SPECIES COMPOSITION AND HOST ASSOCIATION OF THRIPS (THYSANOPTERA) IN THE EASTERN AND GREATER ACCRA REGIONS, GHANA

BY

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DECLARATION

I hereby declare that this thesis is the result of the original research work I, Chia Shaphan Yong personally carried out for the award of Master of Philosophy (M. PHIL.) in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS) from the University of Ghana, Legon. All references to other people's work have been duly acknowledged and the thesis has not been submitted in part or whole for the award of a degree elsewhere.

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ABSTRACT

Thrips are crop pests causing damage to a wide range of crops ranging from fruits to vegetables to ornamentals through direct feeding or oviposition on plants. The main objective of this study was to determine the species composition of thrips and their host range in some selected parts of Greater Accra and Eastern Regions of Ghana. Thrips were collected from flowers, leaves and twigs of vegetable, ornamental and tree crops by beating and jarring and identified to species level. Fifty sticky traps comprising 25 each of Blue and Yellow traps were also set in vegetable farms for 7 months, September 2014 to March 2015 to trap thrips species. Data on average daily temperature and rainfall were collected from the Ghana Meteorological Agency located at Mempasem in the Greater Accra Regionand used to establish their relationship with trap catches. Farmers' knowledge of thrips and their pest management practices was assessed using a survey questionnaire. Abundance of thrips was studied on vegetable crops and within plant distribution of *Thrips palmi* determined on cucumber plants. Over twenty species of thrips were recorded. Major thrips species recorded include; *T. palmi*, *Megalurothrips sjostedti*, *Frankliniella schultzei* and *Thrips tabaci*. In all, 13367 adult thrips were captured by traps. Individual trap types were 8206 (61.4%) and 5161 (38.6%) by the Blue and Yellow traps, respectively. Generally, there was no significant difference (P =0.363, DF = 1, P>0.05 = α) among trap catches. Both rainfall (R^2 = 0.0142, P = 0.530, P > 0.05 = α) and temperature (R^2 = 0.0603, P = 0.191, P > 0.05 = α) were not significantly correlated to trap catches. However, the number of thrips in sticky traps from one locality (East Legon) was significantly positively correlated (R^2 = 0.1346, P = 0.0461, P <0.05 = α) with average weekly temperature. Only 29% of the farmers interviewed knew thrips and had experienced thrips on their crops. Survey results showed a 100% reliance on chemical pest control by farmers with most of them dependent on personal experience for agronomic practices.

Mean number of thrips was significantly higher (Fpr =0.012, DF = 12, $P < 0.05 = \alpha$, LSD = 1.15) on eggplant and cucumber compared to other vegetables examined. Four plant species including eggplant, cucumber, gboma and sweet pepper were examined for thrips abundance recorded *T. palmi* infestation. Even though there was no significant difference (Fpr = 0.6292, $P > 0.05$) among thrips counts from various plant species, more adult *T. palmi* were recorded on cucumber leaves. For within plant distribution, there was a significant (Fpr = 0.0036, $P < 0.05$) difference among mean numbers of thrips on young, middle and bottom leaves, with counts from young (mean = 16.1) and middle (mean = 10.1) leaves significantly higher (q = 5.337 > q-critical =3.532, $\alpha = 0.05$) compared to the bottom (mean =3.2) leaves.

In conclusion, several species of thrips infest vegetable and ornamental plants in Southern Ghana and are polyphagous insects, infesting a wide range of plants species. *Thrips palmi* was recorded in Ghana for the first time. Knowledge of thrips was very limited among crop growers. The improvised sticky traps were effective in capturing thrips, thus may be good for monitoring early and small thrips populations in the field.

DEDICATION

I dedicate this work first to the Almighty God for his sufficient grace over my life and to my family.

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LIST OF ABBREVIATIONS

ARPPIS	African Regional Postgraduate Programme in Insect Science
CABI	Centre for Agriculture and Biosciences International
CPPC	Caribbean Plant Protection Commission
EC	European Commission
EPPO	European and Mediterranean Plant Protection Organization
EU	European Union
EUROPHYTE	European Union Notification System for Plant Health
FVO	Food and Veterinary Office
NPPO	National Plant Protection Organization

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CHAPTER ONE

1.0 INTRODUCTION

Thrips (Thysanoptera: Thripidae) are important crop pests that cause damage to a wide range of crops such as fruits, vegetables and ornamentals. Much of the injury they cause is through direct feeding or oviposition, but there are several species which also transmit plant viruses that are harmful (Samler, 2012).

Thrips are relatively small insects, ranging from 0.5 to 2 mm long. Other common names include thunder flies, thunder bugs, thunder blights, storm flies, storm bugs, corn flies and corn lice (www.amentsoc.org/insects/fact-files/orders/thysanoptera.html, accessed on 31 March 2015).They are mainly plant-feeders and many crops especially fruit and vegetable crops are susceptible to thrips infestation (Palmer, 1990). Thrips occupy a wide variety of ecological niches and so several species may be present on a single plant (Palmer, 1990). Egg plants *(Solanum melongena*), pepper (*Capsicum annuum*), okra (*Abelmoscus esculentum)*, sweet pepper (*Capsicum annuum var*.), cucumber (*Cucumis sativus*), Amaranthus species and onion plants (*Allium cepa*) are a few of the vegetable crops in Ghana which are affected by thrips. Thrips are widely distributed in Southern Ghana and are found in the Savannah and forest ecosystems (Banfo, 2009). These pest populations would build up rapidly on host plants if not treated and would cause; injury to the plants, delayed maturity, stunted growth, and yield loss (Samler, 2012). Thrips prefer rapidly growing-plant tissues and as a result, fruit buds are damaged, leaving scars on the flowers. Scars can also be left on fruits such as citrus and avocados, reducing their marketability and consumption.

Recently, many African countries have developed large production programmes for fruits and vegetables in order to export to the European Union (EU) markets (Singh, 2002). In 1994, Africa for example supplied about 92% of EU imports of green beans, with Kenya contributing 29% of total supply (Singh, 2002). Kenya's success in the production and marketing of fruits and vegetables could be because it is an equatorial country alongside agro-climatic conditions which allow for year round crop production (McCulloch and Ota, 2002). Ghana, like Kenya, is an equatorial country that relies on small-scale farmers for agricultural production with the climatic conditions and farm structures being similar to the situation in Kenya. Many African and other developed countries are entering the export market with fruit and vegetable crops, thus intensifying competition (Singh, 2002).

Despite the remarkable returns from fruit and vegetable production worldwide, including Ghana, the activity is constrained among other factors by viral diseases such as watermelon mosaic viruses, tomato spotted wilt virus, bud necrosis virus (Capinera, 2000), nematodes, declining soil fertility (Obeng-Ofori and Ankra, 2002) and insect pests such as aphids, whiteflies, fruit flies, mealybugs, Diamondback moth and thrips among others, particularly the melon thrips, *Thrips palmi* Karny (Thysanoptera: Thripidae) which is an international quarantine pest necessitating the use of high rates of pesticides and artificial fertilizers. Thrips have been reported in many African countries including Ghana (Funderburk *et al.*, 2007). However, although *Thrips palmi* has been reported in Ivory Coast, Mauritius, Nigeria, Reunion and Sudan, there are no records in Ghana (www.cabi.org/iscdatasheet/53745, accessed on 2 January 2015).

Thrips are important quarantine pests of fruits and vegetables. Due to the small size of the pest, detection in the field is difficult, so quarantine procedures are difficult to manage the pest. Continued and increasing number of interceptions by European Union (EU) member States in consignments of fruits and vegetables originating from Ghana due to the presence of harmful organisms of concern to the EU led to a drop in Ghana's export of these commodities (Final Report of an Audit carried out in Ghana by FVO, 2012). In mid-July 2014, the European Commission (EC) sent a warning letter to the National Plant Protection

Organisations (NPPOs) in eight countries, warning that strict action against the import of fruit and other products from specific countries would be taken if they fail to improve compliance with phytosanitary regulations (Http://www.freshplaza.com/article/124021/EU-warns-fruit-exporting-countries, accessed on 30th January 2015). Four of the countries notified include; Ghana (pumpkins and aubergines), Dominican Republic (squashes, eggplant and mango), Kenya (pumpkin, mango and basil) and Uganda (paprika). In July 2014, the EU imposed a temporary ban on Ghanaian vegetable imports after consignments were identified as not meeting quality standards (Http: //www.freshfruitportal.com/2014/07/31/eu-closes-door-on-ghanaian-vegetables-imports, accessed on 31 March 2015). In 2013, Ghana received 181 interceptions due to detection of harmful organisms in vegetable consignments and thrips accounted for 135 of the interceptions (Europhyte 2013 Food and Veterinary Office Annual Report, 2014).

1.1 Justification

Thrips are serious pests of crops, yet little is known about their species composition and population trends, especially of *Thrips palmi*, a quarantine pest, in Ghana. This lack of information and the frequent interceptions of Ghanaian vegetable crops on account of *Thrips* by the EU member states necessitated this study (Final Report of an Audit carried out in Ghana by FVO, 2012).There is absence of adequate and convenient methods for assessing population trends of thrips. Farmers depend mostly on excessive use of pesticides which often leads to high pesticide residues in fruits and vegetables as well as increased cost of production. Although the use of pesticide application has contributed tremendously in ensuring regular supply of fresh vegetables to urban markets in Ghana, this has happened at a high cost, as the health implications of the excessive use of pesticides have been enormous. Therefore, it is important to monitor and record the different thrips species found in Ghana. The study also examined the population dynamics of thrips in an effort to gather important information for both growers and researchers that could be used to improve thrips management programmes.

1.2 Research Objectives

1.2.1 Main Objective

The main objective of this study was to determine the species composition of thrips and their host range in Ghana.

1.2.2 Specific Objectives

The specific objectives were to;

1. Identify thrips species and their corresponding horticultural and ornamental host plants in some selected parts of Greater Accra and Eastern Regions.
2. Assess farmers knowledge of thrips and management practices employed against them.
3. Compare the suitability of two sticky traps in monitoring thrips populations andestablish the possible presence of the invasive species, *Thrips palmi* in Ghana.
4. Determine the population trends of these insects in these parts of Ghana and establish a relationship between trap catches and weather factors (temperature and rainfall).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Taxonomy of Thrips

De Geer in 1744 (Physapus), first described these insects and Linneaus later placed the species known at the time, in a genus called Thrips, and in 1836, Haliday ranked these insects to the Thysanoptera order. Thysanoptera are distributed worldwide predominating in tropical, subtropical, and temperate regions (Lewis, 1997; 1973).

From the order Thysanoptera, more than 5000 species from two suborders: Terebrantia and Tubulifera and in nine families: Merothripidae, Aeolothripidae, Heterothripidae, Adiheterothripidae, Thripidae, Uzelothripidae, Fauriellidae, and Phlaeothripidae, are recorded (Mound, 1997). About 93% of Thrips species belong to the families Thripidae and Phlaeothripidae (Mound, 1997). Over 2000 species make up the family Thripidae in two hundred and ninety genera recorded globally (Mound and Morris, 2007). These species are grouped into four subfamilies, including; Panchaetothripinae, Dendrothripinae, Sericothripinae and Thripinae with 125/35, 95/13, 140/3 and 1700/225 species/genera, respectively (Mirab-balou and Xue-xin, 2011). The following eight genus-groups are currently used: *Anaphothrips*, *Frankliniella*, *Thrips*, *Megalurothrips*, *Taeniothrips*, *Mycterothrips*, *Scirtothrips* and *Trichromothrips* genus-groups (Mound and Palmer, 1981; Mound and Masumoto, 2009). Most thrips of the family Thripidae associate mainly with living plants and so, majority of thrips pests fall within this family (Kambiz, 2014). There are several genera each with at least a few species regarded as pests of various crops worldwide. Some of such genera include; *Anaphothrips* Uzel, 1895, *Aptinothrips* Haliday, 1836, *Caliothrips* Daniel, 1904, *Chirothrips* Haliday, 1836, *Dendrothrips* Uzel, 1895, *Limothrips* Haliday, 1836, *Scirtothrips* Shull, 1909 (Moritz *et al.*,2009; 2004).

2.1.1 Thrips species

Some major species of thrips attacking crops in Africa include: African bean flower thrips (*Megalurothrips sjostedti*), *Thrips tabaci, Selenothrips rubrocintus, Frankliniella schultzei,Retithrips syriacus*, *Tubufera* sppand *Liothrips* spp (Banfor, 2009), Coffee thrips (*Diarthrothrips coffeae*), Black tea thrips (*Heliothrips haemorrhoidales*), Banana thrips (*Hercinothrips bicinctus*), Citrus thrips (*Scirtothrips aurantii*), Cacao or red banded thrips (*Selenothrips rubrocinctus*), Tomato thrips (*Ceratothripoides brunneus*), Cereal thrips (*Haplothrips spp*), Tea thrips (*Scirtothrips kenyensis*), the Western flower thrips (*Frankliniella occidentalis*) (http://www.infonet-biovision.org/thrips, accessed on 29/09/2014) and *Thrips palmi*.

2.2 Biology of thrips

2.2.1 General biology

Most thrips attacking plants have a simple life history that varies but little fundamentally in the different species (Bailey, 1938). After a few days the delicate, soft-bodied larvae hatch and immediately begin feeding gregariously. The length of all the stages varies, of course, with the temperature. Under favorable conditions the larvae attain full growth in 7 to 10 days, when feeding ceases and the larvae either drop to the ground or rest quietly on the host. Some mature larvae such as the pear thrips make an earthen cell in. the soil, in which they transform. During this period the wings and other organs develop, and in 4 to 14 days, the adult stage is reached (Bailey, 1938). During the growing season and the warmer parts of the year the generations more or less overlap. The greatest seasonal abundance depends on the requirements of the particular species. Ordinarily, however, thrips are most numerous during the warmer and drier seasons; being small and rather delicate, they are destroyed by severe weather conditions.

2.2.2 Life cycle of thrips

Thrips undergo gradual metamorphosis. A generally, female thrips deposit eggs in slits made in the leaf tissue by their sharp ovipositors. Each female lays 25 to 50 eggs which hatch (in two to seven days) into active nymphs. Immature thrips resemble adults, but the immature lack wings and are lightly coloured. There are two nymphal stages followed by two resting stages: the prepupa and pupa. The resting stages can be found either on the host or in the soil below the host. Under favourable conditions, the developmental period from egg to adult ranges from 11 days to three weeks depending on the species, hence, a population may increase quite rapidly. Parthenogenesis occurs in many species. Eggs take from 3 to 16 days to hatch according to the species and conditions.

2.2.2.1 Eggs

Thrips lay very tiny egg, with each egg measuring about 0.25 mm long and 0.1 mm wide. They appear whitish when freshly laid and turn pale yellow toward maturation. Eggs are usually laid singly inside the plant tissue, and are therefore not visible. However, some thrips, for example *Haplothrips* spp, lay eggs singly or in clusters attached to the plant surface (http://www.infonet- biovision.org/thrips, accessed on 29/09/2014).

2.2.2.2 Larvae

The metamorphosis of thrips is somewhat intermediate between incomplete and complete. The first two instars are called larvae. The first and second instar larvae are very small (0.5 to 1.2 mm), elongated, slender, and vary in colour from pale-yellow, orange or red according to the species. They have piercing-sucking mouthparts. They resemble a miniature version of the adults but do not have wings.

2.2.2.3 Pre-pupae and pupae

In the suborder Terebrantia, the first two instars are followed by the third and fourth instars which are inactive, do not feed, and have external wing pads. The third instar is called a prepupa and the fourth the pupa, and are often spent on the ground in soil or litter. In the suborder Tubulifera, the third and fourth instars are prepupae and the fifth pupa. They possess short wing buds but lack functional wings. During these stages, thrips are inactive and do not feed and therefore they do not do cause any damage to the plants. Pupation may occur on a plant or in the soil beneath, depending on species (http://www.infonet-biovision.org/thrips, accessed on 29/09/2014).

2.2.2.4 Adults

Adult thrips are tiny, measuring approximately 1 to 1.5 mm long, slender and usually winged. The wings are long, narrow and fringed with long hairs, and at rest, are tied on the back along the body. Their colour varies according to the species. Most species are black, brown or yellow.

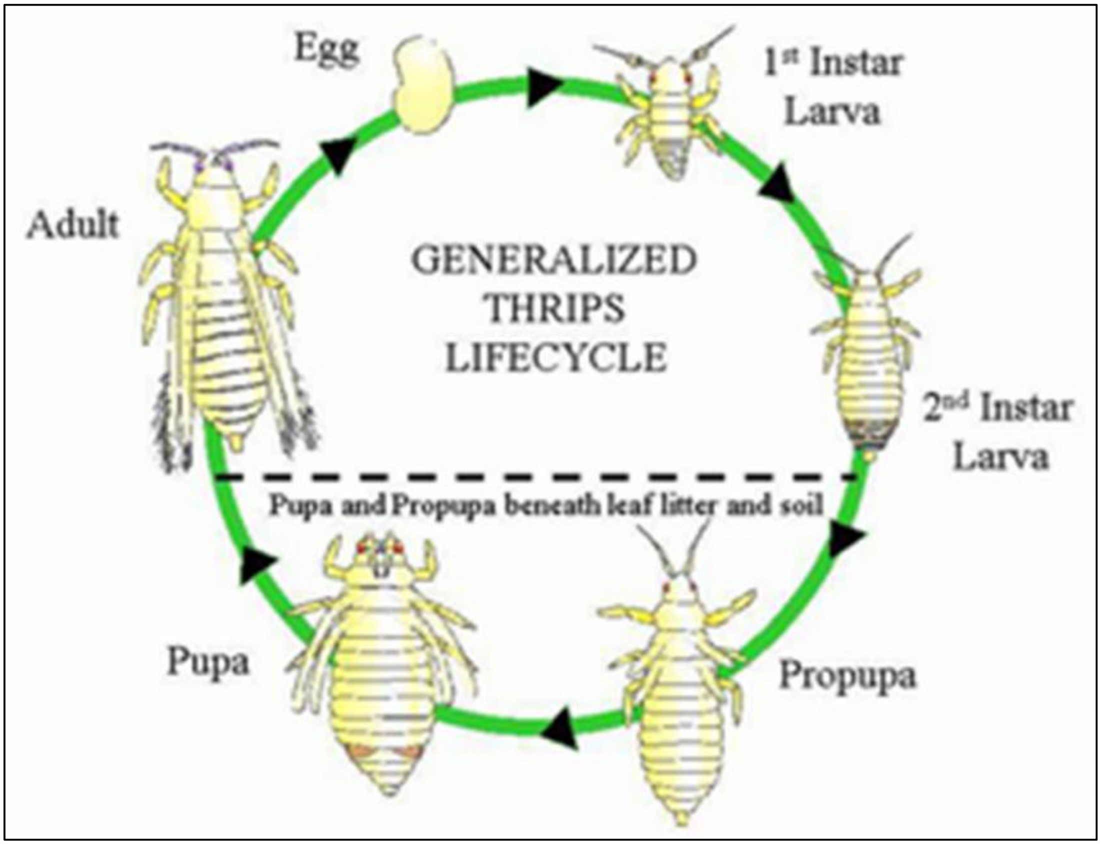


Figure 1: Diagram showing a generalized thrips lifecycle (Center for Invasive Species Research, University of California Riverside).

2.3 Behaviour and habits

2.3.1 Dispersal behaviour

Thrips generally depend on two modes for dispersal; artificial and natural dispersal (Hector, 2006). Artificial dispersal is usually human-assisted and is facilitated by the increasing international transportation of agricultural products. Thrips are easily transported in various products including potted and cut flowers and several fruits and vegetables that are imported and exported across borders. They are difficult to spot in a port inspection due to their small size. The eggs of thrips are found inside plant tissues and signs left by the ovipositing female are minimal (Hector, 2006). Secondly, natural dispersal is accomplished mostly by fight. Flight is the major method of active dispersal; however, they can be aerially dispersed by drifting in wind currents for many miles. Just before flying, thrips of the macropterous forms bend their abdomen and use setae located on abdominal tergites V to VIII to comb those located on the wings with the objective of increase the surfacing area of the wings, facilitating take-off (Ellington, 1980).

2.3.2 Feeding behaviour

The mouthparts of thrips are one of the identifying characters of the order Thysanoptera and are located on the underside of the head, forming a mouth cone. This structure is formed by a single mandible. Thrips use the mandible to feed by "punching" a hole in the external walls of the tissue to be fed upon and then using the stylets to suck the liquids from inside the tissues (Kirk, 1997). Thrips generally, feed on diverse plant tissues including leaves, flowers, fruits, pollen and some fungal tissues such as spores and hyphae. Thrips display a similar feeding behavior for all plant tissues. Once landed on an appropriate substrate on which they want to feed, thrips start a process of probing on the tissues. They start using the legs and antennae, walking in circles or forming "figure eight" on the tissue. Once they find a suitable spot, thrips use their mandible to probe and open a small hole in the cell wall (Hector, 2006). A small amount of liquid comes from this small puncture. Thrips test the liquid for the correct nutrients compositions using their palps. If the tissues and nutrient composition are adequate, they use their mandible and head to punch a bigger hole in the tissue and start feeding. This causes nearby cells to collapse. If the damage occurs in the ovary in the flower, these marks will become magnified during the fruit development and the scars become very noticeable, reducing fruit quality (Kirk, 1997a; Liburd *et al.*, 2006).

2.3.2.1 Pollen-feeding

Pollen-feeding is also observed in thrips, mainly among flower thrips that feed on individual pollen grains. Depending on thrips species and instar, grain volume, and temperature (Kirk, 1987), the time spent on each pollen grain varies and falls between 3 to 120 seconds. Thrips can ingest pollen from the anthers or the grains found around the flowers and leaves. The potential damage that flower thrips can cause on pollen quantity depends on the plant production of pollen and thrips population present in the field. Extremely high population of thrips and very low production of pollen may affect the availability of pollen grains for fertilization (Hector, 2006). A single thrips could potentially destroy between 0.2-0.7percent of the pollen in a flower per day, assuming that it feeds exclusively on pollen (Kirk, 1987). In addition, thrips might destroy the anthers or the pollen on stigmas, which would affect pollination. The damage caused by thrips on plant fertilization depends on many factors such as timing, amount of pollen produced by the plant, amount of pollen destroyed by thrips, effectiveness of pollinators and temperature (Kirk, 1987). In addition to interfering with pollen availability and fertilization, thrips balance their diet by consuming other plant tissues (Kirk, 1997).

2.3.3 Predation

Thrips show a feeding behavior known as predation. A few specialist predators among thrips have some behavioral adaptations such as speed or color among others. The most common preys are mites and eggs. Some of the most common species of predatory thrips are *Haplothrips kurdjumovi* Karny, which feed on moth and mite eggs (Putnam, 1942), *Scolothrips sexamaculatus* (Pergande), which feed on mites that form webs (Trichilo and Leigh, 1986), and *Trichinothrips breviceps* Bagnall, which feed exclusively on psocids (Kirk, 1997). Some species of thrips feed on other thrips larvae. These include; *Aeolothrips intermedius* Bagnall, which feeds on thrips immature through their abdomen (Kirk 1997a). Some of the polyphagous thrips are well known as pests. However, they can switch from being pests to become predators. For example, *Frankliniella occidentalis* (Pergande) feed on mites in cotton (Trichilo and Leigh, 1986) and prey on two spotted spider mites.

2.3.4 Migration

Migration is not pronounced. The adults move about very little when sufficient food is available. Thrips species are generally weak fliers. Local migrations, such as occur in the pear thrips and the western flower thrips, are usually occasioned by a shortage of food or by the discovering of a more desirable supply (Bailey, 1938). In such events, the migration is for only a few hundred yards, generally in the direction of the prevailing wind.

Thrips are found on the most tender, succulent portions of the host plants; usually in buds, in blossoms, under bracts, in leaf sheaths, or on bulbs. Usually the host range of thrips is very wide, though some species, such as the gladiolus thrips, exhibit a narrower choice than others. This cosmopolitan host range and the habit of living somewhat concealed make control difficult and eradication almost impossible. Heavy rains and cold weather are most important factors that affect natural control of thrips (Bailey, 1938).

2.3.5 Reproductive behaviour

Factors such as plant species and quality (age, vigor, phenological stage) affect the net reproductive rate of thrips populations. Abiotic conditions affect the reproduction of thrips as well. These include light regimen, temperature, and humidity (Kirk, 1997b). There are relationships among thrips from the same or from different species and these can be understood through some intrinsic behaviour displayed. The first one is the use of semiochemicals such as alarm pheromones, aggregation pheromones, and defensive mechanisms, (Terry, 1997). Males of *F. occidentalis* produce some type of substance with an attractive effect on females of the same species (Kirk and Hamilton, 2004). The females of Terebrantian species raise the tip of their abdomen during oviposition, test the plant tissues using the setae in the last abdominal segment, and insert the ovipositor into plant tissues (Hector, 2006). While in this position; the saw-like ovipositor cuts a space for the egg in the tissue, which is pushed out by a contraction of the abdomen. Thrips prefer to lay their eggs in mature non-expanding tissues to avoid having the eggs crushed by the expanding cells (Terry, 1997). Oviposition preferences depend on the species. Most species prefer to oviposit on leaves or on floral tissues. In citrus, *F. bispinosa* oviposit in the floral tissues, it has a preference for the pistil- calyx area followed by the petals and finally, filaments and anthers (Childers and Anchor, 1991). Other thrips species lay their eggs close to the inner veins of the leaves or in the fruits. The place and plant stage determines the damage caused by these thrips due to oviposition. Thrips that lay their eggs and feed in the commercial part of the plant, flower or fruits, are considered as major pests of agricultural sector (Hector, 2006).

2.4 Ecology of thrips

2.4.1 Ecology and diversity

In Thysanoptera, Tubulifera has one family and Terebrantia eight families distributed worldwide (Moritz *et al.*, 2004b). The females in Tubulifera do not have an ovipositor and the distal abdominal segment is similar to the males. This segment is tubular in shape and ends in a series of setae. The forewings in Tubulifera have neither venation nor setae except for the base. Terebrantia are the most common suborder and the one that has the greatest effect on agriculture. Close to 94% of the total pest species are in this suborder, all of them in the family Thripidae (Moritz *et al.*, 2004b).

2.4.2 Effects of climatic conditions on thrips population

The influence of weather on the activity and rate of multiplication of insects and the natural growth of population determines the total variability in thrips populations in crops (Kirk, 1997). Understanding the effects of weather on thrips population dynamics is essential in predicting thrips population. Weather variables such as rainfall, temperature, relative humidity and wind have significant effects on thrips numbers (Kirk, 1997). Relatively high temperatures and lack of rainfall have been associated with increase in onion thrips population, while high relative humidity and rainfall reduce thrips population (Hamdy and Salem, 1994). Temperature and relative humidity also influence the intrinsic rate of natural increase of the thrips (Murai, 2000). A basic understanding of the relationship of these factors with thrips population aids in developing an integrated management strategy for thrips in crops and in determining the potential pest management needs for a given climatic trend (Waiganjo *et al.*, 2008).

2.5 Insecticide resistance

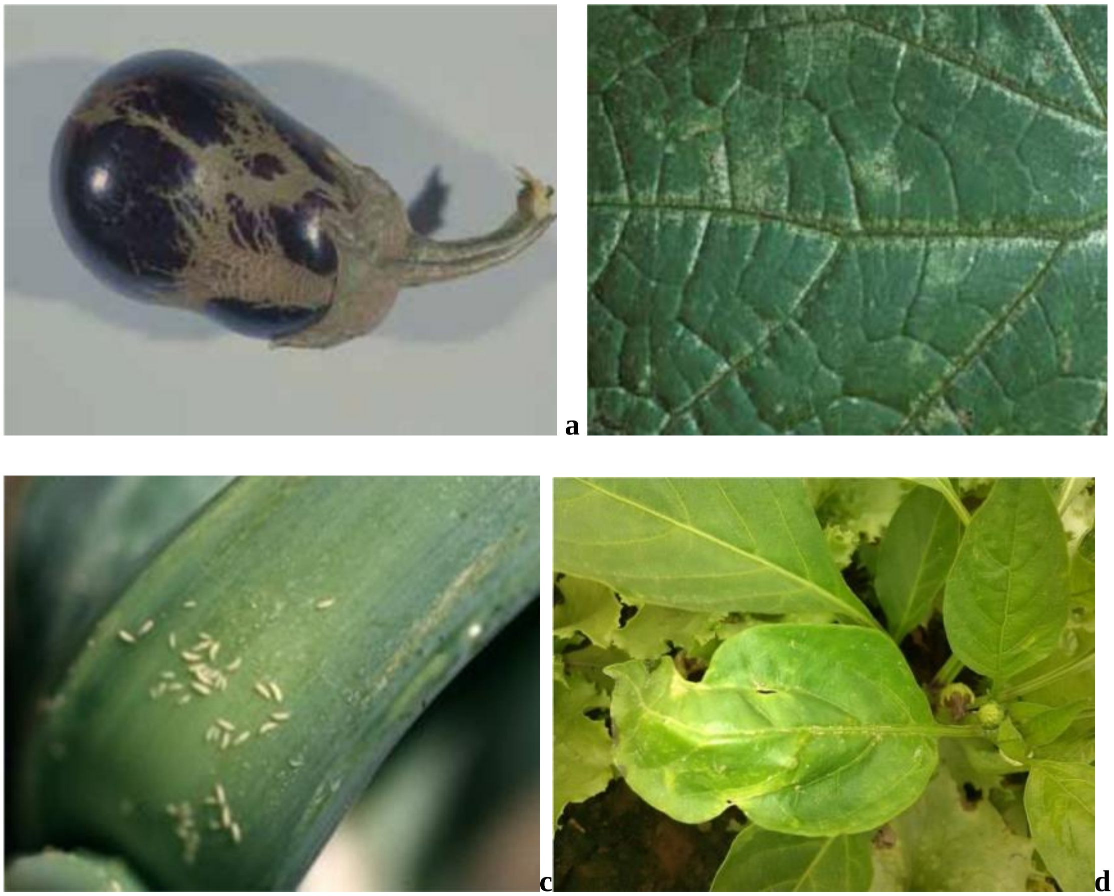
In an attempt to protect vegetable crops from high pressure from insect pests, farmers rely mainly on indiscriminate and widespread use of synthetic insecticides in vegetable cultivation and this has led to insecticide resistance development in the insect pests (Odhiambo *et al.*, 2010).With insect populations developing resistance to insecticides, the probability of losing most of the beneficial insects including pollinators and natural enemies is extremely high due to increase in dosage and frequency of insecticide application (Owusu, 1997). Lack of adequate knowledge on appropriateness of insecticides, application time and dosage has resulted in decreased yields and undesirable chemical residues in produce.

The development of resistance to insecticides is of paramount concern with thrips (Sparks *et al.*, 2001). The potential for resistance is high because there is generally a single mode of action or chemistry that is effective for each pest species, and because female thrips reproduce without mating (parthenogenetic reproduction). Thus, thrips that survive an insecticide application produce individuals that can survive exposure to the same type of insecticide. The location of thrips on onion plants and other plants also affects the efficacy of insecticides and the development of resistance. In the neck and leaf folds, thrips are somewhat protected from insecticide exposure. This reduces the effectiveness of the treatment, but may also ensure that some susceptible individuals remain within the population (Sparks *et al.*, 2001). Resistance has not only developed against insecticides targeting western flower thrips, but also insecticides used to treat other pest species. Correspondingly, a number of different resistance mechanisms have been characterized to date, including metabolic detoxification, reduced penetration, altered target site resistance, and knockdown resistance (Bielza, 2008). Behaviour and ecology of thrips can minimize exposure to insecticides and they are well suited to evolve resistance to multiple classes of insecticides. There have been incidences of resistance reported to all major classes of insecticides from all regions of the world (Bielza *et al.*, 2007b; Kay and Herron, 2010; Weiss *et al.*, 2009) since the first reported case of control failures with insecticides (toxaphene, an organochlorine). Despite early reports regarding difficulties with pyrethroids, they have continued to be used against western flower thrips extensively, with the same outcome of resistance development (Thalavaisundaram *et al.*, 2008).

2.6 Economic importance of thrips

2.6.1 Direct damage

Many thrips are destructive pests of plants, especially grain crops, fruits and vegetables, and ornamentals. Feeding activities result in plant deformities, scarring, loss of yield, and in some cases, transmission of plant pathogens. Predatory thrips are however beneficial in that they may control mites and other small insects that are pests. Most thrips considered as severe pests are polyphagous. Due to their high adaptability, thrips can feed on various resources and modify their larval stages, adapting to various environmental conditions. Thrips are notorious in moving their population to alternate hosts during the season when the main hosts are not very favourable. For example; the flower thrips, which reproduce and feed in the flowers of crops and in the absence of flowers, they migrate to nearby crops and wild flowers to continue their cycle (Kirk, 1997b). Thrips pierce plant cells with their mouthparts and feed on the plant cell sap, leading to the collapse of plant cells. This results in deformed flowers, leaves, stems, shoots and fruit. Silvery flecked scars or small black fecal spots also develop on the leaves and fruits (Plates 1). Thrips also damage buds and flowers through their egg laying and this often leads to deformed fruits being formed (Sonya *et al.*, 2004).



a b c d

Pate 1: Direct damage**: a)**Scarring on garden egg fruit, **b)**Silvering damage to a cucumber leaf(L. Zhang and H. Brown, Diagnostic Services, Darwin, 2008), **c)** Thrips and damage on onion leaves (Whitney Cranshaw, Colorado State University, Bugwood.org) and **d)**Feeding damage on sweet pepper plant.

2.6.2 Virus transmission

2.6.2.1 Tomato spotted wilt virus (TSWV)

In addition to causing direct damage to crops, thrips also spread plant viruses. For example, the Western Flower Thrips (WFT), onion thrips, and tomato thrips spread the TSWV. Plate 2 shows a typical example of fruit damage in tomato associated with thrips virus transmission to the tomato plant. The concentric ring pattern is indicative of TSWV. This damage can show up many weeks after virus transmission occurred. TSWV was first found in Western Australia in the 1920s, causing sporadic epidemics in vegetable and ornamental crops (Sonya *et al.*, 2004). The efficiency with which the virus is transmitted differs between species: WFT is the most efficient vector of TSWV. TSWV affects mainly tomatoes, capsicum, and lettuce where it can cause up to 100 per cent crop loss. Plants such as grapes, stone, pome fruit, strawberry, brassica, and cucumber are not affected by the virus (Sonya *et al.*, 2004). Plants infected with TSWV show one or more of the following symptoms: irregular necrotic (dead) spots on leaves, black or purple stem streaks, chlorosis (yellowing), chlorotic blotching, chlorotic or necrotic ring spots and line patterns on leaves and fruit, leaf distortion and deformation, dropping of leaves or shedding of buds, dieback and leaf collapse, stripes on petals and plant death caused by wilting (Sonya *et al.*, 2004).


a**b**

Plate 2:a)TSWV symptom/ damage to susceptible tomato fruit **b)** Dimpling of tomato fruit surface caused by thrips feeding. **(**Authors*:* D. Riley, R. Srinivasan, S. V. Joseph, and S. Diffie).

2.6.2.2 Tospovirus

Tospovirus is one of the most damaging groups of pathogens in agriculture. Recently, the spread of infected plants and vectors has increased due to the increase in international trade, worldwide (Hector, 2006). Thrips and viruses are probably two of the most difficult things to detect in the ports of entry. Thrips eggs inside the plant tissues infected with the viruses are virtually impossible to detect (Lathman and Jones, 1997). There are 16 species of viruses in the genus *Tospovirus*, family: Bunyaviridae, recognized as plant pests, and they are transmitted by 11 species of thrips, of the family Thripidae (Ullman, 2005).

Thrips acquire viruses in the first or early second instar when there is a close connection between mid-gut, visceral muscles and salivary glands (Moritz *et al.*, 2004a). Once the wing muscles start developing and the supra-oesophageal ganglion moves towards the head the connection between the salivary glands, the mid-gut, and the visceral muscles is ended stopping the movement of virus particles into the salivary glands. If the thrips did not acquire the virus during this short period, it will not be able to acquire the virus due to the lack of this connection. In adult thrips, the virus is located in the malpighian tubes, in the lumen, the hemocoel, and in the salivary glands. Until recently, the only proven way thrips transmit the virus is through the salivary glands during feeding. However, there is enough evidence to support the possibility that the virus might be transmitted through excrements and oviposition wounds (Moritz *et al.*, 2004a).

2.6.3.0 Thrips as quarantine pests

Thrips pose a phytosanitary risk to agricultural crops in international trade. *Thrips palmi* for example is an A1 quarantine pest for European Plant Protection Organization (OEPP/EPPO, 1989) and an A2 pest for The Caribbean Plant Protection Commission (CPPC). In the EPPO region, *T. palmi* presents a serious threat to a wide variety of crops grown under glass. It could possibly establish on field crops in southern areas of the EPPO region, as has happened for *Frankliniella occidentalis* (EPPO/CABI, 1996a) which was originally considered to present a risk only under glass. *Thrips palmi* is not apparently a vector of TSWV (EPPO/CABI, 1996b) but it does vector closely related viruses in Japan and Taiwan.

2.6.3.1 *Thrips palmi*

Thrips palmi is a polyphagous pest of much economic importance (Kirk 1997). It has a wide host range that includes at least 50 different plant species (Wang and Chu 1986). Damage caused by *T. palmi* is primarily due to feeding by adults and immature on leaves and fruits of its host plant. Feeding may result in damaged terminals of the host, bronzing of leaves, which at the time of severe infestation may completely dry and die off, as well as production of scarred and deformed fruits. *T. palmi* may also cause host damage by transmitting at least 6 of the known tospoviruses (Nagata *et al.*, 2002). Worldwide serious infestation of *T. palmi* has been detected on plants from family Solanaceae (eggplants, pepper, and potato), Cucurbitaceae (cucumber, watermelon, cantaloupe, and squash), and Leguminosae (kidney bean, snap bean, broad bean, cowpea, soybean, and white clover) (Talekar 1991; Nakahara, 1984). *T. palmi* is native to Southeast Asia, specifically at Java (Indonesia) where it was reported by Karny (1925) as a pest of tobacco.

2.6.3.2 Distribution of *Thrips palmi*

Its distribution was limited to Southeast Asia until the mid-1970s (Capinera, 2008) when a serious outbreak occurred in southern Japan (Sakimura *et al*., 1986). Subsequently, it became established in most of the Asian countries; Bangladesh, Brunei Darussalam, China, Hong Kong, India, Japan, Malaysia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan and Thailand. Currently, *T. palmi* has a wide distribution around the globe and it occurs in almost all the habitable landmarks of the world: Australia, Guam, New Caledonia, Samoa, Wallis and Futuna (Oceania); Netherland (Europe); Mauritius, Nigeria, Reunion, and Sudan (Africa); Brazil, Guyana, and Venezuela (South America); Antigua and Barbuda, Barbados, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Martinique, Puerto Rico, St. Lucia, St. Kits and Nevis, Trinidad and Tobago (Central America and Caribbean); Hawaii and Florida (North America) (CABI, 1998).

2.6.4 Thrips as pollinators

Thrips pollinate numerous plant species, either alone or in conjunction with other vectors (animals, wind). An adult thrips can transport up to several hundred pollen grains. They can move within a plant, between neighbouring plants, or even be transported on the wind to distant conspecific plants. Some species are highly specific to particular host blossoms (thrips.info/wiki/Thrips_and_pollination, accessed on 30/09/2014). Wind-pollination is commonly confused with thrips-pollination because netting rarely can exclude these insects, and plant breeders relying on hand pollination for specific crosses sometimes obtain unusual results due to pollen carried by thrips. Some thrips species are known only from particular hosts but the degree of thrips host specificity is often uncertain due to lack of detailed observations (Mound, 2013). Female and male thrips visit male blossoms at anthesis cued by scent, colour and possibly form. They feed on pollen and mate. Gravid females primarily oviposit here or on other male anthesis (period during which a flower is fully open and functional) blossoms but can also move to preanthesis male blossoms for oviposition. Rapid build-up of thrips populations can occur on male blossoms alone or on sterile (but usually nutritive) preanthesis male blossom appendages, prior to female blossom anthesis (thrips.info/wiki/Thrips_and_pollination, 30/09/2014).Certainly with so many species of Thysanoptera known to utilize pollen, the potential for thrips to effect pollination is possible. However, thrips have been systematically overlooked by pollination biologists. These small insects have generally been considered only a minor or secondary contributor to pollination of some plants, many of which are crops. This attitude is partly due to thrips lacking a number of characters that are deemed essential to be an efficient pollinator (Kirk, 1997a). Such characters include; thrips are tiny and have no specific organs or structures that carry pollen; they carry only a small number of pollen grains per individual; and they are assumed to be poor fliers with little directed flight, and rarely leave their flowers. However, these traits are not always true for thrips, nor are these traits always limitations. Thrips do have some directed flight, and some species do move between flowers very often. Members of both Frankliniella and Thrips genera are considered important pollinators of some crops. Even though individual thrips only carry a few grains, sometimes up to hundreds of grains (Kirk, 1997a), they can move between plants and flowers in high numbers.

2.7 Management strategies for thrips and spread of TSWV

2.7.1 Monitoring

Monitoring to identify when thrips arrive and to determine population levels is helpful in designing an appropriate control strategy. The numbers present can be used to determine action thresholds for applying pesticides. When considering appropriate action threshold levels, it is important to remember that no single number will always be a reliable guide. Climate is a factor to consider in designing control strategies. Hot and dry conditions favor thrips damage, and cool rainy weather hinders their damage. In drier years, fewer thrips per leaf can be tolerated before yield losses result (Fournier *et al.*, 1995). In onions, thrips must be controlled before the crop reaches the early bulbing stage, so that populations do not exceed manageable levels (Coviello *et al.*, 1993). Sticky traps (figure 2) could be placed in the empty greenhouse to attract many of the remaining adult thrips. It is important that the greenhouse contains no plant material for this strategy to work.

Figure 2: Yellow sticky traps used to monitor thrips in greenhouses and in fields. (Sonya *et al.,* 2004)

2.7.2 Cultural control

2.7.2.1 Farm sanitation

Weed destruction in the field and surrounding margins can help to reduce thrips populations, since these areas serve as overwintering and re-infestation sites. Drought stress increases the susceptibility of onions to thrips damage. Adequate irrigation throughout the growing season is a critical factor in minimizing damage (Fournier *et al.,* 1995). Thrips are particularly attracted to flowering weeds as they feed on the pollen. Thrips feed on and reproduce in weeds, particularly if there are no cultivated crops being grown. When a new crop is planted the thrips move off the weeds and onto the new crop. Weed-free areas of at least 10 m around the crop are necessary. This can be bare ground, closely mown grass, concrete, stones, or some other hard surface. Care should be taken when spraying weeds with herbicides because as the weeds die off, thrips can move off the weeds onto crop (Sonya *et al.,* 2004). Weeds act as reservoirs for TSWV and thrips. Plants infected with TSWV should be removed when the first symptoms of the disease are seen. Dispose of plants by burning or burying (Sonya *et al.,* 2004). The plants may be sprayed with insecticide first, to ensure that any thrips infected with TSWV are killed. Seeds do not habour TSWV; hence, it is advisable to grow plants from seeds where possible. However, if buying seedlings check with suppliers to ascertain that they monitor for thrips.

2.7.2.2 Soil fertility

Soil fertility management may also affect thrips infestation and damage. Lack of adequate soil calcium may invite higher populations of thrips (Rateaver and Gylver, 1993). Nutritional balance can reduce thrips attack. High nitrate levels will invite thrips, and the effects of excessive nitrate are compounded by shortages of potassium, sulfur, boron, and manganese. Foliar applications of soluble calcium will balance the excess nitrogen (Cantisano, 1999).

2.7.2.3 Thrips proof mesh

Thrips in confined environments such as glass or screen houses can be prevented by barriers of fine mesh which help to prevent thrips' movement. However, this mesh is expensive and since there is need to cover all vents and doorways, air circulation is reduced and extra venting may be required. Trials have indicated that the maximum hole size for the exclusion of WFT is 0.192 mm (Sonya *et al.*, 2004).

2.7.2.4 Greenhouse sterilization

Greenhouses should be sterilized between crop plantings. This could be done by steaming the soil to kill pupae and by fumigating the greenhouse to kill adults (Sonya *et al.*, 2004). Alternatively, keep the greenhouse hot, dry, and empty for at least one week, or longer in cold weather. Any thrips in egg or pupal stages will hatch and subsequently die.

2.7.2.5 Plant quarantine

The spread of thrips and TSWV mostly takes place through the movement of plant materials (Sonya *et al.*, 2004). So, it is good to inspect incoming plant material thoroughly for thrips. Plants are held in a monitored quarantine area if possible for up to two weeks. This allows enough time for all eggs to hatch and pupae to emerge. Quarantining plants ensures that they are not infected with TSWV. A quarantine area may be a glasshouse used specifically for that purpose, or a sectioned-off holding area. This can be made using a double thickness of shade cloth treated with permethrin.

2.7.3 Biological control of thrips

2.7.3.1 Parasitism and predation

A number of beneficial organisms work to suppress thrips. These include ladybird beetles, minute pirate bugs, ground beetles, big-eyed bugs, lacewings, hover flies, predatory mites, and spiders (Hoffmann *et al.*, 1996). However, these predators and parasites may be hampered by the fact that thrips feed under close-fitting leaves and down in the leaf sheaths where they are difficult for predators to find. Insecticides, even those cleared for use in organic production; also tend to work against beneficial predators and parasites. They should therefore be used minimally and applied with caution **(**Kuepper, 2004**)**. Occasionally, thrips populations may explode, as large numbers migrate from nearby vegetation. In such circumstances, in-field populations of beneficial predators and parasites may not be adequate. The numbers of predatory and parasitic insects and arachnids can be increased on the farm by providing protective habitats for them. These habitats; often called refugia, can be integrated into crop rotation planning **(**Kuepper, 2004**)**.Naturally occurring fungal diseases can also devastate thrips populations (Hoffmann *et al.*, 1996).

2.7.4 Chemical control

Thrips can be difficult to control effectively with insecticides, partly due to their mobility, feeding behavior and protected egg and pupal stages (Bethke *et al.*, 2014); hence, improper timing of application of insecticides, failure to treat proper plant parts and inadequate spray coverage when using contact insecticides, could be likely mistakes that can prevent potentially effective insecticides from actually providing the needed control (Bethke *et al.*, 2014). Therefore, taking action before the thrips become established, helps limit population increase. It is also good to reserve the insecticides recommended for the control of thrips until thrips is found in crops. Use small droplets (less than 100 microns) rather than large droplets, as they are more effective. Droplet size can be checked using water-sensitive paper. The leaves stay wet longer and prolong exposure of the thrips to the insecticide (Sonya *et al.*, 2004). Mixed insecticides may not be compatible and could cause phytotoxic effects to the crop and be dangerous to human health. This would likely increase the level of resistance in the thrips population, as thrips are being exposed to multiple insecticides, rather than just one. Proper control of thrips should take place before flowering where possible because once thrips enter the flowers; they are difficult to reach with insecticides as they are hidden. The pH affects the activity of insecticides and so should be checked (Sonya *et al.*, 2004). A neutral pH is best (pH 6.5 to 7.0).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study site

In this study, a survey of vegetable crops and ornamental plants was undertaken in some vegetable growing areas and ornamental gardens in Greater Accra and Eastern Regions of Ghana (Table 1).

Table 1: Localities from which thrips were collected

Region	Locality
Eastern Region	Akuapim-Mampong
	Tutu-Akuapem
	Ahwerase
	Aburi Botanical Gardens
Greater Accra	Ashaiman
	Dzorwulu: North Dzorwulu and Ebony
	Opebia (Kotoka International Airport area)
	Haatso
	Tema Harbour
	East Legon
	University of Ghana farm; Legon
	Department of Animal Biology and Conservation Science, University of Ghana, Legon

Accra Metropolitan Area lies in the coastal Savannah zone of Ghana with a bimodal rainfall pattern. It covers about 240 square kilometres with agricultural lands covering about 1,091 hectares (MoFA, 2013). The average annual rainfall records between 750 mm to 810 mm and the mean monthly temperature ranges from 24.7^{o}C to 28^{o}C with an average of 26.8^{o}C (mofa.gov.gh/site/?page_id=1561,accessed on 15 February 2015). In Accra, there are about 800-1000 vegetable crop farmers of whom 60% and 40% produce exotic and indigenous or traditional vegetable crops respectively (Obuobie *et al.*, 2006). Major crops produced include exotic vegetable (Lettuce, cabbage, cucumber, spring onion and cauliflower while the traditional crops include; tomato, okro, garden eggs, onion, sweet and chilli pepper (Obuobie *et al.*, 2006).

3.2 Sample collection

A number of methods were employed in collecting thrips samples. Thrips were collected from flowers, leaves and twigs of host plants by beating and jarring. Thrips that fell unto the plastic tray placed under the host plants were picked off with a fine paint brush into the collecting fluid, a mixture of 70% alcohol and 5% acetic acid in the ratio 4:1 in plastic vials. Adult thrips were also collected from plants by taking samples of heavily infested leaves and flowers. Plant parts found with thrips were also slowly lowered into plastic bottles containing the collecting fluid and the cap applied. The plant parts were then shaken vigorously to dislodge thrips from them. Dislodged thrips in alcohol were transported to the laboratory for identification. Specimens stored in alcohol were kept in the dark to prevent loss of colour before identification.

3.2.1 Maceration of thrips for slide mounting

Sample specimens from field storage bottles were placed in watch glasses and collecting fluid replaced with fresh 60% alcohol and stored for 20 minutes and later replaced with 5%

Potassium hydroxide (KOH). The insect abdomen was gently punctured behind the hind coxae using micro- pins to allow rapid entry of the KOH (Palmer, 1990). When soft, the specimens were gently massaged to expel the body contents. Potassium hydroxide was washed off with 60% alcohol and stored for 15 to 25 minutes then replaced with Xylene and left to stand for 5 to 10 minutes and then washed off with 60% alcohol. Acetic acid was then introduced and allowed to stand for 5 to 10 minutes and then washed off with 60% alcohol. Specimens were then passed through a series of alcohol concentrations starting from 65%, followed by 75%, 85%, 90% and 95% ethanol to initiate gradual dehydration of the specimens. Thrips were placed in each of the above mentioned alcohol concentrations for 5 to 8 minutes to avoid any moisture interactions at the final stage of slide mounting.

3.2.2 Slide mounting

The process of mounting was facilitated by preparing a small mounting block. A clean 16mm diameter cover slide was placed on the mounting block and a drop of Canada balsam placed onto the centre of the cover slip and into this position, a specimen was placed with ventral side uppermost. The legs and wings were spread and the antennae straightened by pressing on the basal segments with a fine needle. A clean microscope slide was inverted and lowered firmly but gently onto the specimen. The preparations were allowed to stand untouched for one day until the specimens were firmly held on the slides.

3.2.3 Insect identification

The specimens were identified using identification keys according to Palmer (1990). Thrips were identified to species level. Identification was based on morphological features of the thrips. For reference purposes, the specimen on the microscope slide was placed with the head directed towards the determiner and on the right hand side, a label was placed indicating the host plant of the thrips, country, locality, date and name of collector (Coll.). On the left hand side, a label was placed indicating the name of specimen, name of author and name of the determiner (Det.).

3.3 Farmers' knowledge of thrips and insecticide usage pattern

A total of 50 farms were visited and the purpose of the survey explained to the farmers and 35 of them responsible for management decisions of their farms who consented were interviewed. Assessment was based on voluntary collaboration of the farmers. Each farm had more than one type of crop cultivated and management was mainly by family labour. A Questionnaire consisting of open and closed ended questions were designed and used to obtain data through interviews with farmers in the farms and direct observation of farming practices during interviews. The survey assessed farmers' knowledge of thrips and other insect pests, pest management practices, insecticide application pattern, storage and disposal of empty insecticide containers, precautionary measures taken during insecticide application and the source of farmers' technical knowledge on pest management. The data obtained from the survey were summarized using the Statistical Package for Social Science (SPSS) v20.0 and presented in tables, bar and pie charts.

3.4 Population trends of thrips

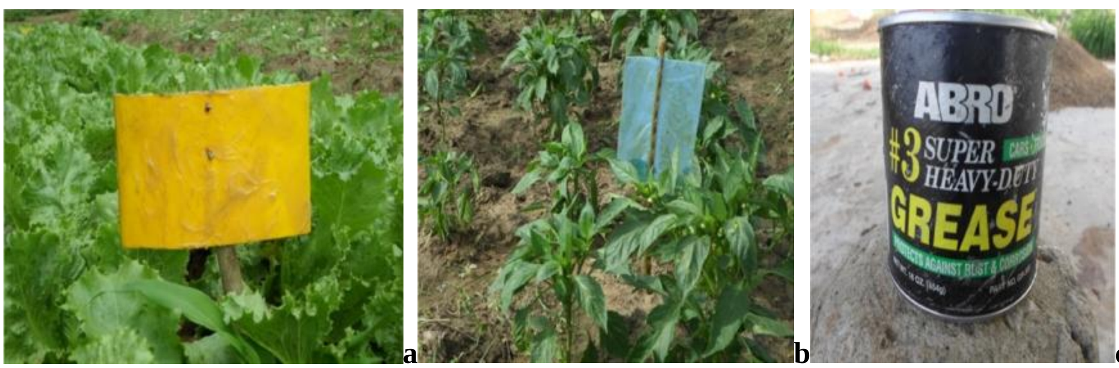
This study was aimed at evaluating and comparing the relative suitability of blue and yellow sticky traps in determining the relative abundance of thrips on the various host plants monitored.

3.4.1 Trap performance in capturing thrips

Plastic yellow plates measuring 25 cm by 20 cm (Plate 3a) were improvised. Blue cardboard papers measuring 25 cm by 20 cm (Plate 3b) were also improvised and each piece of the paper was inserted into a transparent poly bag. Grease (ABRO #3 super heavy-duty grease) (Banfo 2009), an adhesive was applied on surfaces of both the yellow and blue boards (Plate

3c). The sticky boards were then fastened to pieces of wood and pinned randomly in the field. Length of the wood was adjusted by replacing with longer ones as the plants grew taller. Each field had ten traps including five blue and five yellow traps placed 10 m apart. Traps were re-randomized every two weeks to minimize effects due to position of traps.

Adult thrips were recorded weekly. Polybags from traps were removed and sent to the laboratory and insects collected using fine paint brush (soaked in Xylene) into glass wells and viewed under a light microscope and counted. Trap catches were recorded with respect to the trap colour. At the same time, ten plants were randomly sampled. Leaves, flowers and stems of these plants were inspected. Flower petals were opened and inner surfaces examined for adult thrips. Adult thrips were counted with the aid of a magnifying hand lens.



a b c

Plate 3: (a) Yellow sticky trap**(b)** Blue sticky trap and **(c)** Grease container

3.4.3 Abundance of adult thrips on Vegetable crops

The abundance of thrips on plant species was studied on eggplant (*Solanum melonge*na), cucumber (*Cucumis sativus),* sweet pepper (*Capsicum annuum var)* and gboma (*Solanum macrocarpon),* cabbage (*Brassica oleracea var. capitata)*, *Amaranthus creutus*and lettuce (*Lactuca sativa*) which are some of the commonly cultivated vegetables in southern Ghana. Samples were collected from these crop canopies in commercial farms across the study area. Ten flowers or leaves (a flower or leaf per plant) were collected from every plot for each plant species. Samples were placed in brown envelopes and transported to the laboratory, dislodged in 70% ethanol, viewed under a microscope (OLYMPUS SZ61), counted and recorded. Data on abundance of adult thrips on each crop were averaged for all samplings and mean number of adults per crop compared using one way analysis of variance. Data was log-transformed ($\log_{10}$ (x+1)).

3.4.4 Abundance of *Thrips palmi* and associated thrips species

Four plant species including; eggplant (*Solanum melonge*na), cucumber (*Cucumis sativus)*, sweet pepper (*Capsicum annuum var)* and Gboma (*Solanum macrocarpon)*were examined in a commercial vegetable farm at East Legonfrom January 2015 to March 2015. These plant species were transplanted in early January 2015. Each crop was planted in a separate plot, but both plots were close to each other. On each plot, ten leaves/flowers per plot depending on the host plant (a leaf/flower per plant), were randomly collected. Samples were processed as described above (section 3.43 above).Adult thrips were mounted on microscope slides for further identification to species level.

3.4.5Within plant distribution of *Thrips palmi*

Thrips exhibit differential feeding preference for various parts of its host plants. Based on thrips abundance on the plant species sampled, *T. palmi* was the only thrips species collected on cucumber leaves; hence cucumber was used for this study. Cucumber was directly seeded on a flat ground. The field was irrigated once a week. Sampling began three weeks after planting. Within-plant distribution of *T. palmi* on cucumber was studied in a commercial field at Haatso with field size of 0.16acres. On each sampling date, three plants were randomly selected from the edges and middle point of the cucumber plot. Each plant was stratified into three sections: a freshly emerged terminal leaf bud (2-5 days old), a middle leaf and a bottom leaf (from the top). All samples were transported in brown envelopes to the African Regional

Postgraduate Programme in Insect Science (ARPPIS) laboratory, University of Ghana, Legon where samples were placed in a plastic bowl with 70% ethanol for about 30 minutes to dislodge various life stages of thrips. Samples were carefully taken out of the cup leaving thrips in ethanol. The plastic bowl with its content was then placed under light microscope to record number of adult and larval thrips.

3.5 Meteorological Data

Data on average daily temperature and rainfall were collected from the Ghana Meteorological Agency located at Mempasem in the Greater Accra Region. Average weekly temperatures and total weekly rainfall were calculated from the raw data and used to study their relationship with thrips population on sticky traps.

3.6 Statistical Analyses

Trap captured data for the 30 weeks of data collection were analyzed for the whole study period. Data on trap catches, abundance of thrips and within plant distribution of thrips were square root ($\sqrt{x}$) and log-transformed ($\log(x+1)$), respectively. The general analysis of variance was used to determine the effect of trap colour and variation in abundance and distribution of thrips. Where analysis of variance (ANOVA) showed significant difference among means of plant parts (treatment), the Tukey-Kramer honestly significant difference (HSD) test was used to separate the means for the preferred plant parts.

CHAPTER FOUR

4.0 RESULTS

4.1 Plant survey for associated thrips species

Various vegetable and ornamental plants as well as some tree crops and weeds randomly surveyed were found to host thrips species (Table 2). Thrips were found in flowers, leaves and fruits in all the fields surveyed. However, not all plant species contained thrips during the survey. For instance, no thrips were found in *Theobroma cacao* (Cocoa plants), *Citrus sinensis* (Orange plants) and *Carica papaya* (Paw-paw plants) (Table 2). More thrips were collected from cowpea plants followed by Gboma and Onion plants (Table 4).

4.2 Species composition of thrips

Thrips palmi Karny, *Megalurothrips sjostedti* Trybom, *Microcephalothrips abdominalis* Crawford, *Frankliniella schultzei* Trybom, *Thrips tabaci* Lindema, among other thrips species were collected and identified from various host plants across localities during this study (Table 3). *F. schultzei*, *M. sjostedti* and *T. palmi* were the most abundant thrips species on vegetable crops in terms of number of identified thrips on slide mounts (Table 4). On ornamental plants, *M. sjostedti* was the most abundant thrips species followed by *Haplothrips* sp. Among ornamental plants surveyed, *Thumbergia erecta* and *Rullia blumei* hosted most of the thrips followed by the *Jasminium* plant (Table 5).

Table 2: Plant species surveyed for associated adult thrips and estimated thrips population across some localities in Greater Accra and Eastern Region from July 2014 to March 2015.

Category	**Common name of plant**	**Scientific nameof plant**	**Thrips status**	**Estimated population**
Vegetable	Egg plant	*Solanum melongena*	Present	**
	Cowpea	*Vigna unguiculata*	Present	**
	Gboma	*Solanum macrocarpon*	Present	**
	Onion	*Allium cepa*	Present	**
	Tomato	*Solanum lycopersicum*	Present	**
	Pepper	*Capsicum annuum*	Present	**
	Sweet pepper	*Capsicum annuum var.*	Present	**
	Cucumber	*Cucumis sativus*	Present	**
	Amaranthus	*Amaranthus creutus*	Present	**
	Sorrel	*Hibiscus sabdariffa*	Present	**
	Lettuce	*Lactuca sativa*	Present	**
	Cabbage	*Brassica oleracea var. capitata*	Present	**
	Cauliflower	*Brassica oleracea var. botrytis*	Present	**
	Water melon	*Citrullus lanatus*	Present	**
	Leeks	*Allium ampeloprasum*	Present	**
	Spring Onion	*Allium fistulosum*	Present	**
	Okra	*Abelmoscus esculentum*	Present	**
Ornamentals				
	King's Mantle	*Thurmbergia erecta*	Present	**

****** = More than ten adult thrips collected per leaf/ flower of each plant species

Table 2 cont'd: Plant species surveyed for associated adult thrips and estimated thrips population across some localities in Greater Accra and Eastern Region from July 2014 to March 2015.

Category	**Common name of plant**	**Scientific name of plant**	**Thrips status**	**Estimated population**
Ornamentals	Blue bell flower	*Rullia blumei*	Present	**
	Verbena	*Verbena* sp	Present	**
	Moss red rose	*Portulaca grandiflora*	Present	**
	Turkeyberry	*Solanum torvum*	Present	**
	Jasminium	*Jasminium* sp	Present	**
	Nerium	*Nerium oleander*	Present	**
	Catharanthus	*Catharanthus alba*	Present	**
	Hibiscus flower	*Hibiscus rosa-sinensis*	Not found	
Tree crops				
	Cocoa trees	*Theobroma cacao*	Not found	
	Mango trees	*Mangifera indica*	Present	**
	Orange trees	*Citrus sinensis*	Not found	
	Pawpaw trees	*Carica papaya*	Not found	
Weeds				
	Grass	*Heliopsis sp*	Present	**

**** = More than ten adult thrips collected per leaf/ flower of each plant species

Table 3: Thrips species identified from associated host plants across some localities in Greater Accra and Eastern Region

S/N	Scientific Name	Family	Subfamily	Host Plant
1	*Acaciothrips ebneri*, Karny	Phlaeothripidae	Phlaeothripinae	*Capsicum annuum*
2	*Aleurodothrips fasciapennis*, Franklin	Phlaeothripidae	Phlaeothripinae	*Capsicum annuum*
3	*Antillothrips* sp*	Phlaeothripidae	Phlaeothripinae	*S. melongena, Abelmoscus esculentum*
4	*Chirothrips* sp	Thripidae	Thripinae	*Vigna unguiculata*
5	Dendrothrips sp*	Thripidae	Dendrothripinae	*Vigna unguiculata,*
6	*Dolichothrips* sp*	Phlaeothripidae	Phlaeothripinae	*Vigna unguiculata*
7	*Eurhynchothrips* sp	Phlaeothripidae	Phlaeothripinae	*Brassica oleracea var. capitata*
8	*Frankliniella shultzei*, Trybom	Thripidae	Thripinae	*C. annuum, S. lycopersicum, Allium cepa, C. annuum var.*
9	*Haplothrips* sp	Phlaeothripidae	Phlaeothripinae	*Vigna unguiculata, Rullia blumei, weeds*
10	*Hercinothrips femoralis*, Reuter*	Thripidae	Panchaetothripinae	*Capsicum annuum var*
11	*Karnyothrips* sp*	Phlaeothripidae	Phlaeothripinae	*Solanum melongena*, *Brassica oleracea var. botrytis*

* = Thrips species captured by sticky trap on the field

S/N = Number of thrips species identified

Table 3 cont'd: Thrips species identified and associated host plants.

S/N	Scientific Name	Family	Subfamily	Host Plant
12	*Megalurothrips sjostedti*, Trybom	Thripidae	Thripinae	*V. unguiculata, S. melongena, T. erecta, Verbena*
13	*Microcephalothrips abdominalis,* Crawford*	Thripidae	Thripinae	*Brassica oleracea var. botrytis, S. melongena*
14	*Panchaetothrips noxius*, Priesner	Thripidae	Panchaetothripinae	*Apium graveolensvar. dulce, Glycine max*
15	*Podothrips denticeps*, Hood*	Phlaeothripidae	Phlaeothripinae	*Solanum melongena*
16	*Retithrips syriacus*, Mayet*	Thripidae	Panchaetothripinae	*Apium graveolensvar. dulce*
17	*Selenothrips rubrocinctus*, Giard	Thripidae	Panchaetothripinae	*Capsicum annuum*
18	*Sericothrips adolfifriderici*, Karny	Thripidae	Thripinae	*Vigna unguiculata*
19	*Stenchaetothrips melanurus*, Bagnall*	Thripidae	Thripinae	*Rullia blumei*
20	*Stictothrips maculatus*, Hood*	Phlaeothripidae	Phlaeothripinae	*Capsicum annuum var*
21	*Taeniothrips xanthocerus*, Hood	Thripidae	Thripinae	*Lactuca sativa, Portulaca grandiflora*
22	*Thrips palmi*, Karny	Thripidae	Thripinae	*Cucumis sativus, Solanum melongena, Capsicum annuum var., Solanum macrocarpon*
23	*Thrips tabaci*, Lindeman	Thripidae	Thripinae	*Allium cepa, Cucumis sativus, Citrullus lanatus*

* = Thrips species captured by sticky trap on the field. **S/N** = Number of thrips identified.

Table 4: Number of thrips species on permanent slide mounts identified from various vegetable crops

Host plant	***Frankliniella schultzei***	***Megalurothrips***	***Thrips tabaci***	***Stenchaetothrips***	***Selenothrips sp***	***Eurhynchothrips***	***Aleurodothrips sp***	***Sericothrips sp***	***Thrips palmi***	***Chirothrips sp***	***Haplothrips sp***	***Karnyothrips sp***	***Taeniothrips sp***	***Dolichothrips sp***	***Acaciothrips sp***	***Podothrips sp***	**Total Number of thrips**
Solanum melongena	**4**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**4**	**1**	**-**	**1**	**-**	**-**	**-**	**1**	**12**
Vigna unguiculata	**1**	**9**	**-**	**-**		**-**	**-**	**4**	**1**	**2**	**1**	**-**	**-**	**2**	**-**	**-**	**20**
Solanum macrocarpon	**2**	**4**	**3**	**-**	**-**	**1**	**-**	**-**	**3**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**13**
Allium cepa	**10**	**-**	**1**	**1**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**13**
Solanum lycopersicum	**4**	**3**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**7**
Capsicum annuum	**1**	**2**	**-**	**-**	**1**	**1**	**1**	**-**	**2**	**2**	**-**	**-**	**-**	**-**	**1**	**-**	**11**
Capsicum annuum var.	**5**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8**
Cucumis sativus	**1**	**1**	**2**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6**

Table 4 cont'd: Number of thrips species on permanent slide mounts identified from various vegetable crops

Host plant	***Frankliniella schultzei***	***Megalurothrips***	***Thrips tabaci***	***Stenchaetothrips***	***Selenothrips sp***	***Eurhynchothrips***	***Aleurodothrips sp***	***Sericothrips sp***	***Thrips palmi***	***Chirothrips sp***	***Haplothrips sp***	***Karnyothrips sp***	***Taeniothrips sp***	***Dolichothrips sp***	***Acaciothrips sp***	***Podothrips sp***	**Total Number of thrips**
Amaranthus sp	**2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**8**
Hibiscus sabdariffa	**-**	**4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**4**
Br. ole va botrytis	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**2**
Citrullus lanatus	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**
Allium fistulosum	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**2**
Abelmoscus esculentum	**1**	**1**	**-**	**-**		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2**
Lactuca sativa	**-**	**1**	**-**	**-**		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**2**
Brassica oleracea var. capitata	**1**	**1**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3**
Total number of thrips per crop	**32**	**29**	**8**	**1**	**1**	**3**	**4**	**4**	**17**	**6**	**1**	**2**	**1**	**2**	**1**	**1**	**115**

Table 5: Number of thrips species on permanent slide mounts identified from various ornamental plants

Host plant	***Frankliniella schultzei***	***Megalurothrips***	***Thrips tabaci***	***Stenchaetothrips***	***Selenothrips* sp**	***Eurhynchothrips***	***Aleurodothrips* sp**	***Sericothrips* sp**	***Thrips palmi***	***Chirothrips* sp**	***Haplothrips* sp**	***Karnyothrips* sp**	***Taeniothrips* sp**	***Dolichothrips* sp**	***Acaciothrips* sp**	***Podothrips* sp**	**Total per plant species**
Jasminium	**3**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**4**
Neriumoleander	**-**	**2**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3**
Catharanthus alba	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1**
Thurmbergia erecta	**-**	**5**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**5**
Rullia blumei	**-**	**3**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**1**	**-**	**-**	**-**	**-**	**-**	**5**
Verbena sp	**-**	**3**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3**
Portulaca grandiflora	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2**	**-**	**-**	**-**	**2**
Solanum torvum	**-**	**4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**4**
Heliopsis sp	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**4**	**-**	**-**	**-**	**-**	**-**	**4**
Total	**3**	**19**	**1**	**1**	**-**	**-**	**-**	**-**	**-**	**-**	**5**	**-**	**2**	**-**	**-**	**-**	**31**

4.3 Insect identification

The morphological features that helped in the identification of *Thrips palmi*, *Thrips tabaci*, *Frankliniella schultzei* and *Megalurothrips sjostedti* are as follows:

4.3.1 *Thrips palmi* Karny

Adult is yellow in colour (Plate 4a) with dark setae. The antenna is seven segmented, with antennal segment VII being shorter than segment VI (Plate 4b). Antennal segments VI-VII are brownish distally. The head bears a pair of ocellar setae arising just outside the ocellar triangle. The ocelli are red-pigmented (Plate 4c). The forewing is pale in colour. The pronotum of *T. palmi* has two pairs of posteroangular setae. The anterior end of metanotum possesses distinct transverse lines and toward the posterior end are present a pair of campaniform sensilla.

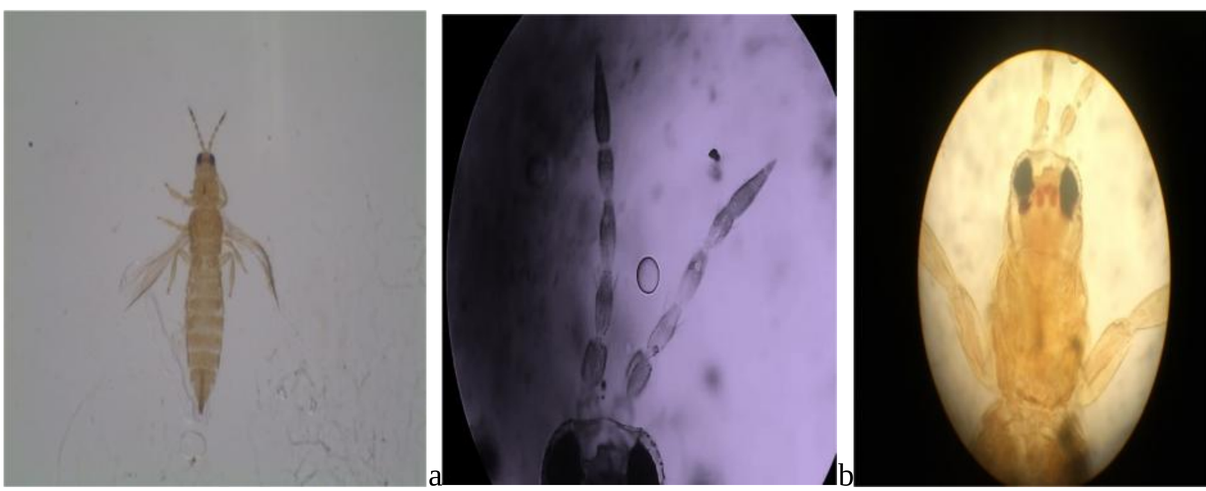


Plate 4: (a) Adult *T. palmi* (**b**) Seven segmented antennae of an adult *T. palmi* (**c**) Head of an adult *T. palmi* showing red-pigmented ocelli.

4.3.2 *Thrips tabaci* Lindeman

The body colour of adult is highly varied, ranging from yellow to brown (Plate 5a) depending on temperature during development. It bears seven segmented antennae (Plate 5b). Antennal segments III-IV brown with pale basal halves. Unlike *Thrips palmi*, its ocellar pigment is usually grey and never red. Forewing is pale in colour. The head bears ocellar setae whose bases arise within the ocellar triangle.

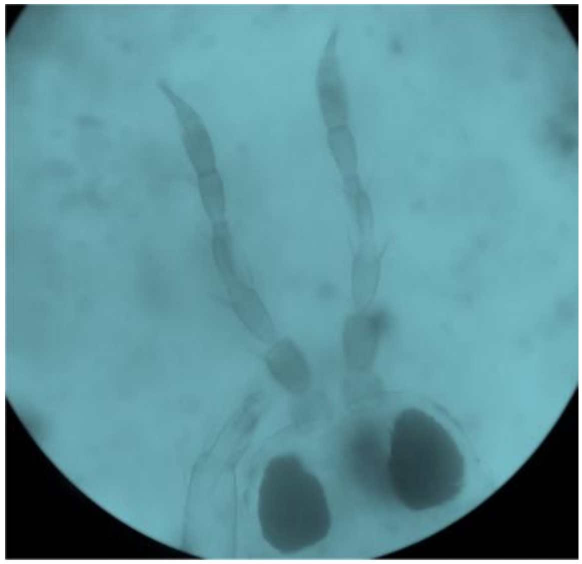

a

b

Plate 5:(**a**) Adult *Thrips tabaci*,(**b**) Seven segmented antennae of an adult

4.3.3 *Frankliniella schultzei* Trybom

Both sexes are fully winged. Two forms exist; dark-brown (Plate 6a) and yellow forms. It bears eight-segmented antennae (Plate 6b). Antennal segments III-IV bear forked sensorium. Antennal segments III-V appear yellowish at least at bases. Antennal segment VIII is longer than segment VII (Plate 6b). Ocellar setae present and arise close together between anterior margins of the hind ocelli. *F. schultzei* lack the campaniform sensilla on the metanotum.

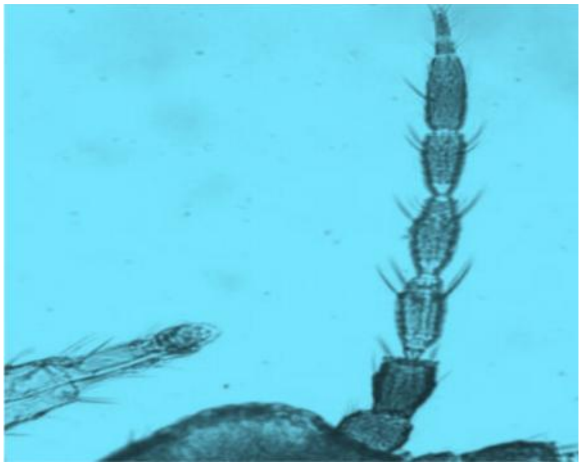
 a  b

Plate 6:(a) Adult *F. schultzei*(**b**) Antenna of an adult *F. schultzei*with eight antennal segments

4.3.4 *Megalurothrips sjostedti* Trybom

Adults appear dark to brown (Plate 7a) in body colour. The antennae are eight-segmented with paler antennal segment III(Plate 7b). Forewings bear a small gap in setae row. Abdominal tergite VIII possesses a number of microtrichia grouped anterolateral to the spiracles.

 a  **b**

Plate 7:(a) Adult *M. sjostedti*, **(b)** Head of adult *M. sjostedti* showing paler antennal segment III

4.4 Farmers' knowledge of thrips and insecticide usage pattern

4.4.1 Farmers' knowledge of thrips

A Questionnaire (Appendix 1) was used to obtain data through interviews. Most (71%) of the farmers interviewed did not know thrips and only 29% of them knew and had experienced thrips on their crops. Apart from thrips, farmers also mentioned some insect pests they encounter on their crops. These insects include; white flies, aphids, Diamond Back Moth (DBM) larvae, caterpillars and leaf miners; with DBM larvae (27.8%), Aphids (25%) and White flies (22.2%) being the most mentioned of these pests (Figure 3).

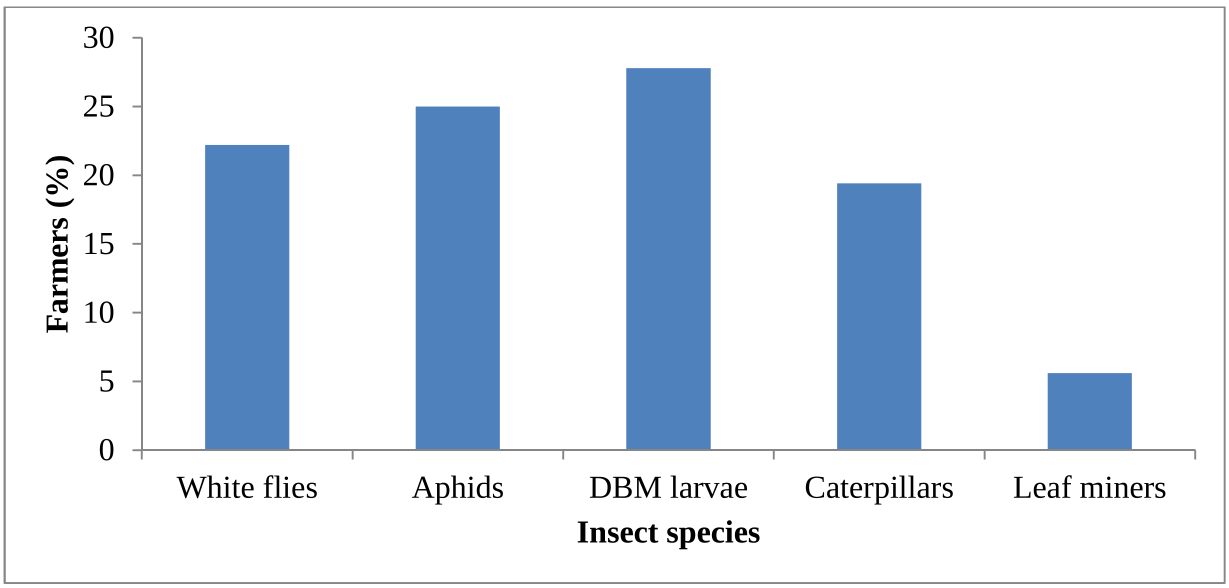


Figure 3: Percentage response on farmers' knowledge of insects other than thrips on crops infesting crops assessed using survey questionnaire.

4.4.2 Insect pest control

In all the farms visited, insecticide application was the only insect pest control method practiced. Farmers used a wide variety of insecticides and other agro-chemical products to combat insect pests and fungal attacks (Table 6). Attack® 5%WDG, Anty Ataa®and Cydim super®were the most commonly used insecticides with Attack® 5%WDG as the highest (33%) insecticide used by farmers against insect pests (Figure 4). Farmers acquired knowledge on insect pest control through personal experience in vegetable cultivation, fellow farmers and Agricultural extension officers.

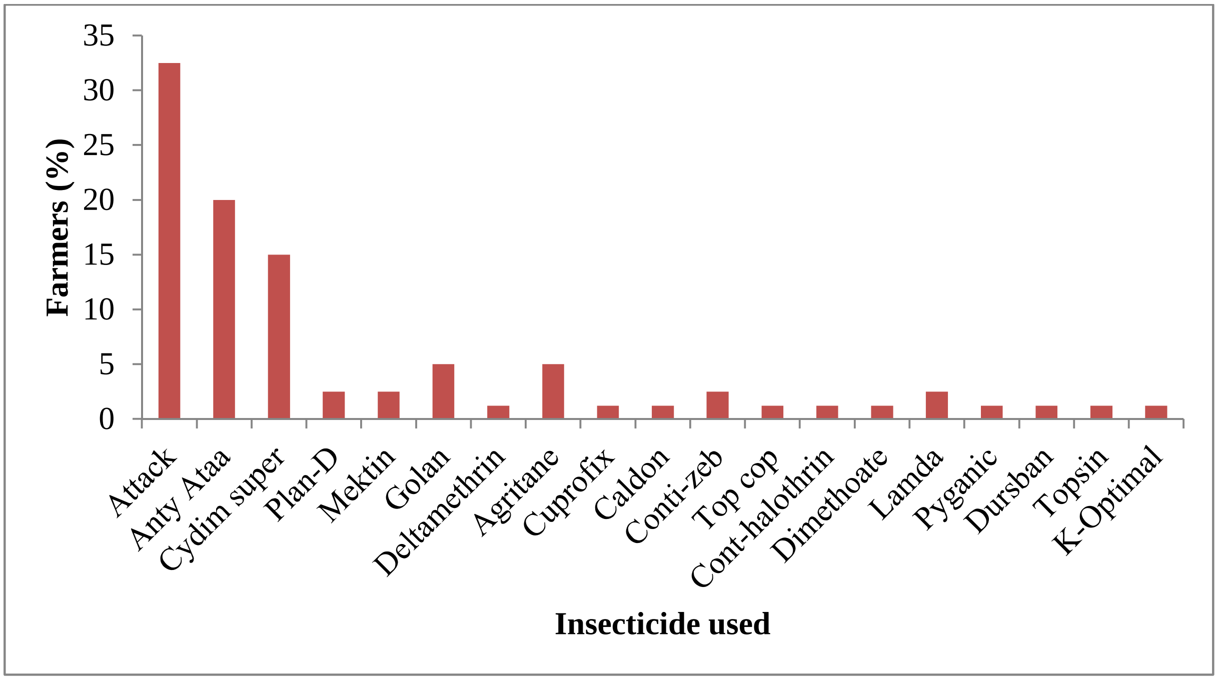


Figure 4: Percentage response on insecticides used by farmers against insect pests during survey.

Table 6: Commonly used pesticides and their active ingredients.

Insecticide/Agro-chemical	**Active Ingredient**
Attack® 5%WDG	5% Emamectin Benzoate
Anty Ataa®	200 g/L Imidacloprid
Cydim Super®	400 g Dimethoate and 36 g Cypermethrin
Golan SP	Actemiprid
Agrithane®	800 g/Kg Manco-zeb
Plan D	Deltamethrin
Mektin 1.8EC™	Abamectin
Lambda-Cy EC™	25 g/L Lambda-Cyhalothrin
Conti-zeb	Manco-zeb
Dursban ®E	480 g/L Chlopyriphos
Deltamethrin	Deltamethrin
Topsin-M	Methylthiophanate
Conti-halothrin	Cyhalothrin
Cuprofix 30 DISPERSS	30% Manco-zeb and 12% Copper Sulphate
Caldon®	Dinoseb
Top Cop®	Basic Copper Sulfate
Dimethoate	Dimethoate
K-Optimal 35 EC	15 g/L Lambda-Cyhalothrin and 20 g/L Acetameprid
Pyganic EC 1.4	Pyrethrum

4.5 Population trends of thrips

4.5.1 Trap Performance in capturing thrips

A total of 13367 adult thrips were captured by all traps out of which 8206 (61.4%) and 5161 (38.6%) thrips were captured by the Blue and Yellow traps respectively. However, there was no significant difference (ANOVA: Fpr =0.363, DF = 1, P > 0.05 = α) among trap catches (Appendix 2).Figure 5 shows mean (± S.E) number of thrips caught by different trap types in five different fields from September 2014 to March 2015.

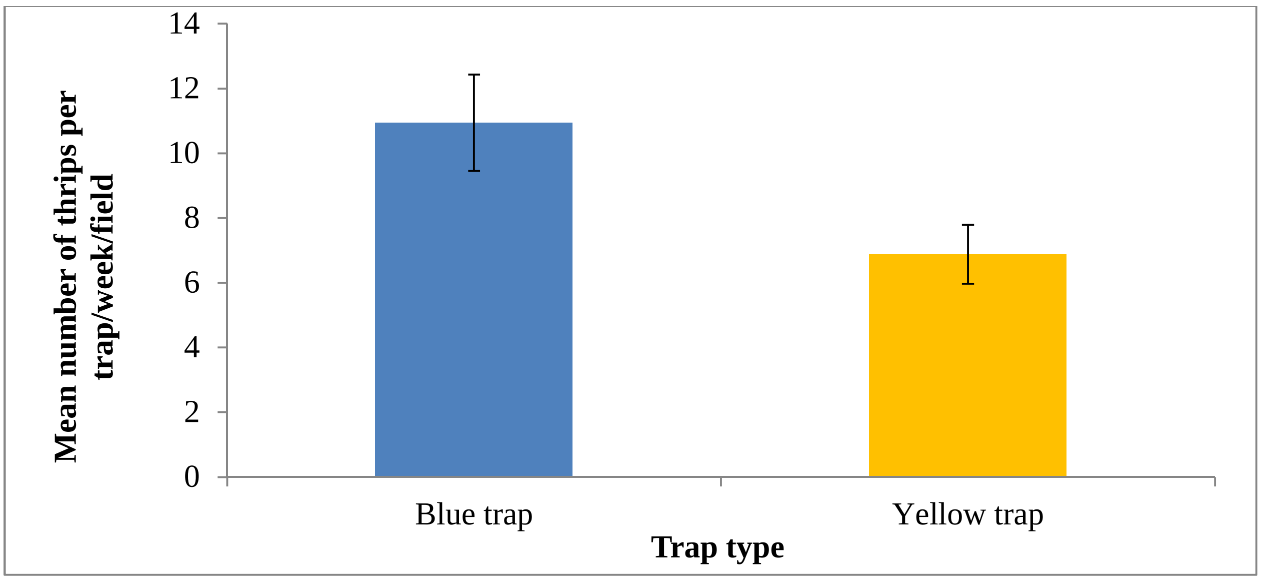


Figure 5: Mean (± S.E) number of thrips caught by different trap types in five different fields from September 2014 to March 2015

The mean trap catches among localities showed a significant difference (Fpr = 0.007, DF = 4, P < 0.05 = α) (Appendix 3) as well as among sampling months (ANOVA: Fpr = 0.049, DF = 6, P < 0.05 = α)(Appendix 4). More thrips per trap (mean: 14 ± 2.5) were captured at Opebia while Dzorwulu had the least thrips count per trap per week (Figure 6). There was no significant difference in mean thrips count per trap among Opebia, University of Ghana farm and Haatso but

Opebia and University of Ghana farm recorded significantly higher number of thrips compared to those from East Legon and Dzorwulu. The mean trap catches for September, October, November, December and March were not significantly different but significantly different from those of January and February. A higher mean number of thrips per trap were captured in October during the study (Figure 7).

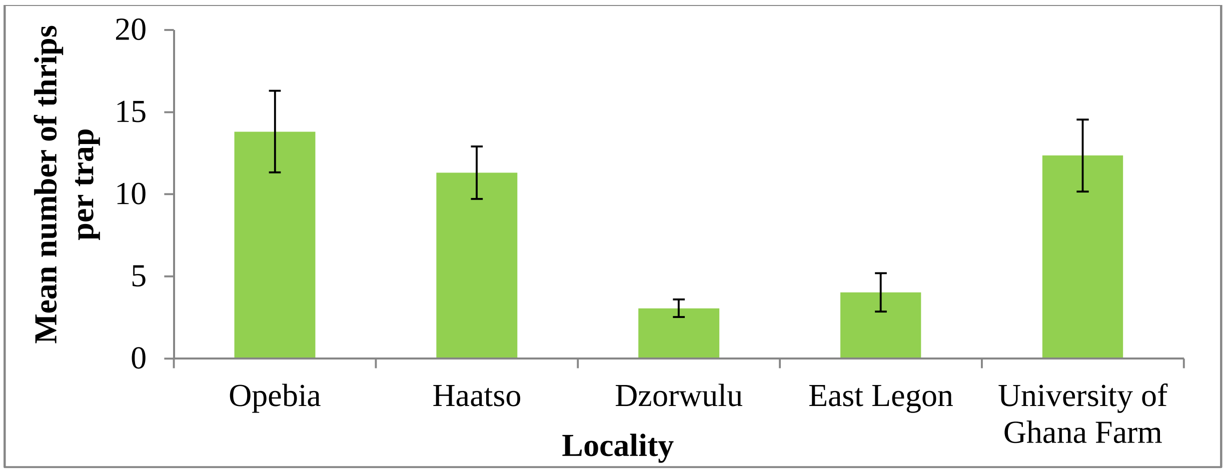


Figure 6: Mean (± S.E) number of thrips per trap captured in different localities September 2014 to March 2015

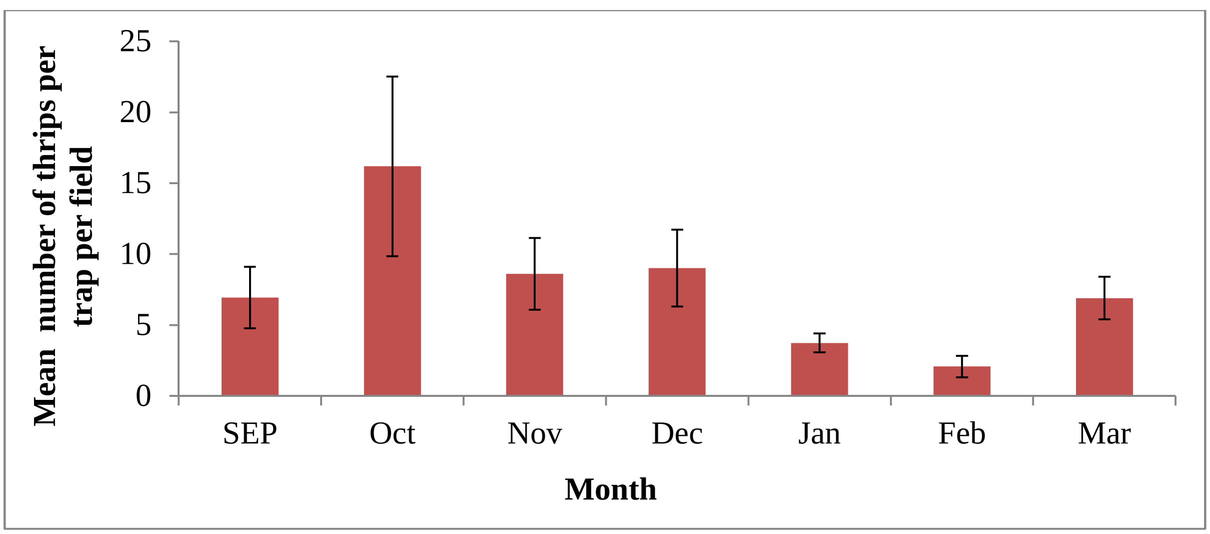


Figure 7: Mean (± S.E) number of thrips per trap captured in different months from September 2014 to March 2015

4.5.2 Abundance of adult thrips on Vegetable crops

The mean number of thrips among various vegetable crops surveyed showed significant differences (Fpr = 0.012, DF = 12, $P < 0.05 = \alpha$) (Appendix 5). There was no significant difference in mean thrips count per plant between eggplant and cucumber but both were significantly different from the rest of the crops surveyed (Table 7).

4.5.3 Abundance of *Thrips palmi* and associated thrips species on vegetable crops

Survey results for abundance of *Thrips palmi* on some vegetable crops showed no significant difference (ANOVA: Fpr = 0.099, DF = 1, $P > 0.05 = \alpha$) (Appendix 6) in mean number of adults and larvae of thrips. The mean number of adult *T. palmi* per plant was not significantly different among selected host plants (AONVA: Fpr = 0.629, DF = 3, $P > 0.05 = \alpha$) (Appendix 6).Although there was no significant difference among host plants, more adult thrips than larvae were collected from the surveyed plants except for cucumber plants where more (18 ± 6.7) larvae were captured. Higher (22.5 ± 6.6) number of adult thrips was collected on eggplant (Figure 8). In the course of sampling the four host plants for *T. palmi*, other thrips species were identified and the most abundant species besides *T. palmi* was *Megalurothrips sjostedti* followed by *Frankliniella schultzei*. Only *T. palmi* was identified on cucumber plants during this survey (Figure 9).

Table 7: Mean (± S.E) number of thrips per vegetable crop across various localities surveyed.

Plant species	Mean (±S.E) number of thrips
Eggplant	5.5 (6 ± 1.1)[a]
Cucumber	4.8 (5 ± 1.2)[a]
Cauliflower	2.7 (3 ± 0.7)[b]
Gboma	2.7 (3 ± 0.5)[b]
Onion	2.6 (3 ± 0.7)[b]
Cowpea	2.6 (3 ± 0.5)[b]
Pepper	2.5 (3 ± 0.4)[b]
Okra	2.2 (2 ± 0.4)[b]
Amaranthus	1.6 (2 ± 0.2)[bc]
Sweet pepper	1.2 (1 ± 0.3)[cd]
Cabbage	0.6 (1 ± 0.2)[cd]
Lettuce	0.3 (0 ± 0.1)[d]
Tomato	0.3 (0 ± 0.1)[d]
LSD	**1.2**

Means followed by the same letter are not significantly different at 5% probability level.

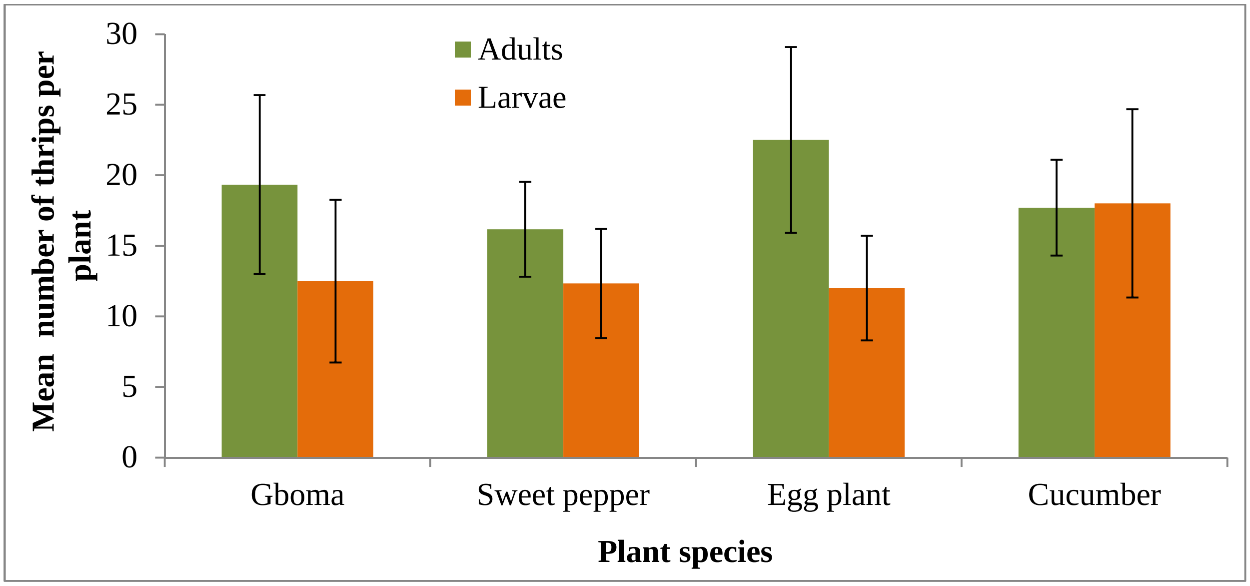


Figure 8: Mean (± S.E) number of adult and larval thrips per plant collected over six weeks February to March 2015.

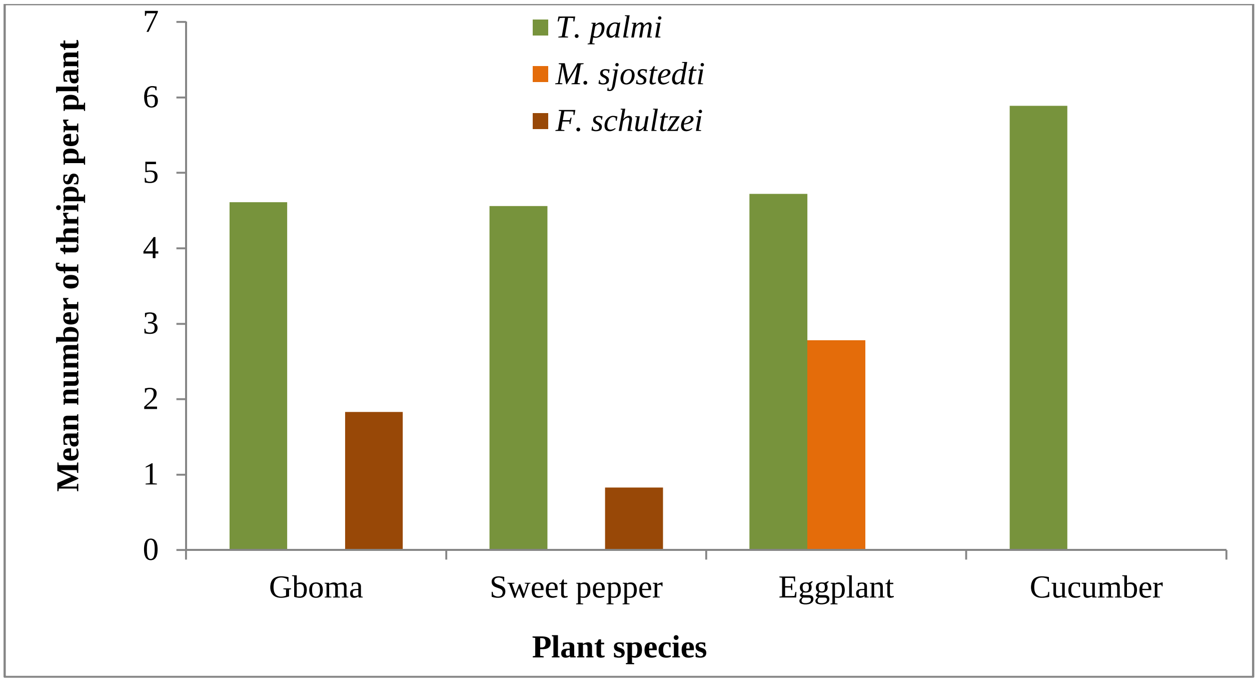


Figure 9: Mean (± S.E) number of adult thrips species per plant collected over six weeks February to March 2015.

4.5.4 Within plant distribution of *Thrips palmi*

The mean number of adults on cucumber leaves were not significantly different from mean larval counts ($P = 0.163$, $P > 0.05 = \alpha$, $DF = 1$) (Appendix 7). There were significant differences in mean numbers of thrips among young, middle and bottom leaves (ANOVA: ($P = 0.004$, $P < 0.05 = \alpha$, $DF = 2$)(Appendix 7). The significant difference was found to occur between the young and bottom leaves ($q(YL, BL) = 5.337 > q\text{-critical} = 3.532$, $\alpha = 0.05$) (Appendix 8). Figure 10 shows interaction between mean number of adult and larvae of *T. palmi*. It indicates that the number of thrips decreased from young leaves (mean = 16.2) through middle leaves (mean = 10.1) to the older bottom leaves (mean = 3.2).

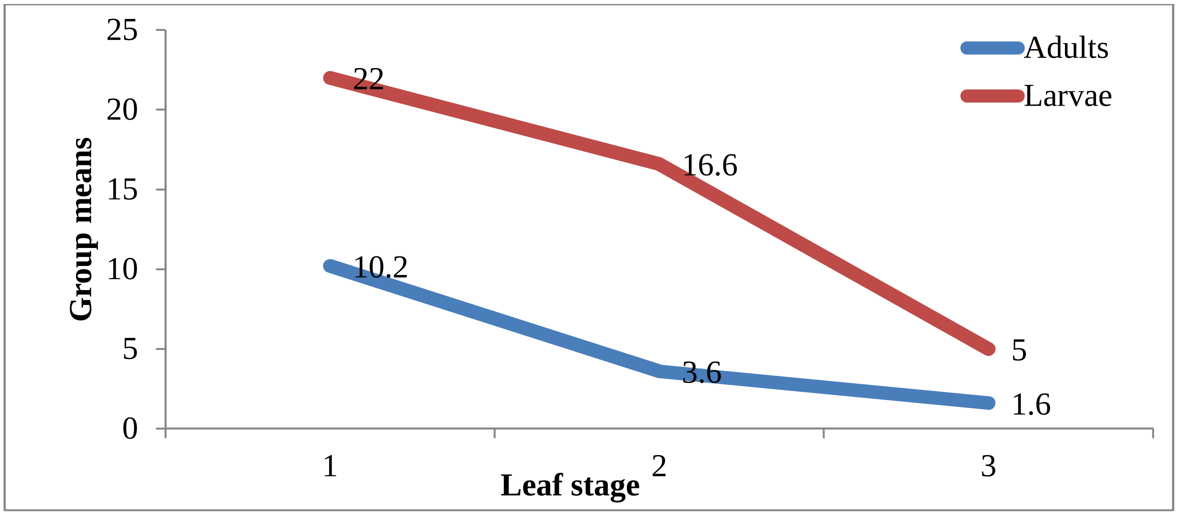


Figure 10: Factor Interaction comparison chart of mean number of *T. palmi* collected at different levels of cucumber plants (x-axis: 1 = Young Leaf, 2 = Middle Leaf and 3 = Bottom Leaf).

4.6 Relationship between trap catches of thrips and weather factors

In general, there was a negative correlation (P-value = 0.191; α = 0.05) between average weekly temperature and total weekly trap catches for all study fields (Figure 11). However, individual fields trap catches for East Legon were positively correlated (P-value = 0.0461; α = 0.05) to average weekly temperatures (Figure 12). There was a negative correlation (P-value = 0.530; α = 0.05) between total weekly rainfall and total weekly trap catches (Figure 13).

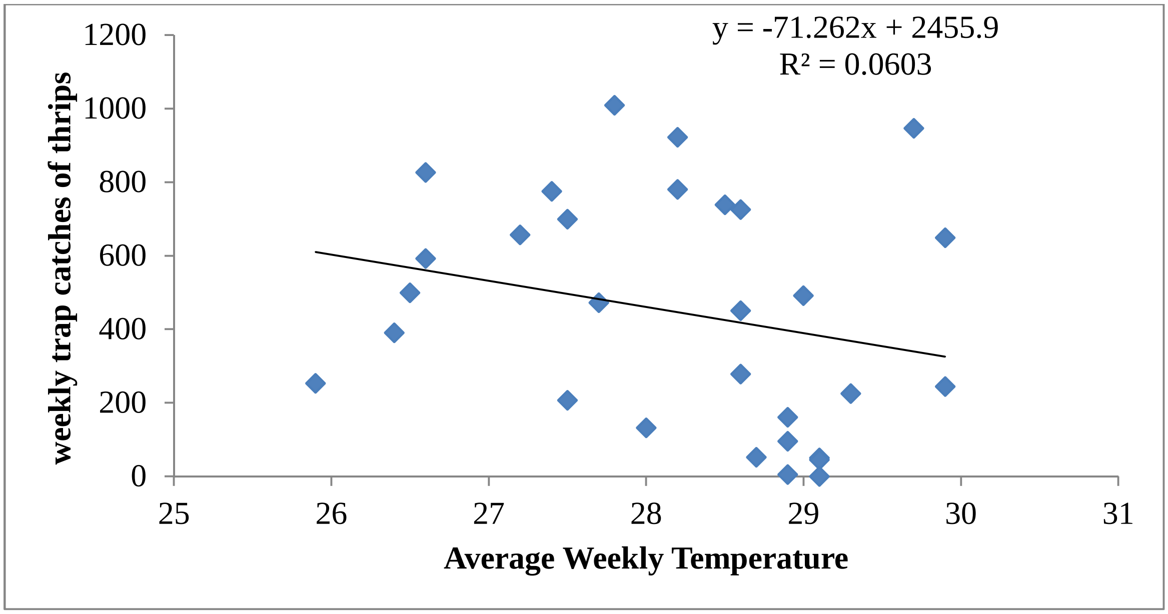


Figure 11: Average weekly temperature and total weekly trap catches of thrips from vegetable crops in some parts of Greater Accra (September 2014 to March).

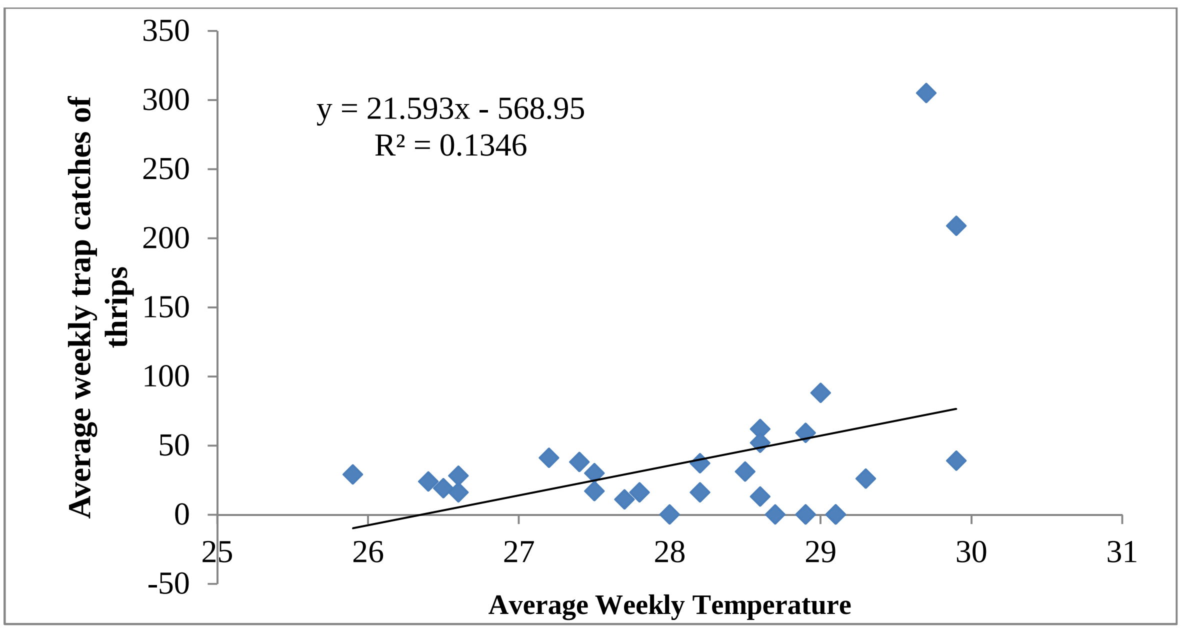


Figure 12: Average weekly temperature and total weekly trap catches of thrips for one vegetable farm (East Legon) in Greater Accra (September 2014 to March).

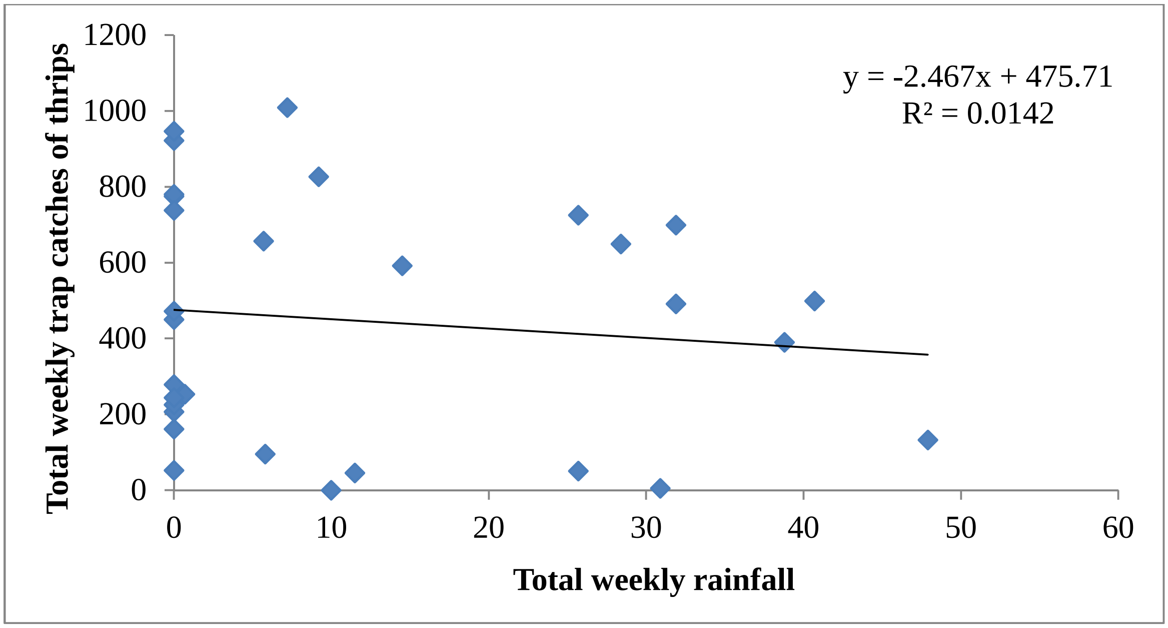


Figure 13: Total weekly rainfall and total weekly trap catches of thrips from vegetable crops in some parts of Greater Accra from September 2014 to March.

CHAPTER FIVE

5.0 DISCUSSION

Over twenty species of thrips species were collected from mostly actively growing plant tissues. This observation confirmed the report by Bailey (1938) that thrips are found on the most tender, succulent portions of the host plants; usually in buds, in blossoms, under bracts, in leaf sheaths, or on bulbs. Among several thrips species identified was the melon thrips, *Thrips palmi*. The identification of thrips species in this study agrees with Funderburk *et al.* (2007) who noted that thrips have been reported in many African countries including Ghana. Banfor (2009) in his M. Phil. thesis recorded a number of thrips including *Megalurothrips sjostedti* and *Frankliniella schultzei* among others which were also found in this current study. In addition to the thrips species reported in above cited reports, *T. palmi* was found to infest several vegetable crops during this current study. This result varies from reports by EPPO (2015); CABI (2015) and FVO (2012), indicating that *T. palmi* was absent in Ghana.

Thrips species infested more than one host plant, confirming polyphagy in thrips as reported by Kirk (1997b). The author indicated that the flower thrips reproduce and feed in the flowers of crops and in the absence of flowers, these insects migrate to nearby crops and wild flowers to continue their cycle. Thrips were also collected from ornamental plants and tree crops, indicating that these could serve as alternative hosts to thrips when vegetable crops are out of season.

Farmers could easily identify other insects but only a few could identify thrips. This difficulty in identifying thrips by farmers could be attributed to the small size of an adult thrips compared to other insect pests which are relatively larger. Even in farms with high infestation of thrips, the farm owners did not know what the problem was.

Farmers relied on chemical insecticides for pest control, with Attack®, Anty Ataa® and Cydim Super® being widely used. This is confirmed by Odhiambo *et al.* (2010) who pointed out that in an attempt to protect vegetable crops from high pressure from insect pests, farmers rely mainly on indiscriminate and widespread use of synthetic insecticides in vegetable cultivation and this has led to insecticide resistance development in the insect pests. Unfortunately, these insecticides were not applied specifically for thrips pests, confirming the lack of knowledge of thrips. This result is partly in line with the report by Daniela *et al.* (2008) whose findings indicated that inappropriate management of pesticides use is a cause for concern.

In most farms visited, more than one crop was grown and this could probably account for spread of thrips since thrips are polyphagous. Farmers acquired farming and pest control practices from their several years of experience, fellow farmers as well as from Agricultural extension officers. This result was in agreement with a report by Adu-Dapaah and Oppong-Konadu (2002) who found that farmers adhered to good agronomic practices most of which were acquired from colleagues and/or from several years of experience in tomato growing or from agricultural extension officers. However, there were variations in the way this knowledge was translated into actual farm practice since no particular pattern was observed.

The improvised Blue and Yellow sticky traps effectively captured thrips species. Generally, there was no significant difference (Fpr =0.363, $P > 0.05 = \alpha$) in mean number of thrips among Blue and yellow traps, although the blue trap captured more thrips than the yellow trap. This suggested that the two trap colours used did not have a significant influence over number of thrips trapped. Natwick *et al.* (2007) reported that Blue traps consistently captured more adult *Thrips tabaci* and *Frankliniella occidentalis* than Yellow traps in onion and lettuce fields. However, the work by Natwick *et al.* (2007) was carried out over a short period of two months.

The study locality probably had an effect on the general trap performance as there was a significant difference in mean trap catches among localities (Fpr = 0.007, $P < 0.05 = \alpha$).

Even though there was an overall negative correlation between temperature and trap catches of thrips, the correlation was not significant ($R^2 = 0.0603$, $P = 0.191 > \alpha = 0.05$). This negative correlation could likely be due to the fact that weather data was not collected directly on the fields where traps were placed, but from a Meteorological agency at Mempasem. The number of thrips in sticky traps from one locality (East Legon) was significantly positively correlated ($R^2 = 0.1346$, $P = 0.0461$, $\alpha = 0.05$) with average weekly temperature, thus confirming a report by Kirk (1997) who stated that weather variables such as rainfall and temperature have significant effects on thrips numbers. Relatively high temperatures and lack of rainfall have been associated with increase in onion thrips population. Boissot *et al*. (1998) reported a decrease in density of thrips before the mean temperature reached its maximum and that higher rainfall and high relative humidity were responsible for the thrips population decrease.

In the present study, total weekly thrips counts decreased with increase in total weekly rainfall, suggesting that higher rainfall probably decreased thrips population in sticky traps as reported by Kirk (1997). Results of this study suggested that all four plant species surveyed for *T. palmi* were infested with *Thrips palmi*. The number of thrips species other than *Thrips palmi* found on the crops was relatively small, suggesting an insignificant damage potential by these species. *Thrips palmi* was thus the major pest of concern. Garima *et al*. (2010) also found *Thrips palmi* alongside *Frankliniella schultzei* on cucumber plants. However, *Thrips palmi* was relatively less abundant and so cucumber was considered the main host for *F. schultzei* in the above cited report.

In this present study, larval counts were slightly higher than adult counts on cucumber for *T. palmi*. However, this difference was not significant. Adult counts were higher than larval counts in other plants, thus, these crops could be considered as less suitable hosts of the pest. This observed pattern could be attributed to the fact that no thrips were found in flowers of cucumber during this study in the study site, thus making *T. palmi* more abundant. Talekar (1991) and Nakahara (1984) reported a serious infestation of *T. palmi* detected worldwide on plants from family Solanaceae (eggplants, pepper, and potato), Cucurbitaceae (cucumber, watermelon, cantaloupe, and squash), and Leguminosae (kidney bean, snap bean, broad bean, cowpea, soybean, and white clover).

There was a significant difference among mean thrips counts from young leaves, middle leaves and bottom leaves of cucumber when within plant distribution of *T. palmi* was studied on cucumber plants. *Thrips palmi* was reported by Kawai (1990) to be well adapted to young tissues of eggplant and cucumber, which provided high food resources. Capinera (2000) reported that *Thrips palmi* has a wide host range and prefers host of family Cucurbitaceae and Solanaceae, where adults and larvae preferably feed on leaves of host plant. Garima *et al.* (2010) found *Thrips palmi* on leaves of cucumber plants in the course of studying the abundance of *F. schultzei*. However, Garima *et al.* (2010) did not state the preferred plant part infested by the pest. In this present study, *Thrips palmi* preferred the young leaves to the older-bottom ones.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The results of this study revealed an extension of the existing list of thrips species recorded in Ghana. The invasive *Thrips palmi* was identified for the first time in Ghana on vegetable crops including eggplants (*Solanum melongena*), gboma (*Solanum macropon*), sweet pepper (*Capsicum annuum var*.) and cucumber (*Cucumis sativus*). *Thrips palmi* like other thrips species is polyphagous; closely associated with several vegetable crops and is cosmopolitan as the pest was identified in several localities surveyed during this study. Thrips were present throughout the dry and rainy seasons, but tended to increase during dry seasons especially in the presence of host plants.

Thrips palmi prefers and is closely associated to the young, succulent cucumber leaves based on studies on within plant distribution of the pest on cucumber at Haatso, one of the vegetable growing areas in Accra metropolis.

Based on the number of thrips captured by sticky traps, both the Blue and Yellow coloured sticky traps can be used alongside visual inspection of crops for a better thrips pest monitoring program. The sticky traps could however be more convenient in detecting early and small populations of thrips in the field to inform quick control measures against negative effects of population build-up.

6.2 RECOMENDATIONS

It is imperative for major stakeholders in pest management programmes including; Agricultural extension workers, Universities as well as the Ministry of Food and Agriculture to intensify the education of vegetable and fruit crop growers on how to distinguish thrips from other insect pests to enable them apply specific management strategies, especially now that horticultural sector is faced with interceptions by the European Union, one of the main market outlets for Ghanaian horticultural produce.

Similar work should be carried out in other Regions of Ghana to establish the presence or otherwise of *Thrips palmi* for the whole country especially in vegetable and fruit crop growing areas. The improvised sticky traps used in this study are not only effective, but also cheap and easy to produce by small scale vegetable crop farmers.

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APPENDICES

Appendix 1: Sample Questionnaire

Survey studies on Farmers' knowledge of Thrips and Insecticide usage pattern

Instructions: Fill in the blank spaces and place a tick where appropriate.

1. Name of survey agent…………………………………………………………………..
2. Date……………………………………………………………………………………..
3. Farmers' name…………………………………………………………………………….
4. Survey site…………………………………………..
5. Crops cultivated?

   ..………………………………………………………………………………………

6. Do you know thrips? **Yes, No**
7. Which crops do they attack?

   ..../........................../.........................../.............................../......................../

   ..../........................../............................./.........................../……...................

8. What are some other insects you find on your crops? ..../ ……………../ …………/ ………………/ ……………………/ ……………./ ………………./ etc……
9. How do you differentiate thrips from other insects on your crops? ....

   ....……..............

10. **Where do you find thrips on crops?**
    - a.) Flowers
    - b.) Leaves
    - c.) Stems
    - d.) Others (specify)
11. **Thrips pest management practices**

    Which method do you use in controlling thrips?

    a. Chemical control

    b. Others (specify)……………………………………………………………………

12. **If you use chemicals, list the different insecticides you use(d):**

…………………………………………………………………………………………..

……………………………………………………………………………………………….

13. **Pattern of use of insecticides**

a. Threshold of insects:

Are the insecticides effective? **Yes** or **No**

b. How often do you apply insecticides to your crops? ....

c. How do you use various insecticides?

i) As a mixture

ii) Alternatively (one after the other)

d. Which indicator do you use as a guide to spray?

i) Calendar basis

ii) Presence of thrips

iii) Presence of damage

e. What insecticide dosage do you use on your farm?

i) Below recommended

ii) Recommended

iii) Above recommended

f. What equipment do you use in spraying?

i) Knapsack sprayer (hand operated)

ii) Others (specify)……………………………………………………………………….

14. **Precaution during insecticide application**

   a. Do you wear protective clothing during insecticide application?

      i) **Yes,** always

      ii) **Yes**, sometimes

      iii) **No**

   b. Insecticide storage

      How or where do you store your insecticides?

      In rooms/Barns/Tree tops/Boxes in farms/Burry in soil/Keep in hidden bushes

15. **Disposal of empty insecticide containers**

   a. How do you handle empty insecticide containers?

   i) Throw them away

   ii) Use as water containers

   iii) Use in storing seeds

   iv) Burry them in the soil

   v) Sell them out to other people

16. **Source of farmers' knowledge on pest thrips control**

   a. Where do you get professional advice on proper use and handling of insecticides?

      i) Fellow farmers

      ii) Customers

      iii) Experience

      iv) Mass media

      v) Agricultural extension officers

      vi) Others (specify)……………………………………………………………………

   b. If by extension officer, how often do you receive such advice?

      ………………………………………………………………………………………

17. Where do you buy insecticides? ....

18. What is the interval between insecticide application and subsequent watering?

      ………………………………………………………………………………………

19. Do you keep farm records on your insecticide usage patterns? **Yes** **No.**

'Thanks for your cooperation'

Appendix 2: Analysis of Variance for trap performance in catching thrips

Source of Variation	DF	SS	MS	VR	F pr.
Block stratum	4	540.82	135.21	1.43	
Treatment (Trap type)	1	99.41	99.41	1.05	0.363
Total	9	1018.32			

Appendix 3: Analysis of Variance for effect of study locality on mean trap catches

Source of Variation	**DF**	**SS**	**MS**	**VR**	**F pr**
Locality	4	853.26	213.31	4.34	0.007
Residual	30	1476.01	49.20		
Total	34	2329.27			

Appendix 4: Analysis of Variance for effect of sampling month on mean trap catches

Source of Variation	DF	SS	MS	VR	F pr
Month	6	804.46	134.08	2.46	0.049
Residual	28	1524.82	54.46		
Total	34	2329.27			

Appendix 5: Analysis of Variance for number of thrips and associated plant species

Source of Variation	DF	SS	MS	VR	F pr
Plant species	12	32.879	2.740	2.36	0.012
Residual	78	90.516	1.160		
Total 90 123.395					

Appendix 6: Analysis of Variance for abundance of *Thrips palmi* on host plants

Source Of Variation	SS	DF	MS	F	P-value	F-crit
Sample						
(Adults & larvae)	0.4340	1	0.4340	2.8373	0.0999	4.0848
Columns						
(Host plants)	0.2679	3	0.0893	0.5837	0.6292	2.8387
Total	6.8796	47				

Appendix 7: Analysis of Variancetable for within plant distribution of *Thrips palmi* on cucumber plants (two-factor with replication)

Source Of Variation	SS	DF	MS	F	P-value	F crit
Sample						
(YL, ML & BL)	2.5196	2	1.2598	7.1777	0.0036	3.4028
Columns						
(Adults & Larvae)	0.3637	1	0.3637	2.0721	0.1629	4.2597
Total	7.3430	29				

Appendix 8: Tukey's Honestly Significant Difference for within plant distribution of *Thrips palmi* on cucumber plants

Group parings	Mean differences	Order of pairs	q-value	q-critical (α = 0.05)
(YL, ML)	1.089-0.782 = 0.307	3rd (Smallest)	2.314	3.532
(YL, BL)	1.089-0.381 = 0.708	1st (Largest)	5.337	3.532
(ML, BL)	0.782-0.381 = 0.401	2nd (largest)	3.023	3.532

*YL = Young Leaf, ML = Middle Leaf and BL = Bottom Leaf