The Potential of Coloured Sticky Traps with Kairomonal Attractants (LUREM-TR) in Management of Thrips on Tomato and French beans

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A Thesis Submitted in Partial Fulfillment for the Degree of Master of Science in Agricultural Entomology in the Jomo Kenyatta University of Agriculture and Technology

2011

DECLARATION

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

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To God whose invisible footprints dot every page of this work. To my mom, Alice, who taught me the virtues of hard work and perseverance and my dad, Daniel, for teaching me the value of education. To my Auntie, Vicky and my siblings for their encouragement, motivation, patience and understanding.

ACKNOWLEDGEMENTS

I highly appreciate and acknowledge the financial support for this endeavor from Federal Ministry for Economic Cooperation and Development (GTZ-BMZ) Germany through thrips IPM program, (*icipe*). My sincere gratitude goes to Dr. Sevgan Subramanian, the project leader, thrips IPM for awarding me the Dissertation Research Internship Program (DRIP) fellowship and whole heartedly introducing me to the fascinating world of Thysanopterans and providing me with all the necessary support that I required during my study. His constant research guidance, moral support and his keen supervision throughout the study gave me a lot of inspiration and made me what I am. It is my pleasure to thank Capacity building Division for all their support during my stay at *icipe.*

Many thanks to my university supervisors Dr. Helen Kutima and Dr. Zipporah O. Lagat, for their great input through, critical comments, valuable suggestion that shaped this research work. They tirelessly guided me through supervisory meetings, amended and reviewed the draft thesis. I am indebted to Dr. Monicah Waiganjo for making this work a success through constant follow up of my field experiments and the thesis drafts. I am indebted to Johnson Nyasani whose constant ideas, suggestion and corrections have had a great impact on the success of this work and Daisy Salifu for her guidance on data analysis. My sincere gratitude to Joyce (KARI- Thika), Dr. S. Muya (JKUAT) and colleagues at the thrips IPM program for their endless support. Finally, 1 would like to thank Faith for her support, care, understanding and encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ACRONYMNS AND ABBREVIATIONS

BFT	Bean Flower Thrips
CBR	Cost Benefit Ratio
EIL	Economic Injury Level
ETL	Economic Threshold Level
ET	Economic Threshold
HCDA	Horticultural Crops Development Authority
IPM	Integrated Pest Management
KARI	Kenya Agricultural Research Institute
MOA	Ministry of Agriculture
RCBD	Randomized Complete Block Design
TSWV	Tomato Spot Wilt Virus
WFT	Western Flower thrips

ABSTRACT

Tomato *Lycopersicon esculentum* (Mill) and French beans *Phaseolus vulgaris* (Linnaeus) are among the most income generating vegetable crops for the domestic and the export market in Kenya, respectively. Thrips are among the key pests hampering the production of these crops due to their direct and indirect damage to the crops. Effective monitoring and timely implementation of pest management strategies is important for successful thrips management. Coloured traps and kairomonal attractants have been used widely globally for thrips monitoring but their use and effectiveness has not been evaluated for thrips complex found in Kenya. The effect of the addition of kairomonal attractant, LUREM-TR to increased attraction of adult thrips to commercially available blue and yellow sticky traps was examined in outdoor French beans and tomato production fields. Field experiments for each crop over two cropping periods were carried out in a randomized complete block design with four replicates. Six treatments were adopted: blue, yellow and clear sticky traps either with or without LUREM-TR attractant. In tomato, blue sticky traps caught 1.66 – 5.08 times as many thrips as yellow traps, and upto 13.24 – 59.12 times more than clear traps. In French beans, blue sticky traps caught 2.05 – 3.52 times as many thrips as yellow traps, and 22.07 – 29.31 times more than clear traps. Blue traps were most attractive to *Megalurothrips sjostedti* (Trybom), *Ceratothripoides brunneus* (Bagnall) and *Frankliniella schultzei* (Trybom). *Hydatothrips adolfifriderici* (Karny) were only attracted to yellow traps. Blue and yellow traps were equally attractive to *Frankliniella occidentalis* (Pergande) in tomato while in French beans blue was the most attractive.

Addition of LUREM-TR attractant increased percentage thrips captures between 0.87 - 66.97% on tomato and 29.6 – 158.4% on French beans. However, the attractant did not influence the captures of *C. brunneus*, the key thrips species found on tomato. Dipterans were significantly captured on blue traps while yellow traps were most attractive to thrips natural enemies, aphids, whiteflies, hoppers, coccinelids and hymenopterans in the two crops. Correlations between total trap captures and absolute measure of thrips estimated by destructive and non-destructive sampling in both crops indicated significant positive correlation on blue traps with LUREM-TR except on first tomato trial where there was no such correlation. Maximum temperature, wind run and sunshine were positively correlated with thrips densities, while minimum temperature and rainfall were negatively correlated with thrips densities. A threshold of 300 thrips was found to be effective in management of thrips and was comparable to weekly applications of Alpha cypermethrin and *Metarhizium anisopliae* (Metsch) in yield/ha. However, due to the higher cost of chemical application than the fungus, the cost benefit ratio with chemical application was much lower than the fungus application. The net income was highest when fungus was applied at a threshold of 300 thrips captured on blue traps with kairomone per week and it decreased at higher thresholds due to the increased damage by the pest. Hence, based on the economic optimization model, the optimum threshold for application of *M. anisopliae* was at 300 thrips captured on blue sticky trap with kairomone per week when net income was maximum. Therefore this study indicates that exploiting the response of pest thrips species to blue trap and LUREM-TR attractant has strong potential for improving monitoring and timely management of thrips in outdoor tomato and French beans production.

CHAPTER 1

1.0 GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 Tomato and French beans production in Kenya

The horticultural sub-sector has had a tremendous growth over the last decade to become a major foreign exchange earner, employer of labour and key contributor to food security in Kenya. In 2008, the industry generated US$1 billion in foreign exchange from exported commodities and directly and indirectly employing over 4 million people (HCDA, 2009). Total horticultural production is estimated to be close to 3 million tonnes making Kenya one of the major producers and exporters of horticultural products in the world (HCDA, 2009). Tomato *Solanum lycopersicum* (Mill) and French beans *Phaseolus vulgaris* (Linnaeus) are among the most important horticultural crops in Kenya and are grown mainly for domestic and export market respectively (HCDA, 2005). French beans ranks first among vegetables produced for the export market in Kenya and contribute more than 20% by volume and nearly 10% by value of vegetable exports and rank second after cut flowers in volume and value among export crops (MOA, 2009), while production of tomatoes in Central province alone was estimated at 75,101 tonnes and valued at over Ksh. 1 billion (KARI, 2005). The annual export from fresh vegetables fetches about 30 – 40% of foreign exchange in Kenya (HCDA, 2009).

1.2 Constraints in tomato and French beans production due to thrips

Pest and diseases are amongst the major challenges to tomato and French beans production (Michalik *et al.*, 2006). Monda *et al.* (2003) found that the major diseases include rust, fusarium wilt, nematodes and blights while the major insect pests are bean fly, thrips, aphids and mites. The silvery lesions on French bean pods makes the product unfit for export market (Plate 1.1). Losses of upto 40 - 60% of pods in the presorting at the farm level and another 20% at the collection points have been reported (Lohr, 1996).

In tomato, leaves may crinkle and die, growing tips may become stunted, discoloured and deformed and fruits may abort or develop scar tissue (Ghidiu *et al.,* 2006). Thrips feeding on the flowering parts causes necrosis and/ or abscission of flower buds, opens flower peduncles and causes curling of pods which in turn leads to yield losses of about 20 -70% (Edema and Adipala, 1996). Direct damage on tomato fruit caused dimpling which in turn leads to cosmetic losses (Nault *et al.,* 2003). Indirect damage of thrips is attributed to being vectors of disease-causing virus (Wangai *et al.,* 2001). In East Africa region thrips are among the most frequently reported pests of tomato and they also vector tospovirus diseases (Subramanian *et al.,* 2009) (Plate 1.2). Thrips currently rank as primary pests of French beans and secondary pest on tomato crops in Kenya (MOA, 2006; Waiganjo *et al.,* 2006).

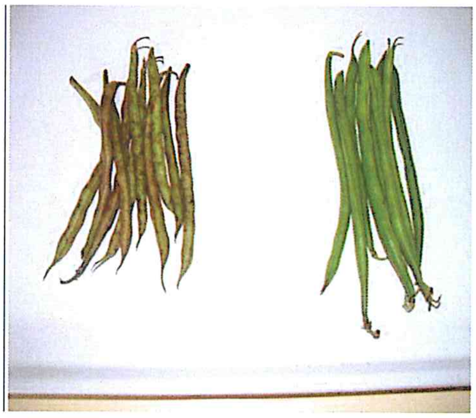

Plate 1.1: French bean pods on the left are damaged while those on the right are undamaged

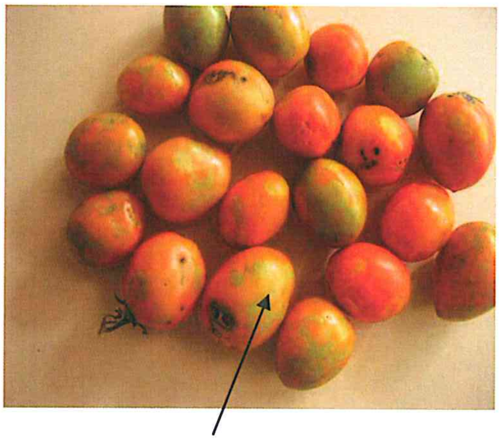

Plate 1.2: Green ring pointed by arrow indicate symptoms of TSWV on tomato

1.3 Biology of thrips

Worldwide, almost 6000 species belonging to the order Thysanoptera are recognized in nearly 800 genera (Mound, 2008). There are two suborders, Terebrantia with saw like ovipositor for endophytic oviposition and the Tubulifera without saw like ovipositor with exophytic oviposition (Hussey, 1969). Sub-order Terebrantia includes seven families, with the members of the family Thripidae comprising of economically important pest while Tubulifera includes only one family and few economically important pests. The family Thripidae (suborder Terebrantia) consists of primary pest species and includes two genera, *Thrips* and *Frankliniella* which are serious pests of agricultural crops (Mound, 1997). Thrips feed by using the modified left mandible mouthpart to pierce plant cells and their stylets to suck out their contents resulting in the typical silvery lesions on the leaves and other plant parts (Lewis, 1997). They have a very short life cycle (Reitz, 2008) (approximately 18 to 22 days under ideal conditions) and complete multiple generations per year (Lewis, 1997). Thrips development progresses through two larval instars and inactive pre-pupa and pupal stages. The adult, egg and larval stages are found on the host plant. Each female produces an average of 50 endophytic eggs which hatch in 4 to 16 days. The larval stage feed on the plant tissues and lasts for 4 to 14 days and pupates in the soil or leaf litter. The pupal period lasts for 3 to 12 days. Emerged adult feeds on leaves and flowers and can live for 7 to 30 days.

1.4 Commonly adopted control options for thrips

1.4.1 Cultural control methods

1.4.1.1 Use of resistant cultivars

Resistant cultivars may provide a useful component of integrated management of thrips. Some work has been conducted on eggplant, cowpea, maize, onion, cotton, cabbage, peanuts, wheat, chrysanthemums, and rice with the western flower thrips being the most extensively studied species (Parrella and Lewis 1997; Owusu *et al.,* 1998). Studies have successfully shown cowpea cultivars e.g. Sewe and Sanzibanili that are resistant to thrips have a great impact on the growth and development of thrips thereby delaying the pest from reaching the economic damage threshold (Alabi *et al.*, 2004). Nderitu *et al.* (2007) found that French bean cultivar, Impala supported the lowest thrips infestation while cultivar J12 was the most tolerant with high count of thrips but low pods damage score. Tomato variety, Roma had the highest marketable yield upon mechanical inoculation of Tomato spotted wilt virus due to its resistance to the disease (Ramkat *et al.*, 2006).

1.4.1.2 Intercropping

Intercropping reduces pest populations by increasing environmental diversity. Mixed cropping has been shown to reduce thrips populations in different crops possibly because thrips are repelled by the lower light intensities in the mixed crop (Kyamanywa and Ampofo, 1988). It was reported that the mortality caused by mycosis on *M. sjostedti* was significantly higher when cowpea was intercropped with maize and treated with *Metarhizium anisopliae* than in a monocrop situation (Ekesi *et al.,* 1999). Intercropping snap beans with African marigold (*Tagetes erecta)* and Coriander (*Coriandrum sativum),* significantly reduced the population of thrips on snap beans (Kasina *et al.*, 2006) and enhanced the percentage of marketable pods (Nderitu *et al.,* 2009). Thrips damage on a sole crop of French bean was highest (63 – 68 % yield loss) compared to when French bean was intercropped with sunflower, Irish potatoes and baby corn crops. The least damage to French bean pods (35–37 % yield loss) was recorded when French beans were intercropped with baby corn (Nyasani *et al.*, 2010).

1.4.1.3 Mulching

Mulching with wood shavings or straw mulch can be adopted as a strategy to improve on yield under agro ecological settings (Larentzaki *et al.*, 2008). Black polythene papers (Hajek, 2003) suppress weeds and keep the soil moist and warm for rapid plant growth to evade susceptible stage of thrips attack and hinders the life stages of the thrips especially prepupa and pupa.

1.4.2 Synthetic and botanical pesticides based control

Most farmers rely on foliar pesticides to control thrips on tomato and French beans (Nault *et al.*, 2003; Nderitu *et al.*, 2008). Significant yield increases have been achieved due to the application of synthetic insecticides for controlling French bean pests in Kenya (Nderitu *et al.*, 2008). Without chemical protection, thrips reduce French beans yield, at times leading to complete crop failure (Nyasani *et al.*, 2010). Compared with the control, treatment using insecticide obtained the highest reduction of adults *M. sjostedti* (range 52–95%) and larvae thrips population (64–97%) in cowpea crop (Ngakou *et al.*, 2008). Despite the efficacy of insecticides, there are also disadvantages linked with their use, including high cost, residues and development of pest resistance (Nderitu *et al.*, 2001; Kasina *et al.*, 2006).

Dayan *et al.* (2009) reported that botanical pesticides are plant extracts which have been formulated and used for pest control. Neem is known to have wide range of effects on the pest such as deterring feeding, oviposition, repellency, insect growth regulation, sterilant, mating disruptor and toxicity (Singh and Doharey, 2001). Thoeming *et al.* (2006) found that when bean seeds were dressed before planting with neem extracts, the population of *F. occidentalis* was effectively reduced in flowers. Oparaeke *et al.* (2006) reported cowpea protection from *M. sjostedti* when sprays of *Afromomum melagueta*, *Xylopia aethiopica* and *Zinger officinarum* were applied. Pyrethrum is a natural insecticide and pyrethrins, like all members of the pyrethroid insecticide family, kill insects by disrupting their nervous systems (Crosby, 1995).

1.4.3 Biological control methods

Many beneficial organisms work to suppress thrips and pose no risk to humans and the environment (Desneux, 2008). Predators have recently been receiving much interest as thrips population regulators. *Orius* spp. has been successfully used as biological control agent against *F. occidentalis* for instance in beans (Xu *et al.*, 2006) and control of thrips in sweet pepper and greenhouse cucumber (Messelink *et al.*, 2006). Silveira *et al.* (2004) attributed *Orius insidiosus* as aggressive predator and will seek out thrips even in closely protected areas such as deep within the flowers. Numerous attempts have been made on exploration of hymenopterous parasitoids on thrips (Loomans, 2006) as biological control. A parasitoid *Ceranisus femoratus* was found successful (Neuenschwander and Markham, 2001) in control of *M. sjostedti* in cowpeas through classical programme.

Thrips especially WFT has demonstrated a strong capacity to resist chemical insecticides (Nderitu *et al.*, 2001) and research on alternative management options is being sought. Among the alternatives under investigation are insect pathogens. Thus, fungi, which infect by penetrating directly through the insect integument, are the most promising microbial biocontrol agents for these insects (Niassy *et al.*, 2009). Selected entomopathogenic fungi have been successfully applied as bio insecticides towards bean flower thrips, *M. sjostedti* (Ekesi *et al.*, 1998; Ngakou *et al.*, 2008) and *F. occidentalis* (Ekesi *et al.*, 1999, Maniania *et al.*, 2001; Niassy *et al.*, 2009). Fungal products have some desirable traits that they leave no toxic residues, generally harmless to beneficials (Ekesi *et al.*, 1999) and pose minimal risk to humans and the environment (Goettel *et al.*, 2001). Formulations based on *Beauveria bassiana*, *M. anisopliae* and *Lecanicillium muscarium* significantly reduced thrips populations in greenhouse vegetable and floral crops under research conditions (Ugine *et al.*, 2006; Gouli *et al.*, 2008).

1.5 Biological characteristics that facilitate success of thrips

The cryptic feeding behavior of thrips within the flower buds (Heming, 1993; Moritz *et al.*, 2001) often makes difficult the timely detection of damage and also controls tactics to reach the target thrips. Reliable taxonomic identification is also a challenge due to the very small size of the thrips and the diverse characters for identification. Short life cycle, high fecundity (Murai *et al.*, 2001), the ability to gain resistance to a wide range of chemical pesticides (Jensen, 2000) has also contributed to the outbreak of thrips species such as *F. occidentalis* (Nderitu *et al.*, 2010) and *Thrips palmi* (Canon *et al.*, 2007). Many thrips species are generally invasive (Morse and Hoddle, 2006) and are not constrained by highly specialized evolutionary relationships with particular host plants and polyphagy predisposes certain species as potential invaders.

1.6 Development of coloured sticky traps for thrips

The primary cues in location of a host plant by thrips are colours such as blue, white, and yellow (Frey *et al.*, 1994; Terry, 1997; de Kogel and Koschier, 2003; Chu *et al.*, 2006; Natwick *et al.*, 2007). UV reflectance also plays a role in thrips host selection (Mazza *et al.*, 2010). Matteson and Terry (1992) suggested that thrips use peak sensitivity to yellow-green in long-range orientation to plants and then use contrasts within plants to find flowers and are able to locate blue spectral hues when both UV and yellow-green receptors are initiated. Different colour preferences of many species of thrips have been studied by numerous scientists (Hoddle *et al.,* 2002; Held and Boyd 2008) to enhance the attractiveness and sensitivity of various traps.

Determination of colour preference of crop pests has helped to develop pest traps using attractive colours. Specific coloured traps provide opportunities for sampling, monitoring, estimating populations and management of various species of thrips under greenhouse and field conditions (Terry, 1997; Chu *et al.,* 2006). Studies have indicated that *F. occidentalis* and *F. schultzei* are attracted to blue colour (Chen *et al*., 2004, Chu *et al.,* 2006; Allsopp, 2010). Ranamukhaarachchi and Wickramarachchi (2007) evaluated the efficacy of coloured sticky traps for attractiveness to *Ceratothripoides claratris.* However, there is absence of information on the influence of coloured traps for attraction of other key pest thrips like, *M. sjostedti*, *H. adolfifriderici* and *C. brunneus*.

1.7 Aggregation and alarm pheromones for thrips

Adult males of *F. occidentalis* produce an aggregation pheromone that attracts both male and female adults (Hamilton *et al.,* 2005) which could have many roles in the complex interactions within and between the sexes at aggregation sites (Kirk *et al.,* 2004). The compounds such as (R)-lavandulyl acetate and neryl (S)-2-methylbutanoate and five other minor components were detected in the headspace volatiles of adult male, while absent with females of *F. occidentalis* (Kirk and Hamilton, 2004; Hamilton *et al.,* 2005).

Milne *et al.* (2002) indicated that males of *F. schultzei* form aggregations on the corollas of flowers and that the females landing within these aggregations sometimes mate there.

1.8 Kairomonal attractants for thrips

A kairomone is a semiochemical (a chemical substance used in communication) produced and released by an organism that benefits another organism which receives it and is an individual of a different species (Brown *et al.,* 1970). Thrips have been shown to respond to olfactory cues (De Kogel and Koschier, 2003; Kirk and Hamilton, 2004; Hamilton *et al.,* 2005). Chemical stimuli play a role in locating host plants by insects (Prokopy & Owens, 1983). The approach of influencing pest behaviour using materials of plant origin has shown promise in a number of situations (Teulon *et al.,* 2010) like improving monitoring of thrips population, mass trapping (El- Sayed, 2006), lure and infect, attract and kill, and push-pull strategies (Van Tol *et al.*, 2007).

Murai *et al.* (2000) pointed out that some of the known thrips lures are commonly found in thrips host plants and are therefore presumably involved in the natural thrips host plant finding processes. A number of lures, including some that elicit strong thrips responses e.g. ethyl isonicotinate (Teulon *et al.,* 2007a) are very rare in nature. Some floral volatiles that commonly occur in plants e.g. P-anisaldehyde, ethyl nicotinate and ethyl isonicotinate have been examined to find chemical attractants for several species of thrips (Davidson *et al.,* 2009). Methyl isonicotinate is a newly discovered thrips lure that has not yet been recorded from thrips host plants (Davidson *et al*., 2005). The addition of lures to coloured traps increases trap efficacy (Terry, 1997).

1.9 Economic threshold in thrips management

Economic threshold is the pest density at which management intervention must be taken to prevent the pest from reaching the economic injury level. Economic thresholds (ETs) are an important component (Nabirye *et al.,* 2003; Pizzol *et al.,* 2010) of a cost-effective IPM program and are useful for decision-making in the application of pesticides. Threshold depends on the crop (thrips damage and crop tolerance differ between crops), but it may also depend on the traps spatial density, location, geometry, or colour. Using traps only, Shipp *et al.* (2000) estimate threshold at between 20 and 50 thrips per day on a cucumber crop at a density of roughly 1 trap per 35 m^2 at which action should be taken. For Steiner and Goodwin (2005) it ranges between 20 and 30 trapped individuals per week on a hydroponic strawberry crop at which insecticides should be applied. Martin, (2005) suggested a threshold of 0.1 thrips/plant from 50 or 100 plants sampled for application of insecticides.

1.10 Statement of the problem

Global crop losses caused by insect pest organisms are estimated at 25% to 50%. Lack of information on alternative crop protection strategies to use of pesticides (Horrigan *et al*., 2002) has led to injudicious use of pesticides. Tomato and French beans are among the key vegetables grown in Kenya and other developing countries. Thrips are among the major biotic constraints to tomato and French bean production causing extensive direct and indirect feeding damage. Chemical pesticides are the most widely and frequently used management option for thrips resulting in high cost of production, high levels of toxic residues on the product, development of pesticides resistance, environmental pollution and disruption of IPM programmes.

Further increasing concerns of markets in developed world on some of the quarantine thrips species and on maximum residue limits for chemical pesticides has driven the need for an integrated approach for management of thrips with less reliance on pesticides. However very little information on the evaluation of such IPM strategies for thrips management are available in Kenya. Although some information on the use of coloured sticky traps with kairomonal attractants is widely available globally, information on the same for attractiveness to the complex of thrips in East Africa is completely unknown and needs to be evaluated. Further there is need to assess how these monitoring tools can be integrated with other IPM strategies for thrips such as use of entomopathogens. This study addresses the aspects of coloured sticky traps as a tool for effective monitoring and for timely application of IPM strategies for management of thrips on tomato and French beans.

1.11 Justification of the study

Integrated pest management (IPM) is a combination of appropriate farming practices, biological control, botanical control, cultural control, with host plant resistance to reduce the reliance on synthetic pesticides for crop protection in agriculture and horticulture (Peshin *et al.,* 2009). Generally thrips are very difficult to control (Moritz *et al.,* 2004) because of various biological attributes (e.g., polyphagy, vagility, high fecundity, body size, cryptic behavior) and because they have become resistant to a wide range of commonly used insecticides (Jensen, 2000). Hence there is a strong interest in developing alternative methods to insecticides for thrips pest management (Bielza *et al.,* 2008). Based on our literature review, sticky traps (Natwick *et al.,* 2007) and kairomonal attractants (Davidson *et al.,* 2008) emerge as a promising option for thrips monitoring and timely application of various management strategies. Due to this momentous impact by synthetic insecticides it makes it a green issue and hence development of sustainable and non-polluting plant protection strategies is of global importance for viable food production and conservation of a functional environment. Similarly entomopathogenic fungi (Ekesi *et al.,* 1998; Gouli *et al.,* 2008) are emerging as a viable alternative to toxic pesticides for thrips management. Hence there is a need to evaluate options of integrating the use of entomopathogens with other IPM tools for monitoring such as coloured sticky traps with kairomonal attractants to establish thresholds for timely application of entomopathogens for effective management of thrips. Considering the above research needs the following research hypothesis and objectives as detailed below were formulated.

1.12 Hypotheses

i. Different thrips species do not respond equally to blue and yellow sticky traps with or without LUREM-TR on tomato and French beans

ii. Coloured sticky traps with or without LUREM-TR are not a useful tool to monitor thrips population dynamics on tomato and French beans

iii. Trap capture based thresholds for application of entomopathogenic fungi are not effective for management of thrips on French beans

1.13 Research objectives

1.13.1 General objective

To determine the potential of coloured sticky traps with kairomonal attractants (LUREM-TR) in management of thrips on tomato and French beans

1.13.2 Specific objectives

i. To determine the response of different thrips species to blue and yellow sticky traps with or without LUREM-TR in tomato and French beans

ii. To validate thrips monitoring using coloured sticky traps with or without LUREM-TR with the population dynamics of thrips on the crops

iii. To estimate trap capture based thresholds for application of entomopathogenic fungi for effective management of thrips on French beans

CHAPTER 2

2.0 GENERAL MATERIALS AND METHODS

2.1 Study site

Field studies were carried out at Kenya Agricultural Research Institute (KARI) – Thika (0^0 59' S and 37^0 04' E) at an altitude of 1,548m above sea level with an average annual rainfall of 1018 mm. The area falls under the marginal coffee agro-ecological zone. The soils are well-drained, dark reddish brown deep nitosols (Jaetzold and Schmidt, 1983).

2.2 Crop establishment

Land was ploughed and harrowed to fine tilth using disc harrow tractor but the field furrows and demarcation was done manually. Seedlings of tomato variety (CAL J) were raised in a nursery. The first and the second trial on tomato for evaluation of thrips attraction to various coloured sticky traps with or without LUREM-TR (Plate 1.3) were conducted from 2nd February to 6th April 2010 and 19th May to 17th August 2010, respectively. Tomato seedlings were transplanted to four replicated blocks each measuring 8m x 60m at an intra row spacing of 60cm and inter row spacing of 80cm.

The first trial on French beans was carried out from 4th May to 27th July 2010 and the second trial from 1st September to 9th November 2010 to determine the attraction of thrips to coloured traps with and without LUREM-TR (Plate 1.4). French beans were planted at the recommended intra row spacing of 10cm and inter row spacing of 50cm. Blocks were separated by fallows of 3m x 60m. At sowing and transplanting of French beans and tomato respectively, Diammonium Phosphate (DAP) was applied at the rate of 200kg/ha and mixed well with the soil before planting while Calcium Ammonium Nitrate (CAN) was applied at the rate of 200kg/ha three weeks after the crop emergence (first trifoliate leaf stage). No systemic or foliar insecticides were applied during the course of the study. Plants were maintained using standard cultural practices recommended for the research area (Jaetzold and Schmidt, 2007).

Plate 1.3: Colored traps with or without kairomone placed in tomato field at KARI–Thika

2.3 Monitoring thrips populations on the crops

2.3.1 Coloured sticky traps

Densities of various thrips species and other pests were monitored using blue, yellow and clear sticky traps measuring (10 x 25 cm) (Plate 1.3 and 1.4). Yellow and blue sticky traps were purchased from Plant Research International B.V, Wageningen, UR the Netherlands. Transparent sticky cards with the same dimensions were made at the laboratory and coated with Tanglefoot (aerosol formula) (The Tanglefoot Co. Grand Rapids, MI). The traps have marked grids through which small equal pieces can be made with ease.

Plate 1.4: Colored traps with or without kairomone placed in French beans field at KARI – Thika

2.3.2 Plant sampling

Destructive sampling (flowers and leaves) and non destructive sampling (tapping of whole plant on a white enamel tray) were adopted to determine population dynamics of thrips on the crop and also to evaluate their reliability as a thrips monitoring tools. All the sampling methods were performed on the same date throughout the cropping period. Samples were collected once per week by for a period of eight weeks. Leaf and flower samples as per the method developed by (Steiner, 1990) were taken within two meters of the traps to correlate trap captures to absolute counts of thrips on plants to determine if trap captures were indicative of thrips populations on leaves and flowers. Three leaves and three flowers were picked from top, middle and bottom of the plant canopy and from the same plant for each on a weekly interval. The picking was carefully handled to avoid disturbing the thrips. The leaves were individually placed in plastic jars stuffed with paper towel and labeled, while the flowers were dipped in vials containing 60% alcohol into which small pencil written labels were placed. Thrips were extracted from flowers and leaves and processed for identification using a dissecting microscope. Sample specimens of each thrips species were slide mounted and preserved in the laboratory. Data collection was done between 8 am – 5pm.

2.3.3 LUREM-TR attractants

These attractants were purchased from Plant Research International B.V, Wageningen, UR the Netherlands. It is a dispenser containing a kairomonal attractant for attracting thrips, to be used in combination with Horiver sticky traps. The LUREM-TR attractants have a broad range of attraction to several species of thrips and attracts both male and female. The dispenser has perforated membrane which is coated with a foil which is removed when placing the lures on the traps.

2.4 Thrips processing and identification

From the eight possible grids on each trap, four grids were selected at random in zigzag for thrips sampling process. The glue on the sticky coloured traps was carefully dissolved using kerosene and thrips collected using a fine brush. These thrips were then transferred into vials with 60% alcohol for 24 hours. Later the specimens were macerated in 5% NaOH for about 4 hours and clearing of fat bodies was determined with a microscope. The specimens were then washed three times with distilled water and the mixture was replaced with 60% alcohol and stored for at least 24 hours. Sequential replacements of alcohols was made at 70% for 1 hour, 80% for 20 minutes, 95% for 10 minutes, absolute alcohol for 5 minutes then finally with clove oil and the specimen were left to stand for at least 30 minutes before mounting began. Mounting was done on slides with cover slips using Canada balsam. Specimens on slides were labeled with original data and identified using the LuCID Key, Pest thrips of the world (Moritz *et al.*, 2004) and the dichotomous key on thrips and *Ceratothripoides* species (Mound, 2009). Thrips natural enemies that included; *Orius insidiosus* (Say), *Ceranisus menes* (Walker) and other insect pests that included aphids, whiteflies, hoppers, dipterans, coleopteran, coccinelids and hymenopterans were counted and identified upto genus level under a microscope.

2.5 Data analysis

Data on total numbers of thrips, key thrips species, natural enemies and other insects attracted to various coloured sticky traps with or without attractants were analyzed using analysis of variance (ANOVA) SAS 9.2 (SAS Institute, 2008). Correlations for different sampling methods and weather parameters were analyzed using PROC CORR (SAS institute, 2009) and R statistical software.

CHAPTER 3

3.0 RESPONSE OF THRIPS SPECIES TO BLUE AND YELLOW STICKY TRAPS WITH OR WITHOUT KAIROMONAL ATTRACTANT (LUREM-TR) ON TOMATO AND FRENCH BEANS

3.1 Introduction

Colour and odour are thought to be an important host finding cues for thrips (Thysanoptera, especially Thripidae) (Terry, 1997). Coloured traps are commonly used for trapping and monitoring thrips in greenhouses (Jacobson, 1997) and there has been considerable interest in utilizing the response of thrips to semiochemicals to improve thrips capture and for other thrips pest management strategies (Hamilton *et al.*, 2005; Koschier, 2008). Host selection process is a complex phenomenon which involves visual cues such as colour, shape *etc.* (Chu *et al.,* 2006; Harman *et al.,* 2007) and chemical cues (Teulon *et al.,* 2010; Junker *et al.,* 2010). Colour is often considered the most attractive feature of flowers for many species of anthophilous insects (Prokopy & Owens, 1983; Schoonhoven *et al.*, 1998; Lunau, 2000; de Kogel Koschier, 2003). In thrips, vegetative species and mainly flower-inhabiting species respond to the colour and floral odours of their host plants (Prokopy and Owens, 1983; Terry, 1997; Koschier *et al.,* 2000).

The response of thrips to colour and odour in experimental bioassays implicates vision and olfaction as important host finding cues for thrips (Smits *et al.,* 2000). Their response, especially colour, has been used to develop traps for monitoring thrips for pest management (Chen *et al.*, 2004) but there is potential to use odours to develop alternative methods for thrips pest management (Davidson *et al.,* 2007; Koschier, 2008). Historically, many compounds derived from plants have been identified as thrips lures for a range of thrips species (Kirk, 1985; Koschier *et al.*, 2000; Murai *et al.*, 2000) and are therefore presumably involved in the natural thrips host plant finding processes. In thrips, olfactory cues in conjunction with visual cues are used to locate host plants. *F. occidentalis* were attracted to extracted chrysanthemum volatile chemicals in choice tests, but were unable to locate the flowers without visible clues (Koschier *et al.*, 2000, de Kogel & Koschier, 2003). Blue traps combined with the odour geraniol captured 1.9 times as many *F. occidentalis* than colour alone (Frey *et al.,* 1994).

LUREM-TR attractants has been tested successfully, resulting in a new patented product to attract western flower thrips, onion thrips and many others, to improve the monitoring and application of integrated pest management. Blue trap with the addition of LUREM-TR attractant increased captures of *Thrips tabaci* (Lindeman) (Kruistum *et al.* 2010) and *Thrips palmi* (Karny) (Teulon *et al.,* 2010). Coloured sticky traps are the most useful tools for pest monitoring programme (Natwick *et al.,* 2007) because they offer a simple and rapid method of obtaining estimates of thrips population densities (Chu *et al.,* 2006) than the labour-intensive absolute methods of counting individuals. The objective of this study was to investigate the response of different thrips species occurring on French beans and tomato crops to blue and yellow sticky traps in combination with the kairomonal attractants (LUREM-TR) and assess their validity for monitoring systems.

3.2 Materials and methods

3.2.1 Treatments and field experimental design

The following treatments as detailed below were applied in the field experiments of tomato and French beans.

I. Blue Horiver sticky trap – without kairomone 

II. Blue Horiver sticky trap – with kairomone 

III. Yellow Horiver sticky trap - without kairomone 

IV. Yellow Horiver sticky trap - with kairomone 

V. Clear sticky traps – without kairomone 

VI. Clear sticky traps – with kairomone 

A randomized complete block design was adopted with each treatment replicated four times. Tomato and French bean crops were raised in an experimental field measuring 41m x 60m in size. French bean variety (Amy) was planted in 60 x 8 m blocks with an intra-row spacing of 10 cm and an inter-row spacing of 50 cm. Experiments on French beans were conducted for two seasons. The first trial was conducted from 9th May to 27th July, 2010 while the second trial was conducted from 1st September to 9th November, 2010. Similarly Tomato variety (CAL J) was planted in 60 x 8m blocks with an intra-row spacing of 60cm and an inter-row spacing of 80cm. Experiments with tomato were conducted for two seasons with the first trial from 2nd February to 13th April, 2010 while the second was conducted from 2nd June to 24th August, 2010.

Blocks were separated from each other by a fallow path of 3m wide. The first trap was placed at a distance of 5m from the edge of the experimental block. Treatments indicated above were placed at random with a distance of 10m between the traps on each of the four blocks (Figure 3.1). Sticky cards were mounted vertically on wooden stakes with the bottom edge of the trap about 10cm above the crop canopy. Sticky traps were picked and replaced after every one week till crop senescence and simultaneously samples of thrips were collected by tapping two plants within a distance of 2m from each trap.

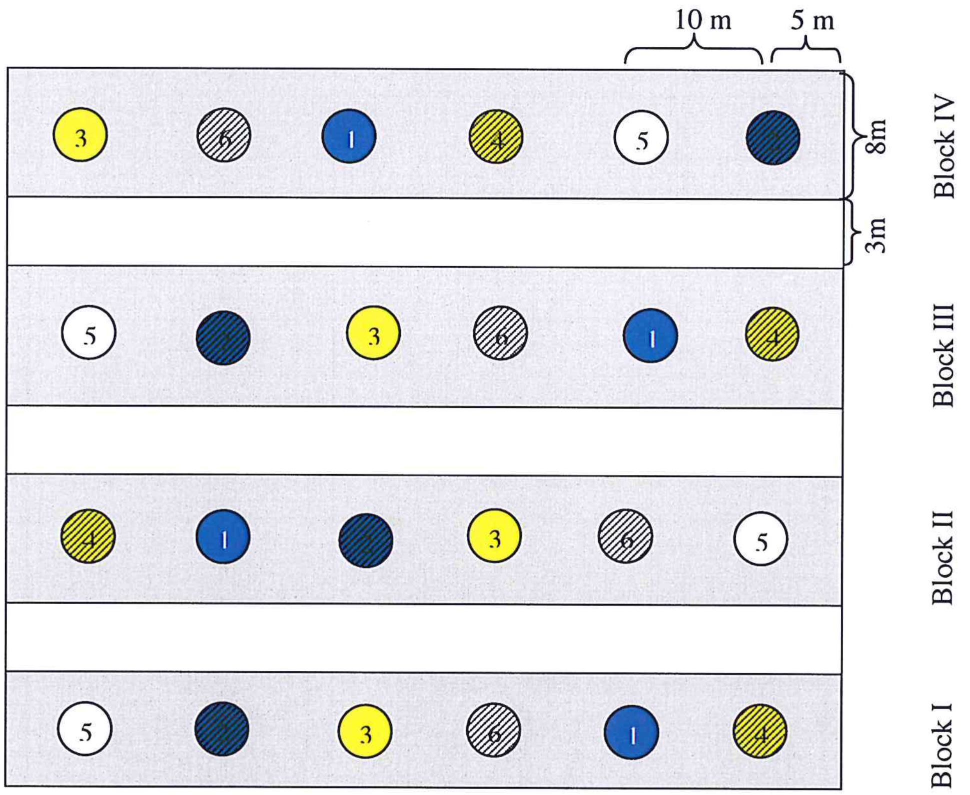

Figure 3.1: Experimental design for monitoring thrips using coloured sticky traps

Blue traps, Yellow traps and Clear traps
Circles with cross lines – with Kairomone; Circles without cross lines – without kairomone
NB/ Measurement 41m X 60m – shaded patch – cropped area, white patch – uncropped area

Samples of leaves and flowers were also collected as and when the traps were replaced. This procedure was repeated once per week across 8 weeks of the cropping period starting from three weeks after planting. After removal, the sticky traps with thrips catches were placed in transparent polythene sheets, labelled and carried to the laboratory. In the laboratory four squares from the eight available marked squares on the traps were sampled, processed, mounted and identified as detailed in Chapter 2.

3.3 Data analysis

Data on key thrips species, natural enemies and other pests attracted to various coloured sticky traps with or without attractants were analyzed with repeated analysis of variance (ANOVA) SAS 9.2 (SAS Institute, 2008). Specific mean comparisons were made using Tukey's HSD test at P = 0.05. Analysis of variance (ANOVA) was done for *F. schultzei* and *F. occidentalis* (thrips found on both host plants) to see if the captures were influenced by the host plants SAS 9.2 (SAS Institute, 2008).

3.4 Results

3.4.1 Influence of coloured sticky traps with and without kairomone to thrips on tomato (Trial I)

There were three major species of thrips associated with tomato crop, namely *F. schultzei, F. occidentalis* and *C. brunneus*. Blue traps without kairomone caught 1.66 times as many total thrips as yellow traps and 13.24 times as many caught on clear traps ($F_{2, 15}$ =2238.76, P <0.0001) (Table 3.1). The kairomone enhanced the total thrips catch by 1.29, 1.30, 1.58 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$=139.78, P<0.0001). Blue traps with kairomone were most attractive (1829.6 ± 40.86) while clear traps without kairomone were the least attractive (107.0 ± 5.51) ($F_{5, 15}$ =926.23, P<0.0001).

F. schultzei were significantly attracted to blue traps ($F_{2, 15}$ =755.71, P<0.0001). The kairomone enhanced the *F. schultzei* catch by 1.33, 1.45, 1.79 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =56.31, P<0.0001). Blue traps with kairomone had highest catches of *F. schultzei* (930.9 ± 48.15) while clear traps without kairomone had the lowest catches (35.2 ± 3.43) ($F_{5, 15}$ = 311.16, P<0.0001). Blue and yellow traps were equally attractive to *F. occidentalis* but they were significantly different in attraction to clear traps ($F_{2, 15}$ =488.04, P<0.0001). The kairomone enhanced *F. occidentalis* catches by 1.40, 1.19, 1.60 times in blue, yellow and clear traps, respectively ($F_{1,15}$ =36.50, P<0.0001). *F. occidentalis* preferred blue (410.1±20.65) and yellow traps (395.1±19.99) with kairomone over all other treatments ($F_{5,15}$=202.18, P<0.0001) (Table 3.1).

C. brunneus were significantly attracted to blue traps ($F_{2, 15}$ = 90.32, P<0.0001). The kairomone enhanced the *C. brunneus* catch by 1.09, 1.67, 2.42 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =17.73, P<0.0001). Blue traps with (62.86 ± 5.89) and without kairomone (58.2 ± 5.57) were the most attractive while clear sticky traps without the kairomone attractant were the least attractive (4.6 ± 1.10) ($F_{5, 15}$ = 38.48, P <0.0001)(Table3.1).

Table 3.1: Captures of key thrips species on coloured sticky traps with and without LUREM-TR on Tomato trial I (23^{rd} Feb-13^{th} April, 2010)

Treatment	Sum of mean thrips catches per trap over eight weeks (± SE)			
	Frankliniella schultzei	***Frankliniella occidentalis***	***Ceratothripoides brunneus***	**Totals thrips**
1.Blue trap	693.79±36.47b	297.73±15.40 b	58.21±5.57a	1419.16±32.92b
2.Blue trap + LUREM-TR	930.91±48.15a	410.08± 20.65a	62.86±5.89a	1829.68±40.86a
3.Yellow trap	295.98±16.86d	329.71±17.09b	26.31± 3.13c	857.35± 21.91d
4.Yellow trap +LUREM-TR	428.97±23.43c	395.12± 19.99a	44.49± 4.54b	1113.15±26.97c
5. Clear trap	35.21±3.43f	32.27±3.17 d	4.60±1.10e	107.00±5.51f
6. Clear trap+ LUREM-TR	62.92± 5.02e	51.72± 4.25c	11.30±1.84d	168.94±7.21 e
Treatment - $F_{(5, 15)}$ (P-value)	311.16 (<.0001)	202.18 (<.0001)	38.48 (<.0001)	926.23 (<.0001)
Colour – $F_{(2,15)}$ (P-value)	755.71 (<.0001)	488.04 (<.0001)	90.32 (<.0001)	2238.76 (<.0001)
Kairomone – $F_{(1, 15)}$ (P-value)	56.31 (<.0001)	36.50 (<.0001)	17.73 (0.0008)	139.78 (<.0001)
Interaction – $F_{(2, 15)}$ (P-value)	1.93 (0.1801)	2.37 (0.1272)	4.46 (0.0303)	3.96 (0.0416)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

3.4.2 Influence of coloured traps with and without kairomone to thrips and their natural enemies on tomato (Trial II)

Trap colour significantly influenced the total thrips catch ($F_{2,\ 15}$ =1070.5, P<0.0001). Blue traps without kairomone caught 5.08 times as many total thrips as yellow traps and 59.12 times as many caught in clear traps (Table 3.2). The kairomone enhanced the total thrips catch by 1.15, 1.29, 1.61 times in blue, yellow and clear sticky traps, respectively ($F_{1,\ 15}$=18.2, P<0.0001). Blue traps with kairomone were most attractive (23893.0± 1968.13) while clear traps without kairomone were the least attractive (353.3± 30.64) ($F_{5,\ 15}$ =431.6, P<0.0001). *F. schultzei* were significantly attracted to blue traps than the other treatments ($F_{2,\ 15}$ =641.3, P<0.0001). The kairomone enhanced the *F. schultzei* catch by 1.53, 1.22, 1.68 times in blue, yellow and clear sticky traps, respectively ($F_{1,\ 15}$ =27.8, P<0.0001).

Blue and yellow traps were equally attractive to *F. occidentalis* and significantly different from clear traps ($F_{2,\ 15}$ =1289.7, P<0.0001). The kairomone increased *F. occidentalis* catch by 1.49, 1.24, 2.78 times in blue, yellow and clear sticky traps, respectively ($F_{1,\ 15}$ =180.4, P<0.0001). Blue traps were significantly attractive to *C. brunneus* ($F_{2,\ 15}$= 491.3, P<0.0001) while the kairomone had no significant effect ($F_{1,\ 15}$ = 0.9, P =0.353). Blue traps without kairomone (16174.0± 2259.40) were the most attractive while clear without kairomone were the least attractive (174.2± 25.15) ($F_{5,\ 15}$ =197.4, P<0.0001). Yellow traps significantly attracted thrips N. enemies than the other treatments ($F_{2,\ 15}$ =159.5, P<0.0001) while the kairomone did influence the attraction.

Table 3.2: Captures of key thrips species on coloured sticky traps with and without LUREM-TR on Tomato trial II

(15th June-24th August 2010)

Treatments	Sum of mean thrips catches per trap over eight weeks (± SE)				
	Frankliniella schultzei	***Frankliniella occidentalis***	***Ceratothripoides brunneus***	**Totals thrips**	**Thrips natural enemies**
1.Blue trap	2900.6± 282.42 b	843.0± 29.75 c	16174.0±2259.40 a	20747.0±1711.31 a	4.8± 1.11 c
2.Blue trap + LUREM-TR	4524.7±440.04 a	1324.5± 44.70 a	16146.0±2251.19 a	23893.0±1968.13 a	6.2± 1.27 c
3.Yellow trap	1833.2± 178.74 d	831.5±29.40 c	1218.6± 170.78 b	4055.5± 334.84 c	43.8± 4.09 b
4.Yellow trap +LUREM-TR	2343.7±228.29 c	1077.5±37.03 b	1596.2± 224.82 b	5252.4± 433.42 b	58.7± 4.98 a
5. Clear trap	77.3± 8.75 f	38.9± 3.33 e	174.2± 25.15 c	353.3± 30.64 e	4.8 ± 1.11c
6. Clear trap + LUREM-TR	143.8± 15.18 e	101.9± 5.94 d	185.7± 26.91c	566.8± 48.15 d	2.8 ± 0.84d
Treatment - $F_{(5,15)}$(P-value)	259.8 (<.0001)	557.0 (<.0001)	197.4 (<.0001)	431.6 (<.0001)	66.2 (<.0001)
Colour – $F_{(2,15)}$ (P-value)	641.3 (<.0001)	1289.7 (<.0001)	491.3 (<.0001)	1070.5 (<.0001)	159.5 (<.0001)
Kairomone–$F_{(1,15)}$ (P-value)	27.8 (<.0001)	180.4 (<.0001)	0.9 (0.353)	18.21 (0 0.0007)	0.0 (0.9449)
Interaction–$F_{(2, 15)}$ (P-value)	1.6 (0.222)	19.26 (<.0001)	0.5 (0.609)	1.99 (0.1711)	2.09 (0.1582)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

3.4.3 Influence of coloured traps with and without kairomone to non target insects on tomato (Trial I)

Non target insects captured included dipterans, whiteflies, aphids, hoppers, coleopterans, coccinelids and hymenopterans. Dipterans were significantly attracted to blue traps ($F_{2, 15}$ = 460.1, P<0.0001) and to the kairomone ($F_{1, 15}$ = 50.3, P<0.0001). Blue traps with kairomone were the most attractive (1242.3 ± 78.59) and clear traps without kairomone were the least attractive (102.6 ± 8.10) to dipterans ($F_{5, 15}$=192.3, P<0.0001) (Table 3.3). Aphids were significantly attracted to yellow traps ($F_{2, 15}$ =274.9, P<0.0001) and kairomone had no significant effect ($F_{1, 15}$=3.33, P=0.087).

Yellow traps with kairomone were the most attractive to aphids (148.6 ± 12.4) while blue traps without kairomone were the least attractive (10.2 ± 1.73) to aphids ($F_{5, 15}$ =111.5, P <0.0001). Whiteflies were significantly attracted to yellow traps ($F_{2, 15}$=334.8, P<0.0001) and the kairomone ($F_{1, 15}$ =21.4, P<0.0001). Yellow traps with kairomone were more attractive to whiteflies than the other treatments ($F_{5, 15}$=134.9, P<0.0001).

Yellow traps had a significant effect on captures of hoppers ($F_{2, 15}$ =131.4, P<0.0001) while the kairomone had no significant effect on their captures ($F_{1, 15}$ =2.47, P =0.136). Yellow traps with kairomone were more attractive than the other treatments to hoppers ($F_{5, 15}$ =53.9, P<0.0001). Coleopterans were significantly attracted to yellow traps ($F_{2, 15}$ =32.2, P<0.0001) while the kairomone had no significant effect on their captures ($F_{1, 15}$ =0.01, P= 0.904).

Yellow traps with kairomone were more attractive than the other treatments to coleopterans ($F_{5, 15}$ =31.2, P<0.0001). Coccinelids were significantly attracted to yellow traps ($F_{2, 15}$ =74.8, P <0.0001) while the kairomone had no significant effect on their captures ($F_{1, 15}$ =1.97, P=0.18). Hymenopterans were significantly attracted on yellow traps ($F_{2, 15}$ = 165.5, P<0.0001) and the kairomonal attractant ($F_{1, 15}$ = 16.17, P= 0.001). Yellow sticky traps with kairomone were more attractive than the other treatments to hymenopterans($F_{5,15}$= 70.0,P<0.0001).

Table 3.3: Captures of non targets on coloured sticky traps with and without LUREM-TR on tomato trial I (23rd Feb-13th April, 2010)

Treatments	Sum of mean pests catches per trap over eight weeks (± SE)						
	Dipterans	**Aphids**	**Whiteflies**	**Hoppers**	**Coleopteran**	**Coccinelids**	**Hymenoptera**
1.Blue trap	939.8±59.92b	10.2±1.73c	11.8±2.38d	35.9±4.99c	55.3±5.88c	2.4±0.79b	164.3±15.86c
2.Blue trap + LUREM-TR	1242.3±78.59a	13.7±2.08c	28.5±4.78c	62.5±8.01b	81.5±8.12b	3.8±1.02b	285.6±26.60b
3.Yellow trap	364.1±24.37d	105.8±9.20b	626.9±88.37b	173.6±20.33a	87.8±8.60b	24.2±3.08a	766.2±69.43a
4.Yellow trap +LUREM-TR	575.8±37.53c	148.6±12.4a	832.0±116.9a	179.1±20.90a	107.7±10.28a	30.2±3.61a	886.5±79.73a
5. Clear trap	102.6±8.10e	10.5±1.77c	17.0±3.14d	21.4±3.31c	55.1±5.84c	0.4±0.34b	156.0±15.17c
6. Clear + LUREM-TR	162.2±11.85d	10.5±1.77c	35.7±5.79c	20.2±3.19c	31.4±3.80d	0.9±0.48b	195.3±18.64c
Treatment - $F_{(5, 15)}$ (P-value)	192.3 (<0.0001)	111.5(<0.0001)	134.9 (<0.0001)	53.9(<0.001)	16.3(<0.0001)	31.2(<0.001)	70.0 (<0.001)
Colour - $F_{(2, 15)}$ (P-value)	460.1 (<0.0001)	274.9 (<.0001)	334.8 (<0.0001)	131.4(<0.001	32.3(<0.0001)	74.8(<0.001)	165.5(<0.001)
Kairomone - $F_{(1, 15)}$ (P-value)	50.3 (<0.0001)	3.33 (0.087)	21.4 (0.0003)	2.47(0.136)	0.01(0.904)	1.97(0.18)	16.17(0.001)
Interaction - $F_{(2, 15)}$ (P-value)	1.2 (0.3206)	0.83 (0.456)	2.0 (0.1705)	2.94(0.084)	10.5(0.001)	0.26(0.773)	2.66(0.102)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

3.4.4 Influence of coloured traps with and without kairomone to non target insects on tomato (Trial II)

Blue traps were significantly attractive to dipterans ($F_{2, 15}$ =121.7, P<0.0001) while the kairomone had no significant effect ($F_{1, 15}$ =0.2, P=0.688). Blue traps with kairomone were the most attractive to dipterans (1228.1 ± 108.96) while clear traps without kairomone were the least attractive (325.8 ± 30.00) ($F_{5, 15}$ =50.6, P<0.0001) (Table 3.4). Yellow traps were significantly attractive to aphids ($F_{2, 15}$ =816.3, P<0.0001) while the kairomone had no significant effect ($F_{1, 15}$ =1.4, P=0.25). Yellow traps with kairomone had more catches than the other treatments ($F_{5, 15}$ =328.7, P<0.0001) (Table 3.4). Whiteflies were significantly attracted to yellow traps with kairomone ($F_{5, 15}$ =143.5, P<0.0001) and the kairomone had a significant effect ($F_{1, 15}$=14.2, P=0.002).

Yellow traps were significantly attractive to hoppers ($F_{2, 15}$ =147.6, P<0.0001) but the kairomone had no significant effect ($F_{1, 15}$ =1.2, P=0.29). Yellow traps with kairomone had the highest catches of hoppers (363.6 ± 28.94) while clear traps with kairomone had the lowest catches (76.2 ± 7.21) ($F_{5, 15}$=59.6, P<0.0001). Coleopterans were significantly attracted to yellow traps ($F_{2, 15}$=14.6, P=0.0003) while the kairomone had no significant effect ($F_{1, 15}$=0.6, P=0.434). Coccinelids were significantly caught on yellow traps ($F_{2, 15}$ =13.8, P=0.0004). The kairomone had no significant effect on the catches of coccinelids ($F_{1, 15}$=0.0, P=0.965). Hymenopterans were significantly attracted to yellow sticky traps ($F_{2, 15}$ =154.6, P<0.0001). The kairomone had no significant effect on the catches of hymenopterans to the coloured sticky traps ($F_{1, 15}$ =2.3, P=0.145).

Table 3.4: Captures of non targets pests on coloured sticky traps with and without LUREM-TR on tomato trial II (15^{th} June-24^{th} August 2010)

Treatments	Sum of mean pests catches per trap over eight weeks (± SE)						
	Dipterans	**Aphids**	**Whiteflies**	**Hoppers**	**Coleopteran**	**Coccinelids**	**Hymenoptera**
1.Blue trap	1031.5±71.72b	83.2±6.36d	0.9±0.49d	140.9±12.14b	49.5±5.00bc	2.3±0.90b	165.2±13.95d
2.Blue trap + LUREM-TR	1228.1±108.96a	100.5±7.32c	9.8±1.99c	151.5±12.95b	54.6±5.40b	1.9±0.83b	200.0±16.57c
3.Yellow trap	597.5±53.59c	688.4±38.93b	484.7±61.98b	374.8±29.78a	84.8±7.62a	11.4±3.00a	543.5±42.38b
4.Yellow trap + LUREM-TR	663.2±59.35c	855.7±47.85a	626.0±81.21a	363.6±28.94a	74.4±6.85a	14.4±3.78a	687.5±53.33a
5. Clear trap	325.8±30.00d	81.3±6.24d	7.5±1.78c	100.2±9.08c	44.9±4.65c	0.0±0.00c	190.6±15.91cd
6.Clear trap + LUREM-TR	225.2±21.08e	66.6±5.40e	6.9±1.60c	76.2±7.21d	56.2±5.50b	3.7±1.29b	169.2±14.26cd
Treatment-$F_{(5, 15)}$(P-value)	50.6 (<0.0001)	328.7 (<0.0001)	143.5 (<0.0001)	59.6 (<0.001)	6.6 (<0.002)	6.1 (<0.002)	63.4 (<0.0001)
Colour – $F_{(2, 15)}$ (P-value)	121.7 (<0.0001)	816.3 (<0.0001)	324.4 (<0.0001)	147.6 <0.001)	14.6 (0.0003)	13.8 (0.0004)	154.6 (<.0001)
Kairomone–$F_{(1, 15)}$(P-value)	0.2 (0.688)	1.3 (0.252)	14.2 (0.002)	1.2 (0.29)	0.6 (0.434)	0.0 (0.965)	2.3 (0.145)
Interaction–$F_{(2, 15)}$ (P-value)	5.2 (0.018)	5.0 (0.021)	7.4 (0.005)	1.96 (0.175)	1.8 (0.198)	0.1 (0.852)	2.7 (0.096)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

3.4.5 Influence of coloured traps with and without kairomone to thrips and their natural enemies on French beans (Trial I)

There were four major thrips species in the crop namely; *F. schultzei, F. occidentalis, Megalurothrips sjostedti* (Trybom) and *Hydatothrips adolfifriderici* (Karny). Blue traps without kairomone caught 2.05 times as many total thrips as yellow traps and 29.31 times as many caught in clear traps ($F_{2, 15}$ =1356.7, P<0.0001) (Table 3.5). The kairomone enhanced the total thrips catch by 1.43, 1.48, 2.37 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$=114.9, P<0.0001). Blue traps with kairomone were most attractive (6481.4±370.77) while clear traps without kairomone were the least attractive (152.9±10.66) ($F_{5, 15}$=555.6, P<0.0001).

Blue traps were significantly attractive to *F. schultzei* ($F_{2, 15}$ =777.6, P<0.0001). The kairomone enhanced the *F. schultzei* catch by 1.39, 1.49, 2.5 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$=57.8, P<0.0001). Blue traps with kairomone had highest catches of *F. schultzei* (3394.6±273.94) while clear traps without kairomone had the lowest catches (65.1±6.61) ($F_{5, 15}$ = 316.4, P<0.0001). Blue traps were significantly attractive to *F. occidentalis* ($F_{2, 15}$ =638.6, P <0.0001). The kairomone enhanced the *F. occidentalis* catch by 1.47, 1.44, 3 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =72.8, P<0.0001). *F. occidentalis* showed preference for blue traps with kairomone (1145.2±79.99) over all other treatments ($F_{5, 15}$ =263.9, P<0.0001).

Blue traps were significantly attractive to *M. sjostedti* ($F_{2, 15}$ = 282.9, P<0.0001). The kairomone enhanced the *M. sjostedti* catch by 1.59, 2.58, 9.69 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =59.6, P<0.0001). *M. sjostedti* showed preference for blue traps with kairomone (1887.2±307.82) over all other treatments ($F_{5, 15}$ =116.8, P<0.0001). Yellow traps were significantly attractive to *H. adolfifriderici* ($F_{2, 15}$ =94.4, P<0.0001). The kairomone enhanced the *H. adolfifriderici* catch by 1.92, 1.59, 2.28 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$=46.7, P<0.0001). Yellow traps were significantly attractive to thrips natural enemies ($F_{2, 15}$=164.9, P<0.0001) and the kairomone did not influence their captures ($F_{1, 15}$=0.54, P=0.475).

3.4.6 Influence of coloured traps with and without kairomone to thrips and their natural enemies French beans (Trial II)

Blue traps without kairomone caught 3.52 times as many total thrips as yellow traps and 22.07 times as many caught in clear($F_{2, 15}$ =1562.9, P<0.0001) (Table 3.6). The kairomone enhanced the total thrips catch by 1.79, 1.87, 2.06 times in blue, yellow and clear traps, respectively ($F_{1, 15}$ =216.3, P<0.0001). Blue traps with kairomone were the most attractive to total thrips (36596±1968.90) while clear traps without kairomone were the least attractive (890.8± 50.18) ($F_{5, 15}$ =665.2, P<0.0001). Blue traps significantly attracted *F. schultzei* ($F_{2, 15}$ =773.9, P<0.0001). The kairomone enhanced the *F. schultzei* catch by 1.52, 1.63, 2.28 times in blue, yellow and clear traps, respectively ($F_{1, 15}$=100.6, P<0.0001). Blue with kairomone had highest catches of *F. schultzei* (3237.4±213.96) while clear without kairomone had the least catches (107.3± 8.73) (Table 3.6).

Table 3.5: Captures of key thrips species on coloured sticky traps with and without LUREM-TR on French bean trial I

(1st June - 27th July 2010)

Treatment	Sum of mean thrips catches per trap over eight weeks (± SE)					
	Frankliniella schultzei	*Frankliniella occidentalis*	*Megalurothrips sjostedti*	*Hydatothrips adolfifriderici*	Totals thrips	Thrips natural enemies
1.Blue trap	2531.0±204.67b	779.5± 55.0b	1212.0±198.79b	12.2±1.81d	4537.1±260.33b	10.2±1.95b
2.Blue trap + LUREM-TR	3394.6±273.94a	1145.2±79.99a	1887.2±307.82a	23.5±2.60c	6481.4±370.77a	8.2±1.70bc
3.Yellow trap	1435.9±117.09c	522.2±37.42c	59.9±10.64d	43.9±3.80b	2220.0±128.59d	82.1±10.24a
4.Yellow trap+ LUREM-TR	2134.5±173.04b	753.4± 53.20b	161.9±27.07c	70.9±5.20a	3266.8±187.97c	95.8±11.76a
5. Clear trap	65.1±6.61e	20.5± 2.66e	6.4±1.64e	11.2±1.73d	152.9± 10.66f	3.5±1.01cd
6. Clear trap +LUREM-TR	162.3±14.53d	59.9±5.63 d	51.6± 9.21d	25.8±2.75c	357.1± 22.45e	2.4±0.83 d
Treatment-$F_{(5,15)}$ (P-value)	316.4 (<0.0001)	263.9 (<0.0001)	116.8 (<0.0001)	44.9(<0.0001)	555.6 (<0.0001)	66.3 (<0.0001)
Colour – $F_{(2,15)}$ (P-value)	777.6 (<0.0001)	638.6 (<0.0001)	282.9 (<0.0001)	94.4(<0.0001)	1356.7 (<0.0001)	164.9 (<0.0001)
Kairomone–$F_{(1,15)}$ (P-value)	57.8 (<0.0001)	72.8 (<0.0001)	59.6 (<0.0001)	46.7 (<0.0001)	114.9 (<0.0001)	0.54 (0.475)
Interaction–$F_{(2, 15)}$ (P-value)	6.7 (0.008)	7.91 (0.005)	9.0 (0.003)	1.3 (0.29)	9.4 (0.002)	0.98 (0.398)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

Blue traps had a significant effect on the catches of *F. occidentalis* ($F_{2, 15}$ =829.4, P<0.0001) (Table 3.6). The kairomone enhanced the *F. occidentalis* catch by 1.76, 1.80, 1.90 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =122.2, P<0.0001). *F. occidentalis* showed preference for blue traps with kairomone (7004.8±450.52) over all other treatments ($F_{5, 15}$ =352.8, P<0.0001) (Table 3.6). Blue traps had a significant effect on the catches of *M. sjostedti* ($F_{2, 15}$ = 748.8, P<0.0001). The kairomone enhanced the *M. sjostedti* catch by 1.84, 2.07, 2.27 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$ =112.8, P<0.0001). *M. sjostedti* showed preference for blue traps with kairomone (25944.0 ± 2242.32) over all other treatments ($F_{5, 15}$ =320.8, P<0.0001).

Yellow traps were more attractive to *H. adolfifriderici* than the yellow and clear traps ($F_{2, 15}$ =77.5, P <0.0001). The kairomone enhanced the *H. adolfifriderici* catch by 1.29, 1.75, 0.89 times in blue, yellow and clear sticky traps, respectively ($F_{1, 15}$=6.7, P<0.0001). Yellow traps with kairomone had highest catches of *H. adolfifriderici* (241.4 ± 28.52) while clear traps with kairomone had the lowest catches (34.6± 4.93) ($F_{5, 15}$ = 34.4, P<0.0001). Yellow traps significantly influenced the catches of natural enemies ($F_{2, 15}$=67.7, P<0.0001). Kairomonal attractant did not influence captures of natural enemies significantly ($F_{1, 15}$ =0.5, P =0.511). Yellow traps with kairomone (129.8±20.76) and without kairomone had the highest catches (104.2 ± 16.85) while blue sticky traps with kairomone had the lowest catches of natural enemies (16.4 ± 3.27) ($F_{5, 15}$=66.3, P =0.475) (Table 3.6).

Table 3.6: Captures of key thrips species on coloured sticky traps with and without LUREM-TR on French bean trial II (21st Sep- 9th Nov 2010)

Treatment	Sum of mean thrips catches per trap over eight weeks (± SE)					
	Frankliniella schultzei	***Frankliniella occidentalis***	***Megalurothrips sjostedti***	***Hydatothrips adolfifriderici***	**Totals thrips**	**Thrips natural enemies**
1.Blue trap	2131.9± 141.7b	3976.6±256.91b	13982.0±1210.09b	58.3±7.66d	20325± 1095.77b	21.6±4.04b
2.Blue trap + LUREM-TR	3237.4±213.96a	7004.8±450.52a	25944.0±2242.32a	79.7± 10.21c	36596±1968.90a	16.4± 3.27b
3.Yellow trap	984.3±66.36d	2290.0±148.72c	2219.3±193.54d	130.9±15.9b	5788.4±313.46d	104.2±16.85a
4.Yellow trap +LUREM-TR	1606.7±107.17c	4088.2±263.42b	4831.4±420.90c	241.4± 28.52a	10930±590.65c	129.8±20.76a
5. Clear trap	107.3± 8.73f	281.6±19.89e	411.7±37.029f	37.9± 5.28e	890.8± 50.18f	24.8±4.57b
6. Clear trap + LUREM-TR	243.7±17.79e	535.6±36.17d	998.7± 88.06e	34.6± 4.93e	1870.2± 102.95e	19.4±3.71b
Treatment-$F_{(5,15)}$(P-value)	322.4 (<0.0001)	352.8 (<0.0001)	320.8 (<0.0001)	34.4 (<0.0001)	665.2 (<0.0001)	27.6 (<0.0001)
Colour – $F_{(2,15)}$ (P-value)	773.9 (<.0001)	829.4 (<.0001)	748.8 (<.0001)	77.5 (<.0001)	1562.9 (<.0001)	67.7 (<.0001)
Kairomone–$F_{(1,15)}$ (P-value)	100.6 (<.0001)	122.2 (<.0001)	112.8 (<.0001)	6.7 (0.0203)	216.3 (<.0001)	0.5 (0.5111)
Interaction–$F_{(2, 15)}$ (P-value)	4.2 (0.0346)	0.2 (0.8336)	1.2 (0.3334)	3.6 (0.0527)	1.02 (0.3835)	1.3 (0.2994)

Means in the same column followed by the same letter are not significantly different at p= 0.05, Tukey's test.

3.4.7 Influence of coloured traps with and without kairomone to non target insects

French beans (Trial I)

Dipterans were significantly attracted to blue traps ($F_{2, 15}$ =986.1, P<0.0001) and the kairomone had no significant effect on attraction of dipterans ($F_{1, 15}$ =0.02, P =0.89). Blue traps with kairomone were the most attractive (2437.8 ± 109.88) while clear traps without kairomone (266.5 ± 14.27) were the least attractive ($F_{5, 15}$ =395.4, P<0.0001) (Table 3.7). Yellow traps had a significant effect on the captures of aphids ($F_{2, 15}$ = 1375.6, P<0.0001) while the kairomone did not have a significant effect on attraction ($F_{1, 15}$ = 1.5, P =0.245). Yellow traps with kairomone were significantly more attractive to aphids than the other treatments ($F_{5, 15}$ = 551.5, P<0.0001).

Whiteflies were significantly attracted to yellow traps ($F_{2, 15}$ =172.8, P<0.0001) and the kairomone ($F_{1, 15}$ =5.5, P=0.034). Yellow traps with kairomone had a significant influence on captures of whiteflies than the other treatments ($F_{5, 15}$ =74.6, P<0.0001). Yellow traps were significantly attractive to hoppers ($F_{2, 15}$ =139.4, P<0.0001) while the kairomone did not have a significant effect in the attraction of hoppers ($F_{1, 15}$ =1.7, P =0.21). Yellow traps with kairomone significantly attracted more hoppers than the other treatments ($F_{5, 15}$ =57.2, P<0.0001). Clear traps were significantly attractive to coleopterans ($F_{2, 15}$ =18.9, P<0.0001) while the kairomone did not influence the attraction ($F_{1, 15}$=0.07, P=0.79).

Yellow traps were significantly attractive to coccinelids ($F_{2, 15}$ =39.8, P<0.0001) while the kairomone had no significant effect on attraction ($F_{1, 15}$ = 0.0, P=0.967). Yellow traps with kairomone significantly attracted more coccinelids than the other treatments ($F_{5, 15}$ =15.6, P<0.0001). Hymenopterans were significantly attracted to yellow traps ($F_{2, 15}$ =201.5, P<0.0001) while the kairomone had no significant effect on the attraction ($F_{1, 15}$ =15.6, P<0.0001). Yellow traps were more attractive to hymenopterans than the other treatments($F_{5,15}$=65.4,P<0.0001).

Table 3.7: Capture of pests to coloured sticky traps with LUREM-TR on French bean trial I (1st June - 27th July 2010)

Treatments	Sum of mean pests catches per trap over eight weeks (± SE)						
	Dipterans	**Aphids**	**Whiteflies**	**Hoppers**	**Coleopterans**	**Coccinelids**	**Hymenoptera**
1.Blue trap	2217.9±100.29b	120.3±7.30c	3.7±1.23c	307.3±32.10c	98.8±17.80bc	1.9±0.68b	181.7±14.21d
2.Blue trap + LUREM-TR	2437.8±109.88a	108.3±6.76cd	1.8±0.77c	353.4±36.65c	83.4±14.93c	0.4±0.33c	210.0±16.18cd
3.Yellow trap	694.5±33.21c	1003.2±43.1b	295.2±61.52b	539.9±55.24b	98.1±17.48bc	14.6±1.91a	655.0±46.90b
4.Yellowtrap +LUREM-TR	630.2±30.39c	1141.7±48.6a	450.6±91.23a	756.3±76.89a	128.8±22.71b	16.8±2.05a	815.4±57.91a
5. Clear trap	266.5±14.27d	97.1±6.26d	3.8±1.24c	116.8±12.89d	286.9±50.46a	0.0±0.00d	203.2±15.74cd
6. Clear trap + LUREM-TR	271.6±14.49d	112.0±6.93c	0.4±0.35d	101.8±11.36d	231.0±40.04a	0.4±0.33c	225.6±17.29c
Treatment-$F_{(5, 15)}$ (P-value)	395.4(<0.0001)	551.5 (<0.0001)	74.6 (<0.0001)	57.2 (<0.0001)	8.03(<0.0007)	15.6 (<0.0001)	65.4 (<0.0001)
Colour - $F_{(2, 15)}$ (P-value)	986.1(<0.0001)	1375.6(<0.0001)	172.8(<0.0001)	139.4 (<.0001)	18.9(<0.0001)	39.8(<0.0001)	201.5 (<0.0001)
Kairomone-$F_{(1,15)}$ (P-value)	0.02 (0.893)	1.4 (0.245)	5.5 (0.0338)	1.7 (0.21)	0.07 (0.793)	0.0 (0.967)	6.41 (0.023)
Interaction-$F_{(2,15)}$ (P-value)	2.1 (0.154)	2.8 (0.0905)	5.2 (0.019)	2.5 (0.116)	1.18 (0.3355)	1.9 (0.1867)	0.31 (0.7379)

Treatment means in the same column followed by the same letter are not significantly different (p= 0.05), Tukey's test.

3.4.8 Influence of coloured traps with and without kairomone to non target insects, French beans (Trial II)

Blue traps were significantly attractive to dipterans ($F_{2, 15}$ =37.8, P<0.0001) and the kairomone had no significant effect on dipterans attraction ($F_{1, 15}$ =4.0, P=0.063). Blue traps with kairomone significantly attracted more dipterans than the other treatments ($F_{5, 15}$ =17.2, P<0.0001) (Table 3.8). Aphids were significantly attracted to yellow traps ($F_{2, 15}$ =135.0, P <0.000) and the kairomone had a significant effect on attraction ($F_{1, 15}$ =9.9, P=0.006). Yellow traps with kairomone significantly attracted more aphids than the other treatments ($F_{5, 15}$ =54.9, P<0.0001). Whiteflies were significantly attracted to yellow traps ($F_{2, 15}$ =165.7, P<0.0001) while the kairomone had no significant effect on attraction ($F_{1, 15}$ =1.2, P=0.29). Whiteflies showed highest response to yellow trap with kairomone than other treatments ($F_{5, 15}$ =66.6, P<0.0001).

Hoppers were significantly attracted to yellow traps ($F_{2, 15}$ =142.7, P<0.0001) and the kairomone ($F_{1, 15}$ =6.5, P=0.022). Yellow traps with kairomone attracted more hoppers than the other treatments ($F_{5, 15}$ =58.1, P<0.0001). Clear traps were the most attractive to coleopterans ($F_{2, 15}$ =35.5, P<0.0001). The kairomone did not influence catches of coleopterans ($F_{1, 15}$ =2.6, P=0.128). Clear traps with kairomone had a significant effect on attraction of coleopterans ($F_{5, 15}$ =14.7, P<0.002). Coccinelids were significantly attracted to yellow traps ($F_{2, 15}$ =9.6, P<0.002) while the kairomone did not have a significant effect on attraction ($F_{1, 15}$ =0.2, P=0.69). Yellow traps with kairomone attracted more hymenopterans than the other treatments ($F_{5, 15}$ =20.6, P<0.0001).

Table 3.8: Captures of pests to coloured sticky traps with LUREM-TR on French bean trial II (21st Sep - 9th Nov 2010)

Treatments	Sum of mean pests catches per trap over eight weeks (± SE)						
	Dipterans	**Aphids**	**Whiteflies**	**Hoppers**	**Coleopterans**	**Coccinelids**	**Hymenoptera**
1.Blue trap	1206.3±72.59b	22.5±3.53c	3.6±1.38e	81.5±7.20b	98.6±10.68c	1.3±0.80b	278.3±30.03d
2.Blue trap + LUREM-TR	1444.7±86.53a	27.0±4.08c	5.8±1.69cd	86.1±7.52b	117.4±12.49c	0.8±0.55b	323.9±34.81d
3.Yellow trap	902.7±54.75c	122.8±15.34b	666.7±179.40b	211.2±16.26a	160.7±16.64b	6.3±2.77a	655.1±70.22b
4.Yellow trap+ LUREM-TR	1088.6±65.58b	161.1±19.92a	896.0±141.45a	237.2±18.05a	179.4±18.46b	7.8±3.14a	1014.7±106.24a
5. Clear trap	806.7±49.19cd	10.4±2.02d	8.6±2.74c	47.0±4.72d	243.0±24.62a	0.5±0.42b	614.1±65.49b
6. Clear trap + LUREM-TR	752.0±45.97d	21.7±3.46c	9.4±3.09c	68.5±6.28c	275.5±27.66a	1.2±0.70b	458.9±48.72c
Treatment-$F_{(5,15)}$(P-value)	17.2 (<0.0001)	54.9 (<0.0001)	66.6 (<0.0001)	58.1 (<0.0001)	14.7 (<0.0001)	3.9 (<0.017)	20.6 (<0.0001)
Colour - $F_{(2,15)}$ (P-value)	37.8 (<0.0001)	135.0(<0.0001)	165.7 (<.0001)	142.7(<0.0001)	35.5 (<0.0001)	9.6 (0.0021)	44.9 (<0.0001)
Kairomone - $F_{(1,15)}$ (P-value)	4.0 (0.0630)	9.9 (0.0066)	1.2 (0.2910)	6.5 (0.022)	2.6 (0.1288)	0.2 (0.6909)	1.2 (0.2951)
Interaction - $F_{(2, 15)}$ (P-value)	2.9 (0.0851)	1.55 (0.2447)	0.2 (0.8491)	1.7 (0.216)	0.05 (0.951)	0.5 (0.6112)	5.7 (0.0139)

Treatment means in the same column followed by the same letter are not significantly different at p= 0.05, Tukey's test.

3.4.9 Evaluating colour, kairomone and host plants as factors influencing the attraction of *Frankliniella occidentalis* and *Frankliniella schultzei* to coloured sticky traps with or without kairomone for French beans season I and tomato season II

Attraction of *F. occidentalis* and *F. schultzei* to traps was significantly influenced by colour ($F_{2, 33}$= 328.51, P<0.0001; $F_{2, 33}$= 332.79, P<0.0001, respectively) and kairomone ($F_{1, 33}$= 55.75, P<0.001; $F_{1, 33}$= 40.52, P<0.001, respectively) individually. Significant interaction between colour and kairomone was also observed for both *F. occidentalis* ($F_{2, 33}$= 11.43, P=0.0002) and *F. schultzei* ($F_{2, 33}$= 10.76, P<0.0001). The host plants alone did not influence the attraction of *F. occidentalis* ($F_{1, 33}$= 1.29, P=0.26) and *F. schultzei* ($F_{1, 33}$= 0.00, P=0.96). However, for *F. occidentalis* the host plants interaction with colour of the trap was found to significantly influence the attraction (Fig 3.1). Yellow traps placed in tomato crop were more attractive to *F. occidentalis* as compared to yellow traps placed in French beans ($F_{2, 33}$=4.56, P=0.018 (Fig. 3.1). With regards to attraction of *F. schultzei,* the interaction of colour with the host plant did not significantly influence their attraction ($F_{2, 33}$= 0.14, P =0.866) (Fig.3.2).

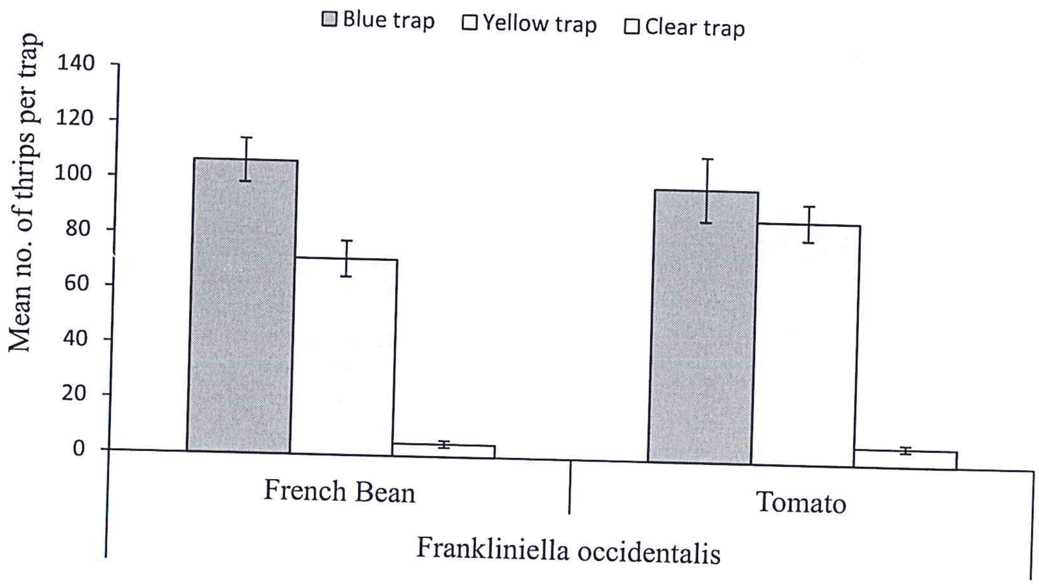

Figure 3.2: Influence of host plant to coloured traps in the attraction of *F. occidentalis*

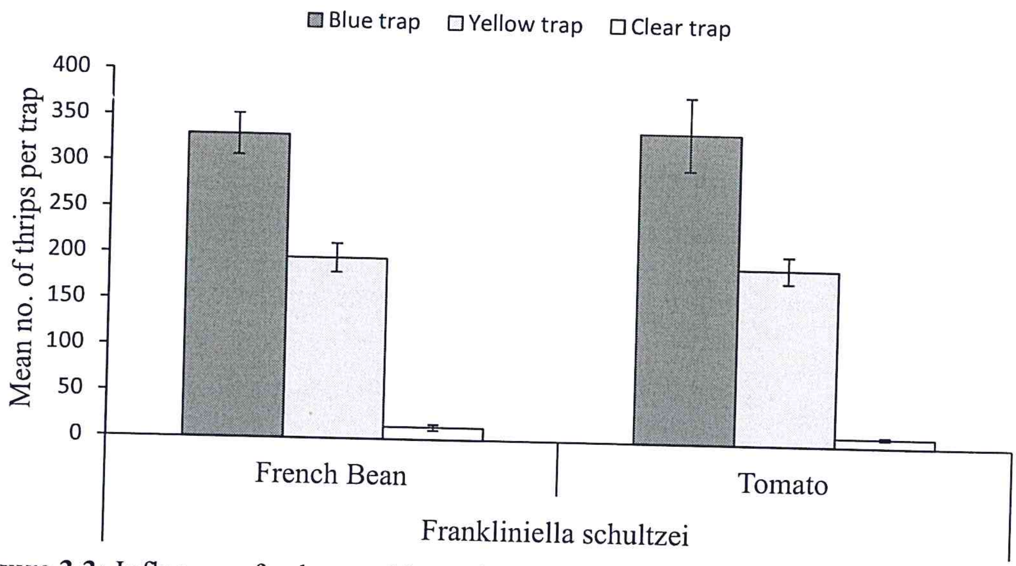

Figure 3.3: Influence of colour and host plant in the attraction of *F. schultzei* to traps

Bars representing mean attraction (± SE) to different coloured sticky traps are inclusive of both with and without kairomone.

3.5 Discussion

Many phytophagous insects respond positively to light reflectance patterns of their host plant, and these responses can be quite specific (Prokopy and Owens, 1983). Result shows that in tomatoes blue traps were the most attractive to *F. schultzei* and *C. brunneus* followed by yellow and then clear traps. In French beans blue traps were attractive to *M. sjostedti, F, schultzei* and *F. occidentalis*. Yellow traps were found to be effective in captures of *H. adolfifriderici* only. Blue has been shown to be effective in the captures of *M. sjostedti* (Gitonga, 1999), *F. schultzei* and *F. occidentalis* (Allsopp *et al.,* 2010). Vernon and Gillespie (1990) suggested that flower thrips have three photoreceptors tuned to 350 to 360 nm in UV, 440 to 450 nm in blue, and 540 to 570 nm in the yellow wavelength. Although there is no past study showing the utilization of visual cues for captures of *C. brunneus,* comparable results were found by (Ranamukhaarachchi *et al.,* 2007) that, blue traps attracted *C. claratris* on a tomato crop.

Both blue and yellow traps were not significantly different in the captures of *F. occidentalis* in tomatoes. Past studies on the attractiveness of *F. occidentalis* have yielded varying results. Hoddle *et al.* (2002) compared blue, yellow and white traps for their efficacy in trapping *F. occidentalis.* Yellow traps outperformed blue and white traps in catching *F. tritici* (Fitch) and *F. occidentalis* in tomato fields (Chu *et al.,* 1995; Hoddle *et al.,* 2002). However, Chen *et al.* (2004) caught significantly more *F. occidentalis* on blue traps than on yellow or white traps in greenhouse experiments and (Chu *et al.*, 2006) found 'true blue' and white to be the most effective of nine colours at trapping *F. occidentalis* in fields of several different crops. Demirel *et al.* (2005) found that blue traps were not attractive to *F. occidentalis* as compared to neon yellow traps.

This study shows that *F. schultzei* was significantly captured on blue traps than on yellow and clear traps in the field trials on both French beans and tomato. Similar results were found by (Allsopp *et al.*, 2010). Utilization of visual and olfactory cues has been documented extensively in Thysanopterans and seems to be correlated with patterns of host use (Terry 1997; Teulon *et al.*, 1999). Kairomone attractant (LUREM-TR) increased thrips captures to traps for *M. sjostedti, F. schultzei, F. occidentalis* and *H. adolfifriderici* but not for *C. brunneus*. LUREM-TR attractant has been reported to increase trap captures of *F. occidentalis, Thrips palmi* (Teulon *et al.*, 2010) and *Thrips tabaci* (Kruistum *et al.*, 2010). The potential of other compounds have been tested successfully on thrips. For example, (Davidson *et al.*, 2009) found anisaldehyde and ethyl nicotinate to elicit positive responses on thrips and thus increased trap captures.

The lack of attraction of *C. brunneus* to LUREM-TR could be because they are not flower thrips and are commonly observed on the leaves as reported from the related *C. claratris* on tomato (Murai *et al.*, 2000), while LUREM-TR, comprises of compounds analogous to floral volatiles (Teulon *et al.*, 2010). Lack of response of *C. brunneus* could also be due to factors of incompatibility of *C. brunneus* with some of the compounds used to make the kairomone. For example, cis-jasmone increased trap capture of New Zealand Flower Thrips (NZFT) 25 - 42 times but not Onion thrips (Teulon *et al.*, 2007).

The negative response could also be attributed to concentration levels of some compounds in the kairomone as observed by (Koschier *et al.* 2000) with eugenol or benzaldehyde which were only attractive at a specific concentration. Hence the reasons underlying lack of attractions of *C. brunneus* to LUREM-TR needs further investigation. Coloured traps have been found to play major role on the thrips response (de Kogel *et al.*, 2003) it therefore follows that lures used in conjunction with coloured sticky traps may provides an additive effectiveness and efficiency in the captures of thrips.

Analysis to compare plant host relationship with *F. schultzei* and *F. occidentalis* (Thrips observed on both the host plants) showed that there was significant interaction between colour and the host plant for captures of *F. occidentalis* and not for *F. schultzei.* Our findings are partly consistent with (Papadaki *et al.*, 2008) who tested the influence of host plant on the population density of *F. occidentalis* on different vegetable cultures in greenhouses and concluded that *F. occidentalis* prefers to lay eggs on the leaves and flowers of tomato more than on French beans. Captures of *F. occidentalis* were found more on blue traps in an onion than lettuce while yellow traps were more attractive to *F. occidentalis* in lettuce than in onion crop (Natwick *et al.*, 2007) .Our findings suggested that yellow traps were influenced by the host plant in captures of *F. occidentalis.*

Research has shown that colour influences captures of non-target insects (Blackmer *et al.*, 2008). Our study indicated that yellow sticky trap was the most attractive to a large number of non-target insects that included; aphids, whiteflies, hoppers, coccinelids and hymenopterans. While, blue sticky traps were most attractive to dipterans compared to yellow traps. Clear traps were most attractive to coleopterans in French beans while yellow traps were the most attractive in tomatoes. Yellow traps have been reported to be universal attractant (Jacobson, 1997; Atakan and Canhilal, 2004) to majority of insects and the beneficials (Abrahamczyk *et al.*, 2010). Knight & Miliczky (2003) reported that the choice of trap colour affected numbers of honeybee (*Aphis mellifera* L.) and non-target muscoid flies captured on sticky delta traps used to monitor codling moth (*Cydia pomonella* L.).

Dipterans were highly captured on blue traps and this was also true by (Chen *et al.*, 2004) who captured more adult dipterans in blue trap. Besides dominant visual cues pests utilizes semiochemical in the location of host plants. In this study aphid and whiteflies showed significant effect on attraction to traps with the kairomone. Similar findings have been reported earlier (Hardie *et al.*, 1995; Bleeker *et al.*, 2011) that aphids and whiteflies respectively, make use of volatile semiochemicals prior to choosing a host plant. Whilst in some pests, the kairomone (LUREM-TR) did not influence the catches. However, their response to other attractants have been reported on leaf hoppers (Todd *et al.*, 1990), *Anomala cuprea* beetles (Coleoptera: Scarabaeidae) (Larson *et al.*, 2001), coccinelids (Hattingh and Samways, 1995), and hymenopterans (Turlings *et al.*, 1993). Exploiting the response of thrips and other pest species to colour and odours has strong potential for improving insect pest management strategies.

3.6 Conclusion

In general, these results provide evidence that colour and odours are important components in host location. Blue traps were the most attractive colour to major thrips species found on tomato and French bean crops except *H. adolfifriderici.* LUREM-TR increased the number of all key thrips captured on traps upto 158% except for *C. brunneus.* Dipterans were attracted more on blue traps while yellow traps were attractive to aphids, whiteflies, hoppers, coccinelids and hymenoptera. Coleopterans were attracted to both clear and yellow. A greater understanding of the behavioural response of thrips and other pests to these colour/odours, including the intrinsic and extrinsic factors that may affect these responses, optimal trap design and odour formulation, will be essential if semiochemical based approaches are to be integrated into pest management programmes. Traps can be used in monitoring population of other insect pests. Yellow traps were found to be general insect attractant.

CHAPTER 4

4.0 VALIDATION OF COLOURED STICKY TRAPS WITH OR WITHOUT LUREM-TR FOR EVALUATING POPULATION DYNAMICS OF THRIPS ON TOMATO AND FRENCH BEANS

4.1 Introduction

Thrips management practices adopted by farmers largely depend on the use of insecticides (Nderitu *et al.*, 2007). However, there are major problems associated with usage of insecticides such as, pesticide resistance in thrips (Morse, 2007) and its deleterious impacts on human health and non-target organisms (Desneux *et al.*, 2007) which leads to legal restrictions on insecticide use. Further application of insecticides for thrips are not always effective as thrips hide mainly in flowers and are difficult to reach by non-systemic insecticides (Hollingsworth *et al.*, 2001). Effective Integrated Pest Management (IPM) strategies for management of key pests like thrips are essential for sustainable production of vegetable crops (Greer and Diver 2000). Effective monitoring of the pest and its natural enemies population is crucial for proper timing of control interventions and successful implementation of IPM strategies (Frey *et al.*, 1994) and to assess the efficacy of interventions.

Among other monitoring methods, sticky traps have been demonstrated to be helpful for evaluating the degree of thrips infestation to various crops (Liburd and Arevalo, 2005) and reduce damage associated with thrips (Affandi and Deni Emilda, 2009). Thrips are found to be key pest of French bean and tomato crops in the East African region

(Waiganjo *et al.,* 2006; Michalik *et al.,* 2006; Nyasani *et al.,* 2010). To validate effective monitoring strategies, information needs to be generated that is specific to these crops and the complex of thrips in this region. Development and inclusion of sampling methods (Pizzol *et al*., 2010) that can accurately and reliably estimate thrips population is essential for studying population dynamics and abundance of thrips in experimental plots and commercial fields for making management decisions (Palumbo, 2003; Joost and Riley, 2004). Coloured sticky traps may potentially be a rapid, cost-effective tool (Southwood, 1978; Chen *et al.,* 2004; Liu and Chu, 2004) that can be used for thrips monitoring. However, rationale of these traps to correctly reflect the absolute estimates of thrips density in the field and the factors determining its success needs to be validated.

Weather pattern plays a major role in the abundance and distribution of thrips (Lewis, 1997). Weather parameters like rainfall affect thrips populations both negatively and positively and affected thrips population recovers slowly (Kirk, 1997; Morsello *et al.*, 2008; Morsello *et al.*, 2010). Rainfall suppresses thrips dispersal by suppressing flight (Lewis, 1997) while temperatures influence the reproduction rate (Rhainds *et al.,* 2007). Thus, with the objective of developing a pest management approach that would enhance our present control tactics, this research was conducted to examine sampling methods for estimating thrips abundance on French bean and tomato crops, to determine the relationships between thrips captured on traps and those found using whole plant sampling. Additionally, the influence of weather parameters on thrips population dynamics was also assessed.

4.2 Materials and methods

The data of thrips captures on the traps and absolute estimate of thrips on the plants was obtained from the field experiments on French beans and tomato as described in Chapter 2 section 2.3.2. Traps catch for each treatment was correlated with thrips count on the crop within the same plot to see how the traps were influencing the thrips population on the actual crop. Thrips population on the crops was estimated using, destructive and non destructive sampling methods.

4.2.1 Weather parameters

Daily weather parameters were tested to see how they played a role in influencing the thrips density. Readings were obtained from weather station records housed at Thika Meteorological Department located about 150m from the experimental fields. The weather parameters that included weekly; minimum temperature, maximum temperature, mean temperature, rainfall, sunshine and wind run were selected based on the available literature on their influence on the thrips population dynamics (Waiganjo *et al.*, 2008; Patel *et al.*, 2009; Morsello *et al.*, 2010). Data included daily rainfall record readings from a rain gauge in millimeters, minimum and maximum atmospheric temperature in degrees Celsius using a thermometer, sunshine hours using Campbell Stokes Recorder (CSR) and wind run in kilometers per hour using an anemometer.

4.3 Data analysis

Thrips complex captured on traps were correlated with number and composition of thrips observed by plant sampling and with weekly means of different weather parameters using spearman correlation coefficient, PROC CORR (SAS institute, 2009). Weekly traps catch and absolute plant sampling estimates were correlated. Similarly, weekly plant sampling by tapping was correlated with the previous week means of different weather parameters.

4.4 Results

4.4.1 Correlation of sticky trap catches of thrips with destructive and non-destructive sampling methods - Tomato – trial I

The influence of traps catch to thrips population on the crop was evaluated. Mean captures of thrips on coloured traps with or without kairomone was weak or negatively correlated with adults thrips counts from destructive and non destructive sampling on plants in the first tomato trial (Table 4.1), where the thrips population was low (Table 3.1). There was significant positive correlation ($r = 0.437$, $df = 26$, $P = 0.02$) between trap catch of clear trap with kairomone and non destructive sampling.

4.4.2 Correlation of sticky trap catches on tomatoes with destructive and non-destructive sampling methods – Trial II

Thrips captures on coloured sticky traps with or without kairomone had a significant positive correlation with destructive and non destructive sampling (Table 4.1). Captures on blue trap with kairomone recorded the highest significant positive correlation ($r = 0.718$, $df = 26$, $P = 1.67e\text{-}0.5$) with destructive sampling while clear trap with kairomone ($r = 0.427$, $df = 26$, $P = 0.0233$) recorded the lowest correlation with destructive sampling. Thrips captures on blue trap with kairomone had the highest positive correlation ($r = 0.844$, $df = 38$, $P = 7.18e\text{-}12$) with non destructive sampling while, yellow trap with kairomone had the lowest correlation ($r = 0.454$, $df = 38$, $P = 0.003$) with non destructive sampling.

Table 4.1: Correlation of thrips catches on coloured sticky traps with or without kairomone with absolute estimates of thrips through destructive and non-destructive plant sampling techniques on tomatoes (23rd Feb-13th April, 2010 - Trial I; 15th June-24th August 2010 - Trial II)

Treatments	**Trial I**				**Trial II**			
	Destructive sampling (leaves + flowers)		**Non-destructive sampling (tapping)**		**Destructive sampling (leaves + flowers)**		**Non destructive sampling (tapping)**	
	r	***P*-value**	*r*	***P*-value**	*r*	***P*-value**	*r*	***P*-value**
1. Blue without kairomone	-0.043	0. 8385	-0.262	0.1765	0.696	3.84e-05*	0.799	6.09e-10*
2. Blue with kairomone	-0.123	0.5658	-0.111	0.5739	0.718	1.67e-05*	0.844	7.18e-12*
3. Yellow without kairomone	-0.013	0.9514	0.115	0.5571	0.428	0.024*	0.504	0.0009*
4. Yellow with kairomone	0.282	0.1812	0.283	0.1439	0.455	0.014*	0.454	0.0032*
5. Clear without kairomone	0.115	0.5895	-0.15	0.4451	0.629	0.0003*	0.635	6.45e-08*
6. Clear with kairomone	0.201	0.3455	0.437	0.0200*	0.427	0.0233*	0.58	8.68e-05*
		df= 22		df= 26		df = 26		df = 38

* *P* values followed by the asterisks indicates significance at 0.05 level

4.4.3 Correlation of sticky trap catches on French beans with destructive and non-destructive sampling methods – Trial I

Correlation between mean thrips captures on coloured sticky traps with or without kairomone with plant sampling methods indicated a significant positive correlation (Table 4.2). Thrips captures on yellow trap with kairomone recorded the highest significant positive correlation (r=0.716, df = 22, *P* = 8.1e-0.5) with destructive sampling while clear trap with kairomone recorded the lowest correlation (r =0.429, df = 22, *P* =0.036) with destructive sampling. Blue traps with kairomone recorded highest significant positive correlation (r =0.824, df = 34, *P*=6.59e-10) with non destructive sampling while clear trap without kairomone had the lowest correlation (r = 0.401, df = 34, *P* =0.015).

4.4.4 Correlation of sticky trap catches on French bean with destructive and non-destructive sampling methods – Trial II

There was a significant positive correlation between the catches on coloured traps with and without kairomone with destructive and non destructive sampling techniques (Table 4.2). Correlation between thrips captured on blue trap without kairomone and destructive sampling recorded highest significant positive correlation (r =0.91, df = 26, P =7.34e-07), while thrips captures on yellow trap with kairomone showed the least significant positive correlation (r =0.537, df = 26, P =0.03) with destructive sampling values. Correlation between thrips captures on traps and non destructive sampling method showed that yellow trap with kairomone and non destructive sampling had the highest significant positive correlation (r =0.924, df = 38, P =4.35e-14) while clear trap without kairomone had the least significant positive correlation (r =0.709, df= 38, P =5.37e-06).

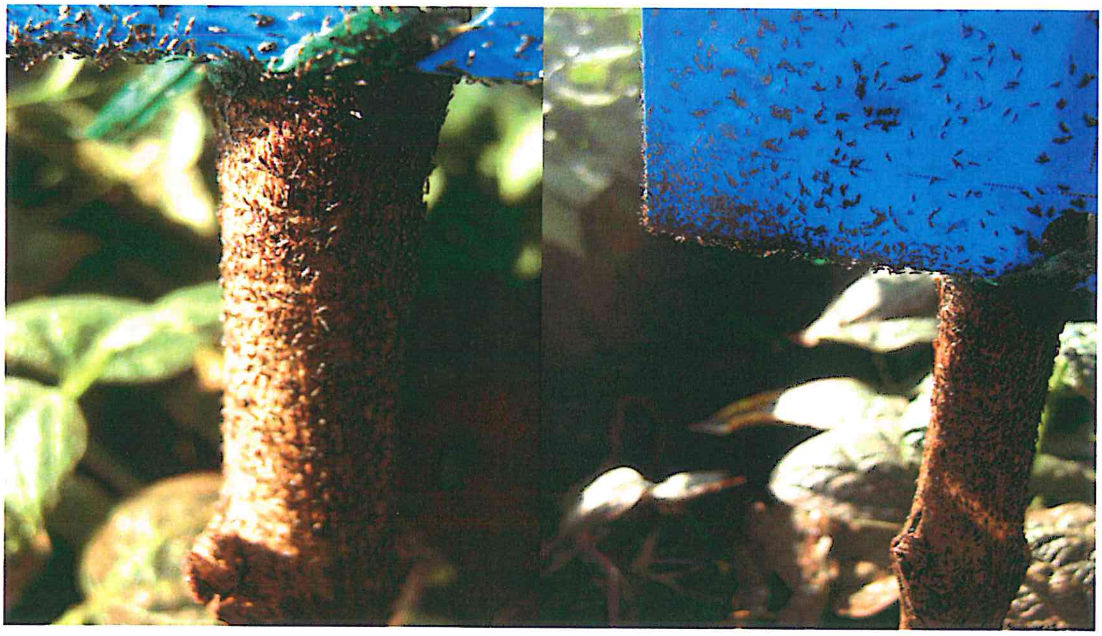

Plate 1.6: Congregation of *Megalurothrips sjostedti* on the stakes used for dispensing the blue sticky trap with kairomone

Plate 1.7: Damage below coloured sticky traps with and without LUREM -TR in French bean fields

Table 4.2: Correlation of thrips catches on coloured sticky traps with or without kairomone and absolute estimates of thrips on plants through destructive and non-destructive plant sampling techniques on French beans (1st June - 27th July 2010 – Trial I; (21st Sep- 9th Nov 2010 – Trial II)

Trap colour with or without kairomone	**Trial I**				**Trial II**			
	Destructive sampling (leaves + flowers)		**Non destructive sampling (tapping)**		**Destructive sampling (leaves + flowers)**		**Non destructive sampling (tapping)**	
	r	***P*-value**	**r**	***P*-value**	**r**	***P*- value**	**r**	***P*- value**
1. Blue trap without kairomone	0.561	0.003*	0.622	4.99e-05*	0.914	7.34e-07*	0.815	1.32e-08*
2. Blue trap with kairomone	0.584	0.004*	0.824	6.59e-10*	0.700	0.0025*	0.909	5.45e-13*
3. Yellow trap without kairomone	0.477	0.018*	0.663	1.03e-05*	0.689	0.0031*	0.813	1.49e-08*
4. Yellow trap with kairomone	0.716	8.1e-05*	0.762	6.49e-08*	0.537	0.031*	0.924	4.35e-14*
5. Clear trap without kairomone	0.527	0.008 *	0.401	0.015*	0.673	0.0042*	0.709	5.37e-06*
6. Clear trap with kairomone	0.429	0.036*	0.506	0.0016*	0.86	1.93e-05*	0.903	1.53e-12*
		df= 22		df= 34		df= 26		df = 38

* *P* values followed by the asterisks indicates significance at 0.05 level

Table 4.3: Weather parameter range in the different crops and trials

Weather parameter	Tomato		French beans	
	Trial I	Trial II	Trial I	Trial II
Mean maximum temperature	26.69 (25.81 – 27.4)	23.71 (21.84 – 25.03)	24.19 (22.76 – 26.48)	28.42 (26.13 – 31.37)
Mean minimum temperature	17.03 (16.74 – 17.39)	12.95 (10.87 – 14.41)	13.94 (12.23 – 15.68)	14.77 (12.36 – 16.71)
Mean daily temperature	21.86 (21.28 – 22.3)	18.33 (17.74 – 19.02)	19.06 (17.74 – 21.08)	21.48 (19.98 – 24.01)
Mean rainfall	8.4 (2.77 – 18.08)	0.07 (0.00 – 0.07)	0.75 (0.00 – 3.53)	1.80 (0.00 – 10.78)
Mean sunshine hours	6.67 (5.50 – 7.83)	4.17 (2.41 – 6.11)	4.19 (3.14 – 5.25)	7.19 (1.36 – 18.81)
Mean wind run	48.85 (43.07 – 54.83)	41.04 (33.93 – 48.09)	38.63 (33.63 – 45.17)	65.60 (51.49 – 82.9)

Values indicated are means over the cropping season and the range (Minimum value – Maximum value)

4.4.5 Influence of weather characteristics on the thrips population dynamics in tomatoes

Correlation was calculated to find out how different weather parameters were influencing the thrips density on the crops. Thrips species *F. schultzei* ($r = 0.56$, $df = 6$, $P = 0.048$), *F. occidentalis* ($r=0.77$, $df = 6$, $P = 0.024$), *C. brunneus* ($r = 0.72$, $df = 6$, $P = 0.043$) and total thrips ($r = 0.69$, $df= 6$, $P = 0.05$) were positive and significantly correlated to the maximum temperature (Table 4.4). Rainfall had significant negative influence on thrips population on the crops for *F. schultzei* ($r = -0.88$, $df = 6$, $P = 0.0003$), *F. occidentalis* ($r = -0.82$, $df = 6$, $P = 0.012$), *C. brunneus* ($r=0.88$, $df = 6$, $P = 0.0038$) and total thrips ($r = -0.88$, $df = 6$, $P = 0.0003$). Minimum temperature, mean temperature and sunshine had weak negative but non-significant correlation, while wind run had weak positive but non-significant correlation with thrips count on the plant. In the second trial minimum temperature had significant negative correlation while sunshine and wind run had significant positive correlation. Mean temperatures and rainfall had negative correlation which was not significant (Table 4.4).

4.4.6 Influence of weather characteristics on the thrips population dynamics in French beans

H. adolfifriderici ($r =0.56$, $df =6$, $P =0.04$) density was positive and significantly correlated to maximum temperature. There was a significant negative correlation for minimum temperature with *F. occidentalis* ($r = -0.64$, $df = 6$, $P=0.04$) and total thrips ($r = -0.648$, $df = 6$, $P=0.04$) (Table 4.5). Rainfall and sunshine were negatively correlated to thrips densities on the crop but had no significant effect. In the second trial *F. occidentalis* (r =0.62, df =6, *P* =0.01), *F. schultzei* (r =0.86, df = 6, *P* =0.005), *M. sjostedti* (r = 0.555, df = 6, *P* = 0.015), *H. adolfifriderici* (r=0.755, df = 6, *P* = 0.003) and total thrips (r = 0.648, df = 6, *P* = 0.048) were positive and correlated to maximum temperature. There was a significant positive correlation between mean temperatures and wind run for all the thrips species Significant positive correlation was recorded between rainfall and *F. schultzei* densities (r = 0.76, df = 6, *P* = 0.03) (Table 4.5).

Table 4.4: Correlation coefficient between thrips population density on tomatoes and the weather factors (23rd Feb-13th April, 2010 trial I and 15th June-24th August 2010 trial II)

Trial I	**Max temp (^{o}c)**	**Min temp (^{o}c)**	**Mean temp (^{o}c)**	**Rainfall (mm)**	**Sunshine (hrs)**	**Wind run (km/h)**
F. schultzei	0.56*	-0.22	-0.39	-0.88*	-0.25	0.61
F. occidentalis	0.77*	-0.20	-0.31	-0.82*	-0.18	0.16
C. brunneus	0.72*	-0.16	-0.26	-0.88*	-0.12	0.22
Total thrips	0.69*	-0.20	-0.33	-0.88*	-0.19	0.18
Trial II						
F. schultzei	0.13	-0.61*	-0.44	-0.05	0.73*	0.76*
F. occidentalis	0.63*	-0.63*	-0.01	-0.25	0.81*	0.77*
C. brunneus	0.20	-0.68*	-0.44	-0.03	0.88*	0.73*
Total thrips	0.20	-0.68*	-0.44	-0.03	0.88*	0.74*

df = 6

*Correlation coefficients followed by an asterisks indicate significance at *P*=0.05 while the others are non-significant

Table 4.5: Correlation coefficient (r) between thrips population density on French beans and the weather factors (1st June - 27th July 2010 trial I & 21st Sep- 9th Nov 2010 trial II)

Trial I	**Max temp (°c)**	**Min temp (°c)**	**Mean temp (°c)**	**Rainfall (mm)**	**Sunshine (hrs)**	**Wind run (km/h)**
F. schultzei	0.17	-0.59	-0.22	-0.62	-0.59	0.18
F. occidentalis	0.15	-0.64*	-0.26	-0.45	-0.62	0.41
M. sjostedti	0.22	-0.57	-0.17	-0.48	-0.53	0.28
H. adolfifriderici	0.56*	0.05	0.33	-0.25	-0.11	0.29
Totals thrips	0.14	-0.65*	-0.27	-0.53	-0.56	0.3
Trial II						
F. schultzei	0.86*	0.56	0.93*	0.76*	-0.07	0.81*
F. occidentalis	0.62*	0.68	0.80*	0.63	0.32	0.68*
M. sjostedti	0.55*	0.71*	0.74*	0.5	0.00	0.70*
H. adolfifriderici	0.75*	0.58	0.83*	0.39	-0.17	0.88*
Totals thrips	0.64*	0.70*	0.76*	0.51	-0.01	0.71*

df = 6

*Significant at p=0.05

4.5 Discussion

Determining the best sampling method involves finding one that is precise, reliable, inexpensive and very easy to adopt (Parajulee *et al.*, 2006). Thrips density and weather parameters in the first trial on tomato indicated weak or negative correlations for all the treatments except for clear trap with kairomone with non destructive sampling method. The negative correlations could be due to adult thrips from nearby plants within the plot being attracted to coloured traps thereby reducing populations on plants and increasing trap catches. Additionally the negative correlation was attained when thrips densities were very low and thus traps captured the few available thrips from the crop. This finding agrees with (Natwick *et al.*, 2007) who found negative correlation which was not significant when they compared thrips population on plant count and trap catches.

Significant positive correlations were found between trap catch and thrip density on plants for all the thrips species on the second tomato trial and the two trials on French beans when the thrips densities were high. Thrips congregated near the vicinity of the traps (Plate 1.6) which clearly explains the positive correlation of trap captures to the absolute estimates on the plants when the thrips population density is higher. The results were similar to those reported by (Cloyd & Sadof, 2003; Shipley, 2006) who found a strong positive correlation made by comparison between the number of thrips caught on sticky traps and the numbers collected using the individual plant sampling methods. The numbers of thrips caught on traps relative to estimated plant populations support the hypothesis that mass trapping (El-Sayed *et al.*, 2006) was significant in the treated area.

It was observed that blue trap with kairomone had the strongest positive correlations and thus could be more sensitive in detecting early presence of thrips in tomato and French beans fields. This may explain the higher prevalence of thrips to blue traps than yellow and clear traps (Chapter 3). The weaker correlations on clear sticky traps are likely as a result of their inability to consistently and highly capture thrips. Similar findings were also found by (Shipley, 2006).

Thrips population varied with cropping period that differed in prevailing weather pattern. It has been reported earlier that thrips population is affected by weather patterns (Lewis, 1997, Gitonga, 1999). The low thrips number in the first trial on tomato, compared with the second trial, could have been due to high rainfall and temperatures that may have suppressed the thrips build up during that cropping period. The population of *C. brunneus* was the lowest while *F. schultzei* was the highest during this trial. The plausible explanation to this was that rains seemed to favour *F. schultzei* observed in the tomato crop on the trial I. Kirk, (1997) and Waiganjo *et al.* (2008) also reported that rainfall is a decisive thrips mortality factor. During the second trial on tomato the population of *C. brunneus* was the highest followed by *F. occidentalis* and *F. schultzei* was the least. This high number may have been caused by weather factors given that it was during warm and humid period which was thought to be the favourable weather for development of *C. brunneus*.

Premachandra *et al.* (2004) obtained comparable results to our findings that hot and humid conditions facilitated reproductive potential and short life cycle of *C. claratris* causing rapid population build up. During this trial on tomatoes, sunshine hours and wind run were significant and positively correlated to thrips catch which agree with findings by (Patel *et al.,* 2009). The lower thermal threshold for egg-to-adult development of *C. claratris* was estimated at 16 and 18°C (Premachandra *et al.*, 2004) which were closely corresponding to our reported prevailing mean temperatures of (17.74 – 19.02°C) at that period. Furthermore, lack of rainfall also facilitated the population build up of thrips as rains can wash thrips off causing a decline in population density (Kirk, 1997).

Long term weather variables such as temperature and precipitation are major factors influencing thrips captures (Morsello *et al.,* 2008). The temperature range in the experimental trials was within optimum of 15 - 30°C (Pearsall, 2002) that allows thrips to take off and control their own flight. On the first trial on French beans, *H. adolfifriderici* was positively correlated to maximum temperature which meant that its development thrived with low maximum, minimum and medium temperatures. Minimum temperature and total thrips capture had negative correlation which was also true by (Patel *et al.,* 2009). In the second trial on French beans there was significant positive correlation between maximum, mean temperature and wind run with the thrips population. The corresponding trial period (Sept – November) coincides with warm and humid weather and that could have enhanced their reproduction rate (Morsello *et al.,*

2008) and flight. Increase in the mean minimum temperature was found to positively influence the population density of *M. sjostedti* and the total thrips. Similar findings were reported for *M. sjostedti* and *F. occidentalis* (Gitonga *et al.*, 2002).

4.6 Conclusion

Utilizing sticky traps in field production may provide a useful tool when scouting thrips population densities in order to develop control strategies since there was a positive correlation between thrips captured on traps and thrips observed on the plant. Results from our study indicate that coloured sticky traps with kairomone could be used as an early detection tool with more sensitivity than the costly and time-consuming plant sampling techniques. Results indicate that blue sticky traps with kairomonal attractant could attract significantly high numbers of thrips and hence further work is needed to explore their potential for a "lure and trap" based management strategies with synthetic or bio-pesticides like entomopathogenic fungi. It was concluded that weather patterns have effects on thrips population. Rainfall and minimum temperatures reduced thrips population while maximum temperatures, wind run were positively correlated and thus increased thrips population. These results can be important in the effort to understand the effect of weather on the development and survival of thrips in the field. This information could be readily applied in the development of appropriate control strategies for thrips in integrated management programs.

CHAPTER 5

5.0 FIELD EVALUATION OF TRAP CAPTURE BASED THRESHOLD FOR APPLICATION OF ENTOMOPATHOGENIC FUNGI IN MANAGEMENT OF THRIPS ON FRENCH BEANS

5.1 Introduction

French bean, *Phaseolus vulgaris*, is widely cultivated by both the small and large-scale farmers across the Central, Eastern, Western and Coast Provinces of Kenya (Muendo and Tschirley, 2004). French beans constitute nearly 20% by volume and 10% by value of all fresh horticultural exports (HCDA, 2009) and ranks second after roses (Nderitu *et al.*, 2007). More than 80% of the French bean production is by smallholders (Nderitu *et al.*, 1995). On French beans, a complex of four thrips species (*F. schultzei, F. occidentalis, M. sjostedti* and *H. adolfifriderici*) inflicts nearly 60 - 80% yield loss.

The insects attack flowers leading to abscission and poor yield; damaged pods are often malformed and rejected by export market (Löhr, 1996; Seif *et al.*, 2001; Nderitu *et al.*, 2001; Nyasani *et al.*, 2010). To manage thrips, farmers rely extensively on synthetic pyrethroid applications especially lambda-cyhalothrin with very minimal efficacy (Nderitu *et al.*, 2001; Nderitu *et al.*, 2008) especially due to high levels of resistance in thrips species such as WFT and BFT (Nderitu *et al.*, 2001).

Monitoring thrips with coloured sticky traps with lures and threshold based management of thrips with either insecticides or more so with low-risk entomopathogenic fungi offers a new interesting opportunity for sustainable control of thrips (Terry, 1997; Berry *et al.*, 2006; Maniania *et al.*, 2003; Nderitu *et al.*, 2008). The coloured sticky traps with kairomonal attractants could be used to monitor the thrips population dynamics in the field as observed in the present study (Chapter 3) (Davidson *et al.*, 2009) and to initiate threshold based application of management options. An examination of the literature shows that authors (Shipp *et al.*, 2000; Kobb *et al.*, 2004) vary widely in the action thresholds they recommend in terms of numbers of trapped individuals. Nabirye *et al.* (2003) documented that, a density of seven thrips per florescence causes economic injury/ damage. While Steiner and Goodwin (2005) indicated 20 - 30 thrips trapped on yellow sticky traps per week on a hydroponic strawberry crop should be used to determine action threshold although the trap density was not specified.

On carnation an action threshold of 20 thrips trapped per sticky trap per week at a trap density of 1 per 100 m^2 was recommend for insecticide application (Cloyd and Sadof, 2003). On rose crops, Kobb *et al.* (2004) recommend an action threshold of 25 to 50 thrips per week on sticky cards placed at a density of 1 trap per 1,000 m^2. Casey and Parrella, (2002) predicted that a mean trap capture between 20 and 50 adults WFT per trap per week corresponded to one to two thrips per flower per week at which cultural and chemical control should be applied. However, thresholds levels may vary depending on season (Rueda *et al.*, 2007), crops stage and its susceptibility to damage and the management practice adopted.

Entomopathogenic fungi especially *Metarhizium anisopliae* are effective in WFT, BFT and onion thrips management in crops like cowpea, onion, chrysanthemum and other greenhouse vegetables (Ekesi *et al.*, 1998; Maniania *et al.*, 2001; Shipp *et al.*, 2002; Ugine *et al.*, 2005, 2007; Gouli *et al.*, 2008). Such products have many desirable traits – they leave no toxic residues, and are generally harmless to beneficial insects and pose minimal risk to human and the environment (Dent, 1999; Goettel *et al.*, 2001). However, for rational use of entomopathogenic fungi it has to be integrated with effective monitoring tools such as the use of coloured sticky traps with kairomonal attractants. A research-based action threshold that is appropriate for timing pesticides applications to control thrips in Kenya French beans fields has not been identified. The research presented herein seeks to identify an action threshold based fungus spray regimen that can be used to replace the existing calendar-based spray regimen currently used to manage thrips in fresh-market French beans in Kenya.

5.2 Materials and methods

5.2.1 Experimental site

Field experiment on French beans was carried out at KARI- Thika (as described in chapter 3). French bean variety Amy were selected and purchased from certified agro veterinary shops at Thika town for planting based on its popularity amongst farmers in the region (Ndegwa *et al.*, 2001). Fertilizer application was done at the recommended rate as detailed in chapter 3. Standard cultural practices of weeding were adopted uniformly for all the treatments.

5.2.2 Thrips sampling and field experimental design

Observations on trap captures were made after every two days to monitor the thrips population build up so that it does not exceed our estimated economic threshold. Pre-treatment counts on the thrips infesting French beans was undertaken a day before application of the treatments. Thrips infesting French beans were sampled by tapping two plants over a white enamel tray selected at random within each plot. This was done 7 days after the first treatment application and continued throughout the cropping period. Thrips processing and identification was done (as detailed in chapter 3). A RCBD was adopted with plot sizes of 6m x 6m. There were four blocks with six treatments each which were separated by paths of 6m wide.

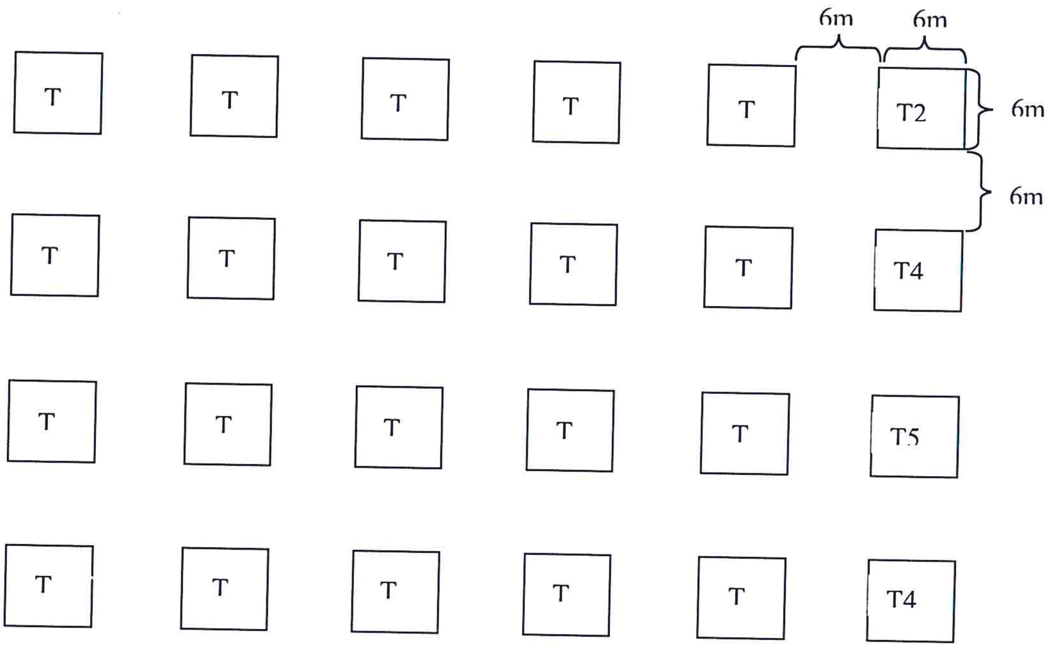

Figure 5.1: Experimental design for management of thrips using different threshold levels of *Metarhizium anisopliae*

5.2.3 Treatments applied

Results of the previous experiments indicated that blue sticky trap with kairomonal attractant correlated the most with the absolute estimates of thrips densities on the plant. Hence blue sticky traps with kairomonal attractants were selected to monitor thrips density thresholds for their management on French beans. Along with the three thresholds based application, weekly application of alpha cypermethrin 10 EC (RS-alpha-cyano-3 phenoxybenzyl (1R, 3R)- 3=(2,2-dichlorovinyl)- 2,2 dimethyl cyclopropane Carboxylate) (Osho industries ltd. Kenya) reflecting the farmer's practice and weekly application of entomopathogenic fungi and an untreated control were also included. The application of the alpha cypermethrin at 208 ml/ha was undertaken as per the farmers' practice of weekly sprays. The control treatments received water sprays as and when the insecticide application was undertaken.

Treatments as detailed below were imposed as per the design given,

i) Weekly application of Alpha-cypermethrin pesticides

ii) Blue sticky trap with LUREM-TR attractant – application of entomopathogenic fungi as and when mean thrips count increases 300 thrips per trap per week

iii) Blue sticky trap with LUREM-TR attractant – application of entomopathogenic fungi as and when mean thrips count increases 600 thrips per trap per week

iv) Blue sticky trap with LUREM-TR attractant – application of entomopathogenic fungi as and when thrips count increases 900 thrips per trap per week.

v) Weekly application of entomopathogenic fungi

vi) Absolute control with water spray

5.2.4 Application of the treatments

An oil-based formulation of *M. anisopliae* strain ICIPE 69 was obtained from the Real IPM Company (Kenya). The fungus contained a minimum of 1x 10^{11} colony forming unit (CFU)/ ml. Application rate was standardized at 200ml/ha with the addition of silwet L-77^{R} (Organo-silicone surfactant/emulsifier) (Loveland, Greeley, CO) at an application rate of 0.2% for 200ml/ha of the fungus. Alpha cypermethrin was standardized at 3ml/12l of water for the four plots. Fungus formulation and the chemical insecticide were applied with a separate CP15 @ knapsack sprayer (Cooper Pegler, Sussex, UK) at an output of 350litres/ha. Spray applications were performed in the evenings between 17.00 and 18.30 pm to lessen any adverse effects of ultraviolet radiation (Moore and Prior, 1993).

5.2.5 Parameters observed and cost benefit analysis

For treatment two, three and four, the coloured sticky traps with kairomonal attractant were placed on the third week after crop emergence. Thrips captures per trap were estimated by counting at weekly interval. Traps were taken to the laboratory for identification of the thrips as detailed in Chapter 3 section 3.3. As and when the captures exceeded the thresholds outlined above sprays of the commercial formulation of ICIPE 69 was undertaken. French bean pods were harvested on a weekly interval from each plot and separated to two grades: marketable (export market with <1 damage score) and non marketable (reject with more than 1> damage score) (Mackenzie key). The total weight of harvested French beans pods was calculated from each treatment and recorded (W, in Kg). Plot sizes were calculated (A, in m^2) for each treatment. The yield per hectare (Y, in Kg) was calculated as; Y= (W x 10000) ÷ A.

The cost of treatment was arrived at as below:

Cost of treatment = cost of chemical/ fungus + labour for spraying @ Ksh 270 + cost of spray equipment renting @ Ksh 100.

The cost of 1litre Alpha cypermethrin was ksh.2720 and that of *M. anisopliae* was 2000 per litre. Alpha cypermethrin and fungus were applied at 208ml/ha and 200ml/ha, respectively which were valued at Ksh 566.66 and Ksh 400, respectively. Hence the cost per application of synthetic pesticides and fungus was worked out as Ksh 966.66 and Ksh 770, respectively. The farm gate value of French bean fresh pods at the region was estimated as Kenya shillings (Ksh) 40.00 per kg (Ndegwa *et al.*, 2010).

Estimation of Economic Threshold Level (ETL) by economic optimization model was calculated as follows: The increase in yield for each treatment over control (C) was calculated as below:

C = Y – X

Where

Y is yield in each treatment (kg)

X is mean yield in untreated control (kg)

The value of additional yield (gross income) (GI) due to treatment over control was calculated as follows:

$GI = C \times V$

Where V is the value of French beans pods per kilogram

The net income (NI) due to treatment application was calculated as:

$NI = GI - N$

Where N is the cost of inputs required in each treatment

The Cost Benefit Ratio (CBR) for each treatment was measured as:

$CBR = NI \div N$

The economic threshold was estimated as the number of thrips per trap per week which corresponds to the maximum net income or which corresponds to the point at which maximum profits was obtained (Headley, 1972).

5.3 Data analysis

Comparisons between treatments for incidence of thrips at each observation, yield per ha, gross income and net income was carried out using univariate ANOVA. Significant means for all ANOVA were separated using Tukey's studentised range (HSD) test, $P<0.05$ (SAS 9.2, 2008).

5.4 Results

5.4.1 Evaluation of trap capture based threshold for application of entomopathogenic fungi in management of thrips on French beans

The application of *M. anisopliae* at different thresholds effectively reduced all thrips population on French beans. There was a significant difference ($F_{5, 15}$ =170.60, P= <0.0001) in the number of observed thrips due to the effects of different treatments (Fig. 5.1). Application of *M. anisopliae* at a threshold of 300 thrips/trap/week recorded the lowest population of the total adult thrips (33.37 ± 2.88) and it was as effective as weekly application of fungus (37.61 ± 3.06) while the highest population (209.98 ± 7.24) was recorded in the control (Fig. 5.1). The number of sprays of *M. anisopliae* decreased with an increase in the threshold. *F. occidentalis* was the most abundant thrips species at 56.26% of the total thrips observed from the sampling. Treatments had significant effect on the population of *F. occidentalis* ($F_{5, 15}$ =81.31, P= <0.0001). Plots treated with alpha cypermethrin (100.8 ± 6.04) and control (95.7 ± 5.86) had no significant difference and had the highest population of *F. occidentalis* as compared to the other treatments.

Fungus applied at a threshold of 300 thrips/trap/week had the least population of *F. occidentalis* (15.84 ± 2.05). The least population of *M. sjostedti* was found on weekly application of *M. anisopliae* (8.17 ± 1.42), while the highest population was recorded in the untreated control (69.5 ± 4.25) ($F_{5, 15}$ =79.32, P =<0.0001). *H. adolfifriderici* were more abundant in the untreated control as compared to the other treatments ($F_{5, 15}$ =17.8, P =<0.0001). *F. schultzei* population was kept low by alpha cypermethrin (1.9 ± 0.68) and fungus application at a threshold of 300 thrips/trap/week (1.89±0.68) as compared to untreated control (17.22 ± 2.07)) ($F_{5, 15}$ =20.95, P= <0.0001). Reduced density of *F. occidentalis* was present on plots that received fungus sprays as compared to those that received chemical spray (Fig 5.1).

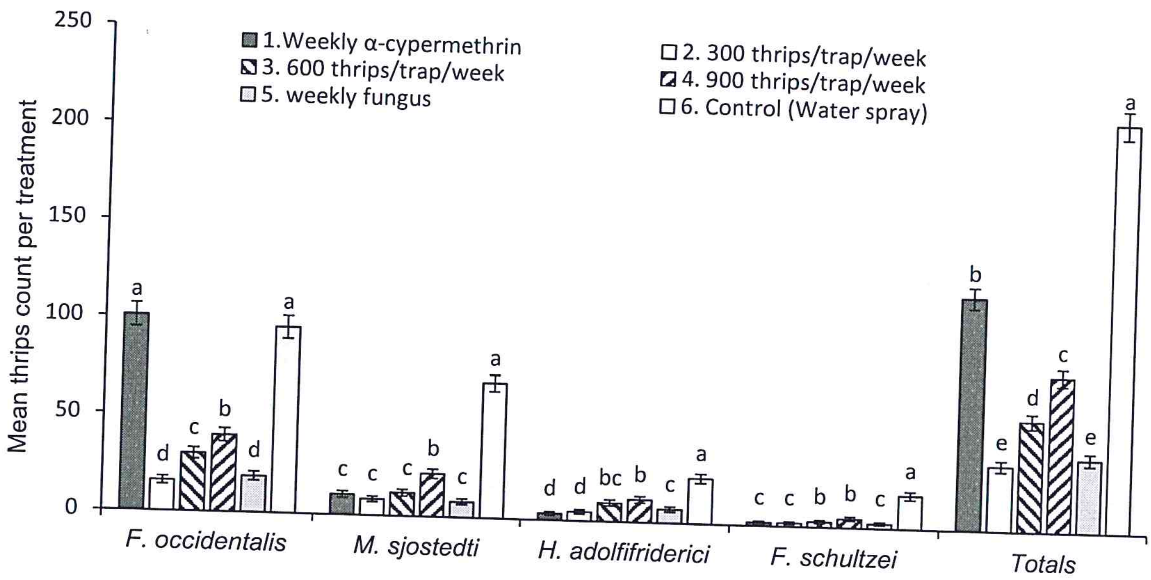

Figure 5.2: Mean number of adult thrips species on French beans as influenced by the treatments

Results (Table 5.1) indicated that thrips infestation caused both quantitative and qualitative yield losses. Quantitatively the total yield of French bean pods was 1285.41kg/ha in the untreated control as compared to 3365.27 and 3455.5Kg/ha in weekly application of fungus and threshold of 300 thrips per sticky trap treatments. This indicated the quantitative yield loss due to thrips infestation under untreated conditions could be up to 62.8%. Qualitatively the unmarketable yield was as high as 259.92 kg (16.77% of the total yield) in the untreated control while it was least in the 300 thrips/trap/week based application of fungus treatments 8.53 (0.25% of the total yield) ($F_{5, 15}$ = 313.04, P <0.0001). Highest marketable yield was obtained from a threshold of 300 thrips per trap (3456.18 ± 208.58) while the lowest was obtained from the untreated control (1283.33 ± 79.04) ($F_{5, 15}$ = 38.94, P <0.0001). Application of *M. anisopliae* at 300 thrips (3456.18 ± 208.58) and weekly sprays of *M. anisopliae* (3371.57 ±203.54) were equally effective as the treatment with weekly spray of alpha cypermethrin (3277.87 ± 197.92) in the production of marketable yield ($F_{5, 15}$ =38.94, P<0.0001). The unmarketable yield was highest in untreated plots (259.92 ± 8.07) while it was least in plots with a threshold of 300 thrips per trap (8.53 ± 1.45) ($F_{5, 15}$ =313.04, P<0.0001).

The total yield per hectare in the *M. anisopliae* treated plots increased with increase in the threshold level for control and it was maximum when the fungus was applied corresponding to a minimum threshold of 300 thrips per trap ($F_{5, 15}$ = 40.02, P <0.0001; Table 5.1). However, the cost of plant protection to maintain thrips population at lower threshold was higher because of more frequent sprays (Table 5.2). The highest cost of protection was incurred for chemical sprays (Ksh. 9366.66) while the lowest cost was incurred at a threshold of 900 thrips (Ksh. 2310.00). Hence, the net income was lowest at application of fungus at maximum threshold due to decreased yield and more unmarketable yield. The cost of alpha cypermethrin application was higher than that of fungus application and this resulted in low cost benefit ratio for the pesticide treatment at weekly interval (1:7.52) while CBR for plots sprayed 3 times at minimum threshold of 300 thrips (1:15.03) was the highest (Table 5.2). The optimum threshold level for use of the fungus was fixed at 300 thrips per blue sticky trap with kairomonal attractant since the net income was at maximum.

Table 5.1: Mean weight (kg/ha) of total yield, marketable and unmarketable French bean pods from different treatments 1st November 2010 – 11th January 2011

Treatment	No. of sprays	Yield of French bean (Kg per ha		
		Total yield	Marketable weight (kg)	Unmarketable weight (kg)
1. Weekly α-cypermethrin	10	3357.87 ± 167.20a	3277.87 ± 197.92a	79.48 ± 4.44b
2. Fungus at 300 thrips	8	3465.42± 172.50a	3456.18 ± 208.58a	8.53 ± 1.45e
3. Fungus at 600 thrips	5	2451.06± 122.77b	2422.34± 146.87b	30.09 ± 2.73d
4. Fungus at 900 thrips	3	2253.33 ±113.14b	2208.33 ±134.17b	46.77 ± 3.40c
5. weekly fungus	10	3381.57 ±168.41a	3371.57 ±203.54a	9.53 ± 1.53e
6. control (water spray)	-	1549.80 ± 78.69c	1283.33 ± 79.04c	259.92 ± 8.07a
F- value (5, 15)		40.02	38.94	313.04
P- value		<0.0001	<0.0001	<0.0001

Within column, means followed by the same letter were not significantly different (P<0.05) by Tukey's HSD test

Table 5.2: Mean yield of French beans, gross return cost of production, net return and marginal rate of return for different spray schedule of *M. anisopliae* and Alpha cypermethrin, 1st November 2010 – 11th January 2011

Treatment [w]	No. of sprays	Yield (Kg/ha) [x]	Yield over control (Kg/ha)	Gross income (Ksh/ha) [y]	Total cost of inputs/ha [z]	Net Income/ha	Cost: Benefit ratio
1. Weekly α-cypermethrin	10	3281.25a	1995.84	79833.60	9366.66	70466.90	1:7.52
2. Fungus applied at 300 thrips/trap/week	8	3455.55a	2170.14	86805.60	6160.00	80645.60	1:13.09
3. Fungus applied at 600 thrips/trap/week	5	2417.36b	1131.95	45278.00	3850.00	41428.00	1:10.76
4. Fungus applied at 900 thrips/trap/week	3	2211.11b	925.70	37028.00	2310.00	34718.00	1:15.03
5. Weekly fungus	10	3365.27a	2079.86	83194.40	7700.00	75494.40	1:9.80
6. Control (water spray)	-	1285.41c	-	-	-	-	-

[w] All the fungus treatments were applied at 1x 10^{11} colony forming unit (CFU)/ ml; alpha cypermethrin 10EC was applied at 3ml/12 l

[x] Within column, means followed by the same letter were not significantly different ($P<0.05$) by Tukey's HSD test

[y] Average value of French beans at farm gate: Ksh.40 per kg

[z] Cost of fungus treatment per spray per ha: Ksh 400/ha +270 Labour +100 Sprayer charge ; cost of alpha cypermethrin treatment per spray per ha: Ksh. 566.6/ha + 270 Labour +100 Sprayer charge

5.5 Discussion

Application of *M. anisopliae* at weekly intervals or at thresholds of 300 thrips per blue trap with kairomonal attractant was equally effective compared to the application of insecticide at weekly intervals. All the thrips species observed on French beans were found to be susceptible to the entomopathogenic fungi. Application of the fungus has been reported to reduce the populations of *M. sjostedti* on cowpea (Ekesi *et al.,* 1998), *Thrips tabaci* Lindeman on onions (Maniania *et al.,* 2003) and *F. occidentalis* on French beans, and subsequently increase the crop yield (Maniania *et al.,* 1997). Results of the present study indicated that *F. occidentalis* was not controlled using synthetic pesticides due to a possible development of resistance (Allsopp, 2010). Widespread use of chemical insecticides for WFT control has led to increased resistance against the major classes of insecticides (Jensen, 2000; Nderitu *et al.,* 2001; Nderitu *et al.,* 2007; Nderitu *et al.,* 2010). Further synthetic pesticides are expensive, ecologically not safer and incompatible with natural enemies (Nderitu *et al.,* 2010). Bio pesticides have been accredited for their compatibility with natural enemies (Thungrabeab *et al.,* 2007; Waiganjo *et al.*, 2008).

However benefits of *M. anisopliae* could be only maximized when they are applied judiciously at appropriate threshold levels of the pest (Ekesi *et al.,* 2001). In the present study, the net benefit accrued to the farmer was highest when *M. anisopliae* applied at a threshold of 300 thrips per trap and the number of sprays required maintaining the thrips population at this threshold level was only 8 sprays as compared to 10 sprays for a weekly spray schedule. Nderitu *et al.,* 2001 reported that farmers make up to 15 sprays per planting season. A similar decrease in the number of sprays of synthetic pesticides with lower threshold values for management of *M. sjostedti* and *F. occidentalis* on French beans (Nderitu *et al.*, 2008) and onion thrips (Nault and Shelton, 2010) have been reported. Ekesi *et al.* (2001) also observed that timing of *M. anisopliae* application was very critical for its effectiveness to control *M. sjostedti* on cowpea. However, in terms of cost benefit ratio values the application of fungus at the 900 thrips per trap provided the higher benefits for the cost incurred in management of the thrips. However, as the overall yield was less the net income were low at 900 thrips per trap threshold due to increased damage by thrips and reduced yield. Subramanian *et al.* (2010), who also found higher cost: benefit ratio for application of *Plutella xylostella granulovirus* against diamondback moth at higher threshold levels requiring lesser sprays although the net income was lesser due to higher damage due to the pest.

In the present investigation, ETL based on the economic optimization model was estimated at 300 thrips per blue sticky traps with kairomonal attractants per week placed at a trap density of 36 m^2 when the net income was highest. Considering traps only, Shipp *et al.* (2000) estimate threshold at between 20 and 50 thrips per trap/day on a cucumber crop with traps at a density of roughly 1 trap per 35 m^2. Scouting facilitation for better timing of intervention (Pizzol *et al.,* 2010) is an important consideration given that thrips are difficult to bring under control once populations have reached high levels. Growers who normally follow a calendar based spray will benefit from scouting if they discover that control measures are not necessary at certain times of the year. A survey conducted among growers of cut orchids showed that growers who based their control-use decisions on the results of scouting for pests made 45% fewer applications of pesticide products compared with those who followed a calendar approach (Hollingsworth *et al.*, 2000).

5.6 Conclusion

Our findings indicate that reliable and regular monitoring of the thrips population dynamics is essential for timely and need based application of eco-friendly pest management tools like entomopathogenic fungi, M. anisopliae. Higher yields and net incomes were obtained at economic thresholds of 300 thrips per trap per week. Thresholds based on attraction to blue sticky traps with LUREM-TR were found to be effective for the timely and optimum application of entomopathogens saving in terms of both the quantity of fungus applied and the labour for application without affecting the effectiveness of the fungus. Optimum thresholds for the fungus application also enable farmers to effectively incorporate fungus as a management tool in their pest management program.

CHAPTER 6

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Trap catches are a common sampling method used by growers globally for monitoring pest population in greenhouses and field conditions but remains unknown in Kenya. This study results indicate that blue traps are the most attractive colour to thrips complex found on tomato and French beans here in Kenya except *H. adolfifriderici*. Additionally blue sticky trap can be used for monitoring of dipterans on French beans and the tomato crops. Yellow traps have the potential for use to monitor *H. adolfifriderici*, aphids, whiteflies, hoppers, coleopterans, coccinelids and hymenopterans. The LUREM-TR attractant increases the captures of thrips on traps except for *C. brunneus* which was not responsive.

The use of blue coloured traps with kairomone LUREM-TR emerges as the best sampling method for early detection of presence of thrips on the crop. Highest positive and significant correlation is found between the thrips captures on the blue sticky traps with LUREM-TR and the actual population of thrips on the plants. This indicates the validity of these traps to reflect the actual population of thrips in both tomato and French bean crops. Weather parameters have a significant influence on the population dynamics of thrips on French beans and tomato. Rainfall and minimum temperatures reduces thrips population while maximum temperatures, wind run positively correlated and thus increases thrips population. Weekly application of *M. anisopliae* and application of fungus at a threshold of 300 thrips/ trap/week is equally effective as weekly application of insecticides. Application of *M. anisopliae* at a threshold of 300 thrips per trap per week provides the maximum net income and further the quality of the French beans pods is high.

6.2 Recommendations

Despite the potential of coloured traps with kairomone for monitoring thrips and their usage for optimal intervention using entomopathogenic, their utilization has been low or never thought of in East Africa. Therefore to further their potential and utilization in the management of thrips and other pests on French beans and tomatoes the following are recommended:

- Optimal use of blue sticky traps for thrips population monitoring in terms of location, height above ground, trap size and spatial density.
- Develop fungus application strategies combining LUREM TR attractant and entomopathogens.
- Validation of threshold levels at farmer level. These ETLs should also be examined on different varieties and cultivars of French beans and tomatoes to minimize the cost of control to the farmer.

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