CULTURAL AND BOTANICAL METHODS FOR THE MANAGEMENT OF THRIPS ON FRENCH BEANS *PHASEOLUS VULGARIS*

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I56/10009/2007

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science (Agricultural Entomology) in the School of Pure and Applied Sciences of Kenyatta University

2015

ii

DECLARATION

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This thesis is my original work and has not been presented for a degree in any other University or any other award.

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This thesis is dedicated to my family members for their support, encouragement and prayers throughout my study and research period.

ACKNOWLEDGEMENTS

I wish to acknowledge my supervisors Dr. Jenard Patrick Mbugi (Kenyatta University), Dr. Subramanian Sevgan (ICIPE) and Dr. Monicah Mukami Waiganjo (KALRO-THIKA), for their continued advice, encouragement, patience, guidance, close supervision, their constructive criticism and comments throughout this research and write up of the thesis. I express my special gratitude to Dr. Subramanian Sevgan (coordinator Thrips IPM Programme) for sponsoring my research work. I sincerely express my gratitude to the ICIPE biostatician Dr. Daisy Salifu for assisting in data analysis. Also acknowledge the technical assistance offered by the following: - ICIPE Thrips IPM technical staff Bernard Muia, and Cathrine A. Awuoche, KALRO-Thika technical staff Mrs. Joyce Muriuki and Kamau Muhia, Field assistants Patrick Mwangi, Bonface Njogu and Peter Njuguna. I also express my sincere thanks to the ICIPE Thrips IPM colleagues Johnson Nyasani, Salou Niassy, and Alex Muvea.

Special thanks the Centre Director, KALRO-Thika for allowing the studies to be carried out at the Centre. I gratefully acknowledge ICIPE, Nairobi, Kenya for providing the laboratory and greenhouse facilities for the study and facilitating transport to the study site.

I thank the Almighty God for enabling me to accomplish this work.

TABLE OF CONTENTS

CHAPTER FIVE

EFFECT OF MULCHING ON INFESTATION AND DAMAGE OF FRENCH BEANS BY THRIPS

CHAPTER SIX

THE EFFECT OF INTERCROPPING, MULCHING AND USE OF BOTANICAL PESTICIDES ON THRIPS INFESTATION AND DAMAGE OF FRENCH BEAN BY THRIPS

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
BFT	Bean Flower Thrips
HCDA	Horticultural Development Authority
ICIPE	International Center of Insect Physiology and Ecology
KALRO	Kenya Agricultural and Livestock Research Organization
IPM	Integrated Pest Management
NAFIS	National Farmer Information Services
NRC	National Research Council
SE	Standard Error
TEPC	Trade Export Promotion Centre
WFT	Western Flower Thrips

ABSTRACT

French bean is the most important export vegetable crop cultivated in Kenya. Pests and diseases are the major constrains to its production. The major pests of French beans are bean flies, thrips, and bean aphids. Amongst these pests, thrips are the most notorious and account for 63 – 68% yield loss of fresh marketable pods. *Frankliniella occidentalis* is the most widespread thrips species which has developed resistance to the commonly used synthetic pesticides. Farmers rely heavily on these synthetic pesticides in order control the thrips and up to sprays of 15 times have been reported per growing season. This act has lead to the contamination of the fresh French bean pods with pesticide residues. The toxicated fresh pods may not be accepted in lucrative markets, more so in Europe. This study therefore, aimed at developing an alternative method of controlling thrips on French beans by use of cultural and botanicals. Laboratory and greenhouse experiments were conducted in two trials to assess the efficacy of botanicals against *Frankliniella occidentalis* infesting French beans. Field experiments were also conducted in two trials to evaluate the effect of different mulches on infestation and damage of French beans by thrips, and to evaluate the effect of integrating intercropping, mulching and use of botanicals on the infestation and the damage of French beans by thrips. The laboratory and greenhouse experiments were carried out at the International Centre of Insect Physiology and Ecology Nairobi in a complete randomized design. Field experiments were conducted at the Kenya Agricultural and Livestock Research Organization, Thika, Kenya in a randomized complete block design with five replicates for mulching experiments and three replicates for the integrated experiments. The laboratory results showed that L-Cyhalothrin caused the highest mean percentage mortality of the first instar *F. occidentalis* followed by Pyrethrum. Neem and Garlic caused the lowest mean percentage mortality. The result from greenhouse experiments showed that the lowest mean number of thrips was recorded on the French beans sprayed by L – Cyhalothrin followed by pyrethrum (soil + foliar), neem (soil + foliar), neem (soil) pyrethrum(soil), garlic (soil + foliar), garlic (soil) and control. The lowest damage score on fresh pods was recorded on the leaves treated with Pyrethrum (soil + foliar) and neem (soil + foliar) while the highest damage scores were recorded on the French beans treated with garlic (soil) and the control. The result from the experiments involving mulching showed that the lowest mean number of thrips was recorded on French bean leaves and flowers mulched with transparent plastic sheets followed by those mulched with dry grass, black plastic mulch, tithonia green mulch and the control. The results from integrated field experiments revealed that maize + dry grass + pyrethrum had the lowest mean number of thrips in flowers followed coriander + dry grass + pyrethrum, dry grass + pyrethrum, French bean a lone, coriander, pyrethrum and dry grass. In flowers the lowest mean number of thrips from French bean plant sprayed by L-Cyhalothrin followed by maize, maize + dry grass + pyrethrum, coriander + dry grass + pyrethrum and dry grass. The most abundance thrips species identified on French beans leaves was *Hydatothrips adolfifriderici* followed by *Megalurothrips sjostedti* while *Frankliniella schultzei* and *F. occidentalis* were very low in number. On French bean flowers, *F. schultzei* was the most abundance followed by *M. sjostedti* while *F. occidentalis* and *H. adolfifriderici* were very few. This study showed pyrethrum and neem pesticides can be used as an alternative chemical management for *F. occidentalis* on French beans in greenhouses. It also revealed that cultural and botanical methods can be integrated to provide an alternative pest management system. The system involves a combination of pyrethrum + maize + dry grass. However, these methods are not as effective and fast acting as synthetic pesticides, but are safer for the environment and consumers.

CHAPTER ONE

INTRODUCTION

1.1 Background

French bean (*Phaseolus vulgaris* L) originated from South and North American continents (Smart, 1969). Globally the crop is widely cultivated in most tropics, subtropics and temperate regions for the immature green pods which are consumed preferably in fibreless state (Silbernagel *et al*., 1991). In Kenya, French beans were introduced from Europe and the commonly grown cultivars are Amy, Samantha, Julia Vernadon, Monel and Kutuless – J12 (KARI Training Manual, 2002). It is the most important export vegetable crop cultivated mainly by smallholder farmers in Kenya (Nderitu *et al*., 2001; TEPC, 2006). In 2011 Kenya produced 42,573 tonnes of French bean earning the country Kshs. 5.8 Billion (HCDA, 2011). French beans have high nutritional contents and contain ascorbic acid, other vitamins, mineral salts and proteins. The export market for French beans is likely to increase due to high demand from the local processing industry and in the export destinations.

Pests and diseases are the major constraints to the successful production of French beans (Löhr and Michalik, 1995). The primary pests of French beans are bean flies *Ophiomyia spp* (Diptera: Agromyzidae); Thrips species mainly *Megalurothrips sjostedti* Trybom (Bean Flower Thrips) and *Frankliniella schulzei* Trybom (Common Blossom Thrips) *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae); Bean aphids, *Aphis fabae* Scopoli (Homoptera: Aphididae) Löhr and Michalik, 1995; Gitonga, 1999, Kedera and Kuria, 2003; Nyasani *et al*., 2012).

Among the species of thrips attacking French beans, the Western Flower Thrips, *F*.

occidentalis the most widespread and resistant to most synthetic pesticide. This pest is quarantine globally (Tommasini and Maini, 1995). *Megalurothrips sjostedti* has been reported to be a very common and widespread pest in Africa (Tamo *et al*., 1993). *Frankliniella schultzei* is a strain which has existed in Africa for long time but there is very little information on its economic importance (Subramanian *et al.*, 2010). Pests often cause significant losses both directly and indirectly. Direct losses include killing plants while indirect losses include reduction in plant vigor, yield and quality of quality, thus affecting the export produce.

The damage on French beans due to attack by thrips includes silvery blotches on leaves and pods, stunted plant growth and distorted pods. This leads to more than 40% abscission of French bean buds, flower abortion and further rejection of 20% of the bean pods at collection points due to blemishes, lesions and malformation (Löhr, 1996; Nderitu *et al*., 2001). Such losses prompt farmers to rely heavily on synthetic insecticides to control thrips. The commonly used synthetic insecticides in Kenya include L – Cyhalothrin, Methiocarb, Thiacloprid, Deltamethrin, Spinosad, Chloropyriphos and Fipronil. However, most of these insecticides which are applied on French beans are cheaper and ineffective (Nderitu *et al*., 2001; Kasina *et al.*, 2006). Farmers on the other hand apply these pesticides several times in a season to manage thrips on French beans. The frequent use of synthetic pesticides has resulted in development of pesticides resistance among thrips, environmental pollution and disruption of integrated pest management program (Nderitu *et al.*, 2007: 2008). Therefore, there is a need to diversify the management options for thrips infesting French beans and reduce over reliance on synthetic insecticides. This would minimize resistance development and enhance compliance to Maximum Residue

Limits prescribed by importers. Hence, environmentally friendly pest management techniques for sustained production of high quality French beans need to be developed. Such management techniques include the use of cultural, botanical and biological control measures.

Cultural pest control methods may be defined as the manipulation of the agronomic practices and environmental conditions to the disadvantage of the pest. The methods include proper ploughing, irrigation, timely planting; planting of resistant crops, crop rotation, intercropping, use of trap crops, mulching, and use of manure (Coaker, 1987; Kasina *et al*., 2006). Cultural practices such as intercropping have been found to be effective in minimizing thrips in cowpea and French beans (Kasina *et al*., 2006).

Botanical pest control methods involve use of plant extracts with insecticidal effects. These methods may provide an alternative for the management of pests than synthetic chemicals as they pose little threat to the environment or to human health. The most commonly used botanicals for the management of thrips are pyrethrum, neem and garlic extracts. Neem is non toxic to humans, biodegradable, less prone to pest resistance and resurgence. Garlic extracts are marketed as commercial pest control products, but their performance is variable, possibly due the low stability of the insecticidal compound. Pyrethrum extracts contains Pyrethrins which has insecticidal properties. Pyrethrins are neurotoxic insecticides characterized by a rapid knockdown effect, hyperactivity and convulsions particularly in flying insects

1.2 Statement of the problem

French bean is an important vegetable crop in Kenya which is usually grown under intensive cropping system with considerable inputs. It is a lucrative source of protein and income to subsistence farmers. French bean production in Kenya is carried out by small scale farmers mainly for export in Europe. The major challenges facing French bean farmers are pests and diseases. In Kenya, French beans are infested by various pests among which thrips are the most important economically. Thrips are unique due to their small size, cryptophillic and polyphagous behavior and have high rate of reproduction. Both indigenous and exotic species of thrips attack French beans in Kenya. The invasive Western Flower Thrips, *F. occidentalis* has been reported to be the most important and widespread pest of French beans in Kenya (Gitonga, 1999).

1.3 Justification of the study

The pest status of thrips had been underrated in the country until when losses of more than 40% were reported by Nderitu *et al.*, 2001 at farm level due to abscission of buds and abortion of flowers. A further 63 - 68% yield loss at collection site due to blotches on pods caused after feeding by thrips (Nderitu *et al.*, 2001; Nyasani *et al.*, 2012). These losses prompted farmers to rely heavily on frequent application of synthetic insecticides to control thrips inspite of the dangers they posed (Löhr and Michalik, 1995; Nderitu *et al.*, 2001; Loughner *et al.*, 2005). Report by Nderitu *et al.* 1997) showed that farmer's applied synthetic chemical insecticide up to 15 sprays per season. Consequently, this lowered the net returns due to the high cost of the pesticides (Nderitu *et al.*, 2008). In addition, pesticides end up killing non target organisms and also lead to pest resurgence and secondary pest outbreaks (Horrigan *et* *al*., 2002). Currently, most synthetic insecticides are unable to control thrips and some species such as *F. occidentalis* have already developed resistance to most convetional pesticides used globally including Kenya (Jensen, 2000; Herron and Gullick, 2001; Kasina *et al.,* 2006; Muvea, 2011). The only solution to this problem is to seek for alternative control methods in order to reduce overreliance on synthetic pesticides. Therefore, farmers need to adopt other alternative pest management options which may include cultural and botanical control. The latter are cheap, effective and environmentally friendly. There use would lead to production of high quality products that meet the strict regulatory requirements of the export and domestic markets especially in terms of pesticide residue levels and quarantine pests. Presently there is little information on the use of cultural control and botanical pesticides for thrips management in Kenya. Some cultural control practices such as intercropping and mulching are simple, ecologically friendly and are easy to adopt by most small-scale farmers. On the other hand botanical pesticides such as pyrethrum, neem and garlic extracts are less toxic to mammals, biodegradable, locally available and do not contribute to pest resurgence. It is in this context that this research was undertaken and to evaluate the efficacy of some cultural methods and botanical pesticides for the management of Thrips.

The study was carried out for the purpose of making a contribution of technology transfer for the development of an integrated thrips management of French beans in Kenya. This method of thrips management is cheap, effective and environmentally friendly. French bean farmers will therefore reduce overreliance on synthetic chemical insecticides for controlling thrips feeding on French beans. Feeding injury typically does not become apparent until after tissue grows and expands. Thus, by the time damage is noticed on pods, leaves or distorted terminals, the thrips that cause the damage are often disappear. No pesticide application will restore the appearance of injured tissues; plants will remain damaged until leaves drop, injury is pruned off or new unblemished fruit is produced.

1.4 Research questions

i. How does botanical pesticides affect the survival of larvae and adult *F. occidentalis* infesting fresh French beans in the laboratory and greenhouse?

ii. How does mulching affect the rate of infestation and the damage of French beans by thrips in the field?

iii. How does integrating intercropping, mulching and use of botanical pesticides affect infestation and damage of French beans by thrips in the field?

iv. How many species of thrips affect infestation and damage of French beans in the field?

1.5 Null Hypotheses

i. Botanical pesticides do not affect the survival of both larvae and adult *F. occidentalis* infesting fresh French beans in the laboratory and greenhouse.

ii. Mulching does not affect the rate of infestation and damage of French beans by thrips in the field.

iii. Integrating intercropping, mulching and botanical pesticides has not affect the rate of infestation and damage of French beans by thrips in the field.

iv. Many thrips species do not affect the rate of infestation and damage of French beans in the field.

1.6 Objectives of the study

1.6.1 General objective

To evaluate the cultural and botanical methods for the management of thrips on French beans in Kenya.

1.6.2 Specific objectives

i. To assess the effect of botanical pesticides against *F. occidentalis* larvae and adult infesting French beans in the laboratory and greenhouse.
ii. To evaluate the effect of mulching on infestation and damage of French beans by thrips in the field
iii. To investigate the effect of integrating intercropping, mulching and botanicals on the infestation and damage of French beans by thrips in the field.
iv. To identify the thrips species those infest and damage French beans.

1.7 Significance of the study

The study was carried out for the purpose of making a contribution of technology transfer for the development of an integrated thrips management of French beans in Kenya. This method of thrips management is cheap, effective and environmentally friendly. French bean farmers will therefore reduce overreliance on synthetic chemical insecticides for controlling thrips feeding on French beans. Feeding injury typically does not become apparent until after tissue grows and expands. Thus, by the time damage is noticed on pods, leaves or distorted terminals, the thrips that cause the damage are often disappear. No pesticide application will restore the appearance of injured tissues; plants will remain damaged until leaves drop, injury part is pruned off or new unblemished fruit is produced.

CHAPTER TWO

LITERATURE REVIEW

2.1 French beans

French beans *Phaseolus vulgaris* are the most important export vegetable in Kenya**.** It ranks second after fresh cut flowers in terms of volumes and value among export crops. In Kenya, French beans are usually cultivated as a monocrop in farms ranging between 0.25 to 1.0 Ha in Kirinyaga, Embu, Meru, Nyeri, Makueni, Machakos, Muranga, Kiambu, Naivasha, Thika, Bungoma, Transzoia, Vihiga, Kericho and Kisii regions (Nderitu *et al*., 1995). The crop thrives better within an altitudinal range of 1000-2100m above sea level and an annual rainfall of 900-1200mm with optimum temperatures ranging from 16^{0}C to 25^{0}C. High rainfall towards the end of the growing season is unfavorable, because it leads to high incidences of pests and diseases. In areas where rainfall is inadequate, irrigation is required to maintain continuous production of French bean pods. French beans can be cultivated in soils ranging from light sandy loam to clay. They grow best on well drained medium loam soils with plenty of organic matter content. A pH ranging from 6.5 to 7.5 is the best for their growth and development, but low pH of less than 4.5 impairs their growth (HCDA, 1996).

2.2 Thrips as pests of vegetables in Kenya

Thrips belong to the order Thysanoptera derived from Greek words *Thysanos* (fringe) and *pteron* (wing) (Lewis, 1997). The order is divided into two suborders namely Terebrantia and Tubulifera. Terebrantia are characterized by the presence of saw-like ovipositor for endophytic oviposition while Tubulifera characterized by a tubular ovipositor suited only for exophytic oviposition (Hussey, 1969). Most of the thrips that are pests belong to the sub order Terebrantia, while most of Tubellifera are fungus feeders. Some of the most important and widespread pest species such as *Frankliniella occidentalis* (Pergande), *Frankliniella schultzei* (Trybom), *Thrips tabaci* (Lindeman), *Thrips palmi* (Karny), *Scirtothrips dorsalis* (Hood) are distributed globally within tropics, subtropics and temperate regions. *F. occidentalis* pest is quarantine globally (Tommasini and Maini, 1995). *F. occidentalis* was introduced into Europe in the early 1980s from Western USA and later into Africa by 1989 (Gerin *et al*., 1994; Kedera and Kuria, 2003).

Thrips have a wide range of host plants with crops belonging to Family Solanaceae, Cucurbitaceae and Fabaceae often acting as hosts. In Africa the most important pest species are *Megalurothrips sjostedti* (Trybom) (Bean flower thrips) (Tamo *et al*., 1993), *F. schultzei* (Common Blossom thrips) Nyasani *et al*., 2010), This species of thrips is polyphagous and is a serious pest of beans and cowpeas in East and West Africa (Kyamanywa and Tukahirwa, 1988; Kyamanywa *et al*., 1993). *T. tabaci* (Onion thrips) (Waiganjo, 2004) and *Ceratothripoides brunneus* (Bagnall) on tomatoes (Varela *et al.*, 2003; Subramanian *et al.*, 2010). Within Kenya, three species of thrips namely *M. sjostedti*, *F. schultzei* and *F. occidentalis* commonly attack French beans (Löhr and Michalik, 1995; Nyasani *et al*., 2012). Apart from the above three species, *Hydatothrips adolfifriderici* (Karny) has also been reported to be a pest of French beans especially in the vegetative stages of the crop (Nyasani *et al*., 2012).

2.3 Biology of thrips

The life cycle of thrips consists of an egg, two active feeding larval instars, and two relatively inactive non-feeding stages designated as prepupa and pupa (Figure 2.1) (Lewis, 1997; Berndt *et al*., 2004). The endophytic female thrips oviposits white, vermiform eggs singly on plant leaves or flower tissues slit by the saw–like ovipositor. On the other hand the exophytic female thrips lay their eggs on the leaf or flower tissues. Endophytic eggs are smooth shelled, while exophytic eggs of tubuliferans have sculptured shells which stick onto the surface of vegetation. An individual female oviposits between 30 and 300 eggs depending on the species and quality of food available (Lewis, 1997). Eggs hatch after 8 days into translucent white or pale yellow, first instar larvae, which immediately aggregate at one spot but later scatter over the leaf surface. The first instar larvae are approximately 1/50 inch in length and the second instar larvae 1/35 of an inch long. After 10-14 days of feeding the mature second instar larvae drop on the ground and conceal themselves in the soil to undergo a short prepupal stage (1-2 days) before changing into pupae (Tommasini and Maini, 1995). Short wing pads that turn back over the head characterize the prepupae.

The pupa matures to the adult in 4-7 days. Most thrips complete their life cycle from eggs to adult in 2-3 weeks depending on temperature and humidity (Ananthakrishnan, 1993; Kirk, 1997). Thrips reproduce faster at an average temperature of 25^0C and a relative humidity of 70%. Soil – dwelling stages survive better in soils with moisture content between 10 and 13% (Lewis, 1997). Adult thrips are weak to good flyers but their small size makes their dispersal susceptible to influences of wind and weather. Their ability to disperse widely within vegetations in commercial horticulture has greatly contributed to their pest status. Their activity peaks during hot weather when up drifts may carry them for greater distances.

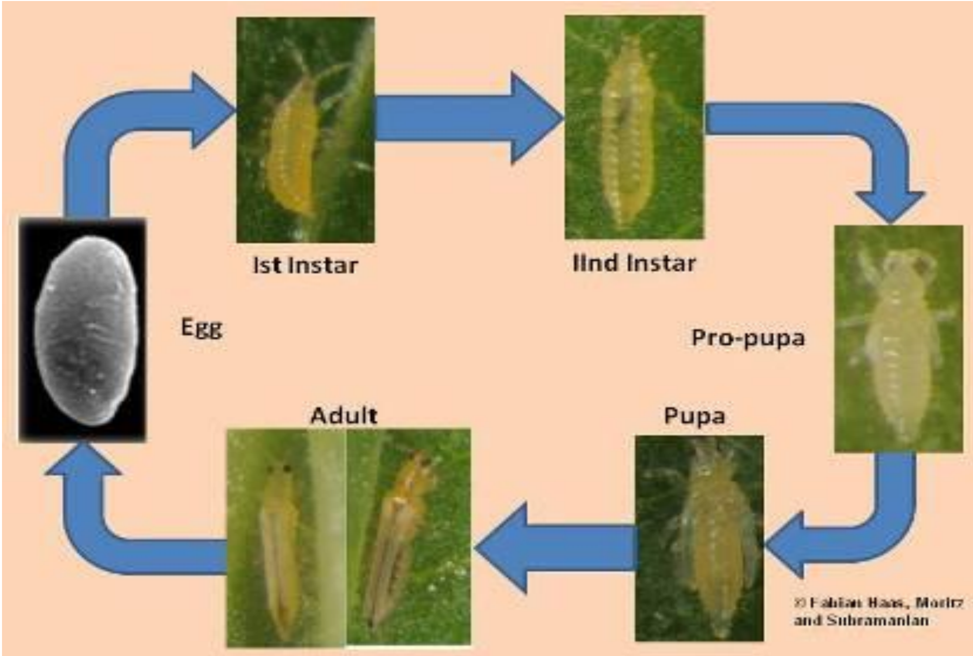

Figure 2.1 Life cycle of *Frankliniella occidentalis*

2.4 Damage caused by thrips

Thrips are major pests of French beans accounting for 63 - 68% yield loss of fresh marketable pods (Nyasani *et al*., 2012). They cause injury to French bean flowers, young stems, shoots, flower buds and leaves with their piercing-sucking mouthparts and ovipositors (Kyamanywa and Ampofo, 1988; Lewis, 1997). During oviposition, some female thrips puncture plant tissues with their ovipositor causing destruction of epidermal and parenchyma cells resulting in brown necrotic spots after drying.

Infestation levels on French beans by thrips peaks during the hot period and especially during the flowering stage (Moritz *et al.*, 1997). During this period of high infestation, thrips cause abortion of flower buds hence reducing pod set and yield significantly (Kibata and Ong'aro, 1997). The damage due to feeding and oviposition also results in poor quality French bean pods (Tamo *et al*., 1993; Ananthakrishnan, 1993; Sithanantham *et al*., 1997). On flowers, petals may exhibit colour break

(Childers, 1997) characterized by pale or dark discolouring of petal tissues that are killed after being fed on by thrips before the buds open. Such injuries may also predispose plant tissues to subsequent invasion by bacterial and fungal pathogens (Lewis, 1973). The larvae of thrips cause more damage than adults due to their large numbers, low mobility, gregariousness and commitment to feeding (Childers, 1997). All the scars made by thrips on the leaves, petals, pods and young stem lead to dehydration of French bean plant leading to leaf and flower fall.

2.5 Management of thrips in French beans

Globally management of thrips is largely dependent on chemical pesticides (Lewis, 1997). However the management of thrips using chemical pesticides has often failed due to their cryptic feeding behaviour (van de Veire and Degheele, 1992), ability to develop pesticide resistance (Immaraju *et al* 1992; Nderitu *et al*., 2001), and incompatibility with biological control agents. Therefore an Integrated Pest Management (IPM) strategy encompassing cultural, chemical, biological and mechanical control methods need to be developed and adopted for the management of thrips (Morse and Hoddle, 2006).

2.5.1 Chemical control of thrips

Chemicals have been in agriculture to control pests on crops for a long time. The major classes of commonly used pesticides include synthetic pyrethroids, organophosphates, carbamates and organochlorides. Alternatively natural pesticides like botanicals are used in pest management. It is difficult to manage thrips effectively with insecticides, partly because of their mobility, feeding behavior, and protected egg and pupal stages. Improper timing of application, failure to treat the proper plant parts, and inadequate spray coverage when using contact materials can prevent potentially effective insecticides from providing control. Most broadspectrum synthetic insecticides, including pyrethroids, organophosphates, and carbamates kill the native species of thrips that outcompete western flower thrips (Hansen *et al*., 2003; Reitz *et al*., 2003; Srivistava *et al*., 2008), leading to dramatic large scale shifts in thrips demographics (Frantz and Mellinger, 2009).

2.5.1.1 Synthetic pesticides against Thrips on French beans

There are several categories of synthetic pesticides used to control thrips on French beans. These chemicals include Carbaryl, Dimethoate, Cypermethrin, Monocrotophos (Karel and Mghogho, 1995) and Lambda – Cyhalothrin (Immaraju *et al*., 1992; Lewis, 1997), Aldicarb and Acephate or Carbofuran. French bean farmers in Kenya rely on pesticides such as Methiocarb, Thiacloprid, Deltamethrin, Spinosad, Chloropyriphos and Fipronil to control thrips. It has been reported by Nderitu *et al.,* 2001 that farmers sprays upto 15 times per crop cycle. Such high frequency of pesticide application is troublesome considering the short growing cycle of French bean plants and the harvesting intervals of fresh pods (Nderitu *et al*., 1997; 2001). However it is hard to manage thrips with synthetic pesticides alone because they infest individual crops in large numbers, have high intrinsic rate of increase, high dispersal capacity and the high ability to develop resistance. For instance *F. occidentalis* has been reported to be resistant to Lambda-Cyhalothrin and cypermethrin (Herron *et al*., 2002; Kasina *et al.,* 2006). The overuse of synthetic pesticides has led to pest resurgence, incompatibility with natural enemies and emergence of secondary pests. Overuse of synthetic pesticides has also constrained the adherence to regulations on maximum pesticide residue levels enforced by the European Union (HCDA, 1997).

2.5.1.2 Botanical pesticides for the management of thrips on French beans

Botanical pesticides refer to plant derivatives used for control pest. Botanical pesticides which have been formulated for pest control in Kenya are neem, garlic and pyrethrum extracts (O'Brien *et al*., 2011) of which pyrethrum and neem have been commercialized. These botanical pesticides are effective against some thrips species infesting French beans (Saxena, 1989)**.**

2.5.1.2.1 Neem pesticides for control of thrips

Neem pesticides are plant extracts derived from the Indian Neem Tree, *Azadirachta indica* (Meliaceae). Azadirachtin is the active ingredient found in neem and its mode of action on insects includes phagorepellency, growth inhibition, oviposition deterrence, mating disruption and chemo sterilization (Prakash and Rao, 1997; Mogue *et al*., 1998). The National Research Council (1992) reported that, neem extracts retarded growth of *F. occidentalis* and were harmless to pollinators. The most important mode of action of azadirachtin is its effect on metamorphosis through the inhibition of the release of prothroracicotropic hormones, allatotrophines and allotoinhibins (Rembold, 1989). It also affects vitellogenesis, which leads to vitallarium and the oviducts being reabsorbed. This culminates in a drastic reduction in egg laying activity of the adult thrips (Prakash and Rao, 1997; Mogue *et al.*, 1998). Neem compounds affect 400-500 species of insect pests (Schmutterer, 1995). Neem seeds contain more than a dozen azadirachtin analogs, but the major forms are azadirachtin and considerable quantities of other triterpenoids, notably 3 –

tigloylazadirachtol, salannin and nimbin (Kraus, 2002). However, the success in the commercial utilization of neem products has fallen well short of expectation due to the relatively high cost of its refined product (Isman *et al.,* 2004; 2005), slow action on pest insects and relatively short persistence due to its sensitivity to temperature and ultraviolet light. This necessitates frequent applications to achieve an effective control of thrips which rapidly build up again from non-treated plant parts or re – colonize from refuges such as soil (Barrek *et al*., 2004).

2.5.1.2.2 Pyrethrum pesticides for control of thrips on French beans

Pyrethrum pesticides are natural pesticides with pyrethrin as the active ingredient. Pyrethrin refers to the oleoresin extracted from the dried flowers of *Chrysanthemum cinerariifolium* (Asteraceae) with hexane or similar non-polar solvents (Glynne – Jones, 2001). It contains three esters of chrysanthemic acid and three esters of pyrethric acid. Among the six esters of pyrethrin, those incorporating the alcohol pyrethrolone, namely pyrethrins I and II, are the most abundant and account for most of the insecticidal activity (Casida *et al*., 1995). The insecticidal action of the pyrethrins is characterized by a rapid knockdown effect, particularly in flying insects, and hyperactivity and convulsions in most insects. Pyrethrins are especially labile in the presence of the ultra violet component of sunlight, a fact that has greatly limited their use outdoors.

2.5.1.2.3 Garlic extract for control of thrips on French beans

Garlic, *Allium sativum* L. Alliaceae, extracts have shown considerable toxicity to a number of pest species across all life stages. Susceptible orders of insects include the Coleoptera, Lepidoptera, Heteroptera and the Diptera (Chiam *et al*., 1999). Garlic extracts have been shown to inhibit egg hatching in mosquitoes (Jarial, 2001) and also have adverse effects on the larvae. However, these products lack consistency in their insecticidal effects. For example, Flint *et al*., (1995) compared the insecticidal effects of two commercial products, Garlic Barrier Ag and Envi Repel with those of chopped garlic extract and steam-distilled garlic oil on the silver leaf whitefly *Bemisia argentifolii*. These authors reported that garlic oil sprays and Envi Repel gave no protection atall whereas a 10% solution of Garlic Barrier Ag reduced insect numbers, and a 10% solution of chopped garlic extract provided the best protection.

Garlic contains a number of compounds toxic to insects including diallyl disulphide and diallyl trisulphide (Flint *et al*., 1995). The highly reactive nature of polysulphides have been reported to be responsible for the toxic effect and may cause inhibition by cross-linking with essential thiol compounds in enzyme structures (e.g. glutathione S-transferase) within the insect body; and thus denaturing enzyme and altering the enzyme functions (Halliwell and Gutteridge, 1999). Thiol containing enzymes belonging to the esterase family such as the Carboxylesterase, glutathione S-transferase have been shown to be involved in insecticide resistance (Guerrero *et al.*, 1999; Riley *et al*., 1999). Bhatnagar-Thomas and Pal (1974) reported that the efficacy of garlic compounds is affected by ability to penetrate into the insect, the ability of the insect to metabolize the compounds and the susceptibility of the target enzyme.

2.6.1 Cultural control methods against thrips

Cultural control include some of the oldest known pest control practices such as the use of mulches, intercrops (trap crops and repellent crops) and crop rotation (Coaker, 1987). These methods manipulate the local crop environment to make it less favorable for pest invasion, reproduction, survival and dispersal. Cultural methods reduce pest numbers either below economic injury level or to sufficiently low in order to allow levels biological control to take effect (Takahashi, 1964; Coaker, 1997).

2.6.1.1 Intercropping for thrips management on French beans

Intercropping is a cultural practice involving growing two or more crops in the same field at the same time (Soule, 1992). The practice has many advantages over monocropping (monoculture); which include suppression of weeds due to dense crop cover, soil conservation, and better use of incident radiation, water and nutrition conservation (Coaker, 1987). In Kenya, French beans are mainly grown as monocrops mostly by small-scale farmers (Nderitu *et al*., 1995) which may lead to build up of pest population. Intercropping systems may also limit pest incidence by modifying the environment or acting as a barrier. Some intercrops camouflage crops against pest invasion.. Intercropping system also divert pests away from the crop at risk and by harbouring beneficial natural enemies of the pests to lower pest population densities below economic injury levels (Kasina *et al*., 2006). Intercropping has been found to be useful for the control of *Megalurothrips sjostedti* on cowpea (Ezueh *et al*., 1984; Kyamanywa *et al*., 1988; Nampala, 2002). Ekesi *et al*. (1999) reported that intercropping enhanced the efficacy of entomopathogens like *Metarhizium anisopliae* against thrips than in monocrop situations. Intercrops provide a habitat that has been shown by Parella and Lewis, 1997 to favour increase in population a major thrips predator *Orius tristicolor* (White) than in monocultures. In Kenya and Uganda, intercropping cowpea with sorghum and maize reduced populations of *M. sjostedti* and *Hydatothrips adolfifriderici* on cowpea buds (Dissemond and Hindorf, 1990; Nampala, 2002). Intercropping French beans with *Tagetes erecta* L., *Zea mays* L., *Coriandrum sativum* L. and *Cleome gynandra* reduced the population of thrips below economic injury level (Kasina *et al.*, 2006; Waiganjo, 2008; Nderitu *et al.*, 2009). On the other hand intercrops and margin crops benefit the farmers because they get extra income.

In some cases intercropping does increase the number of thrips in susceptible crops. Thus, populations of *Thrips palmi* and *T. parvispinus* increased on potatoes when intercropped with shallot and garlic as was *Caliothrips indicus* on groundnuts intercropped with pigeon pea and mung beans (Potts and Gunatti, 1991),

2.6.1.2 Mulching for control of Thrips on French beans

Mulching involves covering the soil surface around a plant with vegetation or any other physical materials for protection against water loss, weed infestation or to enrich the soil. Black polythene papers suppress weeds and keep the soil moist and warm for rapid plant growth to evade thrips attack and hinder pre-pupae stages of thrips from entering the soil for pupation. (NAFIS, 2008). Reflective mulch confuses and repels certain flying insects searching for host plants, apparently because reflecting ultraviolet light interferes with the insect ability to locate plants especially when the crops are young (Hanada, 1991). Plastic mulch creates a specific microenvironment for the plants. The changes in microenvironment, compared to bare ground, include changes in root-zone temperature and in the quantity and quality of light reflected from the mulch surface back to the leaves (Decoteau *et al.*, 1989; Lamont, 2005). The reflected energy from the mulch affects plant growth, development and yields (Schalk *et al*., 1987; Decoteau *et al*., 1989), and the behaviour of insects that visit the plants (Kring, 1972). Reflective aluminium mulch has been reported to repel 33 to 68 percent of the *Thrips tabaci* and *Frankliniella* spp (Brown and Brown, 1992).

The negative aspect of mulching is the increase in crop susceptibility to root rot diseases by making the rooting environment wet (Faber *et al*., 2003). However, reflective mulches cease to repel insects when plant canopy covers more than 60 percent of the soil surfaces (Antignus *et al.,* 1996).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Study sites

The laboratory and greenhouse experiments, which involved use of botanical pesticides, were carried out at International Center of Insect Physiology and Ecology (ICIPE) Duduville Kasarani – Nairobi County ($1^0$13’18.47’S, 36^0 53’45.91’’E). The field experiments were carried out at Kenya Agricultural Livestock Research Organization (KALRO) at Thika in Kiambu County of Kenya (Figure 3.1) (1^0 00’07.76’’S 37^0 04’43.82’’E). This is an area with ideal conditions for French bean production. It has a mean temperature of 19.2^0C, an altitude of 1600m above mean sea level, an average annual rainfall of 1018mm and well-drained loamy soil with high organic matter contents (Jaetzold and Schmidt, 1983).

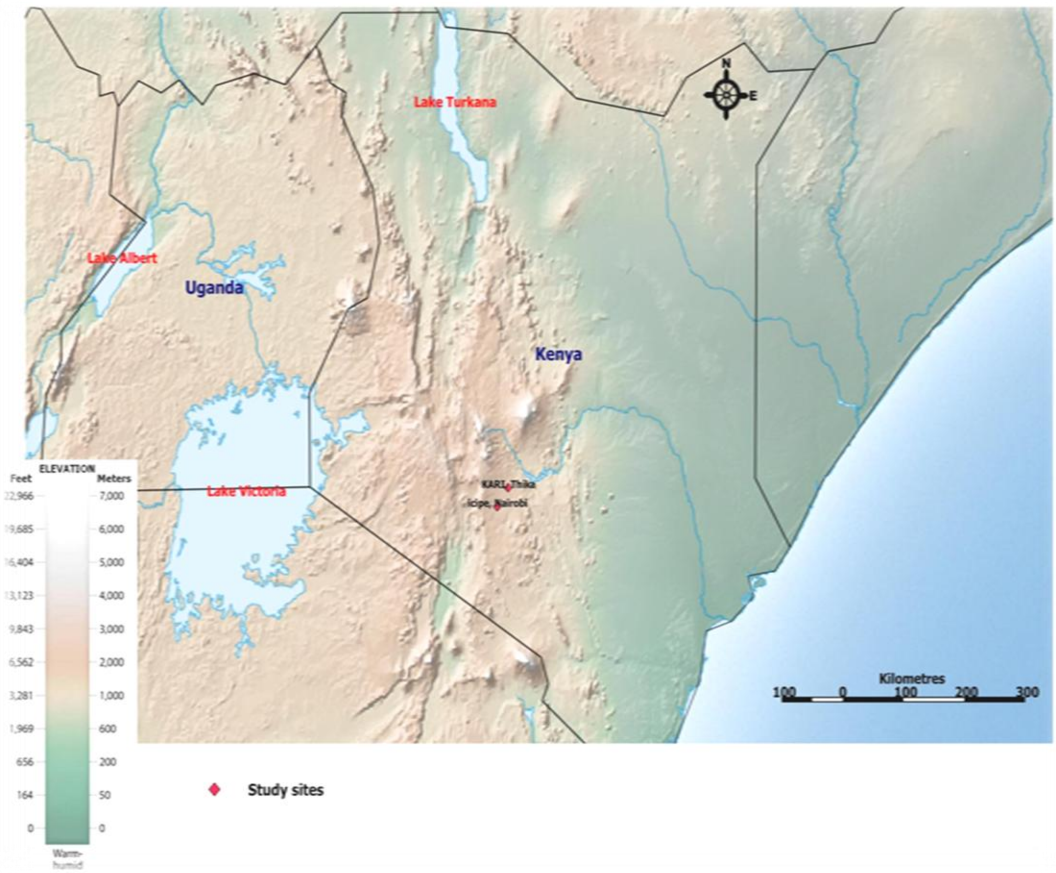

Figure 3.1 Map of Kenya showing the study sites in Nairobi and Thika

3.2 Rearing stock culture of thrips

Adult Western Flower thrips, *Frankliniella occidentalis* (Pergande) collected from thrips infested French bean flowers in Thika were identified using the LuCID key "Pest Thrips of the World" (Moritz *et al*., 2004). The thrips were reared in one litre plastic containers on French bean pods in the Animal Rearing and Quarantine Unit, ICIPE, Kasarani, Nairobi as detailed by Nyasani *et al.* (2012). The lids of the containers were ventilated with 120 mm mesh netting.

The French beans pods used were first washed in 1% sodium hypochlorite for five minutes to surface sterilize the pods and kill any eggs of other insects/thrips. The pods were rinsed in distilled water and allowed to dry for a few minutes. These pods were then dipped in sugar solution which served as thrips food. In each plastic bottle, three fresh bean pods were placed and infested by 300 – 500 adult *F. occidentalis*. After three days the fresh pods with eggs from the bottle were removed making sure that no adult thrips escaped and replaced with fresh pods for further oviposition. These pods were placed in empty plastic bottles with a folded tissue paper below for the eggs to hatch. After 2-3 days when eggs had hatched, the dried pods were replaced by other fresh pods for the larvae to feed. Honey was added in the rearing bottles to provide food for the larvae. The larval stage lasted for nearly 8 days and the bean pods were replaced after three days. The moistened double layered filter paper placed at the bottom facilitated pupation below the paper. The pupal period lasted between 4 – 6 days. Some of the emerging adults were taken back to the stock culture, other adults and larval stages of the thrips were used for laboratory and greenhouse bioassays. The stock culture was maintained on fresh French beans pods. The containers were checked regularly and all the generations were recorded.

CHAPTER FOUR

EFFICACY OF BOTANICAL PESTICIDES AGAINST *FRANKLINIELLA OCCIDENTALIS* INFESTING FRENCH BEANS IN THE LABORATORY AND GREENHOUSE

4.1 Introduction

French beans (*Phaseolus vulgaris* L.) are grown by both small- and large-scale farmers for local and export markets both as fresh bean pods and for the processing industry. The crop accounts for 40% by volume of horticultural exports (HCDA, 2011). Production of this crop is constrained by a number of factors, of which insects and diseases are the most important (Nderitu, 2001). The different insect pests of French beans include Western Flower Thrips (WFT), *Frankliniella occidentalis* (Pergande); Bean Flower Thrips, *Megalurothrips sjostedti* (Trybom); Common Blossom Thrips, *Frankliniella schultzei* (Trybom); Bean fly or Bean stem maggots, (*Ophiomyia* spp.); aphids, *Aphis fabae* (Scopoli) and white flies, *Bemisia tabaci*.

Yield loss caused by thrips exceeds 40% due to abscission of buds and flower abortion. An additional 20% loss occurs at collection points due to rejection of blemished, malformed pods caused due to thrips feeding (Nderitu, 2001; Michalik *et al*., 2006). Recent studies in Kenya by Nyasani *et al*. (2012) reported a 63 - 68% yield loss of fresh pods due to thrips. Report by Nderitu *et al*. (2001) revealed that lack of knowledge and absence of effective alternative pest control methods, have prompted farmers to resort to frequently repeated application of pesticides sometimes even up to 15 sprays per growing season to manage thrips on French beans in Kenya.

The WFT is an invasive pest of great economic significance throughout the world, due to its wide host range and severe damage caused both due to direct feeding and due to its role as a virus vector (Tommasini and Maini, 1995; Lewis, 1997; Reitz, 2009). The adults and larvae feed by piercing plant tissues with their needle-shaped mandible and draining the contents of punctured cells (Kirk, 1997). Feeding by adults and larvae produces scarring on foliage, flowers and fruits, which results in aesthetic crop damage and disrupts plant growth and physiology. Also, oviposition can produce a wound response in fruiting structures, which reduces the marketability of certain horticultural produce (Childers, 1997). The widespread use of chemical insecticides to control the pest has led to high levels of resistance among WFT against the major classes of synthetic insecticides (Kasina *et al.,* 2006; Bielza *et al*., 2007; Bielza *et al.,* 2008; Broughton and Herron, 2009). These synthetic broad-spectrum insecticides not only can disrupt western flower thrips management, they also can disrupt management of other pests including spider mites, whiteflies, and leafminers, by eliminating natural enemies of those pests. The growing awareness and demand about insecticides that are not environmentally hazardous and could be useful to tackle pesticide resistance among insects has stimulated the study on plant-derived compounds for pest management (O'Brien *et al.,* 2009).

Pyrethrum, neem, garlic, sabadilla and *Tagetes erecta* Lineaus are botanical extracts that have long been reported as attractive alternatives to synthetic chemical insecticides. Neem was reported to be effective against bean flower thrips *M. sjostedti* and *F. occidentalis* (National Research Council, 1992) but not as effective as Lambda – Cyhalothrin a commonly used pesticide in Kenya. Neem oil @ 3% was reported to be effective against the mulberry thrips (Subramanian *et al*., 2010).

Pyrethrins are active ingredients extracted from pyrethrum flowers *Chrysanthemum cinerariifolium* Trevir, and are the most widely used botanical insecticide (Isman, 2006). Pyrethrin @ 0.01 % has been reported to cause mortality of adults and embryos but also reduce oviposition by *F. occidentalis* (Ting *et al.*, 2012).

In the current study, the efficacy of pyrethrum, neem and garlic extracts were evaluated against first instar and adult stages of *F. occidentalis* infesting French bean pods in the laboratory and in the greenhouse.

4.2. Materials and methods

Laboratory and greenhouse experiments were carried out at ICIPE, Duduville campus from December 2008 to May 2009. Botanicals evaluated for the management of thrips were commercial neem formulation; Achook® (*Azadirachtin* 0.15% w/w); Pyerin® (pyrethrins 7.5% w/v) and crude garlic extract prepared in the laboratory. These botanicals were compared with a commonly used insecticide Lamda-Cyhalothrin.

4.2.1 Preparation of Garlic extracts and dilution of commercial L-Cyhalothrin, Pyrethrum and Neem formulations

Fresh garlic bulbs (100g) were crushed using a mortar and pestle, shade dried for two days and ground into a fine powder. Twenty grams of the finely ground garlic powder was mixed with 100ml of clean water and left overnight. The following day, the mixture was stirred and allowed to stand for an hour before sieving through a fine muslin cloth. Liquid soap was then added to the mixture at a rate of 5ml per 100ml to act as a surfactant to enhance adhesion on French bean leaves. From this stock mixture, various concentrations of garlic were prepared by adding 5, 2.5 and 1.25 ml of the mixture in 100ml of clean water. For soil application, the garlic powder was prepared by chopping the matured garlic bulbs into small pieces. These pieces were shade-dried and grounded using pestle and mortar into a fine powder. This powder was then applied to the soil around the French bean plant at a rate of one tablespoon (approximately 5g) per plant.

The concentrations of commercial botanical pesticides, Achook® (*Azadirachtin* 0.15% w/w) and Pyerin® (pyrethrins 7.5% w/v) were prepared based on label instructions. Neem concentrations of 5, 2.5 and 1.25% were prepared by adding 5, 2.5 and 1.25 ml of Azadirachtin 0.15% (Achook®) in 100ml of water, respectively. Pyrethrum concentrations of 0.2, 0.1 and 0.05% were prepared by adding 0.2, 0.1 and 0.05ml of Pyerin ® in 100ml of water, respectively. For all neem formulations soap solution was added as a surfactant at rate of 5ml per 100ml.

4.2.2 Dilutions of pyrethrum, L-Cyhalothrin, Neem and Garlic used for Lethality tests

The concentrations used for the lethality tests against first instar *F. occidentalis* larvae were pyrethrum 0.2%, 0.1% and 0.05%; neem 5%, 2.5% and 1.25%; L – Cyhalothrin 0.5%, 1% and 2% and garlic 5%, 2.5% and 1.25%. Two fresh French bean pods were immersed in each concentration and after five minutes the pods were removed and placed in clean sterilized plastic containers ventilated with thrip proof - net. Twenty first instars of *F. occidentalis* were introduced into each container and mortality was observed at 12 hours interval for three days. Each treatment concentration was replicated thrice.

4.2.3 Greenhouse assays on the efficacy of botanical pesticides against *Frankliniella occidentalis* reared on French beans

Plastic pots of 15cm diameter were filled with potting mixture to about three quarters. The mixture was prepared by mixing 1 wheelbarrow full of red soil with 1 wheelbarrow full of manure. Diammonium phosphate (DAP) was applied at the rate of two teaspoonfuls per plastic pot and the soil was mixed thoroughly. The plastic pots were sown with Certified French bean seeds (Cultivar Paulista) at the rate of two seeds per pot and watered every day. The following experimental treatments were carried out on the French bean plants: -

1. Control (foliar spray with distilled water)
2. L-cyhalothrin (foliar spray)
3. Neem (soil application)
4. Neem (soil + foliar application)
5. Garlic extracts (soil application)
6. Garlic extracts (soil + foliar application)
7. Pyrethrum (soil application)
8. Pyrethrum (soil + foliar application)

Each treatment had three replicates, with four potted plants per replicate enclosed within individual cages (1x0.6x0.6m). A completely randomized design was adopted. The potted plants were spaced 30cm apart in the cage. The frames of the cages were made using plastic pipes connected with plastic T-joints. The frames of cage were then covered with light white cloth fitted at the top a transparent polythene paper so as to allow passage of light. Each cage cover had a zipped opening to enable release of insects and ease the process of making observations and data collection. Two weeks after germination of French bean seedlings, soil treatments with pyrethrum powder (Pyrethrin 1.3% w/w), neem powder (Azadirachtin 0.15% w/w) and garlic powder were applied at a rate of 5g per pot. Four weeks after germination, each caged French bean plant in the cage was infested with twenty second instar larvae of *F. occidentalis.* The foliar sprays were undertaken with concentration of 5% neem, 5% garlic extract, 0.2% pyrethrum and 2% L–cyhalothrin (1.75% EC) on the fifth week after germination of French beans. Distilled water was sprayed in the untreated control treatment.

The population of thrips in the different treatments was evaluated by observing larval and adult *Frankliniella occidentalis* on French bean leaves at five days interval. At flowering, samples of four flowers from each plant were collected and kept in 70% ethanol. These flowers were dissected in the laboratory and the number of thrips per flower was recorded. Damage on leaves and pods was assessed by counting the number of scars and corresponding area of damage caused by thrips and rated using a scale scale of 1 – 5 where, 1 = no damage (0% damage); 2= slight damage (≤25% damage); 3= moderate (>25≤50%); 4= severe (>50≤75%); 5= very severe (>75% damage) (Mackenzie *et al*., 1993).

4.2.4 Data analysis

The lethality test data on the mortality of *F.occidentalis* larvae fed on fresh French bean pods treated with various concentrations of botanical pesticides was analyzed using the logistic regression using PROC GLIMMIX in SAS 9.2 (SAS Institute, 2008) and significant differences were assessed using least square mean values. Data on the number of thrips recorded from leaves and in the flowers of French bean plants in the greenhouse were transformed using natural logarithm and subjected to analysis of variance (ANOVA) using SAS 9.2 programme (SAS Institute, 2008). The means were separated using Tukey's HSD test at $p = 0.05$. The data on damage score recorded on leaves and pods were transformed using natural logarithm and also subjected to analysis of variance (ANOVA).

4.3 Results

4.3.1 Effect of L – Cyhalothrin, pyrethrum, neem and garlic pesticides on the mean mortality of *Frankliniella occidentalis* larvae fed on fresh French bean pods in the laboratory.

There were significant differences in the mean mortality of *F. occidentalis* larvae fed on French bean pods treated with different pesticides after 12 hours ($F_{3, 32} = 13.75$. $p <0.0001$), 24 hours ($F_{3, 32} = 47.34$. $p <0.0001$), 36 hours ($F_{3, 32} = 41.55$. $p <0.0001$), 48 hours ($F_{3, 32} = 32.02$. $p <0.0001$), 60 hours ($F_{3, 32} = 27.47$. $p <0.0001$) and 72 hours($F_{3, 32} = 26.32$. $p <0.0001$) (Table 4.1). After 12, 36, 48, 60 and 72 hours, the highest mean mortality was recorded after the treatment with L – Cyhalothrin followed by pyrethrum, neem and garlic. However the mean mortality for neem did not differ significantly from that of garlic in the laboratory experiments.

Table 4.1 Mean percentage mortality ±SE of first instar *Frankliniella occidentalis* after treatment with different doses of L – Cyhalothrin, Pyrethrum, Neem and Garlic pesticides

Hours after treatment	Mean in different treatments				F	p
	L-Cyhalothrin	Pyrethrum	Neem	Garlic		
12	38 ± 04a	18 ± 03b	01 ±01c	00 ± 00c	13.75*	<.0001
24	61± 04a	28 ± 03b	04 ± 01d	08 ± 02c	47.34*	<.0001
36	66 ± 03a	34 ± 15b	07 ± 02c	26 ± 03d	41.55*	<.0001
48	68 ± 03a	46 ± 04b	27 ± 03c	27 ± 03c	32.02*	<.0001
60	71 ± 03a	50 ± 04b	31 ± 03c	28 ± 03c	27.47*	<.0001
72	72 ± 03a	56 ± 04b	33 ± 04c	28 ± 03c	26.32*	<.0001

Means within the same row followed by the same letter are significantly different at p <0.0001(Tukey HSD)

4.3.2 Effects of different concentrations of L – Cyhalothrin, pyrethrum, neem and garlic pesticides on the mortality of *Frankliniella occidentalis* larvae fed on French bean pods

There were significant differences in the mean mortalities of *F. occidentalis* larvae after treatment with different concentrations of L – Cyhalothrin at different time intervals. After 12hrs ($F_{2, 6}$= 18.83, p = 0.0026), 24 ($F_{2, 6}$= 20.45, p = 0.0021), 36 ($F_{2, 6}$= 13.58, p = 0.0059), 48 ($F_{2, 6}$= 9.87, p = 0.0127), 60 ($F_{2, 6}$= 9.87, p = 0.0127) and 72hrs ($F_{2, 6}$= 9.87, p = 0.0127) hour's exposure; the highest mortalities occurred after treatment with a concentration of 2%, followed by1% and 0.5%.

The mortalities of *F. occidentalis* larvae after treatment with different concentrations of pyrethrum at different time intervals showed significant differences. After 12hrs ($F_{2,\,6}$= 10.10, p = 0.0120), 24 ($F_{2,\,6}$= 22.32, p = 0.0017), 36 ($F_{2,\,6}$= 19.69, p = 0.0023), 48 ($F_{2,\,6}$= 26.47, p = 0.0011), 60 ($F_{2,\,6}$= 24.18, p = 0.0013) and 72hrs ($F_{2,\,6}$= 7.26, p = 0.0250) hour's exposure; the highest mortalities occurred after treatment with a dose of 0.2%, followed 0.1% and 0.05%.

The resuilt on the mean mortality of *F. occidentalis* larvae after treatment with different concentrations of Neem at different time intervals revealed that there were no significant differences. After 12 ($F_{2,\,6}$= 0.00, p = 0.9994), 24 ($F_{2,\,6}$= 0.08, p = 0.9296), 36 ($F_{2,\,6}$ = 1.89, p = 0.2304), 48($F_{2,\,6}$= 2.56, p = 0.1575), 60 ($F_{2,\,6}$= 4.05, p = 0.0772) and 72 ($F_{2,\,6}$= 4.49, p = 0.0644) hour's exposure; the highest mortalities occurred after treatment with a concentration of 5%, followed by that of 2.5% and 1.25%. The mean mortality of 2.5% pyrethrum did not differed significantly with that of 1.25% after 12 hours. However after 24 hours it differed significantly.

There were no significant differences in the mean mortalities of *F. occidentalis* larvae after treatment with different concentrations of garlic extract at different time intervals. After 12 ($F_{2,\,6}$= 0.00, p = 1.0000), 24 ($F_{2,\,6}$= 0.00, p = 0.9992), 36 ($F_{2,\,6}$= 3.42, p = 0.1019), 48 ($F_{2,\,6}$= 3.88, p = 0.0829), 60 ($F_{2,\,6}$= 3.74, p = 0.0880) and 72 ($F_{2,\,6}$= 3.74, p = 0.0880) hour's exposure; the highest mortalities occurred after treatment with a concentration of 5%, followed by that of 2.5% and 1.25%. The mean mortality of 2.5% garlic extract did not differed significantly with that of 1.25% after 12 and 24 hours, but after 36 hours it differed significantly.

Table 4.2 Mean percentage mortality (±SE) of first instar *Frankliniella occidentalis* treated with different concentrations of L-cyhalothrin, pyrethrum, neem and garlic pesticides

Treatment	Dose	Mean probability of mortality after different hours post treatment					
		12 hours	24 hours	36 hours	48 hours	60 hours	72 hours
Cyhalothrin	2 %	70 ± 06a	87 ± 04a	100 ± 00a	100 ± 00a	100 ± 00a	100 ± 00a
	1 %	32 ± 06b	70 ± 06b	77 ± 05b	78 ± 05b	78 ± 05b	78 ± 05b
	0.50 %	12 ± 04c	27 ± 06c	27 ± 06c	37 ± 06c	37 ± 06c	37 ± 06c
F - Value		18.83	20.45	13.58	9.87	9.87	9.87
P - Value		0.0026	0.0021	0.0059	0.0127	0.0127	0.0127
Pyrethrum	0.20%	52 ± 06a	65 ± 06a	72 ± 06a	92 ± 04a	95 ± 03a	100 ± 00a
	0.10%	03 ± 02b	15 ± 05b	37 ± 06b	40 ± 06b	43 ± 06b	45 ± 06b
	0.05%	00 ± 00c	03 ± 02c	07 ± 03c	10 ± 04c	12 ± 04c	12 ± 04c
F - Value		10.10	22.32	19.69	26.47	24.18	7.26
P - Value		0.0120	0.0017	0.0023	0.0011	0.0013	0.0250
Neem	5.00 %	02 ± 02a	07 ± 03a	17 ± 05a	35 ± 06a	40 ± 06a	43 ± 06a
	2.50 %	02 ± 02a	05 ± 03a	05 ± 03b	28 ± 06b	35 ± 06b	38 ± 06b
	1.25 %	00 ± 00a	00 ± 00b	00 ± 00c	17 ± 05c	17 ± 05c	18 ± 05c
F - Value		0.00	0.08	1.89	2.56	4.05	4.49
P - Value		0.9994	0.9276	0.2304	0.1575	0.0772	0.0644
Garlic	5%	00 ± 00a	23 ± 05a	48 ± 06a	50 ± 06a	60 ± 06a	60 ± 06a
	2.5%	00 ± 00a	00 ± 00b	25 ± 06b	25 ± 06b	30 ± 06b	30 ± 06b
	1.25%	00 ± 00a	00 ± 00b	00 ± 00c	00 ± 00c	00 ± 00c	00 ± 00c
F - Value		0.00	0.00	3.42	3.88	3.74	3.74
P - Value		1.0000	0.9992	0.1019	0.0829	0.0880	0.0880

Means ± SE within the same column followed by the same letter for each given treatment are not significantly different at p = 0.05

4.3.3 Effects of L- Cyhalothrin, pyrethrum, neem and garlic pesticides on the survival and development of *Frankliniella occidentalis* on French beans in the greenhouse

There were significant differences in the mean number of *F. occidentalis* surviving on French bean leaves after treatments with different pesticides (F=7, 63 = 185.56, p < 0.0001 (Table 4.3). The lowest mean numbers were recorded after treatment with L-Cyhalothrin followed by pyrethrum (soil+foliar), Neem (soil+foliar), Neem (soil) and pyrethrum (soil). The latter was not significantly different from the Garlic (soil+foliar) treatment. The highest mean numbers were recorded from the control experiment treated with water. But the latter did not differ significantly from the mean numbers recorded on garlic (soil+foliar) and garlic (soil).

There were significant differences in the mean number of *F. occidentalis* surviving in French bean flowers after treatment with different pesticides (F7, 35 = 13.61, P<0.0001) (Table 4.3). The lowest mean numbers were recorded after treatment with neem (soil + foliar) followed by L-Cyhalothrin and pyrethrum (soil+foliar) but but they did not show significant differences. These were then followed by the mean numbers after treatment with neem (soil) and garlic (soil+foliar) which also showed no significant but were significantly diffent compared to the mean number after treatment with garlic (soil). The highest mean numbers were recorded after the control experiment (treatment with water) but the latter did not differ significantly from the mean numbers recorded on pyrethrum (soil) treatment.

Table 4.3 Mean numbers (±SE) of *Frankliniella occidentalis* on leaves and in flowers of French bean plants subjected to different pesticide treatments in the greenhouse

Treatment	Leaves	Flowers
L-Cyhalothrin	1.60±0.14a	1.17±0.17a
Pyrethrum(soil+foliar)	2.12±0.14b	1.33±0.17a
Neem(soil+foliar)	3.24±0.14c	1.04±0.17a
Neem(soil)	4.46±0.14d	1.39±0.17b
Pyrethrum(soil)	4.85±0.14e	2.34±0.17d
Garlic(soil+foliar)	4.99±0.14ef	1.39±0.17b
Garlic(soil)	5.12±0.14f	1.53±0.17c
Control(water)	5.19±0.14g	2.29±0.17d
F – Value	185.56	13.61
P – Value	< .0001	< .0001
CV%	26.43	21

Means within the same column followed by the same later are not significantly different at p = 0.05 (adjusted Tukey HSD test).

4.3.4 Effect of L-Cyhalothrin, pyrethrum, neem and garlic pesticides on the mean damage to French bean leaves by *Frankliniella occidentalis*

There were significant differences in the mean damage score recorded on leaves after treatment with various pesticides ($F_{7, 232} = 10.36$, $P<0.0001$) (Table 4.4). The lowest mean damage score was recorded after treatment with pyrethrum (soil+foliar) followed by neem (soil+foliar), L-Cyhalothrin and neem (soil). These were followed by the mean numbers after treatment with pyrethrum (soil), garlic (soil+foliar) and garlic (soil) which also showed no significant differences from the mean numbers recorded on L-Cyhalothrin and neem (soil). The highest mean damage score was recorded from the control experiment (treated with water). Damage to pods was manifested in the form of scars on the surface of pods, shriveled and malformed pods as shown in (Plate 4.1). The damaged leaves had botches on their surfaces as shown in (Plate 4.2).

Plate 4.1 Damage due to a) Scars caused by feeding on the pod surface b) aborted French bean pods and c) Shriveled and malformed pods

Plate 4.2 French bean leaf showing blotches after damage by thrips.

Table 4.4 The mean damage score (±SE) recorded on French bean leaves after application of various pesticides

Treatment	Mean damage score on leaves
Pyrethrum (soil + foliar)	1.90±0.42a
Neem (soil + foliar)	1.90±0.42a
L – Cyhalothrin	2.00±0.42ab
Neem (soil)	2.20±0.42ab
Pyrethrum (soil)	2.40±0.42b
Garlic (soil + foliar)	2.40±0.42b
Garlic (soil)	2.53±0.42b
Water(control)	3.03±0.42c
F – Value	10.36
P – Value	< .0001
CV%	28.46

Means ± SE with the same letter are not significantly differently at p = 0.05(adjusted Tukey HSD test

4.4 Discussion

Results on the mean motality of first instar *F. occidentalis* larvae after treatment with different pesticides in the laboratory experiments showed that there were significant differences. The highest mean mortality rate was recorded after French beans treatment with L-Cyhalothrin a synthetic insecticide compared to botanical pesticides pyrethrum, neem and garlic. The results also showed that the mean mortality of *F. occidentallis* increased with time among all the treatments with the highiest mortality recorded after 72 hours.

The effectiveness of L-Cyhalothrin against *F. occidentalis* in the laboratory situation may be due to its stability in the laboratory where it was protected against ultra violet rays from sun light. In addition, the bioassays were conducted using *F.occidentalis* reared in the laboratory over several generations, which may be more susceptible to pesticides as compared to their counterparts in the field. Similar studies by Kasina *et al*. (2006) and Nderitu *et al*. (2007) reveled that *F. occidentalis* had developed resistance to L-Cyhalothrin in the field. Studies by Ruzo *et al.*, (1987) showed that high temperatures and ultraviolet rays denature the active ingredient of L-Cyhalothrin thereby reducing its effectiveness in the field. Similarly the photochemical studies by Fernandez - Alvarez *et al.* (2007) on lambda-Cyhalothrin under ultraviolet and sunlight irradiation showed that exposure of L - Cyhalothrin to ultra violet light for 20 minutes resulted in nearly complete degradation with losses greater than 95% of the initial applied amounts. This might be the reason as to why farmers apply this insecticide several times per growing season of French beans in order to manage thrips. Nderitu *et al*. (2001) finding reported that farmers apply L-Cyhalothrin fifteen times within a growing period of French beans in order to manage thrips.

Results on the effects of various concentrations of L-Cyhalothrin on *F.occidentalis* larvae at different time intervals showed that there were significant differences. Higher concentration of 2% L-Cyhalothrin caused higher mortality *F. occidentalis* larvae compared to lower of 0.5% concentration. The same concentration of 2% L-Cyhalothrin when applied as foliar sprayed on French bean in the greenhouse it reduced the population of *F.occidentalis* significantly. This was due to the fact that higher concentrations L- Cyhalothrin had more insecticidal ingredients than that of a lower concentration.

Among the botanical pesticides which were used, pyrethrum recorded significantly higher mortality on the first instar *F. occidentalis* larvae than neem and garlic treatments. Similar findings were reported by Ting *et al.* (2012) that natural pyrethrins caused mortality of embryos and adult *F.occidentalis* as compared to neem, rosemary, peppermint, garlic, and cottonseed oils. Consequently, a higher concentration of 0.2% pyrethrum caused a higher mortality of the larvae than a lower concentration of 0.05%. This is because a lower concentrated pesticide has less insecticidal ingredient. Similar finding by Ting *et al.* (2012) showed that 1% pyrethrins caused 69%

mortality while a lower concentration caused 25 % mortality of *F. occidentalis* in two days.

In the greenhouse experiments, pyrethrum which was applied as foliar spray + soil and as powder pyrethrum in the soil significantly reduced the number of *F.occidentalis* on the leaves and in the flowers of French beans. In this finding, French beans treated with pryrethrum (foliar+soil) recorded a lower number of *F.occidentalis* compared to pyrethrum soil application alone. The aim of applying pyrethrum in the soil was to control the pre-pupae and pupae stages of *F.occidentalis* which dwell in the soil. Higher number of *F.occidentalis* recorded on French beans treated with pyrethrum soil treatment alone might be due to its decomposition by microorganism in the soil.

The finding made by Vassiliou (2011) reported that foliar spray of pyrethrum effectively controlled Kelly's citrus thrips feeding on organic grapefruits. The same author recommended the use of pyrethrum and neem for the management of citrus thrips as oppose to some synthetic pesticide which have significant drawbacks, such as the risk of causing outbreaks of secondary pests (Vassiliou, 2007; 2008). Pyrethrum is very effective pesticide against a wide range of insect pests but its use has been limited due to its instability of the insecticidal ingredient when exposed to sun light. In reference to chapter six of these current studies, pyrethrum when applied alone in the field it did not significantly reduced the number of thrips on French beans. Studies carried out by Elizabeth *et al.* (2005) showed that sunscreen increased half – life of pyrethrum thus maintaining its stability and effectiveness in the indoors, but when it is exposed to ultra violet light, it easily decomposes making it ineffective, a fact that has greatly limited its use in the field, Pyrethrum as reported by Davies *et al*. (2007) it mainly contains pyrethrins an active neurotoxins insecticidal ingredient which is effective against a broad spectrum of insects. Similarly toxicity of pyrethrum to mammals is very low as compared to that in the synthetic insecticides. Therefore, pyrethrum is a suitable alternative botanical pesticide for the management of *F. occidentalis.* This pest has developed resistance to many commonly used synthetic insecticides. This clearly indicates the effectiveness of the treatment against both life stages of thrips on the leaf surface (larvae and adults) and the life stages in the soil (pro-pupa and pupa). Therefore a combination of pyrethrum foliar and soil could be used as an alternative pesticide in the management of thrips indoors especially for *F. occidentalis* populations resistant to many other synthetic pesticides (Ting *et al*., 2012). While in open fields the time of application needs to be considered to enhance the efficacy of pyrethrum.

In the laboratory experiments, neem pesticide did not significantly reduce the mean number of *F. occidentalis* larvae on French bean pods as compared to pyrethrum and L – Cyhalothrin. This might be due to slow effects of neems on insect pests. The findings by Nderitu *et al*. (2007) showed that, neem had a slow effect on *F. occidentalis.* Reports by Rembold, 1989 and National Research Council (1992) revealed that neem was mainly a growth inhibitor meaning that its effects are slow on insect pests compared to pyrethrum and L-

Cyhalothrin. The latter affect the insect nervous system leading to quick knock down (Crosby, 1995). The slow effects of neem on *F.occidentalis* larvae might have been due to the lower temperature in the laboratory that may have affected their development. The studies by Theoming *et al.* (2003) showed that lower temperature reduces the rate of feeding and hence reduces neem uptake by the insect pests. If neem is not ingested then it might not kill the insect pest. The results on the effects different concentrations of neem on *F.occidentalis* larvae showed that there were no significant differences on the mean mortality rates. In this study higher concentration of 5% neem caused a higher mortality of the larvae than the concentrations of 2.5% and 1.25%. This finding is in conformity with that of Aliakharpour *et al.* (2011) also reported that neem oil of a 2% concentration was more effective on reducing the number of adult thrips reared on mango panicles than the larvae.

Neem of 5% concentrations significantly reduced the number of *F.occidentalis* on leaves and in flowers of the French beans grown in the greenhouse. The result showed that neem (foliar + soil) was as effective as pyrethrum and L-Cyhalothrin for the management of *F.occidentalis*. Similarly when neem was applied in the soil alone as powder it significantly reduced the mean number of thrips on French beans than the control. This finding is similar to that of Theoming *et al*. (2003) who reported systemic effects of neem to have caused a high mortality of 50.6% of *F. occidentalis* after the application of neem soil treatment. The same author also reported neem soil treatment to have significantly reduced *Ceratothriploides claratris* on young tomato plants. The translocation of neem pesticides ingredients in *Phaseolus* vuigaris has been reported by Theoming *et al.* (2003) to be faster and persistence after four days of application. The systemic action of neem ingredient in the plant tissues is not well known. If the duration of the systemic action is well known for each vegetable crop, then application of neem soil treatment can reduce populations of *F.occidentalis* on French beans under tropical greenhouse conditions. However different microclimate conditions in the greenhouse where French beans were grown in closed cages were very humid environment. This might affected the evaporation and water transport from roots to leaves and therefore reducing the rate of translocation of soil applied neem in the plant.

Garlic extract did not significantly reduce the mean number of *F. occidentalis* first instars larvae on French bean pods as compared to L-Cyhalothrin, pyrethrum and neem both in the laboratory and green house experiments. The finding by Vassiliou (2011) showed that garlic extract had the lowest effects on Kelly's citrus thrips *Pezothrips kellyanus* (Bagnall) compared to pyrethrin and neem which were the most effective. Burubai *et al*. (2012) also reported that garlic extract alone did not reduce *Thrips palmi* on watermelon but in combination with other pesticides it was effective. Bhatnagar – Thomas and Pal (1974) reported that the efficacy of garlic extract is influenced by its ability to penetrate into the insect body system and the ability of the insect to metabolize the insecticidal compounds.

The results on the mean damage score on leaves of French bean after application of various treatments showed that there were significant differences. In the cages where French beans were treated with pyrethrum (foliar + soil) recorded the lowest mean damage score on the leaves. The lowest mean damage score may be due to the effectiveness of pyrethrum on *Franckliniella occidentalis*. Report on the mean numbers *F. occidentalis* which was obtain on leaves of French bean showed lower numbers in the cages where pyrethrum was applied both as foliar spray and soil treatment. This implies that there are fewer numbers of *F. occidentalis* feeding and ovipositing on the French beans leaves. Since damage score was rated using the number of scars caused by punches of mouth parts and ovipositor of this thrips, the lower there numbers resulted to lower damage.

The second lowest mean damage score was recorded on French bean leaves treated by Neem (foliar + soil). The finding from the current studies showed that Neem when applied both as foliar spray and soil application significantly reduced the number of thrips of French bean leaves. The studies reported by Theoming *et al.* (2003) Neem had systemic effects and killed 51% of *F. occidentalis* on French beans. Therefore, the fewer the number of *F. occidentalis*, the lower the damage on the leaves of French beans. The mean damage score obtained on French bean leaves treated by L-Cyhalothrin did not differ significantly with those from Pyrethrum (foliar+soil), Neem (foliar+soil), Neem (soil), Pyrethrum (soil), Garlic (foliar+soil) and Garlic (soil).

The highest damage score was recorded in untreated French beans (control). Similarly, the highest numbers of *F. occidentalis* were obtained on French bean leaves from the control. The more the numbers the more they feed and oviposit on leaves causing scars hence damaging the leaves. Reports by Nyasani *et al.* (2012) showed that thrips caused higher damages on the untreated French beans.

CHAPTER FIVE

EFFECT OF MULCHING ON INFESTATION AND DAMAGE OF FRENCH BEANS BY THRIPS

5.1 Introduction

Cultural practices are an important component of integrated pest management and they have been included in pest management in several cropping systems (Flint and Van den Bosch, 1981). Cultural practices include the use of organic or synthetic mulche to control pests, conserve soil moisture, modulate soil temperature, suppress weed and enhance crop yield and quality (Greer and Dole, 2003). Coaker (1987) reported that cultural practices reduce or delay pest build up to damaging levels and contribute to the overall reduction in pesticides use and the associated costs and side effects.

Mulch is any material applied to the soil as a layer enough to cover the soil surface. Mulches can be either organic/natural such as manure, sludge, sawdust, crop residues, wood chips, straw shredded prunings, plant foliage, paper, sand, gravel or rock or inorganic such as plastic or other polymers. Inorganic mulches such as polyethylene sheet account for the greatest volume of mulch used in commercial crop production. Owing to its greater permeability to long wave radiation, plastic mulch can increase temperature around the plants during night especially in winter when the soil temperature is very low (Benoit and Ceustermans, 1996). Recently black plastic mulches have become popular with good results in rain fed agriculture due to conservation of soil moisture and suppression of weeds (Ghuman *et al*., 2001; Qing *et al.,* 2009).

Mulches can also aid in pest control in different cropping systems. Coarse composted mulch beneath avocado trees reduced the emergence of adult avocado thrips (*Scirtothrips perseae*) by approximately 50% compared with normal leaf duff (Hoddle *et al.,* 2002). Straw mulches in onions reduced thrips populations up to 48% (Gent *et al*., 2006) and increased onion yields between 64 and 74% due to decreased water runoff and increased soil moisture (Jensen *et al*. 2003). The positive effect of ultraviolet reflective mulches especially those of aluminium or silver against thrips have been demonstrated (Stavisky *et al*., 2002; Reitz *et al*., 2003; Van Toor *et al*., 2004; Gent *et al.,* 2006). Transparent plastic sheets have a repellent effect on pest and vector insects, such as thrips (Greenough *et al.,* 1985). These mulches can reduce thrips populations by disrupting their ability to recognize and land on their hosts in early stages (Hanada, 1991), and their use has been reported to reduce *Thrips tabaci* and *Frankliniella* spp. populations in tomatoes and peppers (Scott *et al*., 1989; Brown and Brown, 1992; Stavisky *et al*., 2002; Reitz *et al*., 2003). In another study by Larentzaki *et al*. (2008) it was reveled that mulching onion with dry straw mulch reduced *Thrips tabaci* by 60% and had no effects on natural enemies of pests in the soil. In view of the above stated inference, the aim of this study was to compare the effect of different types of mulches on the abundance of French bean thrips in cropping system.

5.2 Material and methods

The French beans Cultivar Paulista were sown in experimental plots measuring (5 x 3m) with a spacing of 50x10cm. A randomized block design was adopted for the treatments. Between the plots and the blocks there was a spacing of 2m and 5m respectively. There were five treatments each replicated four times. The following experimental treatments were carried out: -

1. French beans without mulch (control)
2. French beans with transparent plastic mulch
3. French beans with black plastic mulch
4. French beans with dry grass mulch
5. French beans with *Tithonia* fresh leaf mulch

In the plots where dry grass and *Tithonia* leaves were used, the mulch was applied two weeks after sowing the seeds while plastic mulches were applied before sowing. In the case of dry grass mulched plots, dense dry grass was laid between the rows of the French bean seedlings. In the case of *Tithonia*, the leaves were placed in the shallow trenches made in between the French bean rows and coved with soil. In case of polythene, black and transparent polythene papers were cut into sizes corresponding to that of plots. Then holes of about 5cm were cut on the polythene sheet depending on spacing of French bean seedlings within the plots. Calcium ammonium nitrate was applied first when the French bean seedlings had produced secondary leaves and later on the onset of the flowering stage. The fertilizer was applied at a rate one table spoon per plant. Harvesting of French bean pods started from the 5th week after germination. Pods from each experiment treatment were picked and packed in small polythene papers. The pods were then graded as marketable and non – marketable according to size and quality. The first grade marketable pods were unblemished, tender, straight, long and at the right harvesting age while the second grade pods were shorter thus less than 12cm long, had minimal blemishes and slight distortion and were slightly past the picking stage. The non marketable pods had many large brown blemishes and were highly distorted. The blemishes on pods were rated on a scale of 1 – 5 score as described by Mackenzie *et al*. (1993).

Data collection commenced twenty five days after sowing. The collection involved randomly selecting ten French bean plants per treatment plot and physically counting the number of thrips on leaves. In addition from each treatment plot, 20 flowers were randomly picked and kept in vials containing 70% ethanol. These flowers were taken to the laboratory at ICIPE Duduville Nairobi where they were dissected and the number of thrips counted using a dissecting microscope. The collected thrips samples were processed in the laboratory mounted on slides and identified using Lucid key (Moritz *et al*., 2004).

5.2.1 Data analysis

The data on the number of thrips recorded from flowers and leaves were transformed using natural logarithm and subjected to analysis of variance (ANOVA). Means that showed significant differences were separated using fisher's protected LSD test.

5.3. Results

5.3.1 The effects of mulching on the number of thrips on French bean

I) Leaves

There were significant differences in the mean number of thrips recorded on French bean leaves 25 days after treatment with different types of mulches ($F_{4, 12} = 95.24$, $p < 0.001$) (Tables 5.1). The lowest mean numbers of thrips were recorded from plots where French beans were mulched with Transparent plastic sheets followed by Dry grass, Black plastic sheet, Tithonia green leaves and unmulched French beans.

There were significant differences in the mean number of thrips recorded on French bean leaves 30 days after treatment with different types of mulches ($F_{4, 12} = 54.12$, $p < 0.001$) (Tables 5.1). The lowest mean numbers of thrips were recorded from the plots mulched with Transparent plastic sheet followed by Black plastic sheet, Tithonia green leaves Dry grass, and unmulched French beans.

There also were significant differences in the mean number of thrips recorded on French bean leaves 35 days after treatment with different types of mulches ($F_{4,\ 12}$ =137.87 , $p < 0.001$) (Tables 5.1). The lowest mean numbers of thrips were recorded from the plots mulched with transparent plastic sheet followed by Black plastic sheet, Dry grass, Tithonia green leaves and unmulched French beans.

There were significant differences in the mean number of thrips recorded on French bean leaves 40 days after treatment with different types of mulches ($F_{4,\ 12}$ = 81.70, $p < 0.001$) (Tables 5.1). The lowest mean number of thrips was recorded from plots mulched with transparent plastic sheet followed by Dry grass, Black plastic sheet, Tithonia green leaves and unmulched French beans.

There were significant differences in the mean number of thrips recorded on French bean leaves 45 days after treatment with different types of mulches ($F_{4,\ 12}$ = 56.83, $p < 0.001$) (Tables 5.1). The lowest mean number of thrips was recorded from plots mulchh plastic sheet followed by Black plastic sheet, Dry grass, Tithonia green leaves and unmulched French beans.

There were significant differences in the mean number of thrips recorded on French bean leaves 50 days after treatment with different types of mulches ($F_{4,\ 12}$ =5.55, $p = 0.001$) (Tables 5.1). The lowest mean number of thrips was recorded from plots mulched with Transparent plastic sheet followed by Tithonia green leaves, Dry grass, French bean alond(unmulched French beans), and Black plastic sheet,

There were significant differences in the mean number of thrips recorded on French bean leaves 55 days after treatment with different types of mulches ($F_{4, 12}$ =18.50, $p < 0.001$) (Tables 5.1). The lowest mean number of thrips was recorded from plots mulched with Transparent plastic sheet and it did not differ significantly from the mean numbers of thrips obtained from Tithonia green leaves mulched plots. However, these means differed significantly with that recorded from French bean alone. The highest mean number of thrips was recorded from plots where French beans were mulched with Dry grass and it did not differ significantly from the mean number of thrips obtained from those mulched with Black plastic sheet.

There were significant differences in the mean number of thrips recorded on French bean leaves 60 days after treatment with different types of mulches ($F_{4, 12}$ = 108.13, $p < 0.001$) (Tables 5.1). The lowest mean number of thrips was recorded from plots mulched with Transparent plastic sheet and it did not differ significantly from the mean number of thrips obtained from French bean plots mulched with Black plastic sheet. However, these means differed significantly with that recorded from Dry grass. The highest mean number of thrips was recorded from plots where French beans were mulched with Tithonia green leaves and it differed significantly from the mean number of thrips obtained from unmulched plots.

II) Flowers

There were significant differences in the mean number of thrips recorded on French bean flowers among the different mulching treatments after 35 days ($F_{4, 12} = 210.87$, $p < 0.001$) and 40 days ($F_{4, 12} = 33.66$, $p < 0.001$) (Table 5.2). After 35 days, the lowest mean numbers of thrips were recorded in French beans plots mulched with dry grass but it did not differ significantly with the mean number of thrips from the plots the mulched with Black plastic sheet. These were then followed by the means obtained from the plots mulched by Tithonia green leaves, Transparent plastic sheet and unmulched French beans.

After 40 days, the lowest mean numbers of thrips were recorded on French beans plots which were mulched with the dry grass followed by those mulched with black plastic mulch. These, were then followed by mean number of thrips obtained from plots mulched by Tithonia green leaves and Transparent plastic sheet which did not differ significantly. The highest mean numbers of thrips were recorded from unmulched (control) French bean plots.

Table 5.1 Mean numbers (±SE) of thrips recorded on French bean leaves under different mulch treatments and on different days

Treatment	25 days	30 days	35 days	40 days	45 days	50 days	55 days	60days
Transparent plastic mulch	21.50±0.65a	47.25±1.18a	111.20±2.10a	148.80±4.39a	154.50±2.72a	195.00±9.01a	128.80±0.63a	117.20±1.11b
Dry grass mulch	23.00±1.29b	63.75±2.72d	157.80±1.75b	155.50±2.02b	192.50±2.22c	217.00±5.34c	148.5±1.76c	119.2±2.39c
Black plastic mulch	34.50±1.56c	50.25±1.32b	154.80±3.90b	193.20±2.02c	184.00±1.68b	226.20±3.68d	145.50±2.25c	94.25±1.89a
Tithonia green leaves	46.75±2.06d	52.75±1.93c	191.80±3.15c	197.50±1.85d	212.00±3.32d	203.20±1.70b	129.20±3.07a	142.80±4.61d
French bean alone	53.50±1.71e	70.75±1.25e	206.50±3.20d	240±7.11e	217.80±2.72e	204±1.32b	142±1.58b	157.80±2.25e
F	95.24	54.12	137.87	81.70	56.83	5.55	18.50	108.13
p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.009	< 0.001	<0.001
CV%	8.1	4.7	3.8	4.4	3.5	5	3.1	15.77
LSD	9.69	8.99	21.03	27.15	22.27	34.97	14.33	3.7

Means within the same column followed by the same letters are not significantly different at p = 0.05. (Fishers protected LSD)

Table 5.2 Mean numbers (±SE) of thrips recorded from 30 French bean flowers per treatment under different mulching treatments

Treatment	35 days	40 days
Transparent plastic mulch	35.00±0.71c	190.80±1.38c
Dry grass	26.00±0.91a	147.50±1.04a
Black plastic mulch	27.50±1.04a	181.80±7.86b
Tithonia green leaves	31.50±1.19b	190.80±2.02c
French bean alone	46.75±1.11d	240.00±1.71d
F	33.66	210.87
p	< 0.001	<0.001
CV%	6.4	3.5
LSD	6.85	24.68

Means within the same column followed by the same letters are not significantly different at p = 0.05(Fishers protected LSD)

5.3.2 The mean number of thrips species collected and identified on French bean leaves in various mulches

There were significant differences in the mean number of *H. adolfifriderici* recorded from different mulch treatments ($F_{4, 12} = 7.98$, $p = 0.002$) (Table 5.3). The lowest mean numbers of *H. adolfifriderici* were recorded in plots mulched with Black plastic sheet and it differed significantly from the mean numbers recorded from Transparent plastic sheet. The mean numbers of thrips obtained from the plots mulched with the dry grass, control and tithonia green leaves did not differ significantly.

There were significant differences in the mean numbers of, *M. sjostedti* (F4, 12 = 14.14, p = 0.001), The lowest mean numbers of *M. sjostedti* were recorded in the plots mulched with Black plastic sheet and it differ significantly with the mean numbers which were recorded from plot mulched with Transparent plastic sheet, Dry grass, Tithonia green leaves and the ulmuched (control). The highest mean numbers of *M. sjostedti* was however recorded in the plots without mulch (control).

There were significant differences in the mean numbers of *F. schultzei* recorded from different mulch treatments (F 4, 12 = 30.20, p < 0.001) (Table 5.3). The lowest mean numbers of *F. schultzei* were recorded in plots mulched by Black plastic sheet and that did not differ significantly with the mean numbers which were recorded from Transparent plastic sheet. These mean numbers were followed by those which were recorded from the plots mulched with Dry grass, Tithonia green leaves and the control.

There were significant differences in the mean number of *F. occidentalis* recorded from different mulch treatments (F 4, 12 = 12.20, p < 0.001), *(*Table 5.3). The lowest mean numbers of *F. occidentalis* recorded in plots mulched by Black plastic sheet followed by Transparent plastic sheet, Dry grass, Tithonia green leaves and the control. The control recorded the highest significant mean number of *F. occidentalis*.

Table 5.3 The mean number (± SE) of different species of thrips collected and identified on French bean leaves after treated with various mulches

Treatment	*Hydatothrips adolfifriderici*	*Megalurothrips sjostedti*	*Frankliniella schultzei*	*Frankliniella occidentalis*
Transparent plastic	50.38±7.23b	30.12±4.36b	6.83±1.26a	5.98±0.89b
Dry grass	63.25±2.20cd	38.00±1.28bc	13.00±0.27b	6.8±0.93c
Black plastic	35.12±2.90a	21.43±1.6a	6.75±0.75a	4.05±0.75a
Tithonia green	76.12±7.09d	45.73±4.35d	15.38±1.40c	8.69±1.04d
French bean alone	73.50±7.37d	51.67±4.22e	17.23±1.41e	10.44±0.45e
P	< 0.001	<0.001	< 0.001	< 0.001
F	7.98	14.14	30.20	12.20
LSD	18.610	9.880	2.716	2.161
CV%	20.2	26.5	14.9	19.5

Means within the same column followed by the same letters are not significantly different at p = 0.05. (Fishers protected LSD)

5.3.3 The effects of various mulches on yield of fresh French bean pods

There were significant differences in the mean total harvested yield of fresh French bean pods from the plots treated with different mulches ($F_{4, 12} = 13.84$, $p < 0.001$, (Table 5.2). The highest mean total harvested fresh pods yield was obtained from the plots mulched with black plastic sheet and it differed significantly with the yield which was obtain from the plots mulched with dry grass and those from the Transparent plastic sheet + pyrethrum. The mean total harvested yield obtained from the plots with French bean alone was significantly lower than the latter. The lowest mean total harvested yield of fresh pods was recorded from the plots where French beans were mulched with Tithonia green mulch and it did not differ significantly from the yield obtained from the control plots.

In addition, the observation made from the plots mulched with transparent plastic sheet showed that this sheet allowed passage of sun light that promoted rapid growth of weeds from beneath, hence affecting the growth of French beans. Plots mulched with black plastic mulch had no weeds growing beneath due to lack of sunlight. French beans growing in black mulch had tremendous growth compared with the other treatments. As regards the dry grass mulch, the French beans showed a faster growth compared with those of the control plot.However, they showed signs of yellowing of the leaves. In the plots where French beans were mulched with green young Tithonia they showed some yellowing of leaves despite applying the recommended dose of both

Diammonium phosphate and Calcium Ammonium Nitrate fertilizers in all treatments.

Table 5.4. Mean yield (±SE) of fresh French pods in Kg recorded from French beans mulched with various mulches

Treatment	Mean total harvested pods
Transparent plastic	1.88±0.27c
Dry grass	2.50±1.02b
Black plastic	5.83±0.27a
Tithonia Green	0.61±0.34d
French bean	0.73±0.29d
p	< 0.001
F	13.64
LSD	1.76
CV%	49.4

Means within the same column followed by the same letters are not significantly different at p = 0.05. (Fishers protected LSD)

5.4 Discussion

Results on the mean number of thrips recorded on French bean leaves showed that there were significant differences among different mulching treatments throughout the growing season. The plots where French beans were mulched with transparent plastic sheets recorded the lowest mean numbers of thrips at 25, 30, 35, 40, 45, 50 and 55 days. Transparent plastic sheets allowed light to pass through thus allowing weeds to grow beneath where they transpired and produced a lot of moisture. The moisture produced then condenses on the inner part of the transparent sheet making it appear white. The white appearance of these sheets reflected light which may have interfered with the ability of thrips being able to locate the host plant especially at the initial stages. This conform to the finding by Kuepper (2004) who reported that white mulch repelled thrips on young crops. In a related study, Hanada (1991) and Terry (1997) showed that transparent plastic sheets mulch confused and repelled thrips when searching for host plants. Similarly Scott *et al*. (1989) reported that transparent plastic sheets repelled 33 to 68% of thrips on young crops.

The numbers of thrips from the plot mulched with the transparent plastic sheet were fewer at early than in later stages. In other words the number of thrips increased with time. As French beans continued growing, they formed connopies which covered the transparent plastic sheets hence reducing their reflective ability. Studies by Kuepper (2004) revealed that transparent plastic sheet ceased to repel insects when plant canopies covered more than 60% of the mulch. Similarly van Toor *et al*. (2004) reported that transparent mulch reflected ultraviolet light which interfered with the ability of *Thrips tabaci* to locate onion plants during early season but their efficacy decreased over time as the crops covered the ground surface. In a related study, Stavisky *et al.* (2002) reported that ultra violet reflective mulches reduced populations of *Frankliniella occidentalis* (Pergande) and *Frankliniella tritici* (Fitch) on tomato flowers.

Observation from the current study showed that transparent plastic sheet allowed light to pass leading to prolific growth of weeds underneath. These weeds competed with French beans for nutrients hence negatively affected the French bean yieid. In Kenya there are no reported studies on the effects of plastic mulch for the control of thrips in any horticultural crops.

In the plots mulched with dry grass the mean numbers of thrips which were recorded on French bean leaves were lower at 25, 30, 35, 40, 45, 50 and 60 days than the control except at 55 day. This was in conformity with the findings of Larentzaki *et al.* (2008) who noted that, straw mulch decreased the numbers of *Thrips tabaci* in onion. Thick dry grass when used as mulch has been reported by Jensen *et al.* (2003) to enhance the effectiveness of natural enemies in onion and avocado cropping systems. Agnew and Mungy (2002) also reported that the natural enemies included predators such as *Blattisocius dentriticus* (Ascidae) and *Neocunaxoides sp* (Cunaxidae) or entomopathogenic fungi in the soil which increase the mortality of soil – dwelling stages of thrips. Similarly, Jamieson and Stevens (2006) reported that some physical or chemical properties of the organic mulch may also contribute to the mortality of thrips especially those stages dwelling in the soil.

Plots mulched with black plastic sheets recorded relatively lower numbers of thrips as compared with the control throughtout the growing session of the French beans. There are no related studies on the effects of black plastic sheets in the management of thrips in Kenya. But one notable observation from the plots mulched by black plastic sheets was that French beans grew faster than those grown in the plots with other treatments. Studies by of Ghuman *et al*. (2001), and Qing *et al.* (2009) revealed that black plastic sheets suppressed the growth of weeds and kept the soil moist and thus warm promoting rapid growth of French beans.

Tithonia green mulch did not control thrips on French bean leaves as effectively as the transparent plastic sheets, black plastic sheets and the dry grass. However, it relatively reduced thrips populations on French bean leaves than the control throught the growing sessions. There are no related studies on the reduction of thrips populations on French beans mulched with Tithonia. The study of Jamieson and Stevens (2006) who reported that some physical or chemical properties of the organic mulch may contribute to mortality pre-pupa and pupa of thrips dwelling in the soil. This could perhaps be the reason why the thrips populations were lower on French bean leaves. Just like French beans mulched with grass, those mulched with Tithonia green leaves also showed more leaf chlorosis at the initial stages. This means more microorganisms facilitating decomposition of Tithonia green leaves might have used a lot of nutrients from the soil especially nitrates; leaving little amount of nitrates being released in the soil for the French beans.

Plots which were not mulched recorded the highest populations of thrips compared to the mulched plots. This is inconformity with the finding by Larentzaki *et al*. (2008) who reported that the unmulched onion recorded higher number of *Thrips tabaci* compared to the mulched plots.

Results on the mean number of thrips recorded on French bean flowers showed that there were significant differences among different mulching treatments at 35 and 45 days. The lowest mean number of thrips was recorded from the plots where French beans were mulched with dry grass. There is no finding conforming to this outcome in Kenya. However, the studies by Hoddle *et al.* (2002), Agnew and Mungy (2002) and Jensen *et al.* (2003) as earlier discussed on French bean leaves may have led to low number of thrips on French bean flowers. Dry grass therefore, should be incorporated in the integrated pest management system as it significantly reduced population of thrips in the flowers, cheaply available and is biodegradable.

Black plastic sheets reduced the number of thrips very effectively after 35 days just like the dry grass but slightly the effectiveness decreased after 40 days. There are no related studies on this finding. But it is likely that black plastic sheet covered the soil surface hence it might have prevented thrip larvae from pupating in the soil.

Transparent plastic sheets did not reduce thrips in the French bean flowers as it did on the leaveas. But they relatively reduce the number of thrips in flowers than the control. Since thrips have cryptic feeding behavior as suggested by van de Veire and Degheele (1992), reflective effects of transparent plastic sheet had minimal effect on the pest in flowers. The covering of the soil by transparent plastic sheets might have prevented the thrips from pupating in the soil hence reducing their numbers on French beans. The control had the highest mean number of thrips in flowers. This inconformity with the findings of Kasina *et al*. (2006) who reported that there were higher numbers of thrips in the control plots than the treated plots.

Results on the mean numbers of *F. occidentalis* recorded on French bean leaves showed that there were significant differences after they were subjected to various mulches. The lowest mean numbers of *F. occidentalis* was recorded in the plots where French beans were mulched with black plastic and transparent plastic sheets. In Kenya plastic sheets especially the black plastics have been used mainly to control weeds in horticultural farms. Their effects on pest management have not been exhaustively exploited. In related studies by Stavisky *et al*. (2002), Reitz *et al*. (2003), Kuepper (2004) and Ludger and Robert (2005) reported that *F.occidentalis* and other species of thrips were reduced by silver reflective mulches on various vegetable crops. In the plots where French beans were mulched with the dry grass, the mulch significantly reduced *F. occidentalis* numbers on French bean leaves than the unmulched plots. There are no related studies on the potential of dry grass mulch in the management of *F. occidentalis* on vegetables in Kenya. The highest number of this thrips species was recorded in the unmulched French bean plots compared to the mulched plots.

Results on the mean numbers of *H. adolfifrederici*, *M. sjostedti* and *F. schultzei* recorded on French bean leaves showed that there were significant differences after they were subjected to various mulches. The lowest mean numbers of these thrips species were recorded in the plots where French beans were mulched with black plastic sheet followed by transparent plastic sheet, dry grass, tithonia green leaves and the control. There are no related studies on the effect of various mulches on these thrips species in Kenya. But one notable observation was that there were increases in the number of these species with time.

In general, the abundance of thrips species collected and identified on French bean leaves showed that the dominant species of thrips was *Hydatothrips adolfifriderici* followed by *Megalurothrips sjostedti*, *Frankliniella schultzei* and *Frankliniella occidentalis* respectively.

Results on the mean yield of fresh French bean pods showed that there were significant differences amongst various mulches. The highest yield which was significantly different was recorded from the plots which were mulched with black plastic sheet followed by the dry grass mulch. French beans mulched with black plastic sheet had tremendious growth due to its effective moisture retention and suppression of weeds. The number of thrips recorded on French bean leaves and flowerswhich were mulched with black plastic sheet was relatively lower compared to those grown in unmulched plots. This could have perhaps contributed to higher yield in black plastic sheet mulched plots. The dry grass mulched plots also registered higher yield than the control. The relationship between mulching with the dry grass and yield has not been studied extensively. However, the studies by Horgan *et al*. (2002) reported that mulching with dry vegetative matters reduced thrips population but had no effect on yield.

Generally thick layer of dry grasses conserve soil moisture which is crucial for crop growth. When these dry grasses decompose they improve soil structure by increasing the organic matter hence aerating the soil. In the plots mulched with transparent plastic sheet weed growth was observed beneath the mulch sheet, which could have resulted in lower yields as compared to the black plastic sheet and the dry grass mulches. The lowest mean yield was recorded from French bean mulched with Tithonia green leaves and this could have which might be due to deprivation of French bean plants of nitrogen due to the decomposition of the Tithonia green leaves. This resulted in leaf chlorosis, stunted growth and low French bean yields.

CHAPTER SIX

THE EFFECT OF INTERCROPPING, MULCHING AND USE OF BOTANICAL PESTICIDES ON INFESTATION AND DAMAGE OF FRENCH BEAN BY THRIPS

6.1 Introduction

Thrips are the most economically important pests of French beans worldwide causing significant reduction in yield (Nawrocka 2003; *Trdan et al.,* 2005). In Kenya, French beans host four species of thrips namely, *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), *Frankliniella occidentalis* (Pergande), and *Hydatothrips aldolfifriderici* (Karny) (Nyasani *et al.,* 2012). Pests are present in all areas where French beans are cultivated and cause up to 68% loss in yield (Nyasani *et al.,* 2012). Currently, farmers manage thrips through repeated applications of insecticides throughout the growing season (Nderitu *et al.,* 2001). However, most insecticides are ineffective because thrips tend to feed in protected regions within the plant such as flowers and developing buds. Life stages found in the soil such as pre-pupa and pupa are also not easily affected by the insecticides (Berndt *et al*., 2004). In addition, some species of thrips such as *Thrips tabaci* are very prolific with many overlapping generations (Shelton *et al.,* 2006; Alimousavi *et al.,* 2007; Nault and Shelton 2010). Lack of integrated pest management control options and the presence of numerous alternate host plants on which the thrips thrive ‘also hinder their management (Brewster, 1994). Development of resistance to the most commonly used insecticides has been reported for many species of thrips, for examples *Frankliniella occidentalis* (Bielza *et al*., 2007; Dağli and Tunç, 2007; Nderitu *et al.* 2007; Bielza, 2008; Dağlı and Tunç, 2008; Weiss *et al*., 2009, Kay and Herron, 2010). Besides increasing the cost of production, the use of pesticides has negative effects on the environment and human health (Burkett-Cadena *et al.,* 2008). Therefore, there is a need to integrate the use of synthetic insecticides with other management methods such as cultural practices and use of botanical pesticides.

One sustainable cultural method of managing pests is intercropping (Finckh and Karpenstein-Machan, 2002; Trdan *et al.,* 2006,), a system in which the intercrop is grown specifically to reduce pest damage on a main crop. Intercropping is traditionally practiced by subsistence farmers in developing countries (Sodiya *et al.,* 2010). The system is characterized by minimal use of pesticides and increased land productivity (Ullah *et al.*, 2007). Intercropping French beans with maize has been reported to control thrips on French beans (Kasina *et al*., 2006). Similarly maize intercropped with cow pea's effectively controlled *Megalurothrips sjostedti* (Ezueh, 1984; Kyamanywa *et al*., 1988). The same applied to Coriander when intercropped with Bulb Onions significantly reduced populations of *Thrips tabaci* (Waiganjo, 2008). Nyasani *et al*. (2012) also reported that there were less numbers of thrips on French bean intercrops mix as compared to a monocrop.

On the other hand botanical pesticides such as pyrethrum, neem and garlic extracts are less toxic to mammals, biodegradable, locally available and do not contribute to pest resurgence. Therefore, in the current study, the best botanical pesticide from the laboratory and greenhouse experiments which was pyrethrum and the best mulch which was dry grass were used as components of an integrated pest management to manage thrips. The other intercrops which were used were selected based on the studies done by Kasina *et al*. (2006), who recommended maize as the best intercrop for the management of thrips. The incorporation of Coriander was due to a recommendation from studies of Waiganjo *et al.* (2008). Currently there are scanty reports on studies carried out in Kenya regarding the management of thrips on French beans based on integrating intercrops, mulching with (dry grass) and pyrethrum pesticides. In the view of the above stated information, this study was therefore undertaken.

6.2 Material and Methods

The French beans Cultivar Paulista were sown in experimental plots measuring 5 x 3m with spacing of 50cm between the rows and 10cm within the row. A randomized block design was adopted for the treatments where there was a spacing 5m between the blocks and 2m between the plots within a block. Diammonium Phosphate was applied at rate of 200kgha^{-1} at planting time. Top dressing was done with split application of Calcium Ammonium Nitrate at a rate of 200kgha^{-1} applied twice first at the primary leaf stage and again before flowering. Weeding was done twice, at two weeks after germination and four weeks after the first weeding. There were nine treatments each replicated three times. The treatments were as follows:-

1. French bean alone

2. French bean + maize

3. French bean + coriander

4. French bean + dry grass

6. French bean + dry grass + pyrethrum

7. French bean + maize + dry grass + pyrethrum

8. French bean + coriander + dry grass + pyrethrum

9. French bean + L – Cyhalothrin.

The intercrops (maize and coriander) were planted one week earlier since French beans have vigorous growth. Two rows of French beans were alternated with one row of intercrop at an intra row spacing of 10cm and an inter row spacing of 50cm. As regards the plots to be treated with pesticides (L-Cyhalothrin and pyrethrum) were applied before and during flowering. Fresh French bean pods were harvested from the fifth week after germination at weekly intervals.

Data collection commenced two weeks after sowing from ten randomly selected French bean plants per plot. From each of the ten plants, leaves were observed for adult and larval thrips by tapping the French bean against white paper and their numbers were recorded. The thrips that dropped on the paper were picked using a camel hair brush dipped in 70% alcohol and retained in 70% alcohol for further processing and identification in the laboratory.

Sampling of flowers started when half of French beans had flowered and 20 flowers were picked per plot randomly. Flowers collected from each plot were kept in a plastic vial. The flowers were then taken to the laboratory where they were dissected; the thrips were sorted out, counted and recorded. The collected thrips were processed and identified using LuCID key (Moritz *et al*., 2004). Damage assessment was done by visual examination on pods and rated on 1-5 score (Mackenzie *et al*., 1993) as detailed in chapters 4 and 5.

6.2.1 Data analysis

The data on the number of thrips in flowers and on leaves were subjected to analysis of variance (ANOVA) using SAS 9.2 stastical package (SAS, 2008). Means that showed significant differences were separated using fishers protected LSD at $p = 0.05$.

6.3 Result

6.3.1. The effects of integrating mulching, intercropping and botanical pesticides on the number of thrips infesting French beans

There were significant differences in the mean number of thrips on leaves among the treatments after 30 days ($F_{8, 16} = 11.70$, $p < 0.001$), 35 days ($F_{8, 16} = 19.13$, $p < 0.001$), 40 days ($F_{8, 16} = 5.33$, $p < 0.003$), 45 days ($F_{8, 16} = 147.49$, $p < 0.001$), 50days ($F_{8, 16} = 52.39$, $p < 0.001$) and 55 days ($F_{8, 16} = 29.20$, $p < 0.001$), (Table 6.1).

After 30 days, the lowest mean numbers of thrips were recorded from the plots where French beans were intercropped with Maize + Dry grass + Pyrethrum but did not differ significantly from the means recorded on the plots where French beans were intercropped with maize alone. These were followed by the mean numbers of thrips recorded from plots treated with Pyrethrum, French alone, L- Cyhalothrin, Coriander + Dry grass + Pyrethrum and Dry grass which were not significantly different from each other. The highest mean numbers of thrips were recorded from the plots where Dry grass + Pyrethrum were applied but it was not significantly different from that where French beans were intercropped with Coriander.

After 35 days, there were significant different in the mean number of thrips on leaves among treatments. The lowest mean number was recorded from the plots treated with Coriander + Dry grass + Pyrethrum. This was followed by Maize, Coriander, Maize + Dry grass mulching + Pyrethrum, L-Cyhalothrin, Pyrethrum, French bean alone and Dry grass. The highest significant mean number of thrips was recorded in plots where French beans were treated with Dry grass + pyrethrum.

After 40 days, the lowest mean number of thrips was recorded in plots where French beans were intercropped with maize. This was followed means recorded from plots treated by Coriander + Dry grass + Pyrethrum and L-Cyhalothrin. These means were followed by those recorded from plot treated with Pyrethrum, Coriander, Maize + Dry grass mulching + Pyrethrum which were not significantly different and French bean alone. The highest mean number of thrips was registered from plot mulched by Dry grass alone followed by those from plot with French bean alone (control experiment).

After 45 days, the lowest significant mean number of thrips was recorded from plots sprayed with L-Cyhalothrin followed by Maize, Coriander, Coriander + Dry grass + Pyrethrum, Dry grass mulching + Pyrethrum and Maize + Dry grass mulching + Pyrethrum. The mean number of thrips recorded from the control (French bean alone) did not significantly differ from that recorded from French bean mulch by Dry grass alone. However the highest mean number of thrips was recorded from plots spayed with Pyrethrum alone.

After 50 days, the lowest significant mean number of thrips was recorded from plots where French beans were intercropped with maize. This was followed by L-Cyhalothrin, Dry grass, Maize + Dry grass mulching + Pyrethrum, Dry grass + Pyrethrum, Coriander + Dry grass + Pyrethrum, Coriander and Pyrethrum. The highest mean numbers were recorded from plots with French bean alone

Finally after 55 days, the lowest mean number of thrips was recorded from the plots where French beans were intercropped with Maize followed by L-Cyhalothrin Maize + Dry grass mulching + Pyrethrum and Dry grass + Pyrethrum. The means recorded from the control plots significantly differed from the latter but did not differ from those recorded from the plots treated Dry grass and Pyrethrum. The highest mean number of thrip was recorded on

French beans intercropped with coriander a lone was significantly different.

There were significant differences in the mean numbers of thrips collected from French bean flowers among all the treatments after 35 days ($F8, 16 = 19.13$, $p < 0.001$), 40 days ($F8, 16 = 33.60$, $p < 0.001$) and 45 days ($F8, 16 = 58.35$, $p < 0.001$) (Table 6.2). After 35 days, the lowest mean number of thrips was recorded from the plot treated with Maize + Dry grass + Pyrethrum, However, this mean did not significantly differ with that recorded from plot where French beans were intercropped with maize and the Dry grass + pyrethrum. These means were followed by those recorded from plots sprayed with L-Cyhalothrin, pyrethrum, mulched with dray grass, coriander and Coriander + Dry grass + Pyrethrum. The highest mean number of thrips was recorded from plots with French beans alone.

After 40 days, the lowest mean number of thrips was recorded from the French bean plots treated with L-Cyhalothrin followed by Maize + Dry grass + Pyrethrum, Maize and Dry grass. These means were significantly different from that obtained from the control plots (French bean a lone). The means recorded from French beans intercropped with Coriander, Dry grass + pyrethrum, Coriander + Dry grass + Pyrethrum and Pyrethrum were significantly lower than the mean from the plots with French bean a lone (control). However, the highest significant mean of thrips was recorded from French beans sprayed with pyrethrum.

After 45 days, the French beans treated with Maize + Dry grass + Pyrethrum, recorded the lowest mean number of thrips which did not significantly differ from that recorded from Maize. These means were followed by the mean number of thrips recorded from the plots sprayed with L-Cyhalothrin. Mean numbers of thrips obtained from coriander, Coriander + Dry grass + Pyrethrum, dry grass + pyrethrum, dry grass, and pyrethrum were significantly lower than that recorded from the control (French bean a lone). In the plots where French beans were sprayed with pyrethrum a lone recorded the lowest significant mean of thrip

Table 6.1. The mean numbers (± SE) of thrips recorded on French bean leaves under different mulching, intercropping and pesticide use treatments

Treatment	30 days	35 days	40 days	45 days	50 days	55 days	60 days
L - Cyhalothrin	16.00±1.53b	27.33±4.37e	22.33±2.03c	24.67±2.03a	45.00±8.89b	60.33±1.73b	71.00±5.29a
Maize	10.33±0.88a	15.00±1.16b	16.67±3.76a	29.33±1.76b	38.67±1.20a	32.67±1.86a	79.33±1.45b
Maize + dry grass + pyrethrum	10.00±1.16a	25.33±1.45d	30.67±7.17d	51.00±0.58f	80.33±1.20c	96.67±11.84c	106.30±3.7c
Coriander + dry grass + pyrethrum	16.00±1.16b	13.67±0.67a	19.00±0.58b	43.00±4.04d	105.70±14.44e	128.00±5.20g	152.30±1.2d
Dry grass + pyrethrum	21.67±0.88c	43.67±18.22g	31.67±1.45e	48.00±1.16e	84.67±7.22d	103.70±1.45d	152.70±3.18d
French bean alone	15.33±0.88b	31.00±2.08e	35.00±2.08f	68.67±1.45g	171.30±2.60h	111.00±4.04e	159.00±1.16e
Coriander	19.67±1.33c	19.00±1.733c	29.00±1.16d	37.00±2.31c	108.00±3.46f	129.00±10.58g	161.00±3.22f
Pyrethrum	14.33±1.53b	28.33±1.76e	29.00±1.73d	108.70±3.28h	140.00±1.00g	124.30±2.02ef	161.30±8.29f
Dry grass	17.00±1.16b	41.67±2.60f	41.33±5.78g	68.67±2.33g	80.00±4.62c	110.70±5.78de	176.00±0.58g
F	11.70	19.13	5.33	147.49	52.39	29.20	45.42
P	<0.001	<0.001	<0.003	<0.001	<0.001	<0.001	<0.001
CV%	24.4	18.1	21.1	6.9	10.9	10.6	7.49
LSD	6.68	5.51	21.23	13.07	35.97	37.32	35.69

Means followed by the same letter within columns do not differ significantly at p = 0.05 (Fishers protected LSD)

Table 6.2. The mean numbers (± SE) of thrips on French bean flowers after being subjected to various integrated mulching, intercropping and pesticide use treatments

Treatment	35 Days	40 Days	45 Days
L-Cyhalothrin	6.67±0.67b	16.00±1.16a	18.33±0.88b
Maize	5.67±0.88a	18.67±2.03a	13.00±1.16a
Maize + Dry grass + Pyrethrum	5.67±0.68a	16.67±0.33a	12.33±1.45a
Coriander + Dry grass + Pyrethrum	10.67±0.88d	55.33±6.06e	25.33±0.88d
Dry grass + Pyrethrum	6.00±0.58a	54.67±2.60e	45.00±2.52e
French bean alone	18.00±1.73e	42.67±3.76c	22.33±1.86c
Coriander	9.00±0.58c	48.00±3.00d	23.00±1.53c
Pyrethrum	7.00±0.58b	63.00±3.06f	54.00±1.16f
Dry grass	8.67±0.67b	36.67±4.33b	47.67±5.04e
F	19.13	33.60	58.35
P	<0.0001	<0.0001	<0.0001
CV%	18.1	13.9	12.3
LSD	5.51	19.22	12.63

Means followed by the same letter in the column do not differ significantly at p = 0.05 (Fishers protected LSD)

6.3.2 Effects of integrating mulch, intercrops and botanical pesticides on the abundance of different thrips species sampled from French bean leaves and flowers

On leaves, there were significant differences in the mean numbers of *F. occidentalis* ($F_{8, 16} = 3.88$, $p < 0.010$). The lowest significant mean number of thrips was recorded from the French beans intercropped with maize. This was followed by the mean number of thrips recorded from the French bean plots subjected to L-Cyhalothrin, Coriander, Maize + Dry grass + Pyrethrum and Coriander + Dry grass + Pyrethrum which were not significantly different. The mean number of thrips recorded from the plot treated with Dry grass and Dry grass +Pyrethrum did not differ significantly from that recorded from the control (French bean alone). The highest significant mean number of thrips was recorded from the plots where French beans were sprayed with pyrethrum (Table 6.3).

There were significant differences in the mean numbers of *F. schultzei* ($F_{8, 16} = 4.42$, $p = 0.006$). The lowest significant mean number of thrips was recorded from French beans intercropped with maize. This was followed by mean number of thrips recorded from French bean plots subjected to L-Cyhalothrin, Maize + Dry grass + Pyrethrum and Dry grass which did not differ significantly. The mean recorded from Maize + Dry grass + Pyrethrum did not differ significantly with those recorded from the plot treated with Coriander and Coriander + Dry grass + Pyrethrum which were significantly different with that from the control (French bean alone). The mean number of thrips recorded from plot treated with Dry grass + Pyrethrum recorded higher mean number of thrips the control (French bean alone). The highest mean number of thrips was recorded from the plots where French beans were sprayed with pyrethrum. However, this mean did not differ significantly that recorded from the plots treated with Dry grass + Pyrethrum.

There were significant differences in the mean number of second most dominant species of thrips recorded on the French bean leaves, *M. sjostedti* after application of various treatments ($F_{8, 16} = 3.72$, $p = 0.012$) (Table 6.3). The lowest significant mean was recorded in the plots where French beans were intercropped with maize. This mean was followed by mean number of thrips obtained from the plots treated with L-Cyhalothrin, Coriander, Coriander + Dry grass + Pyrethrum and Dry grass which were not significantly different. The mean number of thrips recorded from the plot treated with Maize + Dry grass + Pyrethrum and Dry grass did not differ significantly from that obtain in the control (French bean alone). The highest significant mean number of thrips was recorded from the plots where French beans were sprayed with pyrethrum.

There were significant differences in the mean numbers of *H. adolfifriderici* recorded on French bean leaves after applying various treatments ($F_{8, 16} = 2265.44$, $p < 0.001$) (Table 6.3). The lowest significant mean number of *H. adolfifriderici* were identified and recorded from French beans intercropped with maize. This was followed by mean numbers of thrips recorded from the plots where French beans were subjected to Maize + Dry grass + Pyrethrum, L-

Cyhalothrin, Dry grass, Coriander, Coriander + Dry grass + Pyrethrum, Dry grass + Pyrethrum and French beans alone. The highest significant mean number of thrips was recorded from the plots where French beans were sprayed with pyrethrum.

In the flowers, there were significant differences in the mean numbers of *F. occidentalis* obtained from the plots treated with various treatments ($F_{8, 16} = 14.42$, $p < 0.001$) (Table 6.4). The lowest significant mean numbers of *F. occidentalis* was recorded from the plots where French bean was treated with Maize + Dry grass + Pyrethrum. This mean was not significant with that recorded from Coriander + Dry grass + Pyrethrum. These means were followed by the plots those where French beans were grown alone (control) and Maize. The other means obtained from the plots treated with Pyrethrum, Dry grass + Pyrethrum, Dry grass, Pyrethrum, L-Cyhalothrin and Coriander had significantly higher mean numbers of *F. occidentalis* than that recorded from plots with French bean alone. However; Coriander had the highest mean number of *F. occidentalis*.

There were significant differences in the mean numbers of *Frankliniella schultzei* recorded in the French bean flowers obtained from plots treated with various treatments ($F_{8, 16} = 46.42$, $p < 0.001$) (Table 6.4). The lowest mean number of thrips was recorded in the plots with French beans alone which did not differ significantly with that recorded from Coriander + Dry grass + Pyrethrum. These were followed by the plots where French beans were treated with Pyrethrum, L-Cyhalothrin, Dry grass + Pyrethrum, Maize Coriander and Dry grass. All these means were significantly higher than the control experiment.

There were significant differences in the mean number of *M. sjostedti* ($F_{8, 16} = 4.74$, $P = 0.004$) (Table 6.4). The lowest significant mean number for this species was recorded in the plots sprayed with Pyrethrum. This was followed by mean numbers from Dry grass which significantly differs from the latter. The means obtained from French bean flowers treated with Coriander, Maize and L-Cyhalothrin did not differ significantly but differ with that obtained with that from the French bean alone. The highest mean number of *M. sjostedti* were recorded from plots treated with Coriander + Dry grass + Pyrethrum thought it did not differ with those obtained from Dry grass + Pyrethrum and Maize + Dry grass + Pyrethrum.

There were significant differences in the mean numbers of *H. adolfifriderici* obtained from plots treated with various treatments ($F_{8, 16} = 4.04$, $P=0.008$) (Table 6.4). The lowest significant mean number of *H. adolfifriderici* was recorded from plots where French bean was intercropped with Maize. This mean did not differ significantly with those recorded from the plots with French beans a lone, Pyrethrum and Dry grass + Pyrethrum. These means were followed by those from the plots where French beans were subjected to Dry grass, Maize + Dry grass + Pyrethrum, Coriander, Coriander + Dry grass + Pyrethrum and L- Cyhalothrin which did not differ significantly.

Table 6.3. The mean numbers (± SE) of thrips species identified on French bean leaves after being subjected to various integrated mulching, intercropping and pesticide use treatments.

Treatment	*Frankliniella occidentalis*	*Frankliniella schultzei*	*Megalurothrips sjostedti*	*Hydatothrips adolfifriderici*
L – Cyhalothrin	3.38±0.75b	12.71±2.65b	16.10±2.90b	26.14±0.17c
Maize	1.95±0.34a	6.62±0.50a	9.33±0.25a	16.29±0.08a
Maize + dry grass + pyrethrum	3.76±0.33b	14.57±2.40bc	20.14±3.67c	25.05±0.10b
Coriander + dry grass + pyrethrum	3.86±0.36b	16.10±0.75c	17.67±1.54b	30.86±0.08f
Dry grass + pyrethrum	4.81±0.17d	19.71±1.89e	22.57±3.29c	32.33±0.05g
French bean alone	4.29±0.25c	17.05±1.29d	19.33±1.50c	32.92±0.05h
Coriander	3.47±0.33b	15.57±0.76c	17.00±1.84b	27.48±0.21e
Pyrethrum	5.05±0.33e	19.95±.96e	22.62±.81c	36.90±0.10i
Dry grass	4.38±0.78cd	15.14±3.36b	19.00±1.34b	26.86±0.14d
P	< 0.010	< 0.006	0.012	<.001
F	3.88	4.42	3.72	2265.44
CV%	20.8	20.8	21.5	28.32
LSD	1.401	5.691	6.246	0.373

Means followed by the same letter in the column do not differ significantly at p= 0.05 (Fishers protected LSD)

Table 6.4 The mean numbers (± SE) of thrips species identified in French bean flowers after being subjected to various integrated mulching, intercropping and pesticide use treatments.

Treatment	*Frankliniella occidentalis*	*Frankliniella schultzei*	*Hydatothrips adolfifrederici*	*Megalurothrips sjostedti*
L-Cyhalothrin	17.67±3.18	69.00±5.78b	5.67±1.16b	29.00±0.58d
Maize	3.67±0.33b	124.67±4.91c	2.00±1.53a	29.30±2.85cd
Maize + Dry grass + Pyrethrum	2.00±0.58a	176.0±3.46d	4.33±0.67b	42.67±9.35f
Coriander + dry grass + pyrethrum	2.33±0.88b	48.30±7.51a	5.67±1.16c	45.00±10.15c
Dry grass+Pyrethrum	6.67±2.40abc	73.33±9.60a	4.33±1.45bc	38.00±2.00bc
French bean alone	3.00±0.58a	46.67±3.18a	2.33±0.33a	32.70±2.73abc
Coriander	19.67±3.18d	121.57±3.67b	5.00±1.16a	26.70±1.45abc
Pyrethrum	13.33±0.67cd	64.33±8.82a	3.00±0.89a	16.33±3.68a
Dry grass	12.67±0.33d	123.00±9.24c	3.00±2.19ab	23.09±3.46b
P	0.001	0.001	0.008	0.004
F	14.42	46.42	4.04	4.74
CV%	35.1	11.9	31.0	23.50
LSD	5.47	19.39	2.07	12.75

Mean within columns followed by the same letter arenot significantly different at p = 0.05 (Fishers protected LSD)

6.3.3 Effects of integrating mulching, intercropping and pesticide on the yield of fresh French bean pods.

There were significant differences in the mean total harvested yield of fresh French bean pods recorded from various treatments before grading ($F_{8, 16} = 2.99$, $p = 0.030$) (Table 6.5). The highest total harvested fresh pods was obtained from the control plot (French bean alone) and it did not differ significantly with the yield obtain from the plots treated with Dry grass + pyrethrum. These means were followed by those which were obtained from the plots sprayed with Pyrethrum, L – Cyhalothrin and Coriander + Dry grass + Pyrethrum which did not differ significantly. The lowest mean total of the harvested pods yield was recorded from plots where French beans were intercropped with coriander. This mean was significantly different with those recorded from the plots treated with Dry grass, Maize and Maize + Dry grass + Pyrethrum.

There were significant differences in the mean marketable yield French bean pods after the application of various treatments ($F_{8, 16} = 3.13$, $P = 0.025$) (Table6.4). The highest mean marketable harvested fresh pods yield was obtained from plots with French bean alone and it differed significantly with the yield obtain from plots treated with Dry grass + Pyrethrum, Pyrethrum, L – Cyhalothrin, Coriander + Dry grass, Maize, Maize + Dry grass + Pyrethrum and Coriander respectively. The lowest significant mean marketable harvested pods yield was recorded from plots where French beans were intercropped with coriander.

Table 6.5 The mean yield (± SE) of fresh pods from French beans subjected to various mulching, intercropping and pesticide use treatments

	Mean yield of French beans in Kg per treatment	
Treatment	Total Harvested Pods	Marketable pods
L-Cyhalothrin	4.50±0.55bc	3.55±0.44c
Maize	3.29±0.25d	2.80±0.32d
Maize + Dry grass + Pyrethrum	3.14±0.94d	3.03±0.15d
Coriander+Dry grass+Pyrethrum	4.27±0.95abc	3.51±0.82bc
Dry grass+Pyrethrum	5.43±0.56a	4.62±0.35bc
French bean alone	5.76±0.67a	5.63±0.68a
Coriander	2.62±0.14e	2.41±0.30e
Pyrethrum	4.76±0.41bc	4.01±0.71c
Dry grass	3.30±0.47d	2.75±0.15d
P	0.030	0.025
F	2.99	3.13
CV%	26.6	28.0
LSD	1.89	1.740

Means ± SE followed by the same letter in the columns do not differ significantly at p = 0.05 (Fishers protected LSD).

6.4. Discussion

Results on the mean number of thrips recorded on leaves and in flowers showed that there were significant differences among the various treatments. French beans intercropped with maize recorded significantly the lowest mean number of thrips on French bean leaves and flowers respectively. This is in line with the findings by Kasina *et al*. (2006), Nderitu *et al*. (2009) and Nyasani *et al*. (2012) who also recorded reduced the number of thrips on French beans when intercropped with maize. Gitonga *et al*. (2002) reported that maize reduced light penetration and shaded the French bean canopy making the environment undesirable for *F. occidentalis* and *M. sjostedti*. Similarly sorghum intercrop with cowpea also reduced *M. sjostedti* on cowpea (Nampala *et al*., 2002). In a related study by Gachu *et al. (*2012) showed that vegetable intercropped with onions reduced the population of thrips. Studies by Nyasani *et al*. (2012) reported that during flowering there were many thrips in the silk of maize which consequently attracted *Orius* spp, a natural predator of thrips. The research by Emeasor and Ezue (1997), Kyamanywa *et al*. (1993), Kyamanywa and Tukarahawa (1998), and Kyamanywa *et al.* (1998) also reported that Maize intercropped with cowpea and beans harboured *Orius* species, a main predator of thrips which reduced the population of *M. sjostedti* on cowpea and beans. Thus, maize used as an intercrop could perhaps be used as an alternative to synthetic chemicals in the management of thrips in vegetables grown in Kenya.

Maize + Dry grass + Pyrethrum treated plots recorded a lower mean number of thrips which did not differ significantly with that obtained from the plots intercropped with maize at early stages of French beans on leaves and all stages in flowers. The effectiveness of Maize + Dry + Pyrethrum in reducing the population of thrips on French beans might be due to Maize as opposed to Dry grass and Pyrethrum. The result from this study showed that Dry grass, Pyrethrum and Dry grass + Pyrethrum recorded higher population of thrips on leaves than those in plots with French bean alone (control).

French bean sprayed with L-Cyhalothrin recorded higher mean numbers of thrips than those intercropped with maize but lower than the mean number of thrips obtained from the control (French bean alone). This conforms to the findings by Kasina *et al.* (2006), Nderitu *et al*. (2010) and Nderitu *et al*. (2008) who reported L-Cyhalothrin to be ineffective against *F. occidentalis* and very effective against *M. sjostedti on* French beans. The result recorded in this study showed L-Cyhalothrin to be very effective against *F. occidentalis* in the laboratory and greenhouse experiments as oppose to the field experiments. This might be due to the stability of this syththetic pesticide in the shade than in open fields. Studies by Fernandez – Alvarez *et al.* (2007) reported that high temperature and ultraviolet rays denature the active ingredient of L-Cyhalothrin within 20 minutes. This might perhaps caused this pesticide in effective in the field but very effective indoors.

French beans plots mulched with Dry grass alone recorded a lower mean number of thrips compared to the control results from French the bean leaves during early stages of growth. In flowers, Dry grass recorded a generally lower mean 35th and 40th days of flowering stages. After 30th on leaves and 45th in flowers there were higher mean numbers of thrips than the control. In related study by Larentzaki *et al*. (2008) reported that onion mulched with straw reduced the number of *Thrips tabaci*. When the soil is mulched with thick dry grass, the soil moisture is retained making the soil environment unfavorable for soil dwelling stages of some thrips. Lewis (1997) showed that the pre – pupa and pupa stages of some species of thrips thrives better in optimal soil moisture between 10% and 13% moisture beyond these limits can affect thrips development. Hoddle *et al*. (2002), Agnew and Mugy (2002) and Jensen *et al*. (2003) reported that straw mulches increased the natural enemies of pupating thrips in the soil such as predators *Blattisocius dentriticius* (Ascidae) and *Neocunaxoides sp* (Cunaxidae) and entomopathogenic fungi in the onion cropping system. The increase of these natural enemies of thrips in the soil might have increased mortality of the soil dwelling stages of thrips hence slightly reducing population of thrips on French beans.

In the plots where French beans were sprayed with Pyrethrum higher mean numbers of thrips were recorded than those obtained on French bean alone except on the 40^{th} day and 50^{th} on both leaves and in flowers. Contrary to the ineffectiveness of Pyrethrum against thrips in the field, it was very effective in reducing the *F.occidentalis* numbers in the laboratory and green house experiments. on the leaves and in flowers. Natural pyrethrum just like L-Cyhalothrin is known to be easily decomposed by ultraviolet light. Study by Ruzo (1987) reported that the active ingredient in pyrethrum is denatured by high temperature and ultraviolet light rays from the sun. Antonius (2004) reported that pyrethrum pesticides are very effective in the rapid killing of insects but their stability is only for two hours or less a factor that is limiting its use in the field.

In the present study, intercropping French beans with coriander reduced the number of thripst on the leaves comparered with those recorded on French bean alone (control). The reports by Waiganjo *et al.* (2007) showed that when French beans were intercropped with coriander they reduced population of thrips. In flowers, there were more numbers of thrips recorded than those in French bean alone.

There were significant differences in the mean numbers of *F. occidentalis* on leaves. The lowest mean numbers of *Frankiliella occidentalis* was recorded in plots where French beans were intercropped with Maize. This conform with the finding by Gitonga *et al*. (2002) who reported that maize manipulated the microenvironment within the French bean which resulted to the reduction in light penetration on French bean canopies. The same author also reported that *F. occidentalis* and *M. sjostedt* preferred to live on open areas compared with shaded areas, hence are less in the intercropped French bean crops. These findings by Gitonga *et al*. (2002) might be the reason why there was less number of *F. occidentalis* on French bean leaves. The reports by Kasina *et al*. (2006) showed that maize intercropped with French beans significantly suppressed population of thrips below their economic injury level. Maize as an intercrop should be incorporated in the integrated pest management system against *F. ocidentalis.* L-Cyhalothrin, Coriander, Maize + Dry grass + Pyrethrum and Coriander + Dry grass + Pyrethrum reduced the population of *F. occidentalis* lower that those recorded from the control. On the other hand the plots which were treated with Pyrethrum and the Dry grass recorded higher mean number of thrips than the control. But when they were incorporated with intercrops (Maize and Coriander), they significantly reduced population of *F. occidentalis* compared the control. Pyrethrum since its stability last only for two hours in the field as suggested by Antonius (2004) can be incorporated in the integrated pest management since no insect resistance has been reported about it. The studies by Vassiliou (2011) reported that pyrethrum reduced Kelly's citrus thrips on organic grape fruits.

There were significant differences in the mean numbers of *Frankliniella schultzei* recorded on French bean leaves. The lowest mean numbers of *F. schultzei* was recorded in the plots where French beans were intercropped with Maize. There is no related study on the effects of maize on this species but it has been reported by Nyasani *et al*. (2012) to be the most abundant in French bean flowers. Other treatments namely L-Cyhalothrin, Dry grass, coriander, Maize + Dry grass + Pyrethrum and Coriander + Dry grass + Pyrethrum significantly reduced *F. schultzei* than the control. Pyrethrum just like for other species did not control *F. schultzei* on French bean leaves except when incoperated with intercrops.

There were significant differences in the mean numbers of *M. Sjostedt* recorded on French bean leaves. Maize as an intercrop significantly reduced this species of thrips than L-Cyhalothrin. This conformity with the findings of Kyamanywa *et al*. (1993), Kyamanywa and Tukarahawa (1998) and Kyamanywa *et al.* (1998) who reported that maize intercropped with cowpeas and beans reduced the population of *M. sjostedti* on cowpea and beans. The finding by Gitonga *et al.* (2002) reported that *M. sjostedt* preferred to live on open areas compared with shaded areas; hence they were less in the intercropped French bean crops. The instability of L-Cyhalothrin in the field as reported by Fernandez-Alvarrz *et al.* (2007) could have reduced the effectiveness of this insecticide. Maize + dry grass + Pyrethrum, Dry grass and Coriander also reduced *M. sjostedti* on French bean leaves.

There were significant differences in the mean numbers of *Hydatothrips adolfifriderici* recorded on French bean leaves. The lowest mean numbers of *H. adolfifriderici* was recorded in the plots where French beans were intercropped with Maize. There are no specific reports on the effects of maize as an intercrop on *H. adolfifriderici*. But generally Kasina *et al*. (2006) reported maize to have reduced thrips on french beans. In my own opinion this species was present. The research done by Moritz *et al.* (2013) reported that *H. adolfifriderici* is widely distributed in East Africa and mainly causes blotches on the leaves and stems of French beans. However, its economic importance to French beans and efficacy of management strategies are not known. Other treatments which were applied on French beans like Maize + Dry grass + Pyrethrum, L-Cyhalothrin, Dry grass and Coriander recorded lower mean number of *H. adolfifriderici* than the control.

In general, the abundance of thrips species collected and identified on French bean leaves showed the dominant species of thrips was *Hydatothrips adolfifriderici* followed by *Megalurothrips sjostedti*, *Frankliniella schultzei* and *Frankliniella occidentalis* respectively. There were significant differences in the mean numbers of *F. occidentalis* obtained from French bean flowers treated with various treatments. The lowest mean numbers of *F. occidentalis* was recorded from the plots where French bean was treated with Maize + Dry grass + Pyrethrum. There is no related study on the integrated pest management method however, the combined effects of maize, dry grass, and pyrethrum as discussed earlier may have caused unfavourable environment for the infestation of *F. occidentalis*. The other treatment which significantly controlled *F. occidentalis* was Coriander + Dry grass + Pyrethrum. The following treatments namely L-Cyhalothrin, Dry grass, Coriander, Maize, Dry grass + Pyrethrum and Pyrethrum did not controlled *F. occidentalis* in French bean flowers since they recorded higher mean than the control.

There were significant differences in the mean numbers of *F. schultzei* and *H. adolfifriderici* obtained from the French bean flowers treated with various treatments. In all treatments, the mean numbers of thrips species mentioned above were higher than those recorded from the control. This might be due to cryptic behavior of thrips within the flowers which reduces the efficacy of these control agents as suggested by Berndt *et al*. (2004).

There were significant differences in the mean numbers of *M. sjostedti* obtained from the French bean flowers treated with various treatments. *M. sjostedti* was significantly controlled by Pyrethrum in French bean flowers. A similar related study by Vassilliou (2011) reported that pyrethrum reduced the number of Kelly's citrus thrips on organic grape fruits. There are no reports of *M. sjostedti* developing resistance to any synthetic insecticide in Kenya. Therefore, pyrethrum may be used in the management of *M. sjostedti* in French bean flowers.

In French bean flowers, the dominant species observed was *F. schultzei* followed by *M. sjostedti*, *F. occidentalis* and *Hydatothrips adolfifriderici respectively*. Similar trends were reported by Nyasani *et al*. (2012). In another general observation, the mean numbers of thrips recorded from French bean flowers were much higher than those which were obtained on the leaves. A study by Nyasani *et al*. (2012) reveled that there was increased attraction of thrips to French beans during flowering stages. Floral volatiles and analogues of flower volatiles as reported by Muvea *et al*. (2010) are known to enhance the attraction of thrips species such as *F. schultzei, M. sjostedti, F. occidentalis* and *H. adolfifrederici*. This could be attributed to various reasons outlined earlier such as resistance of thrips to L-Cyhalothrin and low field efficacy of pyrethrum.

There were significant differences in the mean total harvested yield of fresh French bean pods recorded from various treatments before grading. The highest mean total yield was recorded in plots with French bean alone (control). Similar findings were reported by Nyasani *et al*. (2012) that a monocrop of French beans recorded higher yield than the intercropped one. In the plots treated with Dry grass + Pyrethrum, Pyrethrum and L-Cyhalothrin recorded higher yields than the plots with intercrops. Plots subjected to intercropping with maize recorded significantly lower yields as compared to the others in spite of the low levels of infestation by thrips. This is in line with the findings of Ezumah *et* *al.* (1987) and Wahua *et al*. (1981) who reported 55% to 61% and 40% to 55% reduction of cowpea yield when intercropped with maize. Nyasani *et al*. (2012) also observed that at 1: 4 ratio of intercropping maize with French beans, the total yield was reduced by 35 to 37%; the low yield from plots with intercrops may be due to the spacing of the French beans and intercropping ratio adopted in the present study. Studies by Van der Meer (1989) attributed the higher yield reduction of soybean when intercropped with maize to interspecific competition and depressive effects of maize crop. There were significant differences in mean marketable yield French bean pods after application of various treatments. The highest marketable mean yield was recorded from plots where French beans were grown a lone but the yield was less than the mean total yield. Despite high yield from the control experiment. The quality of pods was generally lower compared to those pods obtained from plots with intercrops. Hence there is a need to evaluate the optimum spacing between maize and French beans so as to simultaneously minimize the damage due to thrips and sustain the yield potential of French beans. In the study of Nderitu *et al*. (2008) reported that thrips infestation levels in flowers are known to be key determinants for the quality and quantity of French bean yields. In line with this report, there were higher numbers of thrips in most of the French bean flowers collected from all treatments than the control. This translated to having high marketablefrench bean yield in the control than in the plots with treatments.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7.1 General discussion

In Kenya, French beans are grown throughout the year and are sources of income for poor farming communities and are mostly grown by small-holder farmers who cannot afford expensive chemical pesticides. Moreover the chemical pesticides which are used for the control of key thrips such as Western flower thrips species are not effective due to development of pesticide resistance. Therefore, botanical pesticides would provide a viable and eco-friendly alternative to chemical pesticides. However, botanical pesticide alone may be insufficient to provide adequate protection and therefore they should to be integrated with other cultural control options such as mulching and intercropping. In the present study, the efficacy of botanical pesticides, mulching techniques and intercropping were evaluated for the management of thrips affecting French beans.

The current study evaluated the botanical pesticides such as pyrethrum, neem and garlic extracts were undertaken through laboratory, greenhouse trials and field experiments. The parameters that used included thrips mortality, thrips populations, leave damage, yield and pod quality.

Laboratory and greenhouse experiments revealed that 2% L – Cyhalothrin a synthetic insecticide caused 100% mortality of first the instars of *Frankliniella occidentalis* within 36 hours in the laboratory experiments. This is in conformity with the finding by Amarasekare and sheerer (2013) who reported 100% mortality of *Deraeocoris brevis.* L - Cyhalothrine was also more effective in the greenhouse than in the field. The finding by Kasina *et al*. (2006) and Nderitu *et al*. (2007) revealed that *F. occidentalis* had developed resistance against L – Cyhalothrin in French bean fields of Kenya. Further findings by Fernandez - Alvarez *et al.* (2007) showed that the active ingredients of L – Cyhalothrin decompose when exposed to high temperatures and ultraviolet light which could have resulted in its low efficacy in the field. Among the botanical pesticides tested in the laboratory, Pyrethrum was found to be the most effective compared to neem and garlic. However its effectiveness decreased in the greenhouse and it was not effective in field experiments. Vassiliou (2011) reported pyrethrum to be most effective against Kelly's citrus thrips *Pezothrips kellyanus* (Bagnall) compared to the untreated control in the field. Studies by Elizabeth *et al.* (2005) had shown that pyrethrum active ingredient is stable under sunscreen condition. But exposure to high temperature and ultraviolet light denature the active ingredient of pyrethrum making it ineffective (Antonious, 2004). Although Pyrethrum alone did not effectively control thrips infesting French beans in the field, integrated approach involving maize intercropping, dry grass mulch and pyrethrum application significantly reduced number of thrips on French beans. Thus, pyrethrum might be used as an alternative to the synthetic pesticide for the management of thrips especially in greenhouses, while in the open fields an integrated approach needs to be adopted.

Neem pesticides were not as effective as pyrethrum against first instar *F. occidentalis* in the laboratory. However, in the greenhouse experiments, a combination of foliar sprays of neem @ 5% and soil application of neem powder @ 5g per plant crop significantly reduced *F. occidentalis* on French beans just as pyrethrum. Vassiliou (2011) reported neem 3% to be effective against *P. kellyanus* on grapefruits and Subramanian *et al*. (2010) revealed that neem oil 3% reduced *Pseudodentrothrips mori* Niwa on mulberry in the field. Soil application of Neem powder alone was not effective against *F.occidentalis* infesting French beans. Maundu (1999) attributed this to the failure of the crop plant to absorb and the translocation of the bioactive neem ingredients. Schmutterer and Asher (1990) also showed that the rate absorption and translocation of bioactive components of neem vary depending on plant species.

Among the various mulch options which were evaluated namely, Black plastic, transparent plastic, dry grass and green Tithonia leaf mulch; transparent plastic mulch significantly reduced thrips on leaves especially during the early stages while the dry grass mulch significantly reduced thrips infestation in French bean flowers. Transparent plastic sheets allow light to pass through making vegetation underneath to respire releasing water vapour. Accumulations of water vapour in the sheet make it white silvery and hence reflect light. Stavisky *et al.* (2002) showed reflective mulches to be effective against *F. occidentalis* and *Frankliniella tritici* (Fitch) on young tomatoes. The reflective effects reduced as the plants covered the mulch (van Toor *et al.*, 2004). This could be the reason for the less effectiveness of transparent plastic mulch at flowering stage on the flowers as compared to the other mulch treatments. Besides beneficial effect on pest management, polyethylene film also aids in weed management, soil moisture conservation, nutrient conservation and enhances the quality and quantity of yield (Waterer, 1999; Ngouajio and Ernest, 2005). However, plastic mulches also have many limitations compared to organic mulches such as cost of application, probability of ‘burning’ or ‘scorching’ of the young pants due to high temperature of black film, difficulty in intercultural operations such as top dressing with fertilizer, more runoff, environmental pollution and toxic to livestock.

The highest yields of French beans were recorded from the plots mulched with black polythene sheets which were not significantly difference from the dry grass and transparent polythene sheet mulches. Abdul – Baki and Spence (1992) also reported double yield of fresh market tomatoes from the tomatoes mulched with black polythene sheets. Park *et al*. (1996) recorded seed yield increase in soybean by 18 per cent with transparent film and by 15 per cent with black film. Shashidhar *et al.* (2009) reported that the total leaf yield of mulberry was found maximum in the paddy straw mulched plots. Okra production was significantly higher under straw mulch followed by dust mulch over control (Batra *et al.,* 1985).

Dry grass mulch treatment was equally beneficial as transparent and black plastic mulch and resulted in significantly higher French bean yields compared to the green leaf mulch and the unmulched control. The dry grass has a very low reflective property; however its effects on the insect pest depend on its ability to create a micro condition in the soil unsuitable for pest development. At the same time, it creates a favourable condition for the multiplication of the natural enemies of the pest. Sugiyarto (2009) showed that the application of maize residue as mulch enhanced the diversity index of surface and deep soil macro invertebrate by 44% and 73% respectively as compared to the control. Shashidhar *et al*. (2009) reported more numbers of bacterial, fungal and actinomycetes colonies found in *Cassia sericea*, paddy straw and sun hemp mulched plots over the other treatments respectively. Gollifer (1993) reported that the application of organic mulch produced higher yield of the chilli dry fruits compared to the control. Rose *et al*. (1994) and Hassan *et al*. (1994) reported that the organic mulch gave the highest fruit yield of bell pepper over the control. The yield of the potato was increased with paddy straw mulch than unmulched plot (Dixit and Majumdar**,** 1995). Mulching maize with grass increased grain yield by 15–22 per cent and by about 10 per cent in millet in northern Guinea and Sudan savanna regions of Nigeria (Adeoye, 1984).

Evaluation of thrips species numbers on French bean leaves indicated in decreasing order of abundance the the thrips species could be grouped as *Hydatothrips adolfifriderici* > *Megalurothrips sjostedti* > *Frankliniella schultzei* > *Frankliniella occidentalis* while in flowers the decreasing order of their abundance was *F. schultzei* > *M. sjostedti* > *H. adolfifriderici* > *F. occidentalis.* Nyasani *et al.* (2010, 2012) also showed that *M. sjostedti, F. schultzei, H. aldolfifriderici, and F. occidentalis* as the main thrips species on French bean in Kenya in order of decreasing abundance. Although information on the economic importance of *F. occidentalis* and *M. sjostedti* is already known (Alabi *et al*., 2004; Ngakou *et al.*, 2008), information on the economic importance of *F. schultzei* and *H. adolfifrederici* is very minimal.

French beans intercropped with maize significantly reduced thrips numbers on French bean leaves ($p < 0.05$) similar to the L – Cyhalothrin treatment. In the plots where maize was integrated with pyrethrum and the dry grass mulch it significantly reduced thrips in the French bean flowers. This finding is in conformity with the studies of Kasina *et al*. (2006), Nderitu *et al*. (2009) and Nyasani *et al*. (2012) who reported low thrips numbers on the French beans intercropped with maize. However, intercropping French beans to maize and coriander significantly reduced its yield as compared with other treatments but resulted in high quality pods. In the present study a 2: 1 ration was adopted for French bean: Maize intercropping. The findings by Nyasani *et al*. (2012) reported that yield from the plots with French beans alone were almost 1.4 more than that from plots where French beans were intercropped with sunflower and baby corn respectively. The same auther noted that the percentage yield damage was very high of about 63 to 68% from a monocrop of French beans. Muoneke *et al.* (2007) reported lower yield of soybeans when it was intercropped with maize than a monocrop of soybean. Therefore more research is required in order to determine the correct spacing between the intercrops and the French beans which will maximize yield for French beans.

Since most synthetic pesticides which are used to control thrips are very expensive and incompatible with integrated pest management there is need to promote the use of botanical pesticides and cultural practices for the management of thrips on French beans in Kenya. **S**mall scale farmers widely practice inter or mixed cropping as a means of reducing a risk of total crop failure. However, they are yet to harness its advantage for pest management.

This study clearly presented the efficacy of intercropping French beans with maize for thrips management. The study demonstrated the need to validate optimum intercropping densities for sustaining the yield. Further botanical pesticides especially pyrethrum and neem were found to be effective for management of thrips in combination with cultural options such as intercropping and mulching. These are locally available, selective, of low persistence, biodegradable and environmentally friendly. A combination of maize and botanical insecticides could aid in reducing the frequency of synthetic pesticide application and aiding in the production of low pesticide residue crop produce. Hence, reducing the deleterious effect of synthetic pesticides on health, environment and also on biological control agents.

7.2 Conclusions

i. L – Cyhalothrin a synthetic pesticide effectively controlled *Frankliniella occidentals* reared on French bean pods in the laboratory. Amongst the botanical used, only pyrethrum was most effective against *Frankliniella occidentalis* larvae. Neem and garlic did not effectively kill the *Frankliniella occidentalis* larvae reared on French bean pods in the laboratory.

ii. L – Cyhalothrin effectively reduced *Frankliniella occidentalis* in the greenhouse, Pyrethrum (foliar + soil), Neem (foliar + soil), Neem soil effectively controlled *Frankliniella occidentals* on French beans pods in the greenhouse. Pyrethrum soil, Garlic (soil+foliar) and Garlic (soil) did not effectively controlled *Franliniella occidentalis*.

iii. Dry grass mulch was not effective in reducing the number of thrips on French bean leaves, but it effectively reduced thrips numbers in French bean flowers in the field experiments. Trasparent plastic sheet mulch reduced the number of thrips on French bean leaves but was not effective in flowers in the field experiments. However, transparent plastic mulch promoted the growth of weeds beneath the sheet, hence negatively influenced the French beans yield. Black plastic sheet mulch did not effectively reduce the numbers of thrips on French bean leaves but it reduced the number of thrips in flowers. Additionally the black plastic sheets completely suppressed weeds hence promoted rapid growth of the French beans enabling French beans evade pests at early stages. Tithonia green mulch did not reduce the number of thrips on French beans in the field experiments.

iv. *Frankliniella schultzei* was the dominant thrips species in the French bean flowers while *Hydatothrips adolfifriderici* was dominant on leaves. The mean numbers of F. occidentalis were very low both on leaves and in flowers. The general trend observed reveled that the most dominant thrips species collected from the French bean leaves throughout the cropping session was *Hydatothrips adolfifriderici* which was followed by *Megalurothrips sjostedti, Frankliniellaschultzei and Frankliniella occidentalis.* In flowers the trend in increasing order was *F. schultzei, M. sjostedti, F. occidentalis* and *H. adolfifriderici*.

v. L – Cyhalothrin and pyrethrum did not effectively controlled thrips on French beans in the field experiments. Maize as an intercrop with French beans effectively reduced the number of thrips but negatively reduced the yield of French beans. A combination of pyrethrum + maize + dry grass effectively reduced the number of thrips on French beans in the field experiments.

7.3 Recommendations

1. A combination of pyrethrum, maize intercropping at optimal ratios and dry grass as mulch would be the most suitable methodfor the management of thrips on French beans in IPM system. Such an integrated approach will be useful for conserving the natural enemies in the system, reduce the cost of French bean production as synthetic pesticides are generally expensive for the small scale farmers and sustain the environmental health. Further such an integrated approach can significantly reduce the application of synthetic pesticides, which is very essential to meet the standards stipulated for the exports of French beans.

2. Botanicals such as pyrethrum and neem should be used as alternative methods of thrips management to supplement the synthetic pesticides in greenhouses. Pyrethrum when srayed on leaves and applied as powder on the soil effectively controlled *Frankliniella occidentals.* Neem pesticide equally reduced *Frankliniella occidentalis*

when applied as foliar spray and applied in the soil as powder and should be incorporated in the thrips intergrated pest management system.

7.4 Suggestions for further research

i. More studies are required to improve on the formulation of pyrethrum with an aim of enhancing its photo stability in the field.

ii. There is need to conduct research on the evaluation of a combination of soil application of neem and foliar applications of pyrethrum. In this combination, neem will impede the growth and development of insect pest while pyrethrum kills the pest.

iii. Further research on the spacing between maize and French beans is needed so as to optimize intercropping strategy with maize so as to sustain the French bean yield and minimize the thrips damage.

iv. Finally, more research is required on the economic importance of *F. schultzei* and *H. aldififriderici* on vegetables in Kenya.

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