-3-(2-pentenyl)-2-cyclopenten-1-yl 2,2-dimethyl-3-(2-methyl-1-propenyl)cyclopropanecarboxylate
Pyridaphenthion	*O*-(1,6-dihydro-6-oxo-1-phenyl-3-pyridazinyl) *O*,*O*-diethyl phosphorothioate
Trichlorfon	dimethyl (2,2,2-trichloro-1-hydroxyethyl)phosphonate
Vamidothion	2-(2-dimethoxyphosphorylsulfanylethylsulfanyl)-*N*-methylpropanamide