

**Field ecology of western flower thrips *Frankliniella occidentalis* in French
bean agroecosystems in Kenya**

von der Naturwissenschaftlichen Fakultät
der Gottfried Wilhelm Leibniz Universität Hannover
zur Erlangung des Grades

Doktor der Gartenbauwissenschaften

Dr. rer. hort.

genehmigte Dissertation

VON

Johnson Nyasani Ounya (Master of Science)

Geboren am 03. Januar 1982 in Nyamira, Kenia

2012

Referenten

Referent: Prof. Dr. Hans-Michael Poehling
Leibniz Universität Hannover
Institute of Plant Diseases and Plant Protection
Herrenhäuser Strasse 2, D-30419 Hannover, Germany

Korreferent: Prof. Dr. Gerald Moritz
University of Halle
Institute of Zoology
Domplatz 4, 06108 Halle, Germany

Drittprüfer: Prof. Dr. Hartmut Stützel
Leibniz Universität Hannover
Vegetable Systems Modelling
Herrenhäuser Strasse 2, D-30419 Hannover, Germany

Tag der Promotion: 25 April 2012

DEDICATION

This work is dedicated to
my parents (Joseck & Josephine),
wife (Terry),
and
daughter (Sandra)

ABSTRACT

Western flower thrips (WFT), [*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)], is one of the most important pests of French beans (*Phaseolus vulgaris* L.) in Kenya. Control of WFT is difficult because it has a wide host range, high reproduction rate, cryptic feeding habit, and ability to pupate in soil. Development of sustainable integrated pest management (IPM) strategies against the WFT requires a sound understanding of its field ecology in terms of colonisation pattern, seasonal abundance, and feeding and oviposition behaviour. An understanding of seasonal abundance of WFT is important in predicting when and where economically damaging populations may occur, understanding how crop damage occurs, planning efficient sampling protocols, and in developing effective management programmes that are area specific. Information on feeding and oviposition preference of WFT is a key research need for formulation of IPM strategies based on manipulation of cropping systems. However, the above named aspects have not been studied in details within French bean fields in Kenya.

Therefore, the objectives of this study were to determine (1) seasonal abundance of WFT and its natural enemies in French bean agroecosystems in Kenya, (2) the effect of intercrops on thrips species composition and population density on French beans, and (3) feeding and oviposition preference of WFT for crops and weeds encountered in French bean fields in Kenya.

To determine the seasonal abundance of WFT and its natural enemies in field-grown French beans in Kenya, field studies were conducted in two major French bean agroecological zones in Kenya from January 2009 to December 2009. French beans were sampled every two weeks for WFT and natural enemies. Colonisation of French beans with WFT in both small and large scale farms in high and mid altitude zones started at 2- and 3-leaf stage, respectively. There was an increase in the number of WFT from budding stage to podding/flowering stage. A decline in population density of WFT was at crop senescence. Two natural enemies of thrips, [*Orius* spp. (Hemiptera: Anthocoridae) and *Ceraninus menes* (Walker) (Hymenoptera: Eulophidae)], were recorded on French beans in all agroecological zones and their population grew in tandem with the population of WFT. Temperature and relative humidity were weakly correlated with the population density of WFT, while rainfall had a negative effect on the population density of WFT. Overall, the population density of WFT was least in the first growing season (January – April) which was in the long rains season. Higher population densities of WFT on French beans in all farm sizes and agroecological zones were recorded in

the third growing season (September – December) which was in the short rains season. Results from this study suggest that seasonal abundance of WFT in the two agroecological zones is influenced by rainfall (depending on amount), phenological stage of French beans and surrounding host plants (where infestations on French beans arise from).

To study thrips species composition and thrips population density on French beans planted as a sole crop and as an intercrop with either sunflower, Irish potato, or baby corn, in different combinations field experiments were conducted in two seasons. French beans hosted four thrips species, *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), *F. occidentalis* (Pergande), and *Hydatothrips adolfifrigerici* (Karny) in order of decreasing abundance. The main thrips species on Irish potato and sunflower was *F. schultzei*. Baby corn hosted only *Frankliniella williamsi* (Hood) and *Thrips pusillus* (Bagnall). A monocrop of French bean hosted more thrips than a French bean intercrop mix. Plots with French bean alone had about 1.4 times higher yields compared to intercropped plots of French bean with sunflower and French bean with baby corn. However, the percentage of pods that could get rejected on the market due to thrips damage was highest on plots with French bean alone and lowest on French bean-baby corn intercrop mix. This study shows that French beans and its intercrops support different thrips species and in varying densities. Intercropping French beans with other crops compromises on French bean yield but reduces damage to the French bean pods, thereby enhancing marketable yield.

To determine the feeding and oviposition preference of WFT for crops and weeds commonly encountered in Kenyan French bean fields, no-choice and choice experiments were conducted using four important crop and weed plants. Among the crop plants tested, highest feeding and oviposition activity of WFT was recorded on *Cucurbita pepo* and *Phaseolus vulgaris*. All the other crop plants, *Beta vulgaris* and *Capsicum annum*, were of minor importance for WFT feeding and oviposition. Among the weeds tested, *Galinsoga parviflora* was the most preferred host plant for feeding and oviposition compared to *Nicandra physaloides*, *Erucastrum arabicum* and *Amaranthus hybridus*. The results of this study show that *P. vulgaris*, *C. pepo* and *G. parviflora* are both good feeding and oviposition hosts of WFT. *Cucurbita pepo* and *G. parviflora* and may serve as potential sources of WFT outbreaks within French bean fields.

Key words: Natural enemies, *Frankliniella schultzei*, *Hydatothrips adolfifrigerici*, *Megalurothrips sjostedti*, *Phaseolus vulgaris*, phenological stage, population density, Thysanoptera.

ZUSAMMENFASSUNG

Der Kalifornische Blüenthrips [*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)] ist einer der bedeutendsten Schädlinge der sehr häufig in Kenia angebauten Grünen Bohne oder Gartenbohne ("French bean") (*Phaseolus vulgaris* L.). Eine Kontrolle ist schwierig, da dieser Schädling ein großes Wirtsspektrum, eine hohe Reproduktionsrate, eine versteckte Ernährungsweise und die Fähigkeit sich im Erdboden zu verpuppen, hat. Die Entwicklung von nachhaltigen integrierten Pflanzenschutzstrategien gegen diesen Thrips erfordern daher ein fundiertes Verständnis der Ökologie dieser Art bezüglich Besiedlungsmustern, jahreszeitlicher Häufigkeit, Ernährungsweise sowie Eiablageverhalten. Das Verständnis der jahreszeitlichen Häufigkeit ist wichtig zur Vorhersage wann und wo Populationen in ökonomisch bedeutenden Dichten auftreten können, wie Schäden an Kulturpflanzen entstehen, zur Planung von geeigneten Sammelmethode und zur Entwicklung von wirksamen und gebietsspezifischen Managementprogrammen. Hierbei besteht insbesondere Forschungsbedarf bei Ernährungsweise und Eiablageverhalten von *F. occidentalis* zur Erarbeitung von integrierten Pflanzenschutzstrategien die auf der Veränderung von Anbausystemen beruhen. Trotzdem wurden alle diese oben erwähnten Aspekte bislang noch nicht detailliert in kenianischen Bohnen-Anbaugebieten untersucht. Ziele dieser Arbeit sind daher erstens die Erfassung der saisonalen Populationsdichte von *F. occidentalis* und der natürlichen Gegenspieler, zweitens zu bestimmen, welchen Effekt Mischkulturen auf das Artenspektrum und Populationsdichten von Thripsen auf Ackerbohnen haben und drittens, Nahrungs- und Eiablagepräferenzen von *F. occidentalis* für Kulturpflanzen und Unkräuter zu bestimmen. Um die jahreszeitlichen Populationsdichten von *F. occidentalis* und dessen natürlichen Gegenspieler zu ermitteln, wurden in zwei größeren Bohnen-Anbaugebieten in Kenia von Januar bis Dezember 2009 Felduntersuchungen durchgeführt. Die Besiedlung mit *F. occidentalis* begann sowohl in großen als auch kleinen Landwirtschaftsbetrieben in hoch- und mittelhoch gelegenen Gebieten im Zwei- bzw. Dreiblattstadium der Bohne. Die Thripsdichte nahm dabei vom Knospenstadium bis zur Blüte bzw. Fruchtbildung zu und bis zur Seneszenz der Pflanze wieder ab. Zwei Gegenspieler, [*Orius* spp. (Hemiptera: Anthocoridae) und *Ceraninus menes* (Walker) (Hymenoptera: Eulophidae)] wurden auf den Bohnenpflanzen in allen Anbaugebieten gefunden und ihre Populationen nahmen gleichzeitig mit denen von *F. occidentalis* zu. Temperatur und relative Luftfeuchte waren mit der Populationsdichte von *F. occidentalis* nur schwach korreliert, während Regen einen negativen Einfluss hatte. Insgesamt war die Populationsdichte von *F.*

occidentalis im ersten Anbauzeitraum von Januar bis April am geringsten, also während der „langen Regenzeit“ in Kenia. Höhere Populationsdichten wurden auf Bohnen bei allen Betriebsgrößen und Anbaugebieten im dritten Anbauzeitraum von September bis Dezember gefunden, der Abschnitt der Saison mit der „kurzen Regenzeit“ in Kenia. Die Ergebnisse dieser Arbeit deuten darauf hin, dass die jahreszeitliche Dichte von *F. occidentalis* in diesen beiden Anbaugebieten von der Intensität der Niederschläge, vom Wachstumsstadium der Bohne und von benachbarten Wirtspflanzen (von denen der Befall der Bohnen ausgeht) abhängt.

Um die Artenzusammensetzung der Thripse und deren Populationsdichten auf Bohnen zu erfassen, wurden Erhebungen an Bohnen, die entweder allein oder in Mischkultur mit Sonnenblumen, Kartoffeln, oder Zuckermais in verschiedenen Kombinationen gepflanzt wurden während zweier Anbauphasen durchgeführt. Auf Ackerbohnen wurden folgende vier Thripsarten in absteigender Häufigkeit gefunden: *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), *F. occidentalis* (Pergande), und *Hydatothrips adolfifriderici* (Karny). Die Hauptart auf Kartoffel und Sonnenblume war *Frankliniella schultzei*. Zuckermais wurde nur von *Frankliniella williamsi* (Hood) und *Thrips pusillus* (Bagnall) besiedelt. Bohnen-Monokulturen wiesen höhere Thripsdichten auf als Mischkulturen. Bohnen-Monokulturen hatten etwa einen 1,4-mal höheren Ertrag bei der Ernte im Vergleich zu Mischkulturen mit Sonnenblumen oder Mais. Jedoch war der prozentuale Anteil an wegen Thripsschäden nicht mehr marktfähigen Hülsen am höchsten bei Bohnen ohne Mischkultur im Vergleich zu solchen in Mischkulturen. Diese Arbeit zeigt, dass Bohnen und Zwischenfrüchte unterschiedliche Thripsarten in unterschiedlichen Dichten fördern. Obwohl durch Mischkultur die Erntemenge reduziert wird, erhöht sich der Anteil an marktfähigen Hülsen durch verringerte Schäden.

Um die Eiablage- und Nahrungspräferenzen von *F. occidentalis* für Kulturpflanzen und Ackerbegleitpflanzen, die in kenianischen Ackerbohnenfeldern regelmäßig vorkommen, zu untersuchen, wurden „choice“ und „no-choice“-Versuche mit vier wichtigen Pflanzenarten durchgeführt. Die höchste Saugaktivität und die meisten Eiablagen wurden auf *Curcubita pepo* und *Phaseolus vulgaris* festgestellt. Unter den untersuchten Ackerbegleitpflanzen war *Galinsoga parviflora* die am meisten präferierte Wirtspflanze für Nahrungsaufnahme und Eiablage im Vergleich zu *Nicandra physaloides*, *Erucastrum arabicum* und *Amaranthus hybridus*. Die Ergebnisse dieser Arbeit zeigen, dass *P. vulgaris*, *C. pepo* und *G. parviflora* sowohl gute Futterpflanzen als auch Eiablagepflanzen für *F. occidentalis* sind. *C. pepo* und

G. parviflora können mögliche Quellen für Massenvermehrungen von *F. occidentalis* in kenianischen Bohnenfeldern sein.

Schlagworte: Natürliche Gegenspieler, *Frankliniella schultzei*, *Hydatothrips adolfifriderici*, *Megalurothrips sjostedi*, *Phaseolus vulgaris*, Phänologische Entwicklungsstadien, Populationsdichte, Thysanoptera.

ABBREVIATIONS

ANOVA	Analysis of Variance
CORR	Correlation
HCDA	Horticultural Crops Development Authority
HSD	Honestly Significant Difference
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KARI	Kenya Agricultural Research Institute
L.	Linnaeus
L: D	Light: Darkness Photoperiod
LER	Land Equivalent Ratio
MASS	Modern Applied Statistics with S
MCMV	Maize Chlorotic Mottle Virus
SAS	Statistical Analysis System
SE	Standard Error
TSWV	Tomato Spotted Wilt Virus
UM2	Upper Midlands 2
WFT	Western Flower Thrips

TABLE OF CONTENTS

DEDICATION	III
ABSTRACT	IV
ZUSAMMENFASSUNG	VI
ABBREVIATIONS	IX
CHAPTER 1	1
GENERAL INTRODUCTION	1
1.0 IMPORTANCE OF FRENCH BEANS	1
1.1 IMPORTANCE OF PESTS AND DISEASES IN FRENCH BEANS IN KENYA	1
1.2 DAMAGE AND YIELD LOSS DUE TO THRIPS	2
1.3 PROBLEM STATEMENT AND JUSTIFICATION OF THE STUDY	2
1.4 OVERALL OBJECTIVE.....	4
1.4.1 Specific objectives	4
1.5 HYPOTHESES	4
CHAPTER 2	5
SEASONAL ABUNDANCE OF <i>FRANKLINIELLA OCCIDENTALIS</i> AND ITS NATURAL ENEMIES IN FRENCH BEAN AGROECOSYSTEMS IN KENYA	5
ABSTRACT	5
1.0 INTRODUCTION.....	6
2.1 MATERIALS AND METHODS	7
2.2 DATA ANALYSIS	9
2.3 RESULTS	10
2.3.1 Colonisation and temporal pattern of western flower thrips and its natural enemies in large-scale farms	10
2.3.2 Colonisation and temporal pattern of western flower thrips and its natural enemies in small-scale farms	14
2.4 DISCUSSION	18
2.5 CONCLUSIONS	21
CHAPTER 3	22
EFFECT OF INTERCROPS ON THRIPS SPECIES COMPOSITION AND POPULATION ABUNDANCE ON FRENCH BEANS	22
ABSTRACT	22
3.0 INTRODUCTION.....	23
3.1 MATERIALS AND METHODS	25
3.3 RESULTS	27
3.3.1 Thrips population development in 2009 and affinity to different crop plants	27
3.3.2 Population development of thrips species on French beans and intercrops.....	29
3.3.3 Effect of intercrops on the population density of natural enemies on French beans	34

3.3.4 Effect of intercrops on French bean yield.....	37
3.4 DISCUSSION	39
3.5 CONCLUSIONS	42
CHAPTER 4.....	43
FEEDING AND OVIPOSITION PREFERENCE OF <i>FRANKLINIELLA OCCIDENTALIS</i> FOR CROPS AND WEEDS ENCOUNTERED IN KENYAN FRENCH BEAN FIELDS	43
ABSTRACT.....	43
4.0 INTRODUCTION.....	44
4.1 MATERIALS AND METHODS	45
4.1.1 Insect and plant materials.....	45
4.1.2 No-choice and choice tests with crop plants.....	46
4.1.3 No-choice and choice tests with weed plants	48
4.1.4 Choice test with French beans and weeds.....	49
4.2 DATA ANALYSIS	50
4.3 RESULTS	50
4.3.1 Crop plants as feeding and oviposition sites.....	50
4.3.2 Weed plants as feeding and oviposition sites	52
4.3.3 French beans and weeds as feeding and oviposition sites	54
4.4 DISCUSSION	55
4.5 CONCLUSIONS	58
CHAPTER 5.....	59
GENERAL DISCUSSION	59
REFERENCES.....	63
ACKNOWLEDGEMENTS.....	75
CURRICULUM VITAE.....	76
DECLARATION.....	79

CHAPTER 1

GENERAL INTRODUCTION

1.0 Importance of French beans

French bean, *Phaseolus vulgaris* L. (Fabaceae), is the second most important horticultural crop after cut flowers in Kenya (HCDA, 2010). French beans constitute nearly 24% by volume and value of all fresh horticultural exports from Kenya (HCDA, 2010). Farmers also sell their produce to local restaurants and green grocers. French bean is cultivated by both small- and large-scale farmers across Central, Eastern, Western and Coast provinces of Kenya (Onkoba, 2002).

A cup of green French beans contributes very significantly to the vitamin A requirement and can be a moderate contributor of riboflavin, thiamin, calcium, iron and ascorbic acid (Kelly & Scott, 1992). French bean cultivation is labour intensive and requires high inputs compared to maize and most other traditional crops. However it fetches much better returns as compared to the traditional crops (Mwangi, 1998). Labour intensiveness results in creation of employment and improves the livelihoods of small- and large-scale farming communities. Semi-capital intensive nature of French bean production also offers good business to the service sectors like packing, transport, and financial institutions offering credits for production (Onkoba, 2002).

1.1 Importance of pests and diseases in French beans in Kenya

Pests and diseases are the major constraints towards French bean production in Kenya (Nderitu et al., 2007). The major insect pests affecting French bean production in Kenya are: bean stem maggot (*Ophiomyia* spp.), bean flower thrips [*Megalurothrips sjostedti* (Trybom)], western flower thrips [*Frankliniella occidentalis* (Pergande)], bean aphids [*Aphis fabae* (Scopoli)], the African bollworm [*Heliothis armigera* (Hubner)], the legume pod borer [*Maruca testularis* (Geyer)] and white flies [(*Bemisia tabaci* (Gennadius)]. However,

common blossom thrips, [*Frankliniella schultzei* (Trybom)], and *Hydatothrips adolfifrideric* (Karny) are also found infesting French beans (Nyasani et al., 2010, 2012). The pests reduce the quality and quantity of pod yields and affect the length of the production period. Major foliar diseases on French beans include: bean rust [*Uromyces appendiculatus* (Pers.)], bean anthracnose [*Collectotrichum lindemuthianum* (Sacc. et Magn.)], angular leaf spot [*Phaeoisariopsis griseola* (Sacc.)], and common bacterial blight [*Xanthomonas axonopodis* pv. *phaseoli* (Smith)] (Nderitu et al., 1997). Root rot diseases especially [*Fusarium oxysporum* (Schlecht) fsp. *phaseoli*] may also cause considerable yield loss (Nderitu et al., 1997).

1.2 Damage and yield loss due to thrips

Among the thrips species infesting French beans, western flower thrips (WFT) is regarded as the most important pest (Nderitu et al., 2009). In addition to the quantitative and qualitative damage by WFT to plant products through its direct feeding, it also vectors tospoviruses like tomato spotted wilt virus (TSWV) (Kirk, 2002). In Kenya, yield losses of more than 40% due to abscission of flower buds and flower abortion caused by thrips have been reported (Löhr, 1996; Kibata & Anyango, 1996). Additional yield losses due to direct feeding damage of thrips on French bean pods are estimated at 63 – 68% in Kenya (Nyasani et al., 2012).

1.3 Problem statement and justification of the study

Studies on the French bean industry in Kenya indicate lack of proper pests and disease management as major constraints to the improvement of bean production (Nderitu et al., 2007). Western flower thrips is regarded as the most important pest of French beans in Kenya (Nderitu et al., 2009). The shorter life cycle of WFT enable several overlapping generations of thrips within a production cycle of a given crop (Weintraub, 2007). Hence, commercial growers often resort to repeated and indiscriminate application of several groups of insecticides to control thrips (Nderitu et al., 2007, 2008). Foliar sprays of chemical

insecticides often fail to manage thrips because of their cryptic feeding behaviour (Kirk, 1997) and ability to pupate in soil (Berndt et al., 2004). In turn repeated and frequent applications of chemical insecticides against WFT have resulted in development of resistance by the WFT (Jensen, 2000; Nderitu et al., 2007, 2008). Frequent application of insecticides also adversely affects the natural enemies in the ecosystem, pollutes the environment and leaves toxic residues in the harvested produce which are harmful to the consumers and affect the marketability of the produce (Nderitu et al., 1997).

An effective pest management strategy against WFT probably should combine a range of control measures (forecasting, conservation, judicious use of chemical pesticides and biological control options, cultural and physical control options, and combination of these techniques) targeting both foliar-feeding and soil-dwelling development stages of the pest. This requires information on the field ecology of WFT in terms of its colonisation pattern, seasonal abundance, host-plant interactions, feeding and/or oviposition preference for crop and weed plants within croplands. Understanding the colonisation pattern of WFT is important in understanding how crop damage occurs, planning efficient sampling protocols, and developing sustainable pest management strategies (Hansen et al., 2003). An understanding of seasonal abundance of thrips is also important in predicting when and where economically damaging populations may occur, and in developing effective management programmes that are area specific (Northfield et al., 2008). Understanding the feeding and oviposition preference of WFT is a key research need for formulation of integrated pest management (IPM) strategies based on manipulation of cropping practices. However, detailed studies on these aspects in French bean agroecosystems in Kenya have not been conducted so far. Therefore, the aim of this study was to generate baseline information on the field ecology of WFT in French bean agroecosystems in Kenya. The following were the objectives and hypotheses of this study.

1.4 Overall objective

This study was set to generate baseline information on the field ecology of WFT in French bean agroecosystems in Kenya.

1.4.1 Specific objectives

1. To determine the seasonal abundance of western flower thrips and its natural enemies in French bean agroecosystems in Kenya.
2. To determine the effect of intercrops on thrips species composition and population abundance on French beans.
3. To determine the feeding and oviposition preference of western flower thrips for crops and weeds encountered in Kenyan French bean fields.

1.5 Hypotheses

1. Seasonal abundance of western flower thrips and its natural enemies in French bean in different agroecosystems is not the same.
2. Thrips population density on French beans in the intercrop mix (Irish potato, sunflower or baby corn) and monocrop of French beans is different.
3. Feeding and oviposition preference of western flower thrips for crops and weeds commonly encountered in French bean fields is different.

CHAPTER 2

SEASONAL ABUNDANCE OF *FRANKLINIELLA OCCIDENTALIS* AND ITS NATURAL ENEMIES IN FRENCH BEAN AGROECOSYSTEMS IN KENYA

Abstract

The aim of this study was to determine the seasonal abundance of western flower thrips (WFT), [*Frankliniella occidentalis* (Thysanoptera: Thripidae)], and its natural enemies in two major French bean agroecosystems in Kenya. Field studies were conducted in two agroecosystems from January to December 2009. French beans were sampled every two weeks for WFT and natural enemies. Colonization of French beans with WFT in both small- and large-scale farms in high- and mid-altitude zones started at 2- to 3-leaf stage. There was an increase in the population density of WFT from budding stage to podding/flowering stage and it declined at crop senescence. Two natural enemies of thrips, [*Orius* spp. (Hemiptera: Anthocoridae) and *Ceraninus menes* (Walker) (Hymenoptera: Eulophidae)], were recorded on French beans. The population density of *C. menes* was positively correlated with the population density of WFT. The population density of WFT was not correlated with temperature and relative humidity, but was negatively affected by rainfall. The population densities of WFT on French beans were least in the first growing season and highest in the third growing season. The population densities of WFT in the second growing season were slightly higher than those recorded in the first growing season. Results from this study suggest that seasonal abundance of WFT in the two agroecological zones is influenced by the growing season and phenological stage of French beans. Management strategies targeted at WFT would need to start at 3-leaf stage (guided by weekly scouting) to prevent further build-up of thrips population.

Key words: Agroecological zone, *Ceraninus menes*, *Orius*, phenological stage

1.0 Introduction

French bean, *Phaseolus vulgaris* L. (Fabaceae), is the second most important horticultural crop after cut flowers in Kenya, with estimated exports of 18,275 metric tons and a market value of KES 4.4 billion (HCDA, 2010). French beans are grown all year round by both small- and large-scale farmers. Pests and diseases are the major constraints towards French bean production in Kenya (Nderitu et al., 2007). Among arthropod pests of French beans, western flower thrips (WFT), [*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)], is ranked as a major pest in Kenya (Nderitu et al., 2009). However, other thrips species such as *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), and *Hydatothrips adolfifriderici* (Karny) also infest French beans (Nyasani et al., 2010, 2012). Western flower thrips is an invasive pest from western North America and it has spread to most parts of the world (Kirk & Terry, 2003). In Kenya WFT was first reported in 1989 (Kedera & Kuria, 2003). Western flower thrips is polyphagous (Tommasini & Maini, 1995) and has a high reproduction rate (Weintraub, 2007). At moderate temperatures (20 – 25 °C), WFT takes about 2 – 3 weeks to complete its lifecycle, but at 30 °C it may take less than 10 days (Tommasini & Maini, 1995).

Production of French beans all-year in Kenya ensures that thrips have a suitable and continuous breeding environment. The population density of WFT has been reported to peak after the flowering period (Gitonga, 1999; Nyasani et al., 2010, 2012) and during the dry spell (Gitonga 1999) in French bean fields in Kenya. Population dynamics and colonization pattern studies on field pepper and cotton have also reported that WFT inhabits the plants during the reproductive growth stages (Hansen et al., 2003; Osekre et al., 2009). A couple of natural enemies including predators (*Orius* spp.) and parasitoids (*Ceranisus* spp.) have been identified so far as thrips antagonists on French beans in Kenya (Kasina et al., 2006). In Kenya there is a growing need to further develop plant protection strategies for WFT due to the reports on its development of resistance to the commonly used insecticides (Nderitu et al.,

2008; Nyasani et al., unpublished data), but detailed information on pest and natural enemy population dynamics in field-grown French beans is still scarce. Therefore, the objective of this study was to determine abundance and colonization pattern of WFT and natural enemies on French beans throughout the year in real farming situations in different agroecological zones in Kenya with an aim to identify drawbacks and opportunities in integrated pest management of WFT.

2.1 Materials and methods

On-farm studies on the colonization pattern and seasonal abundance of WFT and its natural enemies on French beans were conducted in two agroecological zones in Kenya: high- and mid-altitude zones. Two study sites, Thika and Embu, were located in the mid-altitude zone (900 – 1,900 m a.s.l) while Nakuru and Naivasha represented the high-altitude zone (1,900 – 2,700 m a.s.l). Mid-altitude zones receive bimodal rainfall with long rains season starting from mid March to late May and short rains season from mid October to mid December. Intermittent rainfall is experienced between the two distinct rainfall seasons. Conversely, high-altitude zones receive unimodal rainfall from early March to early June; intermittent rainfall is received in the rest of the months. However, there is a cool-dry spell from July to September in the two agroecological zones. In each study site, one large-scale French bean farmer, and two small-scale French bean farmers were identified. All the selected farm fields were characterized by fairly flat landscapes and well drained soils. Small-scale farms ranged from 0.5 – 1.0 hectares in size whereas large-scale farms were more than 16 hectares in size. In small-scale farms, French bean was grown under surface irrigation (furrow irrigation) during the dry spell and rain-fed in rainy seasons in all agroecological zones. In large-scale farms, French bean was grown under sprinkler irrigation in all agroecological zones. *Phaseolus vulgaris* var. Teresa was the commonly grown French bean variety in all study sites by both small- and large-scale farmers.

In mid- and high- altitude zones in Kenya, French beans are grown throughout the year with three growing seasons per year: January to April, May to August, and September to December. French beans are normally grown side by side or in rotation with other horticultural crops such as zucchini, sweet pepper, spinach beet, and baby corn in small-scale farms. Conversely, French beans are grown as a sole crop in large-scale farms. Kenyan French bean farmers mainly use synthetic pyrethroids to manage WFT. Field observations were made every second week from January 2009 to December 2009. In each French bean field, 10 individual French bean plants were randomly sampled for thrips and natural enemies in a diagonal line transect originating from one corner of the field to the other. The sampled plants were individually beaten over a white enamel tray for 15 seconds at each sampling time. The thrips and natural enemies in the different developmental stages collected on the tray were counted, collected, and placed in small vials containing 95% ethyl alcohol. Sampling was done in the morning between 7.30 to 10.00 hours when thrips are known to be not very active. When French bean plants were at flowering stage, three flowers per plant were randomly collected from 10 individual plants in each French bean field and placed in small plastic vials containing 95% ethyl alcohol. Thrips were extracted from the flowers in the laboratory. All thrips specimens were further processed in the laboratory and identified to species level using the LucID key developed by Moritz et al. (2004). *Ceranisus* specimens collected were described to species level by Triapitsyn (University of California). *Orius* spp. were not identified to species level.

The phenological stage of French beans was recorded at each observation. Phenological stages of French beans were classified into eight classes adopted from Feller et al. (1995): 2-leaf stage (first pair of leaves unfolded), 3-leaf stage (first trifoliolate leaf unfolded), 5-leaf (5th true leaf unfolded), budding stage (first flower buds visible-first petals visible, flowers still closed), flowering (first flowers open, > 50% flowers open), podding/flowering stage

(beginning of pod development, flowering finishing or majority of petals fallen or dry), podding stage (> 80% of pods have reached maturation stage, end of flowering stage), and senescence stage (leaves yellowing, browning and falling). The prevailing weather conditions (temperature, relative humidity, and rainfall) in each study site were recorded throughout the study period at neighbouring meteorological stations 200 – 500 m away.

2.2 Data analysis

Numbers of thrips, *Ceranisus menes* and *Orius* spp. per plant at each phenological stage of French beans were subjected to repeated measures analysis of variance (RM-ANOVA) using R 2.13.1 (R Core Development Team, 2010). Agroecological zone (mid- or high-altitude zone), growing season (1st, 2nd, and 3rd season), and phenological stage were included as factors in the analysis. Significant differences in the mean number of thrips and natural enemies between agroecological zones, growing seasons or phenological stages were compared using Tukey's HSD test at $P < 0.05$. Pearson's product-moment correlation in R (R Core Development Team 2010) was used to determine effect of temperature, relative humidity, and rainfall on the population density of thrips in small-scale farms. Thrips counts per month in each farm were correlated with average monthly temperature, relative humidity, and rainfall. The population densities of WFT and natural enemies recorded in each farm were also correlated. Thrips counts in large-scale farms were not included in the correlation analysis with the prevailing weather conditions because French bean was grown under sprinkler irrigation in these farming systems. Further, it was expected that sprinkler irrigation could act as rain and wash off thrips from the French bean plants, cause flower drop, and influence relative humidity and temperature. The differences in thrips count between small- and large-scale farms were not compared because of the differences in farm size, cropping system and type of irrigation adopted.

2.3 Results

2.3.1 Colonisation and temporal pattern of western flower thrips and its natural enemies in large-scale farms

A three-way interaction between agroecological zone, growing season, and phenological stage on the population density of WFT was not significant ($F_{12, 40} = 0.6677$, $P = 0.991$). However, the population densities of WFT recorded in the different phenological stages and growing seasons were significantly different (phenological stages: $F_{7, 40} = 3.929$, $P = 0.002$, growing seasons: $F_{2, 40} = 3.311$, $P = 0.046$). In general, colonization of French beans with WFT started at 2- and 3-leaf stages in the high- and mid-altitude zones, respectively (Fig. 1A and 2A). The population density of WFT on French beans in the high- and mid-altitude zones was relatively low (< 3 thrips/plant) from 2-leaf to 5-leaf stage in all growing seasons (Fig. 1A and 2A). There was a 2 – 3 fold increase in the population density of WFT from 5-leaf to budding stage in all growing seasons in mid-altitude zones, but in high-altitude zones the increase was only in the third growing season (Fig. 1A and 2A).

Western flower thrips population reached peak densities in the high-altitude zone at podding stage in all growing seasons (Fig. 1A). Conversely, peak densities were reached at podding/flowering in the second and third growing season and podding stage in the first growing season in mid-altitude zones (Fig. 2A). In most farm fields WFT population densities declined after reaching its maximum (Fig. 1A and 2A). The only exception was the third growing season in the mid-altitude zone where population densities remained on a high level (54 thrips/plant) until crop senescence (Fig. 2A). The effect of temperature, relative humidity and rainfall on the population density of WFT is not presented here because French beans were grown under sprinkler irrigation in the large-scale farming systems (see above).

Two natural enemies of thrips, [*Orius* spp. (Hemiptera: Anthocoridae) and *Ceraninus menes* (Walker) (Hymenoptera: Eulophidae)], were recorded on French beans. The combined effect of agroecological zone, growing season and phenological stage did not have an effect on the

population density of *Orius* spp. and *C. menes* recorded on French beans (*Orius* spp.: $F_{12, 40} = 0.857$, $P = 0.593$, *C. menes*: $F_{12, 40} = 0.856$, $P = 0.594$, respectively). The individual factor effect of agroecological zone, phenological stage and growing season on the population density of *Orius* spp. was also not significant (agroecological zone: $F_{1, 40} = 0.891$, $P = 0.350$; phenological stage: $F_{7, 40} = 0.5385$, $P = 0.800$, growing season: $F_{2, 40} = 2.18$, $P = 0.125$). Colonization of French beans with *Orius* spp. started at flowering and budding stage in the high- and mid-altitude zones, respectively (Fig. 1B and 2B).

The effect of phenological stage on the population density of *C. menes* recorded on French beans was significant ($F_{7, 40} = 7.842$, $P < 0.001$). Colonization of French beans with *C. menes* started at podding/flowering stage in both high- and mid-altitude zones (Fig. 1C and 2C, respectively). There was a two fold increase in the population density of *C. menes* from podding/flowering stage to podding stage in the two agroecological zones (Fig. 1C and 2C). In contrast to population development of *Orius* spp. there was a sharp decline in the population density of *C. menes* at crop senescence in the high-altitude zone in all growing seasons (Fig. 1C) while in the mid-altitude zone, the population density of *C. menes* was at the increase (≥ 1 *C. menes*/plant) at crop senescence in the first and second growing season but was absent in the third growing season (0 *C. menes*/plant) (Fig. 2C). Population densities of WFT and *C. menes* were positively correlated ($r = 0.214$, $df = 94$, $P = 0.036$). There was no correlation between the population densities of WFT and *Orius* spp. ($r = 0.029$, $df = 94$, $P = 0.777$).

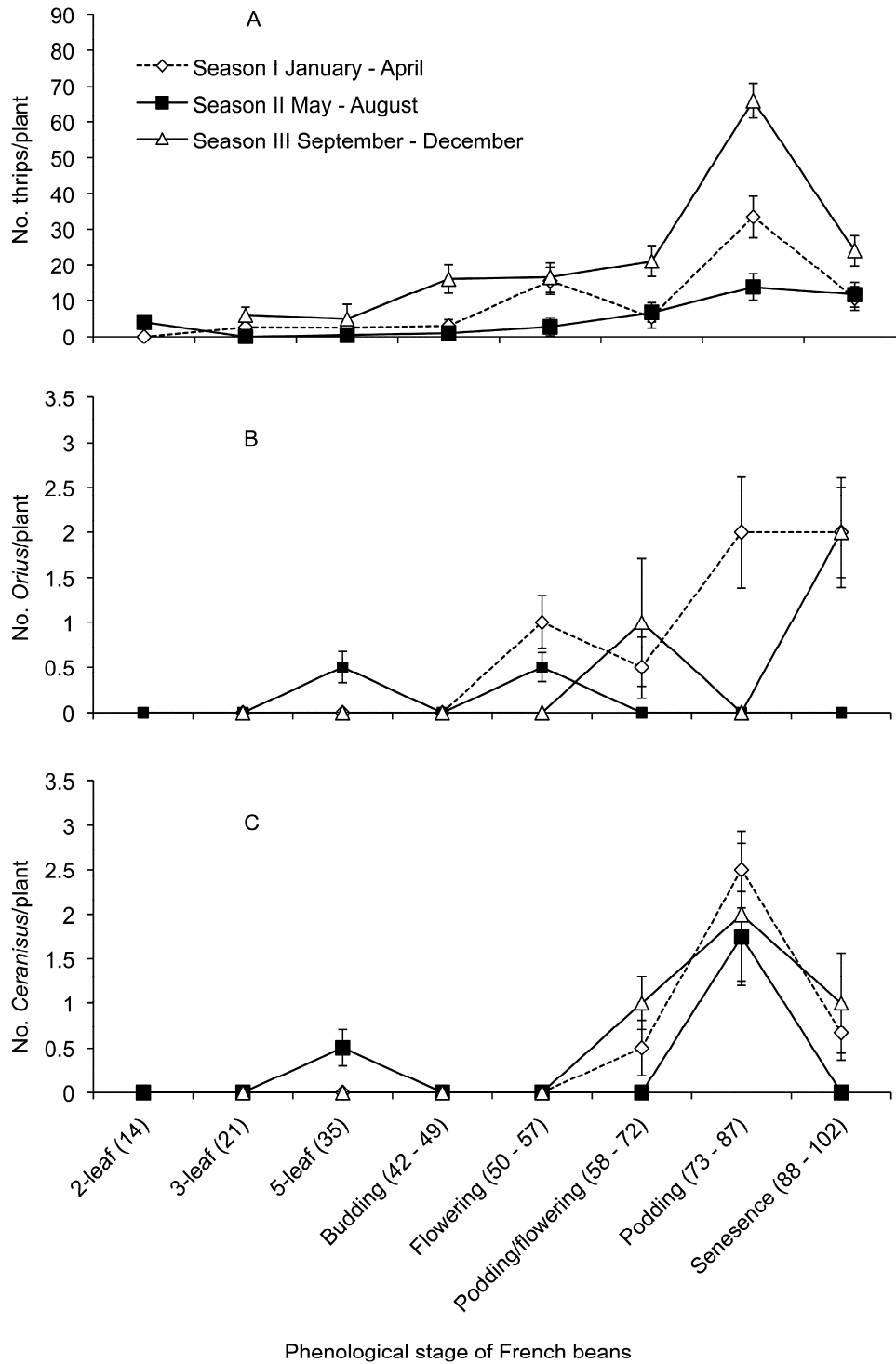


Figure 1. Mean number (\pm SE) of *Frankliniella occidentalis* (A), *Orius* spp. (B) and *Ceranisus menes* (C) per French bean plant at different phenological stages of French beans in the various growing seasons in large-scale farms in high-altitude zone. Numbers in brackets represent number of days after planting (DAP).

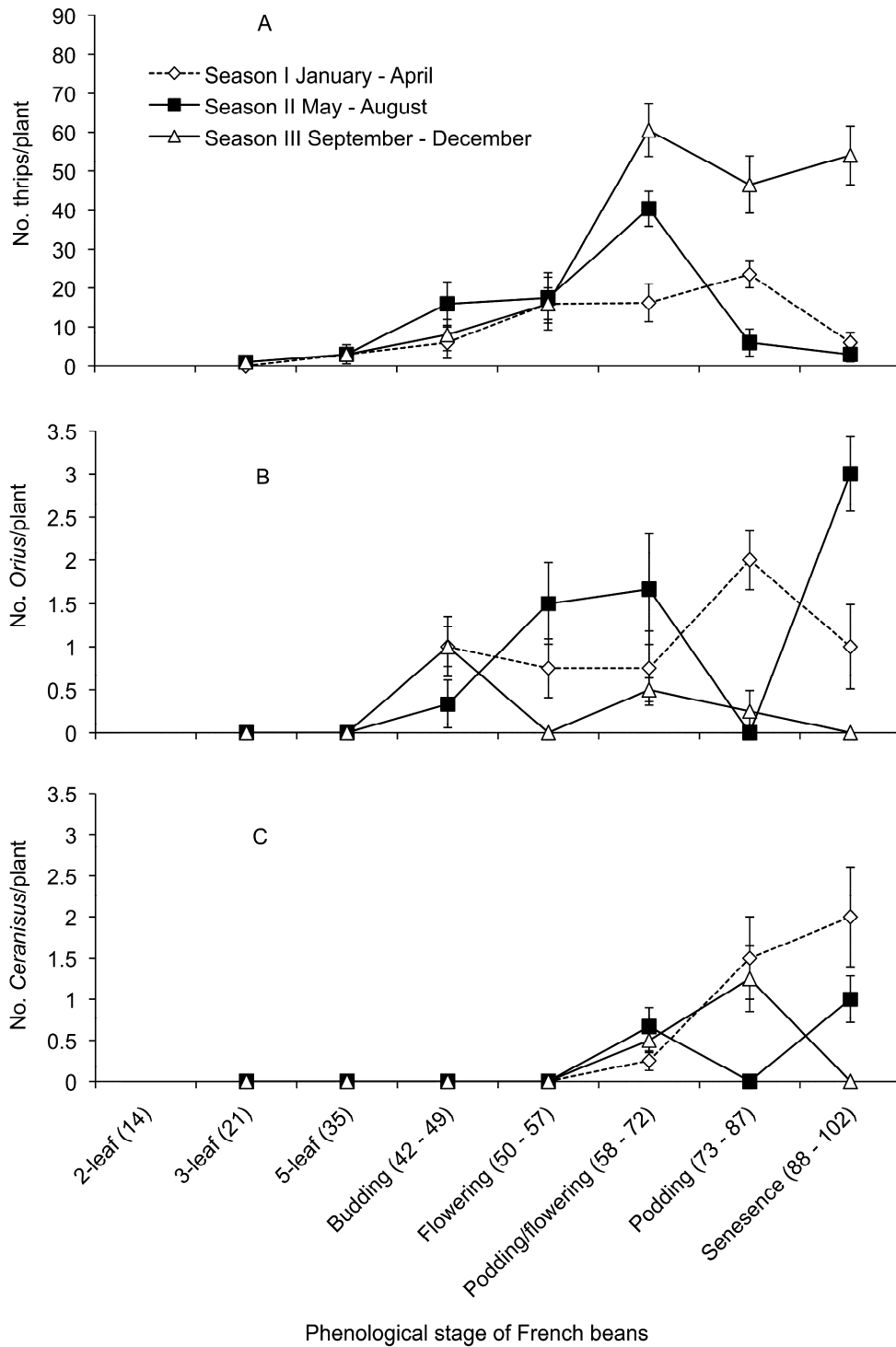


Figure 2. Mean number (\pm SE) of *Frankliniella occidentalis* (A), *Orius* spp. (B) and *Ceranisus menes* (C) per French bean plant at different phenological stages of French beans in the various growing seasons in large-scale farms in mid-altitude zone. Numbers in brackets represent number of days after planting (DAP).

2.3.2 Colonisation and temporal pattern of western flower thrips and its natural enemies in small-scale farms

A three-way interaction between agroecological zone, growing season, and phenological stage did not have an effect on the population density of WFT recorded on French beans ($F_{12, 154} = 0.763$, $P = 0.682$). However, there was variation in the number of WFT recorded in the different phenological stages and growing seasons ($F_{7, 154} = 5.061$, $P < 0.001$ and $F_{2, 154} = 15.375$, $P < 0.001$, respectively). Colonization of French beans with WFT started at 2-leaf stage in the high- (Fig. 3A) and mid- (Fig. 4A) altitude zone and remained at a low level (< 10 thrips/plant) until 5-leaf stage in all growing seasons. There was a 2 to 3 fold increase in the population density of WFT from 5-leaf to budding stage in the second and third growing season in the high- (Fig. 3A) and mid- (Fig. 4A) altitude zone.

The population density of WFT was mainly at the peak at podding/flowering and podding stage in the high- and mid-altitude zone (> 24 thrips/plant and > 42 thrips/plant, respectively) (Fig. 3A and Fig. 4A). The only exception was in the mid-altitude zone in the second growing season where the population density of WFT was at the peak at flowering stage (30 thrips/plant) (Fig. 4A). The population density of WFT on French beans was on the decline at crop senescence in most of the growing seasons (Fig. 3A and 4A). The only exception was in the third growing season where the population density of WFT remained relatively high from podding to senescence stage (65 thrips/plant) in the high-altitude zone (Fig. 3A). There was no correlation between population density of WFT and temperature or relative humidity ($r = -0.004$, $df = 223$, $P = 0.948$ and $r = 0.007$, $df = 223$, $P = 0.9097$, respectively). Rainfall was negatively correlated with the population density of WFT ($r = -0.143$, $df = 223$, $P = 0.031$).

The interaction between agroecological zone, growing season, and phenological stage did not have an effect on the population density of *Orius* spp. and *C. menes* on French beans (*Orius* spp.: $F_{12, 154} = 0.2097$, $P = 0.997$, *C. menes*: $F_{12, 154} = 0.949$, $P = 0.499$). The individual factors (agroecological zone, growing season and phenological stage) also did not have an effect on

the population density of *Orius* spp. recorded on French beans (agroecological zone: $F_{1, 154} = 0.041$, $P = 0.838$, growing season: $F_{2, 154} = 0.633$, $P = 0.531$, phenological stage: $F_{7, 154} = 0.885$, $P = 0.519$). The population densities of *Orius* spp. and WFT were not correlated ($r = 0.086$; $df = 223$; $P = 0.198$). There was variation in peak periods of *Orius* spp. in the mid- and high-altitude zones and in the three growing seasons (Fig. 3B and 4B). The population density of *Orius* spp. was at the peak at podding stage in both high- and mid-altitude zones in the third growing season (3 *Orius*/plant and 1.5 *Orius*/plant, respectively). In the second growing season, the population density of *Orius* spp. was at the peak at flowering stage (2 *Orius*/plant) only in the mid-altitude zone (Fig. 4B). Conversely, in the first growing season the population density of *Orius* spp. was at the peak at podding (1.5 *Orius*/plant) and flowering (1 *Orius*/plant) stage in the high- and mid-altitude, respectively (Fig. 3B and 4B). The population densities of *C. menes* and WFT were positively correlated ($r = 0.377$, $df = 223$, $P < 0.001$). In the early crop stages (2- to 5-leaf stage), the population density of *C. menes* on French beans was very low (< 0.5 *C. menes*/plant) in the high- and mid-altitude zones in all growing seasons (Fig. 3C and 4C). The population density of *C. menes* was at peak at flowering (2.5 *C. menes*/plant) and senescence (3 *C. menes*/plant) stage in the second and third growing season, respectively, in the high-altitude zone (Fig. 3C). In the mid-altitude zone, the population density of *C. menes* was at peak at podding/flowering (1 *C. menes*/plant) and podding (1.5 *C. menes*/plant) stage in the second and third growing season, respectively (Fig. 4C).

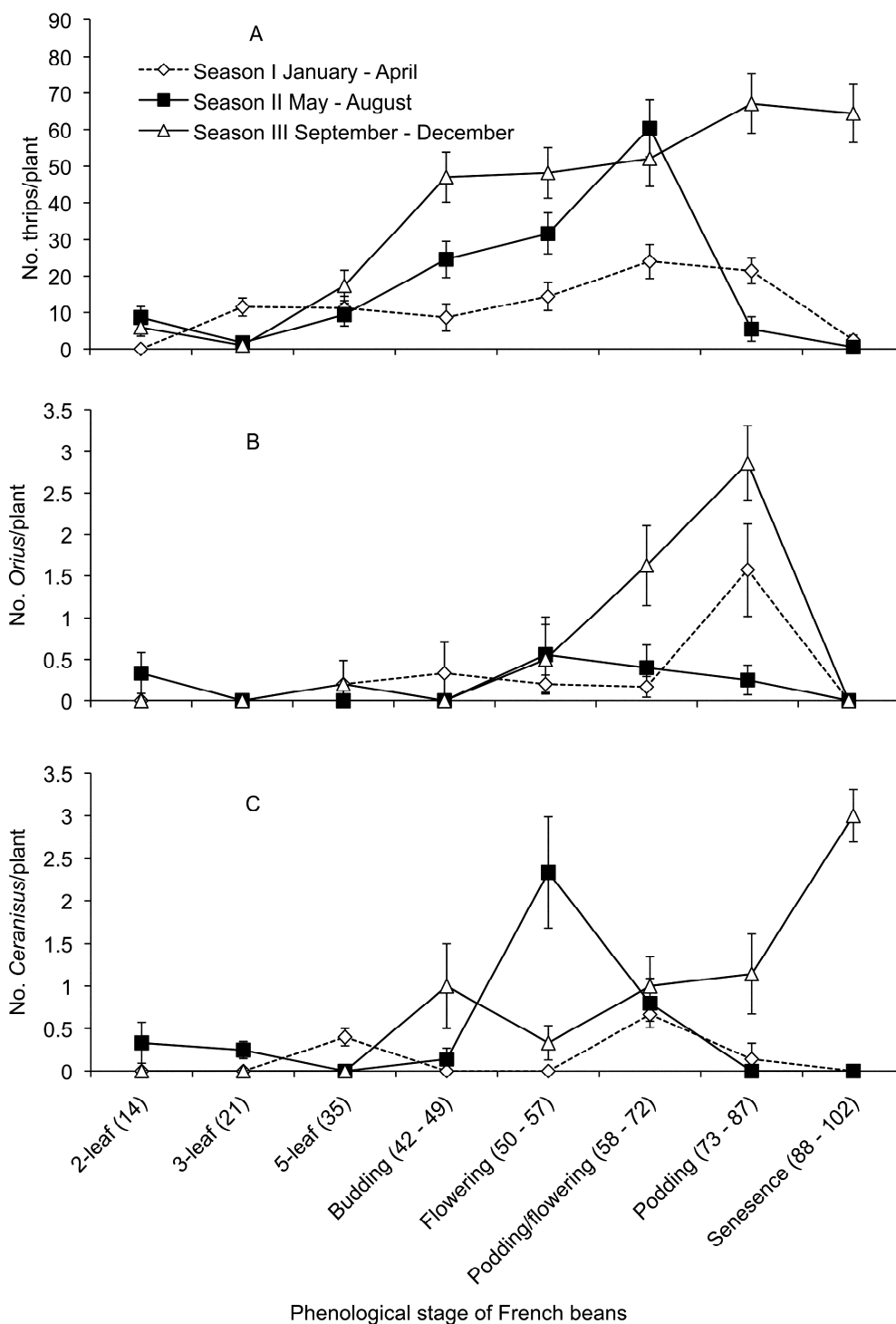


Figure 3. Mean number (\pm SE) of *Frankliniella occidentalis* (A), *Orius* spp. (B) and *Ceraninus menes* (C) per French bean plant at different phenological stages of French beans in the various growing seasons in small-scale farms in high-altitude zone. Numbers in brackets represent number of days after planting (DAP).

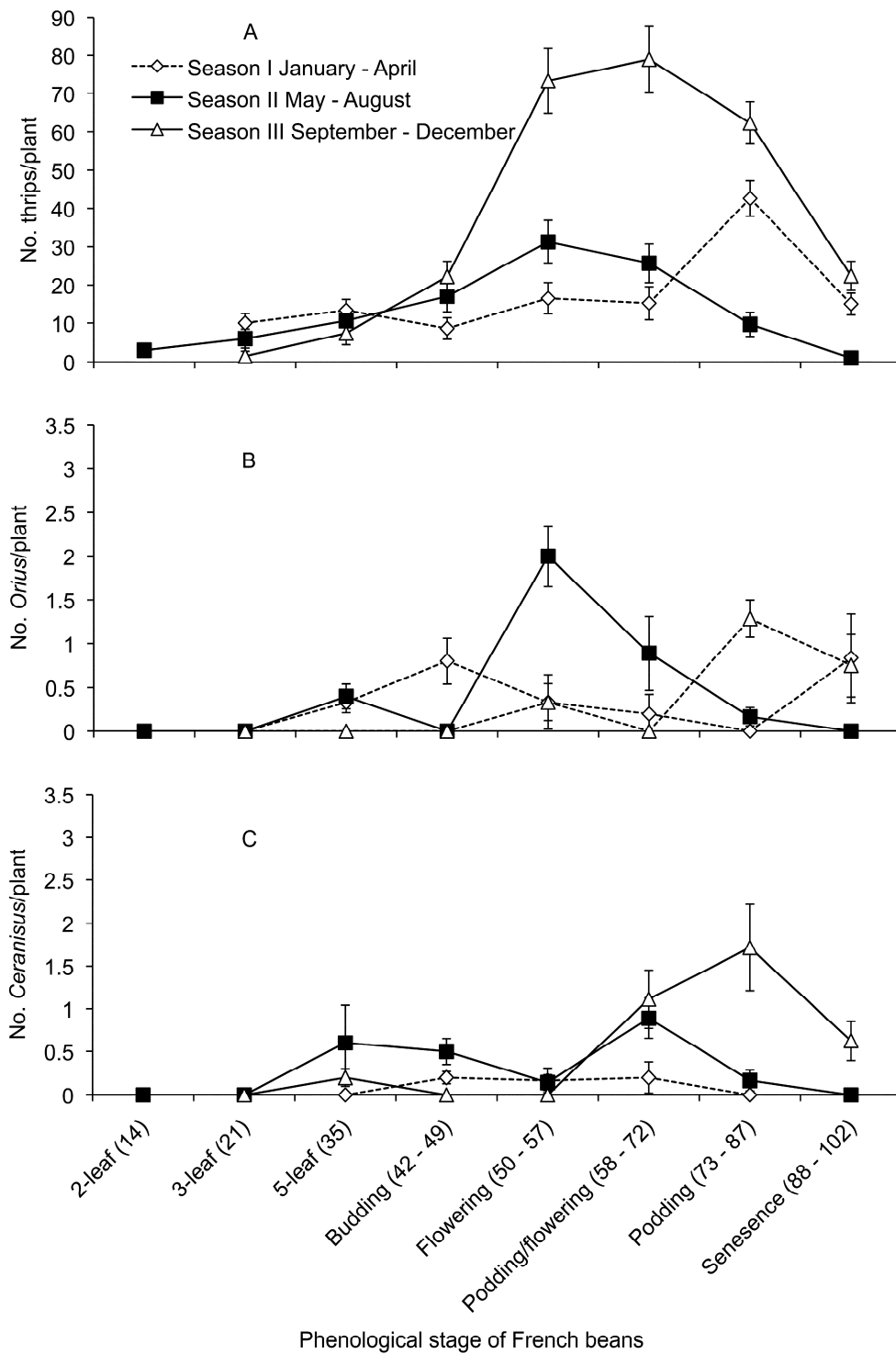


Figure 4. Mean number (\pm SE) of *Frankliniella occidentalis* (A), *Orius* spp. (B) and *Ceranisus menes* (C) per French bean plant at different phenological stages of French beans in the various growing seasons in small-scale farms in mid-altitude zone. Numers in brackets represent number of days after planting (DAP).

2.4 Discussion

Results from this study show that colonization of French beans by WFT in both large- and small-scale farms in the high-altitude zone starts at 2-leaf whereas in the mid-altitude zone it starts at 3-leaf stage. In both farm sizes and agroecological zones there is in general an increase in the population density of WFT on French bean from budding to podding/flowering stage. The population of WFT on French beans peaks early in small-scale farms compared to large-scale farms. A decline in the population density of WFT is at crop senescence. The increase in WFT population density during budding to podding/flowering stage of French beans may have been due to changes in the attractiveness (*i.e.* volatile bouquet) to WFT leading to additional immigration of WFT from the neighbouring crops. Additionally the increase in WFT population during the reproductive phase of French beans may also be due to the reproduction of WFT in French bean flowers. This is supported by the evidence that thrips are known to inhabit non-crop plants from which they migrate into cropping systems (Groves et al., 2002; Buitenhuis & Shipp, 2006; Northfield et al., 2008; Allsopp, 2010). As observed in the present study, as well as in Gitonga (1999), Kasina et al. (2006) and Nyasani et al. (2010, 2012) the population density of WFT on field-grown French beans increases during the reproductive phase, but the relative importance of immigration compared to on crop multiplication needs additional investigations.

The early peak in WFT population in small-scale farms may be due to mixed cropping that ensures multiple “sources” of WFT for immigration into French bean fields. Additionally, small-scale farmers plant a new crop of French beans close to the older French bean fields which may also act as a “source” of infestation to the new crop. Conversely, in large-scale farms new French bean fields are separated from old fields by at least 10 m and this may limit the colonization process because adult WFT are weak fliers (Rhainds & Shipp, 2004). The differences in peak periods may also be due to the mode of irrigation adopted by farmers. Sprinkler irrigation practiced by large-scale farmers may lead to a delay in build-up of WFT

population by washing off thrips of the plant and causing flower drop compared to surface irrigation practiced by small-scale farmers which does not have a direct effect on the plants and thrips. A decline in WFT population density at senescence stage suggests that WFT are able to recognize depletion of plant resources and emigrate to surrounding crop and weed plants. Similar results for WFT on *Leucaena glauca* have been reported by Yudin et al. (1986). This is the first detailed field study to report colonization of French beans by WFT at early phenological stages. Previous studies by Gitonga (1999), Kasina et al. (2006) and Nderitu et al. (2007, 2009) in Kenya have always focused interest on the reproductive phase of French beans ignoring the vegetative phase.

The correlation between temperature or relative humidity and the population density of WFT was not significant. The population density of WFT was negatively correlated with rainfall. Overall, the population density of WFT on French beans in all farm sizes and agroecological zones was low in the first growing season (January – April), which was in the long rains season. The population density of WFT recorded in the second growing season was slightly higher than that recorded in the first growing season. Highest population densities of WFT on French beans in all farm sizes and agroecological zones were recorded in the third growing season (September – December), which was in the short rains season. Our results suggest that potential WFT outbreaks are likely to occur between September and December in all farm sizes and agroecological zones because of the low rainfall (< 0.4 mm/month) and favourable temperatures (23 – 29 °C) for thrips development. Though no economic threshold levels exist for WFT on French beans, the population densities of WFT recorded on French beans in all growing seasons were above the economic threshold (0.7 to 2.1 adults or larvae/flower) established for unripe red pepper, *Capsicum annum* L., (Park et al., 2007). As observed in our study in the long rains season, high amount of rainfall has also been reported to suppress thrips populations by killing larvae, and thrips populations so affected often recover slowly

(Morsello & Kennedy, 2009). In addition, rainfall has been reported to suppress thrips dispersal by suppressing flight (Lewis, 1997). There was no correlation between the population density of WFT recorded on French beans and prevailing temperature. This may be due to the fact that temperature ranges (24 – 29 °C) in all study sites in the entire study period were within the optimal range (25 – 29 °C) for WFT development (Katayama, 1997; McDonald et al., 1998; Reitz, 2008, 2009).

Two natural enemies of thrips were collected from the field studies: *Orius* spp. and *C. menes*. During the three growing seasons, the colonization pattern of *Orius* spp. and *C. menes* was very variable in the surveyed large- and small-scale farms in high- and mid-altitude zones. Results from this study indicated that *Orius* spp. and *C. menes* require the presence of their prey/host on French beans before they can colonize the plant. The peak periods of the two natural enemies on French beans were in mid and late phenological stages. However, the population density of the two natural enemies on French beans was low (< 3/plant) in all farm sizes and agroecological zones. This shows that *Orius* spp. and *C. menes* occur in French beans in low numbers under natural conditions. The low population of natural enemies in small- and large-scale farms could have been due to the negative effects of the synthetic pyrethroids that these farmers were mainly using to control WFT. Field studies by Gitonga (1999) and Kasina et al. (2006) also reported low populations of *Orius* spp. and *C. menes* (< 2 *Orius* or *Ceranisus*/plant) in French bean fields in Kenya. Low populations of *Orius* (< 3 *Orius*/plant) have also been recorded in field-grown soybean (Yoo & O'Neil, 2009) and cotton (Greenberg et al., 2009). *Ceranisus menes* responded to the increase in the population density of WFT whereas *Orius* spp. did not. *Orius* spp. might have failed to respond to the increase in the population density of WFT because they are generalist predators and in this regard they might have been foraging on other pests present on French beans. Conversely, *C. menes* responded to the increase in the population density of WFT and this response could

have been due the fact that *C. menes* is exclusively a parasitoid of thrips. Results from our study indicate that *C. menes* may be worth consideration as a biocontrol agent against WFT in field-grown French beans because of the density relation (numerical response) observed in both small- and large-scale farming systems. However, without additional studies on the parasitism capacity of *C. menes* at low insecticide load any potential of these antagonist for integrated control and any discussion about release schemes remain speculative. Previous studies by Hirose et al. (1993) found *C. menes* to be the most effective natural enemy of *Thrips palmi* (Karny) in egg plant fields in Thailand recording between 40 and 50% larval parasitism.

2.5 Conclusions

In conclusion, this study has shown that there are no large differences in the infestation pattern of French beans with WFT in both small- and large-scale farms and high- and mid-altitude zones in Kenya. Further, it is obvious that the budding stage is the most critical stage for WFT infestation because in that period always a sudden increase in the density of WFT could be observed. Our results also suggest that seasonal abundance of WFT in the two agroecological zones is highly influenced by the growing season and phenological stage of French beans. The results also indicate that similar management strategies against WFT may be adopted for both mid and high altitude zones in Kenya. Management strategies targeted at WFT need to start at 3-leaf stage (guided by weekly scouting) to prevent further build-up of thrips population and since it is difficult to control thrips once they are inside flowers. Application of biorational insecticides at early crop stages of French beans (guided by weekly sampling) would be important to manage the thrips already present on the plants. Further studies are also needed on the movement of WFT into and out of French beans from neighbouring crops that are either grown side by side or in rotation with French beans.

CHAPTER 3

EFFECT OF INTERCROPS ON THRIPS SPECIES COMPOSITION AND POPULATION ABUNDANCE ON FRENCH BEANS

Abstract

This study aimed at determining thrips species composition and thrips population density on French bean planted as a sole crop and as an intercrop with either sunflower, Irish potato, or baby corn, in different combinations. Field experiments were conducted in two seasons to examine: (1) thrips population development and thrips species composition over time, (2) effect of intercrops on thrips population density and natural enemies, and (3) effect of intercrops on French bean yield. The experiments were conducted in a randomised complete block design with four replicates. The thrips population on French beans increased with time. It showed a peak at the flowering stage then started declining when the crops were nearing senescence. French beans hosted four thrips species, *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), *F. occidentalis* (Pergande), and *Hydatothrips adolfriderici* (Karny) (all Thysanoptera: Thripidae) in order of decreasing abundance. The main thrips species on Irish potato and sunflower was *F. schultzei*. Baby corn hosted only *Frankliniella williamsi* (Hood) and *Thrips pusillus* (Bagnall). A monocrop of French bean hosted more thrips than a French bean intercrop mix. Thrips natural enemies such as *Orius* spp. and *Ceranisus menes* (Walker) were recorded in all crop plants but in especially high numbers on French beans and baby corn, respectively. There was a slight reduction in total French bean yield in the intercrop mix when compared with a sole crop of French beans. However, the percentage of pods that could get rejected on the market due to thrips damage was highest on plots with French bean alone (63 - 68%) and lowest on plots with intercrop mix (35 - 39%).

Key words: *Ceranisus menes*, *Frankliniella occidentalis*, *Frankliniella schultzei*, *Hydatothrips adolfriderici*, *Megalurothrips sjostedti*, *Orius*, *Phaseolus vulgaris*.

3.0 Introduction

French bean, *Phaseolus vulgaris* L. (Fabaceae), is the most cultivated horticultural crop by both small- and large-scale farmers across Central, Eastern, Western, and Coast provinces of Kenya (Onkoba, 2002). French beans constitute nearly 20% by volume and 60% by value of all fresh horticultural exports from Kenya (HCDA, 2007). Farmers also sell their produce to local supermarkets, greengrocers, restaurants and fast food kiosks. Pests and diseases are the major constraints to French bean production in Kenya (Nderitu et al., 2007). Pests reduce the quality and quantity of pod yield and affect the entire production period. In Kenya, yield losses of more than 40% have been reported due to thrips feeding, resulting in abscission of flower buds, opening of flower peduncles and flower abortion (Löhr, 1996). Additional losses of 20% at collection points due to rejection of curled pods and pods with blemishes and lesions have been recorded (Löhr, 1996; Kibata & Anyango, 1996).

Four thrips (Thysanoptera: Thripidae) species are common in bean fields in Kenya: *M. sjostedti*, *F. occidentalis*, *F. schultzei*, and *Hydatothrips adolfifrigerici* (Karny) (Nyasani et al., 2010). *Megalurothrips sjostedti* is a common and widespread pest in Africa (Karungi et al., 2000; Alabi et al., 2004; Ngakou et al., 2008). *Megalurothrips sjostedti* and *H. adolfifrigerici* feed mainly on legumes, particularly beans, cowpeas, and soya bean (Nabirye et al., 2003). *Frankliniella occidentalis* is invasive and was reported for the first time in Kenya in 1989 (Kedera & Kuria, 2003). This thrips species is polyphagous, feeding and breeding on more than 240 host plants belonging to 62 plant families, mainly from the Solanaceae family. *Frankliniella schultzei* is widespread around the world in tropical countries and is an efficient vector of tospoviruses (Tommasini & Maini, 1995). There is no information on the role of *F. schultzei* and *H. adolfifrigerici* on French bean production in East Africa as research has always focused on *M. sjostedti* and *F. occidentalis*. Thrips significantly affect the productivity of French bean and their short life cycle enables several overlapping generations of thrips within a production cycle of a given crop (McDonald et al.,

1998). Therefore, growers often resort to repeated and indiscriminate use of several groups of insecticides to control thrips. Foliar sprays of chemical insecticides often fail to manage thrips because of their cryptic feeding behaviour and ability to pupate in the soil (Berndt et al., 2004).

Commercial growers in Kenya rely heavily on pesticides to manage thrips, especially *F. occidentalis* (Nderitu et al., 2007, 2008). However, *F. occidentalis* has developed resistance to pesticides belonging to the carbamate, organophosphate, organochlorine, and pyrethroid chemical groups (Nderitu et al., 2007). Small-scale farmers practice intercropping as a cultural control practice against pests and to obtain greater total land productivity, expressed by the land equivalent ratio (LER) (Songa et al., 2007). Intercropping tends to result in lower levels of insect pests than the corresponding monocropping due to associational resistance of the agroecosystem to herbivores (Finckh & Karpenstein-Machan, 2002). Intercrops attract or repel pests from the main crop and also encourage build-up of natural enemies. Crop structure, chemical environment, and microclimate are factors that can play a role in pest suppression and are components of associational resistance (Rämert et al., 2002). Effects of intercropping on thrips infestations have been evaluated in several systems, such as strawberry with broad beans (Gonzalez-Zamora et al., 1994), sweet pepper with tomato (Nihoul & Hance, 1994), maize with cowpea (Kyamanywa et al., 1993), French bean with maize (Kasina et al., 2006a), and pinto beans with sweet corn (Capinera et al., 1985). In these systems, thrips populations in the intercrop mix were lower than in a sole crop. In the mixed cropping practiced by small-scale Kenyan farmers, the common crop plants grown alongside French bean are baby corn, Irish potato, and sunflower. Baby corn is grown mainly for the export market and Irish potato and sunflower are sold on the local market. However, detailed field experiments looking at the effect of intercrops on thrips species composition and population density on French beans have not been conducted in Kenya and other parts of the

world. In this regard, we set out experiments to look at the effect of intercropping French bean with sunflower, Irish potato, and/or baby corn on thrips species and their natural enemy composition and population abundance.

3.1 Materials and methods

The experiments were conducted at the Kenya Agricultural Research Institute (KARI), Embu station, which is characterised by its fairly flat landscape and well drained soils. KARI-Embu is located in the upper midlands 2 (UM2) agroecological zone at an altitude of 1,480 m a.s.l. (00°30' S and 37°27' E). Its soils are classified as humic nitisols. It receives a mean annual rainfall of 1,238 mm. The rainfall is bimodal, with long rains starting late March to May and short rains starting in October to December. Experiments were conducted during two seasons: the long rains season (March to May 2009) and short rains season (October to December 2009).

Based on the Kenyan farmers' common French bean cropping systems, six treatments were imposed: (1) French bean (var. Amy) alone, (2) intercrop of sunflower (Sf) [*Helianthus annuus* L. var. H-8998 (Asteraceae)] and French bean (Fb) (1Sf:5Fb:1Sf:5Fb:1Sf rows), (3) intercrop of baby corn (Bc) [*Zea mays* L. var. ZS 206 (Poaceae)] and French bean (1Bc:5Fb:1Bc:5Fb:1Bc rows), (4) intercrop of Irish potato (Ip) [*Solanum tuberosum* L. var. Tigoni (Solanaceae)] and French bean (1Ip:5Fb:1Ip:5Fb:1Ip rows), (5) intercrop of baby corn, French bean, and sunflower (1Bc:5Fb:1Sf:5Fb:1Bc rows), and (6) intercrop of Irish potato, French bean, and sunflower (1Ip:5Fb:1Sf:5Fb:1Ip rows). Note that Bc = baby corn, Fb = French bean; Ip = Irish potato and Sf = sunflower and the ratios represent the number of rows for each crop in the order of placement in the experimental plots. The same treatments were used in the two seasons. The treatments were replicated four times in a randomised complete block design. Experimental plots of 5 × 10 m were used. French beans were planted

in rows in the experimental plots, spaced at 50 × 10 cm (rows × plants). Spacing for baby corn, Irish potato and sunflower was 30 cm between plants.

There were 2 m buffers left bare all around the experimental plots. Guard rows of French beans were planted around the main experimental field 2.5 m away from the edge to minimise edge effects. Cultural practices as recommended by Kenya Agricultural Research Institute (KARI) were adopted (KARI, 2005). Starting 21 days after planting, field observations were every 2 weeks for the first two sampling times, and thereafter every week until crop senescence. In each experimental plot, 10 individual plants were randomly sampled and beaten over a white enamel tray to collect thrips and natural enemies. Thrips were further processed in the laboratory and identified using the “Pest Thrips of the World” Lucid key developed by Moritz et al. (2004).

Voucher specimens of slide-mounted thrips are maintained in the thrips specimen collection at the *icipe*, Kenya. The phenological stage of French beans was recorded at each observation. At podding stage, French bean pods were harvested from 20 plants in a 1-m² quadrat from each experimental plot for assessment of yield and damage. Damage on the pods was rated on a scale of 1 to 5 adopted from McKenzie et al. (1993), where 1 = no damage (0%), 2 = slight damage (≤25%), 3 = moderate damage (>25≤50%), 4 = severe damage (>50≤75%), and 5 = very severe damage (>75%). French bean pods in damage score groups 3–5 were weighed to calculate the percentage of unmarketable pods by weight. The prevailing weather conditions were monitored throughout the experiment from a weather station 200 m away.

3.2 Data analysis

To avoid pseudo-replication, the observed insect counts recorded per plant were converted into additive components and the mean population density per plant was calculated. The thrips count data were analysed using repeated measures analysis of variance (ANOVA) using SAS statistical software (SAS Institute, 2008). Long and short rains data were analysed

separately. Yield data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute, 2008). Specific comparisons among treatments were made with Tukey's honestly significant difference (HSD) test at $P = 0.05$. Correlation between the prevailing weather conditions (average daily temperature, rainfall, and sunshine hours) and thrips population per sample date was calculated using Proc CORR (SAS Institute, 2008).

3.3 Results

3.3.1 Thrips population development in 2009 and affinity to different crop plants

The weather pattern during the two seasons was variable. The mean daily temperatures during the long rains (March to May) and short rains (October to December) season were 21.1 and 19.7 °C, respectively. Mean rainfall during the long and short rains was 3.7 and 2.0 mm, respectively. The daily sunshine hours during the long and short rains were 8.5 and 6.6 hours, respectively. Thrips populations per sample date regardless of treatment were strongly correlated with average temperature ($r = 0.604$, $df = 10$, $P = 0.037$). A Pearson correlation analysis failed to explain the effect of rain and sunshine hours on thrips population ($r = 0.367$, $df = 10$, $P = 0.2403$ and $r = 0.274$, $df = 10$, $P = 0.389$, respectively).

The overall thrips population in the long rains season was about three times higher than that recorded in the short rains ($F_{1,3} = 91.40$, $P = 0.002$) (Figure 1). Nevertheless, thrips population development over time was similar in both seasons. Colonisation of crops started at 14 days after plant emergence, the population peaks were at the flowering stage and they declined during crop senescence. The increase in thrips abundance from one week before flowering, to flowering stage, was 2–3-fold in all treatments (Figure 1).

Although population development was similar in all treatments and seasons, several thrips species were recorded on the crop plants. The main thrips species on French beans in the two seasons in order of decreasing population abundance were *M. sjostedti*, *F. schultzei*, *F. occidentalis*, and *H. adolfriderici*. In sunflower and Irish potato, the thrips species observed

in order of decreasing population abundance were *F. schultzei* (>70%), followed by *F. occidentalis* (>15%) and *M. sjostedti* and *H. adolfifrigerici*, which were recorded in low numbers. The thrips species observed on baby corn were different from those that colonised other crops; *Frankliniella williamsi* (>80%) was dominant on baby corn during the short rains and *Thrips pusillus* (>80%) in the long rains season. The pattern of thrips population development on the French bean guard rows in the N/S and E/W directions was the same ($F_{1,3} = 1.27$, $P = 0.341$). There was evidence of equal immigration of thrips in the N/S and E/W directions within the experimental plots ($F_{1,3} = 0.77$, $P = 0.444$).

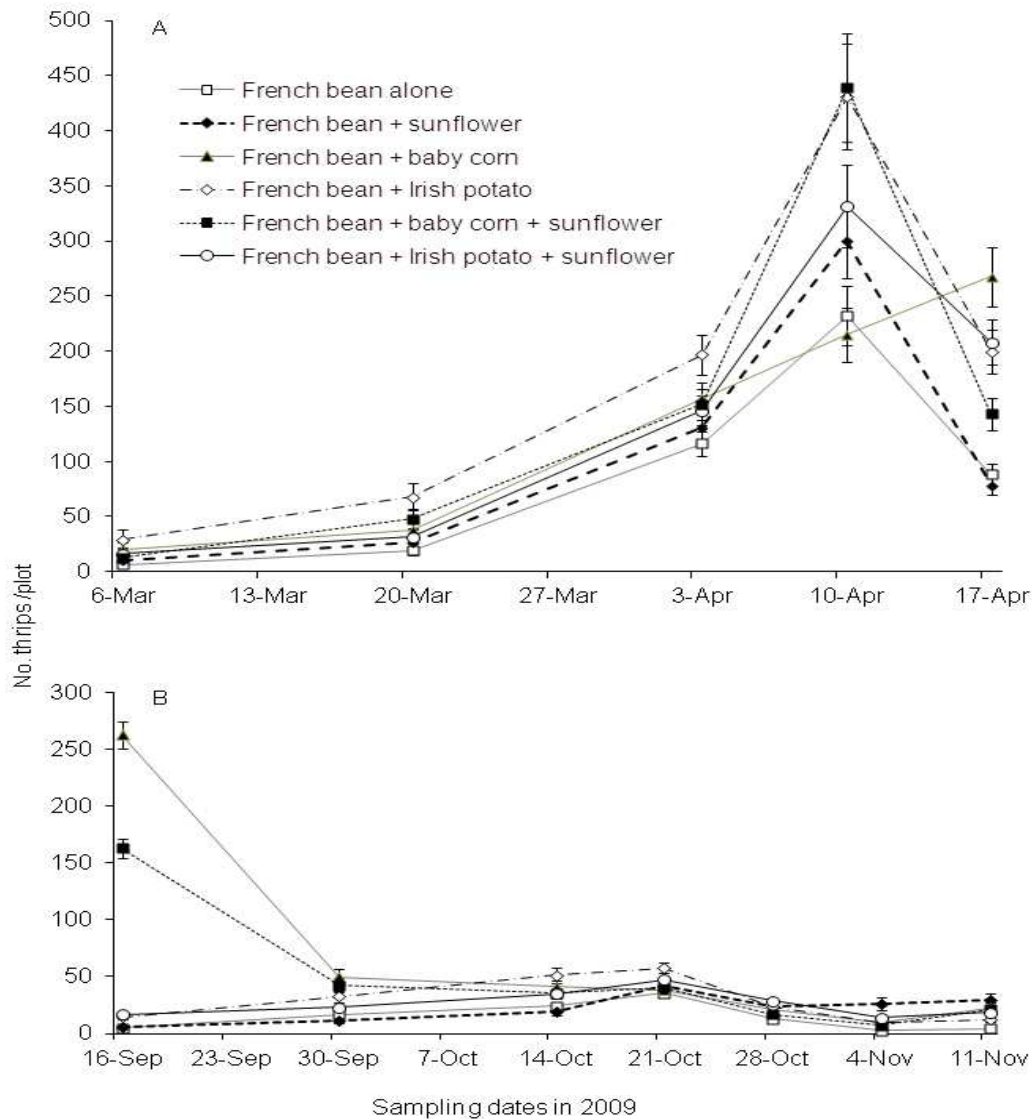


Figure 1: Mean number (\pm SE) of thrips captured in each treatment at the various sampling dates during the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

3.3.2 Population development of thrips species on French beans and intercrops

As the economic importance of insect herbivores depends greatly on the life stage and tissue of the plant they attack, and on their method of feeding, main focus was on the week before flowering (budding) and flowering stage of French beans, which are the most susceptible stages of the crop to damage (Edwards & Singh, 2006). All crop plants used in the experiment flowered at the same time.

Megalurothrips sjostedti

In the long rains season, there was a significantly higher number of *M. sjostedti* on a monocrop of French bean at one week before flowering compared with the population on French bean in the intercrop mix ($F_{5,15} = 26.37$, $P < 0.001$) (Figure 2). However, this difference was no longer significant at flowering 1 week later ($F_{5,15} = 1.14$, $P = 0.383$) (Figure 2). In the short rains season there were no significant differences in the number of *M. sjostedti* hosted by French beans in the different treatments at one week before flowering and at flowering stage ($F_{5,15} = 1.95$, $P = 0.144$ and $F_{5,15} = 2.27$, $P = 0.060$, respectively) (Figure 2).

Though there were no significant differences among treatments, there was a general increase in *M. sjostedti* population from one week before flowering, to flowering stage, in both seasons. A different trend in *M. sjostedti* population on the intercrops that were grown together with French bean was observed. In both the short and long rains seasons, the population of *M. sjostedti* was highest on French beans and lowest on Irish potato and sunflower ($F_{3,9} = 58.57$, $P < 0.001$ and $F_{3,9} = 53.41$, $P < 0.001$, respectively) (Figure 2).

Megalurothrips sjostedti was not recorded on baby corn in the two seasons (Figure 2).

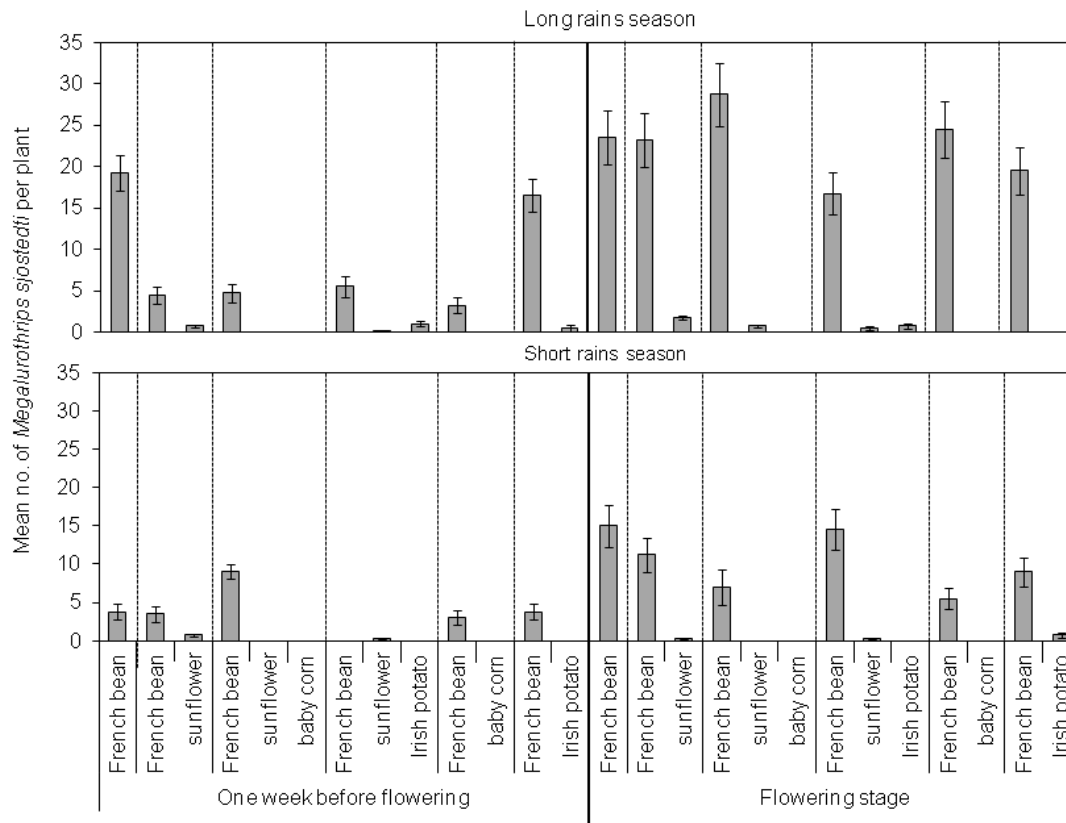


Figure 2: Mean number (\pm SE) of *Megalurothrips sjostedti* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at one week before flowering and at flowering stage in the long and short rains seasons at KARI-Embu, Kenya in 2009. The vertical dotted lines separate the various treatments.

Frankliniella schultzei

There were no significant differences in the number of *F. schultzei* hosted by a monocrop of French bean compared with other treatments at one week before flowering and flowering stage in the long rains season ($F_{5,15} = 1.66$, $P = 0.204$ and $F_{5,15} = 0.48$, $P = 0.784$, respectively) and in the short rain season ($F_{5,15} = 2.61$, $P = 0.068$ and $F_{5,15} = 1.27$, $P = 0.329$, respectively) (Figure 3). In both seasons, a characteristic trend in *F. schultzei* population in the various treatments was observed. The population of *F. schultzei* on French beans decreased with the increase in number of associate crops (Figure 3). The population of *F. schultzei* on sunflower was low at one week before flowering and at flowering stage in the

long rains season (Figure 3). The trend of *F. schultzei* on intercrops was different than on French bean plants. The population of *F. schultzei* on Irish potato at flowering stage was highest compared with French bean and sunflower in the long and short rains seasons ($F_{1,3} = 31.68, P = 0.011$ and $F_{1,3} = 11.88, P = 0.041$, respectively) (Figure 3). *Frankliniella schultzei* was not recorded on baby corn (Figure 3).

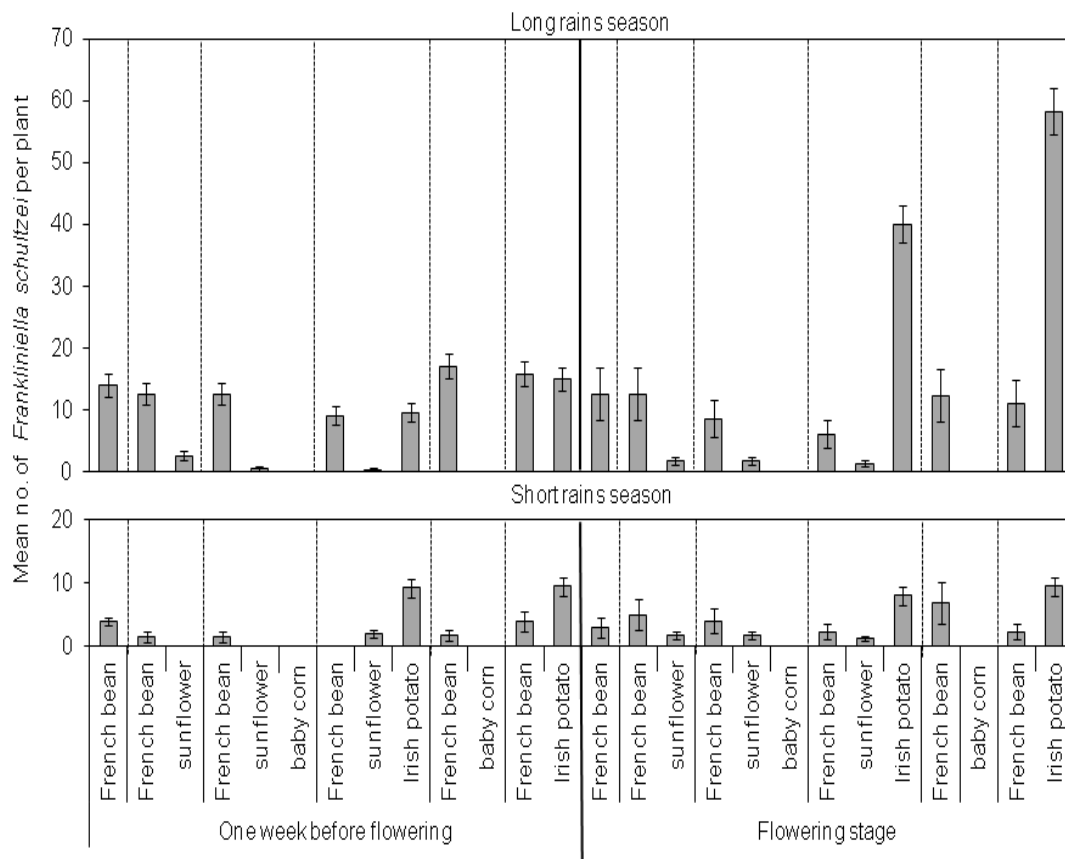


Figure 3: Mean number (\pm SE) of *Frankliniella schultzei* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at one week before flowering and at flowering stage in the long and short rains seasons at KARI-Embu, Kenya in 2009. The vertical dotted lines separate the various treatments.

Frankliniella occidentalis

There was a threefold and twofold increase in the population of *F. occidentalis* on a monocrop of French bean from one week before flowering, to flowering stage in the long and short rains, respectively (Figure 4). There were no significant differences in the number of *F.*

occidentalis recorded on a monocrop of French bean compared with other treatments at one week before flowering and at flowering stage in the long rains season ($F_{5,15} = 0.48$, $P = 0.788$ and $F_{5,15} = 1.21$, $P = 0.353$, respectively) (Figure 4).

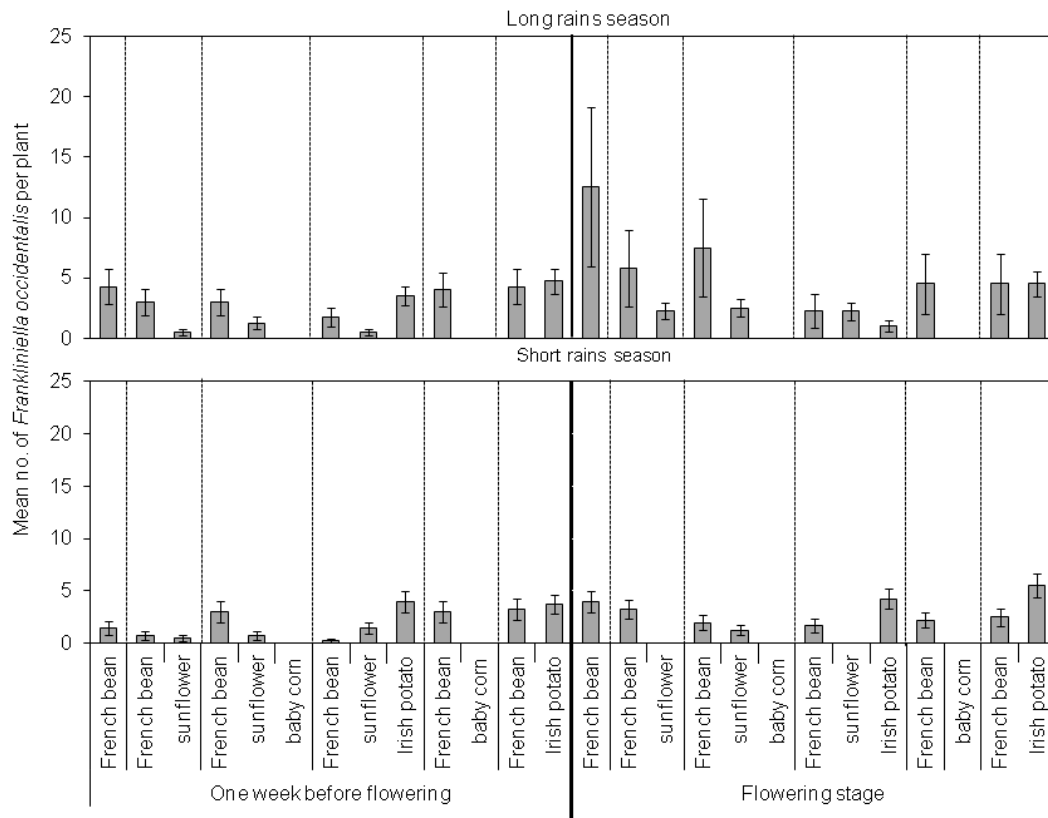


Figure 4: Mean number (\pm SE) of *Frankliniella occidentalis* per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at one week before flowering and at flowering stage in the long and short rains seasons at KARI-Embu, Kenya in 2009. The vertical dotted lines separate the various treatments.

A similar trend was recorded in the short rains season (Figure 4). There were no significant differences in the number of *F. occidentalis* hosted by French beans and Irish potato at one week before flowering and at flowering stage in the two seasons (Figure 4). Sunflower hosted the lowest number of *F. occidentalis* compared with French bean and Irish potato at one week

before flowering and flowering stage in the two seasons (Figure 4). *Frankliniella occidentalis* was not recorded on baby corn (Figure 4).

Hydatothrips adolfiroiderici

The population of *H. adolfiroiderici* on French beans doubled from one week before flowering to flowering stage in the long rains season (Figure 5). However, there were no significant differences in the number of *H. adolfiroiderici* hosted by French beans in all treatments at both one week before flowering and at flowering stage in the long rains season ($F_{5,15} = 0.99, P = 0.454$ and $F_{5,15} = 0.82, P = 0.552$, respectively) (Figure 5).

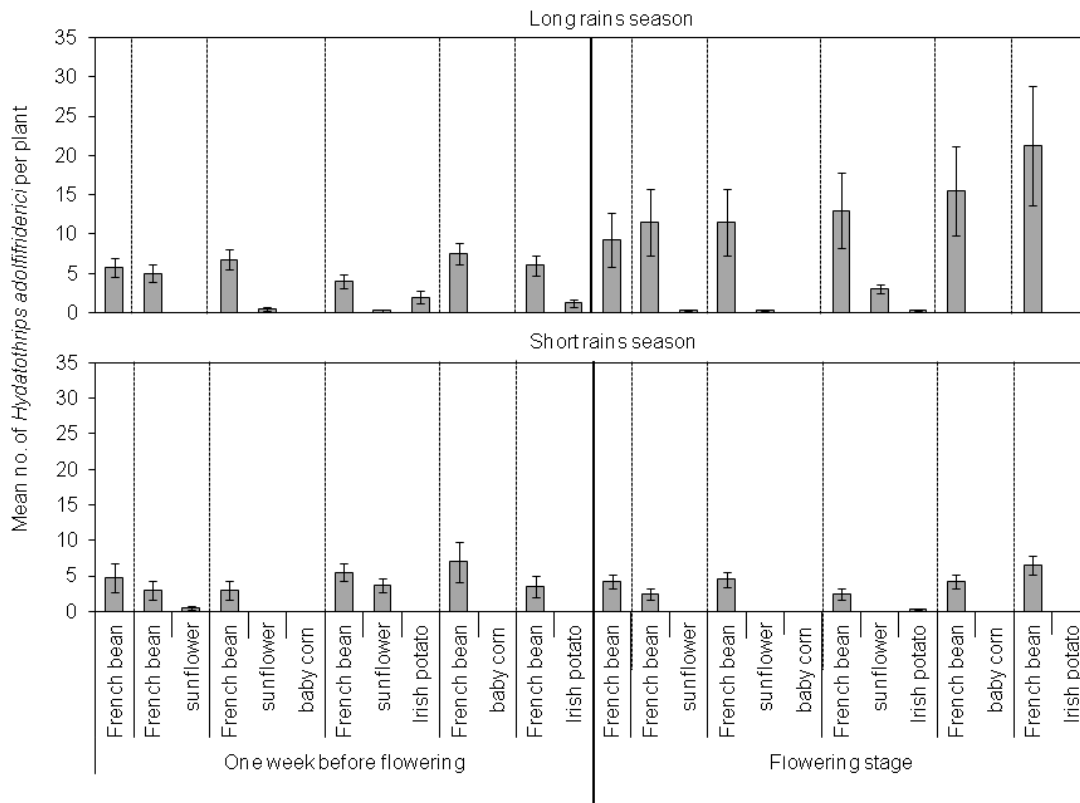


Figure 5: Mean number (\pm SE) of *Hydatothrips adolfiroiderici* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at one week before flowering and at flowering stage in the long and short rains seasons at KARI-Embu, Kenya in 2009. The vertical dotted lines separate the various treatments.

In the short rains season there were no significant differences in the number of *H. adolfifrigerici* hosted on French bean as a monocrop and when intercropped with either sunflower, baby corn, or Irish potato at one week before flowering and at flowering stage ($F_{5,15} = 0.67$, $P = 0.652$ and $F_{5,15} = 2.83$, $P = 0.054$), respectively (Figure 5). The population of *H. adolfifrigerici* on French bean was higher than on sunflower and Irish potato at both one week before flowering and at flowering stage in the two seasons (Figure 5). *Hydatothrips adolfifrigerici* was not recorded on baby corn (Figure 5).

3.3.3 Effect of intercrops on the population density of natural enemies on French beans

Two natural enemies of thrips were collected from the field studies: *Orius* spp. (Hemiptera: Anthocoridae) and *Ceranisus menes* (Walker) (Hymenoptera: Eulophidae). A monocrop of French beans harboured the lowest number of *Orius* spp. (2.3 *Orius*/plant) compared to that recorded on French beans in the other treatments in both the long and short rains season ($F_{5,15} = 2.93$, $P = 0.048$ and $F_{5,15} = 3.83$, $P = 0.019$, respectively). The number of *Orius* spp. recorded on French beans and baby corn in the French bean-baby corn intercrop mix was not different in both the long and short rains season (Table 1). Conversely, the number of *Orius* spp. hosted by sunflower when it was intercropped with French bean alone was about three times higher than that recorded on French bean in both the long and short rains season (Table 1). Irish potato hosted the fewest *Orius* spp. (0.1 *Orius*/plant) compared to French beans (5.3 *Orius*/plant) in the French bean-Irish potato intercrop mix in the long rains season (Table 1). In the long rains season, the number of *Orius* spp. hosted by French bean and Irish potato in the French bean-Irish potato intercrop mix did not differ (Table 1).

Table 1: Mean number (\pm SE) of *Orius* spp. on French bean, sunflower, baby corn, and Irish potato in the various treatments in the long and short rains season at KARI-Embu in 2009

Treatment	Number of <i>Orius</i> spp. per plant for each crop within a treatment			
	French bean	Sunflower	Baby corn	Irish potato
Long rains season				
French bean	2.3 \pm 0.81 c			
French bean + sunflower	4.7 \pm 1.23 b	15.4 \pm 3.37 a		
French bean + baby corn	6.6 \pm 1.52 ab		5.3 \pm 2.21	
French bean + Irish potato	5.3 \pm 1.32 b			0.1 \pm 0.13
French bean + baby corn + sunflower	8.5 \pm 1.81 a	4.5 \pm 1.35 b	3.6 \pm 1.13	
French bean + Irish potato + sunflower	3.1 \pm 0.97 bc	7.3 \pm 1.86 b		0.2 \pm 0.28
F	2.93	5.91	0.81	0.54
d.f.	5, 15	2, 6	1, 3	1, 3
P-value	0.048	0.038	0.435 ns	0.517 ns
Short rains season				
French bean	3.2 \pm 0.95 b			
French bean + sunflower	4.3 \pm 1.13 b	13.9 \pm 1.86 a		
French bean + baby corn	6.7 \pm 1.46 ab		7.4 \pm 1.36	
French bean + Irish potato	5.4 \pm 1.30 b			5.3 \pm 1.16
French bean + baby corn + sunflower	10.7 \pm 1.98 a	5.8 \pm 1.20 b	4.4 \pm 1.05	
French bean + Irish potato + sunflower	3.7 \pm 1.03 b	10.2 \pm 1.59 a		2.2 \pm 0.74
F	3.83	6.43	3.07	4.83
d.f.	5, 15	2, 6	1, 3	1, 3
P-value	0.019	0.032	0.178 ns	0.115 ns

Means in a column followed by the same letter are not significantly different (Tukey's HSD test: $P < 0.05$). ns = not significant.

The number of *C. menes* hosted by a monocrop of French bean was about twice that recorded on French beans in the other treatments in the two seasons ($F_{5,15} = 4.27$, $P = 0.012$; and $F_{5,15} = 5.07$, $P = 0.006$, respectively) (Table 2). The number of *C. menes* recorded on French beans and sunflower in the French-sunflower intercrop mix did not differ in the two seasons (Table 2). Nevertheless, it was observed that the population of *C. menes* on sunflower decreased with the increase in the number of intercrops in the long and short rains seasons (Table 2).

Table 2: Mean (\pm SE) number of *Ceranisus menes* on French bean, sunflower, baby corn, and Irish potato in the various treatments in the long and short rains season at KARI-Embu in 2009

Treatment	Number of <i>Ceranisus menes</i> per plant for each crop within a treatment			
	French bean	Sunflower	Baby corn	Irish potato
Long rains season				
French bean	8.5 \pm 0.81 a			
French bean + sunflower	3.9 \pm 0.95 b	2.5 \pm 0.80		
French bean + baby corn	4.1 \pm 0.97 b		0.1 \pm 0.16	
French bean + Irish potato	2.3 \pm 0.72 b			0.6 \pm 0.47
French bean + baby corn + sunflower	4.9 \pm 1.06 b	1.5 \pm 0.60	0.5 \pm 0.41	
French bean + Irish potato + sunflower	3.7 \pm 0.91 b	0.2 \pm 0.23		0.1 \pm 0.15
F	4.27	3.10	1.24	1.76
d.f.	5, 15	2, 6	1, 3	1, 3
P-value	0.012	0.119 ns	0.346 ns	0.276 ns
Short rains season				
French bean	10.8 \pm 1.61 a			
French bean + sunflower	4.4 \pm 1.00 b	3.7 \pm 0.99		
French bean + baby corn	4.5 \pm 1.01 b		6.5 \pm 1.38	
French bean + Irish potato	4.2 \pm 0.98 b			3.2 \pm 0.90
French bean + baby corn + sunflower	5.7 \pm 1.14 b	1.6 \pm 0.63	4.0 \pm 1.02	
French bean + Irish potato + sunflower	4.3 \pm 0.99 b	0.8 \pm 0.45		1.6 \pm 0.62
F	5.07	4.08	2.72	2.19
d.f.	5, 15	2, 6	1, 3	1, 3
P-value	0.006	0.076 ns	0.197 ns	0.235 ns

Means in a column followed by the same letter are not significantly different (Tukey's HSD test: $P < 0.05$). ns = not significant.

French beans harboured about 41 times more *C. menes* than baby corn in the French bean-baby corn intercrop mix in the long rains season (Table 2). Conversely, there were no differences in the number of *C. menes* hosted by French beans and baby corn in the French bean-baby corn intercrop mix during the short rains season (Table 2). French beans hosted about four times higher number of *C. menes* than Irish potato in the French bean-Irish potato intercrop mix during the long rains season (Table 2). However, in the short rains season there were no differences in the number of *C. menes* hosted by French beans and in the French bean-Irish potato intercrop mix.

3.3.4 Effect of intercrops on French bean yield

Intercropping French bean with other crops had a significant impact on French bean pod yield. A monocrop of French bean yielded about 1.4 times more than French bean intercropped with either baby corn or sunflower in the two seasons ($F_{5,15} = 5.33$, $P = 0.005$ and $F_{5,15} = 4.73$, $P = 0.008$, respectively) (Table 3). The proportion of French bean pods that would get rejected in the market due to thrips damage based on the damage scores on a scale of 1 to 5 varied with the different treatments (Table 3). Thrips damage in a sole crop of French bean was highest (63–68% yield loss) compared to when French bean was intercropped with other crops (Table 3). The least damage to the French bean pods (35–37% yield loss) was recorded when French bean was intercropped with baby corn.

Table 3: Effect of thrips on mean (\pm SE) French bean pod yield, yield loss, and percentage yield loss as influenced by the various treatments at KARI-Embu, Kenya in 2009

Treatment	Long rains season			Short rains season		
	Thrips density at flowering (thrips/plot)	Pod yield (kg/ha)	Yield loss due to thrips damage [kg/ha, (%)]	Thrips density at flowering (thrips/plot)	Pod yield (kg/ha)	Yield loss due to thrips damage [kg/ha, (%)]
French bean alone	137.0 \pm 21.5a	4500 \pm 241a	3060.0 (68)	26.5 \pm 6.5a	5250 \pm 374a	3307.5 (63)
French bean + Irish potato + sunflower	51.0 \pm 8.4b	4250 \pm 227ab	1912.5 (45)	14.0 \pm 3.7ab	4500 \pm 321ab	2160.0 (48)
French bean + Irish potato	58.7 \pm 9.6ab	4000 \pm 214ab	1600.0 (40)	15.0 \pm 3.9ab	3750 \pm 268ab	1612.5 (43)
French bean + baby corn + sunflower	100.2 \pm 15.9ab	3750 \pm 201ab	1312.5 (35)	9.5 \pm 2.6b	4000 \pm 286ab	1560.0 (39)
French bean + baby corn	111.2 \pm 17.6ab	3250 \pm 174b	1137.5 (35)	10.7 \pm 2.9b	3250 \pm 232b	1202.5 (37)
French bean + sunflower	116.2 \pm 18.3ab	3250 \pm 174b	1202.5 (37)	8.5 \pm 2.4b	3500 \pm 250b	1365.0 (39)
F _{5,15}	3.57	5.33		3.92	4.73	
P-value	0.025	0.005		0.018	0.008	

Means in a column followed by the same letter are not significantly different (Tukey's HSD test: $P < 0.05$).

3.4 Discussion

Results from this study show that thrips populations vary with season and are strongly correlated with the mean temperature of the season. This was supported by the high thrips catches recorded during the long rains because of the high temperatures (21.1 °C) that were favourable for thrips reproduction and dispersal. Results from this study are in agreement with those of Stacey & Fellowes (2002) and Pearsall & Myers (2001) who showed that temperature affects the development rate of thrips, and consequently their population dynamics. Rainfall and sunshine hours could not explain the reason for variation in thrips population between seasons. Earlier research has shown that rainfall affects thrips populations both negatively and positively (Morsello et al., 2010). It can suppress populations by killing larvae, and thrips populations so affected often recover slowly (Morsello & Kennedy, 2009). Rainfall also suppresses thrips dispersal by suppressing flight (Lewis, 1997). However, by maintaining adequate soil moisture, rainfall can positively influence thrips populations by fostering plant growth and enhancing pupal survival (Morsello & Kennedy, 2009).

Results from this study clearly show that the main thrips species on French beans in Kenya in order of decreasing abundance are *M. sjostedti*, *F. schultzei*, *H. adolfriderici*, and *F. occidentalis*. Previous studies have placed high emphasis on *F. occidentalis* (Kasina et al., 2006; Nderitu, et al., 2007, 2008) and little emphasis on *F. schultzei* and *H. adolfriderici*. *Frankliniella schultzei* closely resembles *F. occidentalis* and because of a lack of good identification keys in Kenya in the past, it has been mistaken for *F. occidentalis*. Furthermore, *F. occidentalis* has developed resistance to the commonly used pesticides and the other thrips species that are susceptible to the commonly used pesticides have been thought to be of minor importance. Results from this study also showed that a monocrop of French bean favoured the highest population of *M. sjostedti* compared to when French bean was intercropped with baby corn, Irish potato or sunflower. *Megalurothrips sjostedti* also

dominated in the field in the two seasons: the thrips species is native to Africa and is widespread indeed (Nabirye et al., 2003; Alabi et al., 2004; Ngakou et al., 2008). Additionally, natural enemies such as *Orius albidipennis* (Reuter) play an important role in regulating *M. sjostedti* population (Gitonga et al., 2002). In the present study, *Orius* spp. were recorded in high numbers in intercrops compared to a sole crop of French bean and their predation activity could have contributed to the low populations of *M. sjostedti*. Kyamanywa & Ampofo (1988) also reported that the population density and activity of *M. sjostedti* were significantly less in a mixed crop than in the single crop of cowpea. They reported that less light was intercepted by the cowpea canopy in the cowpea/maize mixed crop than in the sole crop of cowpea. The reduced light intensity in the cowpea/maize mixture contributed to the relative scarcity of *M. sjostedti* in the mixture. A similar case was observed in this study.

A monocrop of French bean harboured larger populations of *F. occidentalis* than when French bean was intercropped with baby corn, sunflower, and/or Irish potato. This was due to the attraction of *F. occidentalis* to sunflower and Irish potato in the intercrop mix. The population of *F. schultzei* or *H. adolfifrigerici* on French beans did not depend on the intercrops grown together with French beans.

French bean supported the highest population of *Orius* spp. when intercropped with baby corn and sunflower whereas a monocrop of French bean supported the lowest population of *Orius* spp. Low numbers of *Orius* spp. on French beans in Kenya have been reported by Gitonga (1999) and Kasina et al. (2006a). The biological reason for the high number of *Orius* spp. on French bean in the intercrops was not investigated, but earlier research has shown that polycropping creates a microclimate that favours natural enemies (Rämert et al., 2002; Munyuli et al., 2007). From the field observations made, *Orius* spp. aggregated in French bean and sunflower flowers, and maize silk and tassels. A monocrop of French bean supported the highest population of *C. menes* as compared to when it was grown together

with intercrops. This may imply that the microclimate created by the intercrops does not favour *C. menes* Tamò et al. (1993) found out that *C. menes* was present in high numbers on cowpea because of the larger populations of *M. sjostedti*. In our experiments *M. sjostedti* was also present in high numbers on a sole crop of French bean compared to French bean/intercrop mix.

Sunflower and Irish potato hosted mainly *F. schultzei* (>74% and > 80%, respectively) and *F. occidentalis* (>15% and >16%, respectively). *Megalurothrips sjostedti* and *H. adolfifrigerici* were of minor importance on both sunflower and Irish potato. This implies that *F. schultzei* prefers sunflower (Asteraceae) and Irish potato (Solanaceae) to French bean (Fabaceae) and baby corn (Poaceae) whereas *M. sjostedti* and *H. adolfifrigerici* do not. Schellhorn et al. (2010) showed that *F. occidentalis* and *F. schultzei* prefer feeding and reproducing on plants in the Solanaceae. Results from this study showed that *Orius* spp. prefer sunflower to Irish potato, which is in agreement with Chyzik & Ucko (2002).

In both the long and short rains seasons, baby corn did not harbour thrips that are of economic importance to French bean. Our results are in agreement with those of Kyamanywa et al. (1993) and Kasina et al. (2006a). The only thrips species that were recorded on baby corn were corn thrips, *Frankliniella williamsi* (Hood) and palm thrips, *Thrips pusillus* (Bagnall). This is the first record of corn thrips, *F. williamsi* from East Africa, which has been shown to transmit *maize chlorotic mottle virus* (MCMV) (Jiang et al., 1992). *Thrips pusillus* has been reported from Kenya (Mound, 2010). An intercrop of French bean with Irish potato and sunflower gave good French bean pod yield comparable to a monocrop of French beans, but the thrips population densities on the monocrop of French beans were quite high and the percentage of the produce that could get rejected in the market was also quite high. Irish potato and sunflower were also reproductive hosts of *F. schultzei* and *F. occidentalis* that are of economic importance to French beans.

3.5 Conclusions

The best thrips management strategy may be to have sunflower and Irish potato flower before French beans, in order to attract the *Frankliniella* species to the sunflower and Irish potato flowers. The farmer can then spray the sunflower and Irish potato plants to kill the thrips. This strategy would need to be tested in field studies. The biological reason why *M. sjostedti*, *F. schultzei*, *F. occidentalis*, and *H. adolfriderici* seem to reject baby corn also needs to be studied further to understand the role of baby corn in thrips management.

CHAPTER 4

FEEDING AND OVIPOSITION PREFERENCE OF *FRANKLINIELLA OCCIDENTALIS* FOR CROPS AND WEEDS ENCOUNTERED IN KENYAN FRENCH BEAN FIELDS

Abstract

Western flower thrips (WFT), *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), is an important pest of French beans in Kenya. However, information on the feeding activity and oviposition preference of WFT on crop and weed hosts associated with French beans in Kenya and other parts of the world is lacking. To determine the feeding and oviposition preference of WFT for crop and weed plants commonly encountered in French bean fields in Kenya, no-choice and choice experiments were conducted using four important crop and weed plants. Among the crop plants tested, highest feeding and oviposition activity of WFT was recorded on courgette/zucchini (*Cucurbita pepo* L.) and French beans (*Phaseolus vulgaris* L.). Spinach beet (*Beta vulgaris* L.) and sweet pepper (*Capsicum annuum* L.), were of relatively minor importance for feeding and oviposition. Among the weeds tested, gallant soldier (*Galinsoga parviflora* Cav.) was the most preferred host plant for feeding and oviposition compared to Chinese lantern (*Nicandra physaloides* L.), wild crucifer (*Erucastrum arabicum* Fisch. & C.A. Mey.) and pigweed (*Amaranthus hybridus* L.). *Phaseolus vulgaris* was the most preferred host for feeding and oviposition in the presence of *G. parviflora*, *E. arabicum* and *A. hybridus*. A positive correlation between the number of feeding punctures and the number of eggs oviposited by WFT on crop and weed plants was observed. The results of this study show that *P. vulgaris*, *C. pepo* and *G. parviflora* are both good feeding and oviposition hosts of WFT. *Cucurbita pepo* and *G. parviflora* may serve as potential sources of WFT outbreaks within French bean fields.

Key words: choice test, eggs, host, no-choice test, Thysanoptera, western flower thrips

4.0 Introduction

French bean, *Phaseolus vulgaris* L. (Fabaceae), is the second most important horticultural export crop after cut flowers in Kenya, constituting nearly 24% by volume and value of all fresh horticultural exports from Kenya (HCDA, 2010). Pests and diseases are the major constraints to French bean production in Kenya (Nderitu et al., 2007). Among the insect pests affecting French bean production in Kenya, western flower thrips [*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)] is the most important pest species (Nderitu et al., 2007). However, other thrips species such as *Frankliniella schultzei* (Trybom), *Hydatothrips adolfifridericici* (Karny) and *Megalurothrips sjostedti* (Trybom) also infest French beans (Nyasani et al. 2010, 2012). Direct feeding damage of thrips on French beans includes silvery spots and malformation on leaves, flowers, and pods (Löhr, 1996) resulting in yield losses estimated to be 63 – 68% in Kenya (Nyasani et al., 2012). Currently there are no reports of tospovirus transmission in French beans by thrips.

In general, thrips use crops and weeds as feeding and/or reproductive hosts. Thrips oviposition and reproductive success is influenced by the nutritional quality of the host plant and presence/absence of plant defence compounds (Delphia et al., 2007; Koschier et al., 2007). The amount of nitrogen, aminoacids, and sugar in the diet of thrips can positively correlate with the production of eggs, number of feeding scars, and level of feeding, respectively (Kirk, 1997; Scott-Brown et al., 2002). *Frankliniella occidentalis* is a highly polyphagous pest of many crops and wild plants, and it has been shown to feed on more than 240 host plants (Tommasini & Maini, 1995). Although *F. occidentalis* appears to prefer flowers and is more abundant on flowering plants with flowers than those without flowers (Gerin et al., 1999), it also readily feeds on leaves and stems (Brødsgaard, 2004). For example, on greenhouse cucumber (*Cucumis sativus* L.), females of *F. occidentalis* deposit most of their eggs in the leaves rather than the stems or flowers (Kiers et al., 2000) and prefer younger leaves to older leaves for oviposition (de Kogel et al., 1997).

Frankliniella occidentalis has been shown to use cultivated and non-cultivated host plants as feeding or reproductive hosts (Groves et al., 2002; Norris & Kogan, 2005; Northfield et al., 2008). The population of *F. occidentalis* on French beans in Kenya has been reported to increase at flowering stage (Nyasani et al., 2010, 2012), and such increase is thought to be due to immigration of thrips from neighbouring feeding and reproductive host plants (Groves et al., 2002; Norris & Kogan, 2005). Reproductive host plants are more important to population growth than adult feeding host plants, and they may serve as bridges to build thrips populations that migrate into cropping systems (Northfield et al., 2008). Several protocols exist for testing the suitability of host plants as feeding or reproductive hosts, for example measurement of (silver) damage, population dynamics (Northfield et al., 2008), reproduction (Paini et al., 2007) and egg production (Chaisuekul & Riley, 2005).

However, the preference for or suitability of different plants that occur within French bean fields in Kenya as feeding or oviposition sites for *F. occidentalis* has not been studied. Such information is a key research need for formulation of IPM strategies based on manipulation of cropping strategies. Therefore, the aim of this study was to determine the relative feeding and oviposition preference of *F. occidentalis* for crops and weeds in order to identify potential feeding and/or oviposition hosts of *F. occidentalis* within French bean fields. The selection of crop and weed plants for experimentation were based on earlier field studies examining annual cycles (seasonal increase and decrease in population density) of *F. occidentalis* on French beans and neighbouring plants (Nyasani et al. In press).

4.1 Materials and methods

4.1.1 Insect and plant materials

Initial cultures of *F. occidentalis* were field-collected from French beans at Thika, Kenya in January 2011. Thrips were reared on French bean pods in ventilated plastic jars at The International Centre of Insect Physiology and Ecology's insectary at 25 ± 1 °C, 50 – 60%

relative humidity (RH) with a 12L : 12D photoperiod. The fourth generation of thrips from these cultures was used in the experiment.

Crop and weed plants previously identified as hosts of *F. occidentalis* in earlier field studies on seasonality of *F. occidentalis* on French beans in Kenya (Nyasani et al., 2010; Nyasani et al., In press) were selected for the study. The crop plants chosen were French bean *P. vulgaris* L. Cv. Tana (Fabaceae), sweet pepper *Capsicum annuum* L. Cv. California wonder (Solanaceae), courgettes/zucchini *Cucurbita pepo* L. Cv. Black Beauty (Cucurbitaceae) and spinach beet, *Beta vulgaris* L. var. cicla (Chenopodiaceae). The weed plants chosen were Chinese lantern *Nicandra physaloides* L. (Solanaceae), gallant soldier *Galinsoga parviflora* Cav. (Asteraceae), pigweed *Amaranthus hybridus* L. (Amaranthaceae) and wild crucifer *Erucastrum arabicum* Fisch. & C.A. Mey. (Brassicaceae). Certified seeds of the crop plants and field-collected seeds of weeds were used in the study. The seeds were grown in plastic pots (diameter 30 cm) in a greenhouse to prevent insect pest infestations. Seedlings of the crop/weed plants were transplanted into smaller pots (diameter 10 cm) with one plant per pot. The plants were used in the experiments when they were at 4 – 6-leaf stage. Plants with the same number of leaves (4 leaves) were selected for experimental use. None of the plants used in the experiment were at flowering stage.

4.1.2 No-choice and choice tests with crop plants

The experiments were conducted using exclusion cages made of clear Perspex sheets (75 × 50 × 50 cm) as detailed in figure 1. The exclusion cages were partitioned into four choice compartments measuring 37.5 × 25 × 50 cm with a perforated thrips release chamber (15 × 15 × 50 cm) in the middle. Each choice compartment was provided with a 15-cm-diameter window secured with thrips proof nets for ventilation (Figure 1). The top of each choice compartment and the middle thrips release chamber were provided with sliding doors to enable placement of pots and release of insects.

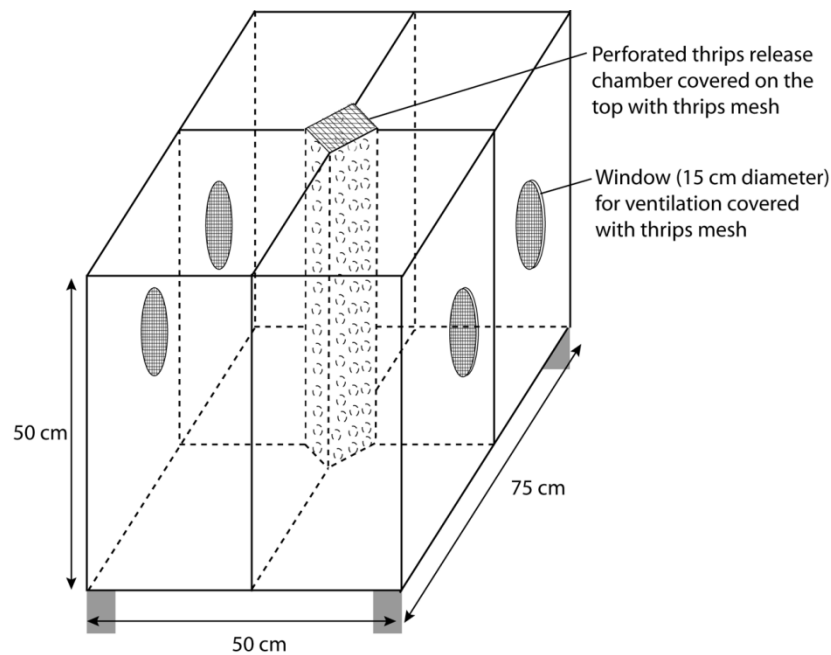


Figure 1: Cage unit for conducting choice and no-choice experiments.

No-choice experiments consisted of four plants of the same plant species in the same cage. A single potted crop plant was placed at the centre of each compartment. Newly emerged adult female and male *F. occidentalis* were allowed to mate for one day before use in the experiments. Forty female *F. occidentalis* that had presumably mated were then released into the thrips release chamber at the centre of each cage using 10 ml transparent plastic vials. Five cages were used for the experiments. The experiments were conducted in the insectary under room temperature conditions (25 ± 1 °C, 50 – 60% RH).

The thrips were left in the cages for 72 h in 12 L : 12 D h photoperiod. After three days (72 h) all adult thrips observed on the plants were collected. The individual plants were cut and placed in plastic bags. All leaves from the plants were cut and stained in boiling lactophenol acid fuchsin solution for 20 – 30 s to aid in identifying eggs under a stereomicroscope. Lactophenol acid fuchsin solution was prepared following procedures described by Nuessly et al. (1995). Stained leaves were immersed in lactophenol acid fuchsin smear in Petri dishes

(9 cm) for one hour before being destained by immersing the leaves in warm water for three minutes. Stained leaves were placed in Petri dishes (9 cm) for microscopic observation. The number of punctures and eggs observed on leaves under a stereomicroscope were counted and recorded.

Choice experiments consisted of four different plant species in the same cage. A single potted plant of each crop plant species was placed at the centre of each compartment. Five cages were used in the experiments. Position effects were neutralised by placing the different host plants in different directions in the different cages. For example, the position of *P. vulgaris* was North East in the first cage, South East in the second, South West in the third, North West in the fourth and North East in the fifth in reference to the centre of the cage. This procedure was repeated with the other crop plants. The experiments were conducted in the insectary under room temperature conditions (25 ± 1 °C, 50 – 60% RH). The other procedures of releasing thrips, cutting leaves after 72 hours, staining, destaining and observation of leaves for number of punctures and eggs were same as described earlier in the no-choice experiment.

4.1.3 No-choice and choice tests with weed plants

Since germination of the field-collected weed seeds was poor, leaf discs were used in these experiments. Leaf discs (1.8 cm) were punched using a cork borer from each of the four weed species selected. Petri dishes (9 cm) layered with agar were used as the test arena. In no-choice test, four leaf discs of one weed species were contiguously placed in a 5×5 cm square on agar in one Petri dish. This was done for all four species. Newly hatched adult male and female *F. occidentalis* were allowed to mate in the rearing jars for one day before being used in the experiments. One adult female *F. occidentalis* that had presumably mated was released at the centre of each Petri dish. The Petri dishes were then sealed using Parafilm[®] wrap to prevent the thrips from escaping. The thrips were left in the Petri dishes for 48 h in 12 L : 12

48 h photoperiod under room temperature conditions (25 ± 1 °C, 50 – 60% RH). The treatments were replicated five times. After two days (48 h) all adult thrips were collected from the Petri dishes. No mortality of adult thrips was observed in all Petri dishes. The individual leaf discs were removed from the Petri dishes and placed in plastic bags. All the leaf discs were stained and destained and observed for number of feeding punctures and eggs following the procedures described above.

Choice experiments were also conducted using Petri dishes (9 cm) following the procedures described in the no-choice experiment above. A single leaf disc (1.8 cm) of each of the four weed species was contiguously placed in a 5×5 cm square on agar in one Petri dish. Five Petri dishes were used in the experiment. Position effects were neutralised by placing the leaf discs of the different host plants in different directions in all Petri dishes. For example, the position of *G. parviflora* was West in the first replicate, North in the second, East in the third, South in the fourth and North in the fifth. The same procedure was done for the other three weed plants. The procedures for releasing thrips and removal of leaf discs from Petri dishes after 48 h were as detailed in the no-choice experiment. All the leaf discs were stained and destained and observed for the number of punctures and eggs following the procedures described above.

4.1.4 Choice test with French beans and weeds

A choice test with *P. vulgaris* and three weed plants (*G. parviflora*, *E. arabicum*, and *A. hybridus*) was conducted using leaf discs (1.8 cm) following procedures described in the choice experiment above. Ten replicates were used in the experiment. Position effects were neutralised by placing leaf discs of the different host plants in different directions in all replicates as described in the choice experiment using weed plants above. Staining, destaining and observation of leaf discs for the number of punctures and eggs was undertaken as described earlier in the choice experiment.

4.2 Data analysis

Count data on feeding and oviposition of *F. occidentalis* from choice and no-choice experiments were analysed by negative binomial regression using R 2.13.1 software (R Development Core Team, 2010) with package MASS (Venables & Ripley, 2002). The negative binomial distribution was chosen, because of its biological appropriateness in entomological studies, ability to handle overdispersion in count data and better goodness of fit measurements (deviance and Pearson χ^2 closer to 1) compared to Poisson or Gaussian distributions (Candy, 2000). *Post hoc* tests of individual pairwise comparisons were made, comparing differences in least square means estimated by maximum likelihood to a chi-square distribution. Pearson's product-moment correlation was used to determine the relationship between feeding damage (number of punctures) and oviposition (number of eggs) of *F. occidentalis* using R 2.13.1 software (R Development Core Team, 2010).

4.3 Results

4.3.1 Crop plants as feeding and oviposition sites

The effect of host plant on the feeding activity and oviposition rate of *F. occidentalis* was significant in the no-choice test ($\chi^2 = 53.61$, $df = 3$, $P < 0.001$ and $\chi^2 = 35.72$, $df = 3$, $P < 0.001$, respectively). In total *P. vulgaris* received 8.1 ± 0.2 feeding punctures and 5.0 ± 0.2 eggs of *F. occidentalis* per leaf within a 72 h experimental period. Oviposition rate on *C. pepo* was similar to *P. vulgaris* but the number of feeding punctures was 1.6 times higher (Fig. 2). In contrast oviposition rate as well as feeding activity was significantly lower by more than two times on *C. annuum* and *B. vulgaris* compared to *P. vulgaris* (Fig. 2). Pearson's product-moment correlation revealed a positive correlation between feeding activity and oviposition in the no-choice experiment ($r = 0.599$, $df = 479$, $P < 0.001$) (Fig. 3). In the choice experiment *F. occidentalis* showed a clear preference for *C. pepo* in its feeding activity and oviposition ($\chi^2 = 67.29$, $df = 3$, $P < 0.001$ and $\chi^2 = 99.13$, $df = 3$, $P < 0.001$, respectively) (Fig. 2). Compared to our focal crop plant *P. vulgaris*, *C. pepo* received seven

times more feeding punctures and eggs per leaf during the 72 h experimental period. In contrast feeding and oviposition activity on the two other crop plants, *C. annuum*, and *B. vulgaris*, was similar to *P. vulgaris* (Fig. 2). Pearson's product-moment correlation revealed that oviposition increased approximately linearly with the increase in feeding activity in the choice test ($r = 0.949$, $df = 105$, $P < 0.001$) (Fig. 3).

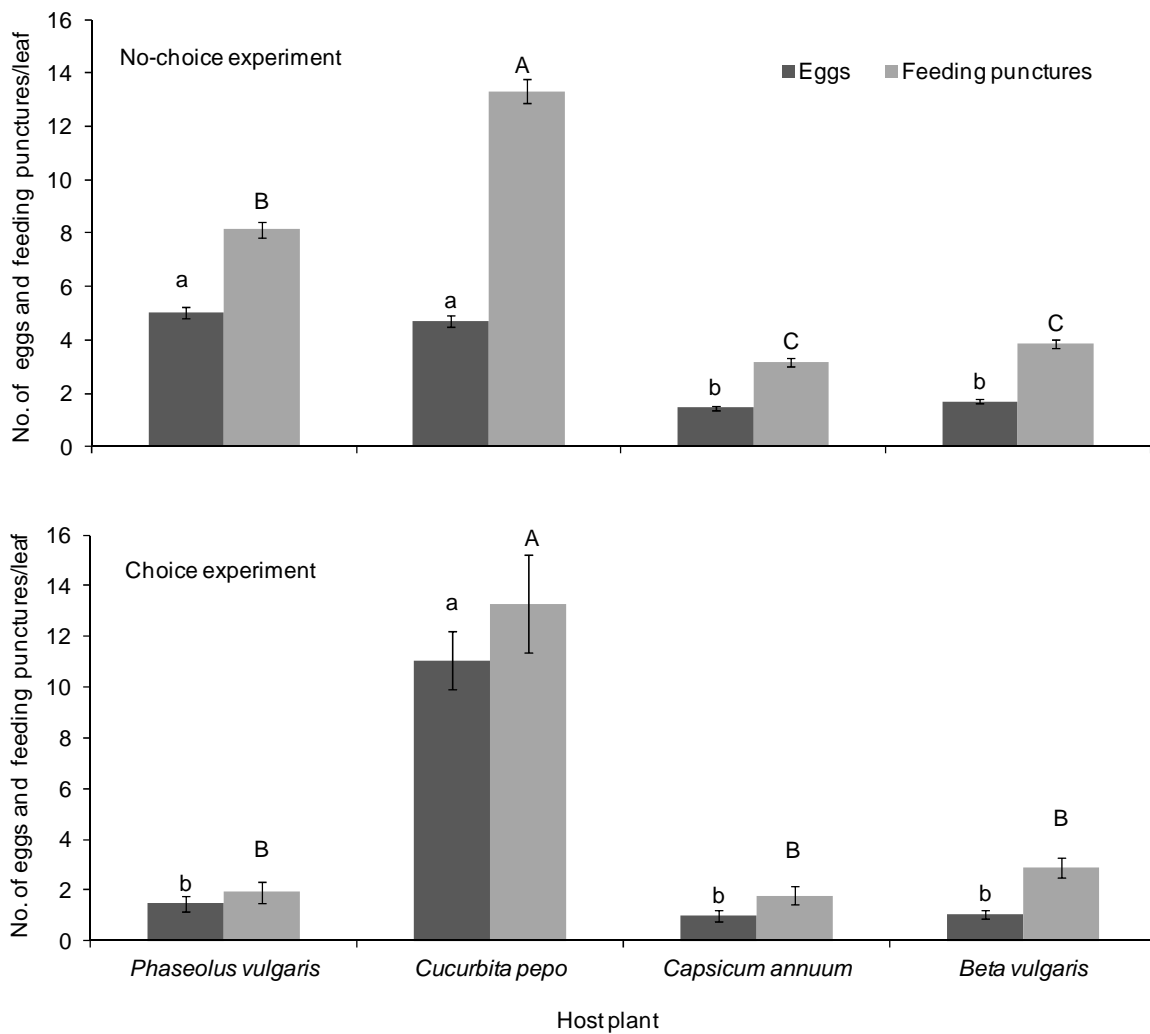


Figure 2: Effect of host plant on feeding damage and oviposition of *Frankliniella occidentalis* on *Phaseolus vulgaris*, *Cucurbita pepo*, *Capsicum annuum* and *Beta vulgaris* leaves in no-choice and choice test. Bars indicate means \pm SE. Means followed by the same upper or lower case letters indicate no significant differences between host plants for feeding damage and oviposition, respectively, by *post hoc* comparisons using chi-square test. Data represents the number of punctures and number of eggs recorded on leaves within 72 h of exposure.

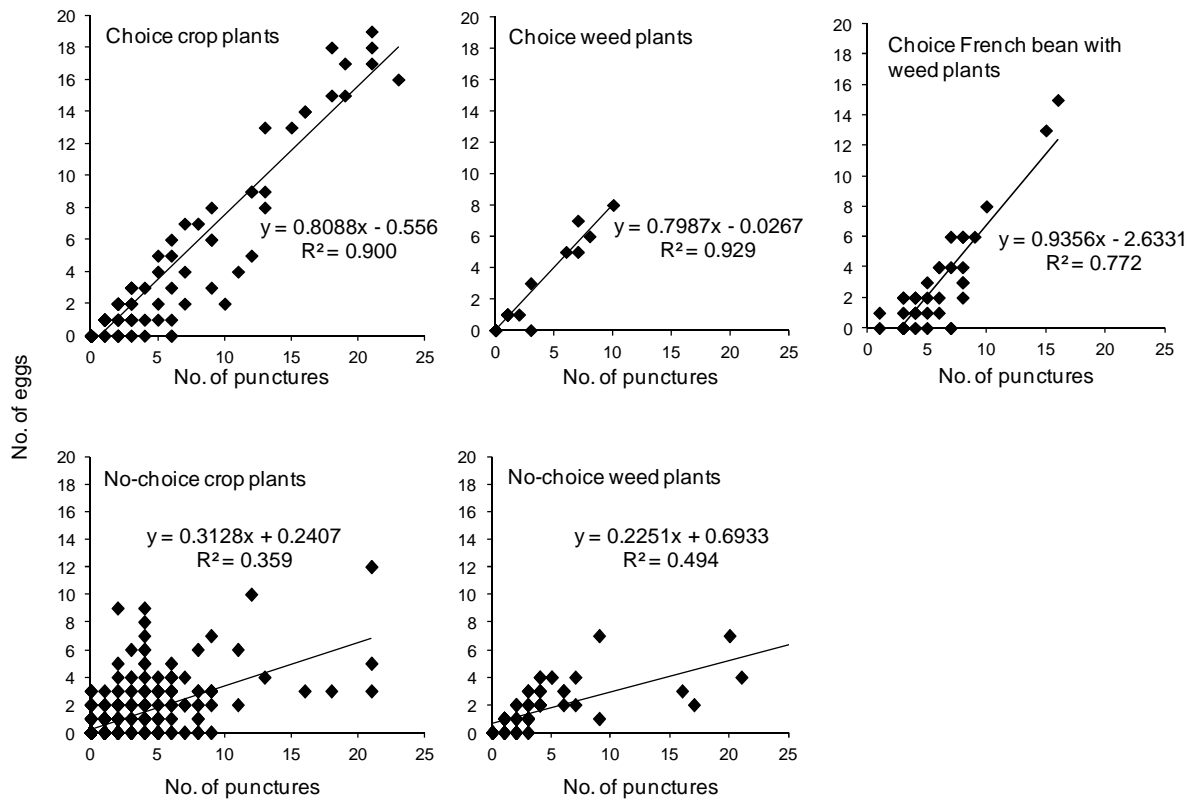


Figure 3: Correlation between the number of feeding punctures and the number of eggs laid by *Frankliniella occidentalis* for the different choice and no-choice tests using crop and weed plants.

4.3.2 Weed plants as feeding and oviposition sites

The effect of weed host plant on the feeding activity and oviposition rate of *F. occidentalis* was significant in the no-choice test ($\chi^2 = 42.61$, $df = 3$, $P < 0.001$ and $\chi^2 = 17.04$, $df = 3$, $P < 0.007$, respectively). *Galinsoga parviflora* received the highest number of feeding punctures (21.0 ± 1.1 punctures) and eggs (9.3 ± 0.3 eggs) per leaf disc within a 48 h experimental period (Fig. 4). *Amaranthus hybridus*, *N. physaloides* and *E. arabicum* received 1.6, 3.0, and 3.3 times fewer feeding punctures, respectively, compared to *G. parviflora* (Fig. 4). Oviposition rate of *F. occidentalis* on *A. hybridus* was similar to *G. parviflora* while *E. arabicum* and *N. physaloides* received 1.9 and 3.7 times fewer eggs in the no-choice test (Fig. 4). Pearson's product-moment correlation revealed a positive correlation between the number

of feeding punctures and the number of eggs laid by *F. occidentalis* in the no-choice test ($r = 0.708$, $df = 78$, $P < 0.001$) (Fig. 3).

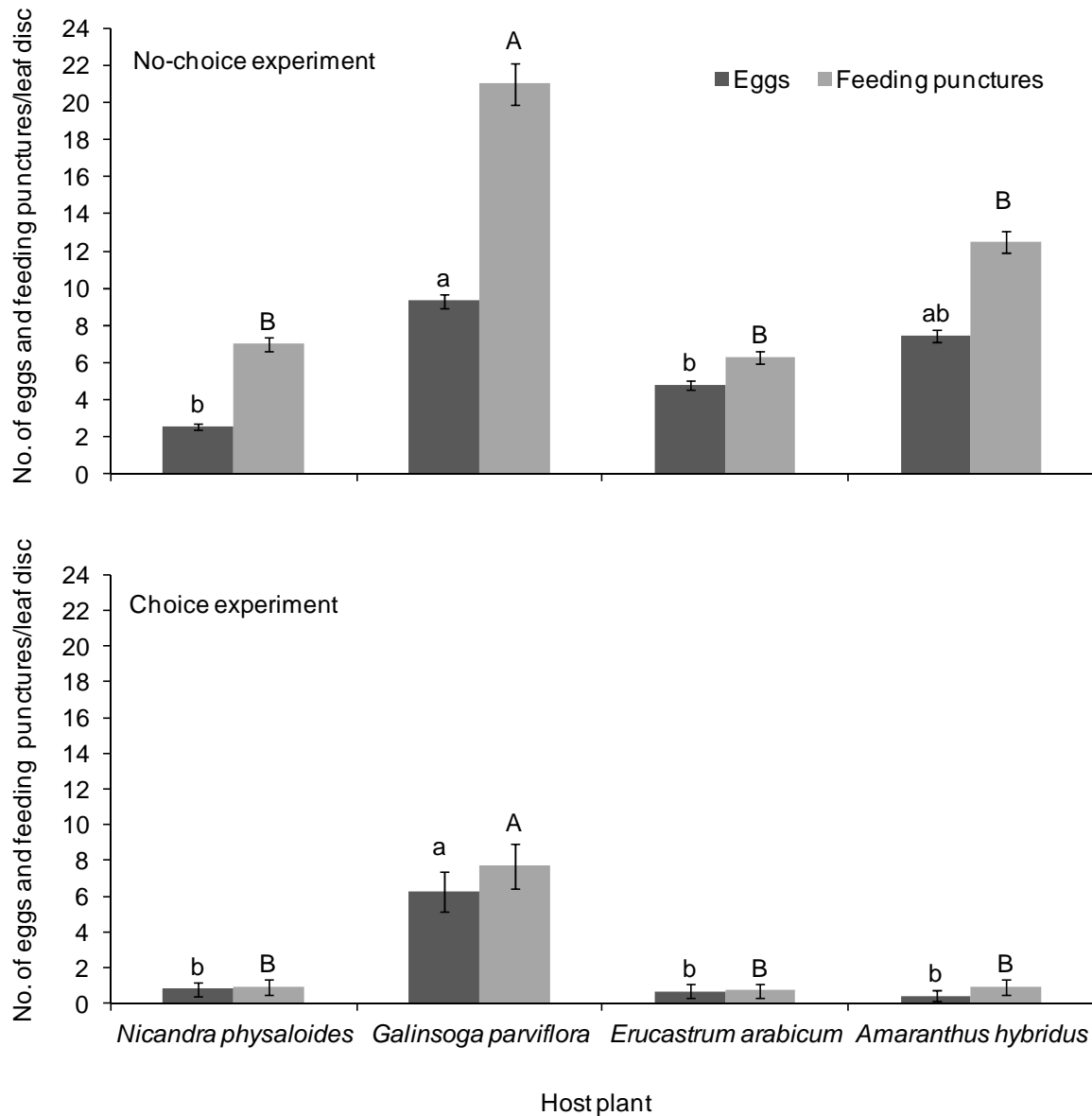


Figure 4: Effect of host plant on feeding damage and oviposition of *Frankliniella occidentalis* on *Nicandra physaloides*, *Galinsoga parviflora*, *Erucastrum arabicum* and *Amaranthus hybridus* leaves in no-choice and choice test. Bars indicate means \pm SE. Means followed by the same upper or lower case letters indicate no significant differences between host plants for feeding damage and oviposition, respectively, by *post hoc* comparisons using chi-square test. Data represents the number of punctures and number of eggs recorded on leaf discs within 48 hours of exposure.

The effect of weed host plant on the feeding and oviposition rate of *F. occidentalis* was significant in the choice test ($\chi^2 = 29.99$, $df = 3$, $P < 0.001$ and $\chi^2 = 30.24$, $df = 3$, $P < 0.001$, respectively). *Frankliniella occidentalis* showed a strong preference for *G. parviflora* in its feeding (7.7 ± 1.2 punctures per leaf disc) and oviposition (6.2 ± 1.1 eggs per leaf disc) activities (Fig 4). *Nicandra physaloides*, *A. hybridus*, and *E. arabicum* received more than 8 times fewer feeding punctures and eggs per leaf disc compared to *G. parviflora* (Fig. 4). Pearson's product-moment correlation revealed a strong positive correlation between the number of feeding punctures and the number of eggs laid by *F. occidentalis* in the choice test ($r = 0.964$, $df = 18$, $P < 0.001$ (Fig. 3).

4.3.3 French beans and weeds as feeding and oviposition sites

The effect of host plant on the feeding activity and oviposition rate of *F. occidentalis* was significant in the choice test ($\chi^2 = 35.87$, $df = 3$, $P < 0.001$ and $\chi^2 = 41.69$, $df = 3$, $P < 0.001$, respectively). *Phaseolus vulgaris* was the most preferred host for feeding (8.2 ± 0.9 punctures) and oviposition (5.2 ± 0.7 eggs) by *F. occidentalis* (Fig. 5). The feeding activity of *F. occidentalis* on *E. arabicum* and *G. parviflora* was similar to *P. vulgaris* (Fig. 5). Conversely, *G. parviflora*, *E. arabicum* and *A. hybridus* received 2.4, 4.4, and 9.4 times fewer eggs, respectively, compared to *P. vulgaris* (Fig. 5). Pearson's product-moment correlation revealed a strong positive correlation between the number of feeding punctures and the number of eggs laid by *F. occidentalis* in choice test involving French beans and the three weed plants ($r = 0.878$, $df = 38$, $P < 0.001$) (Fig. 3).

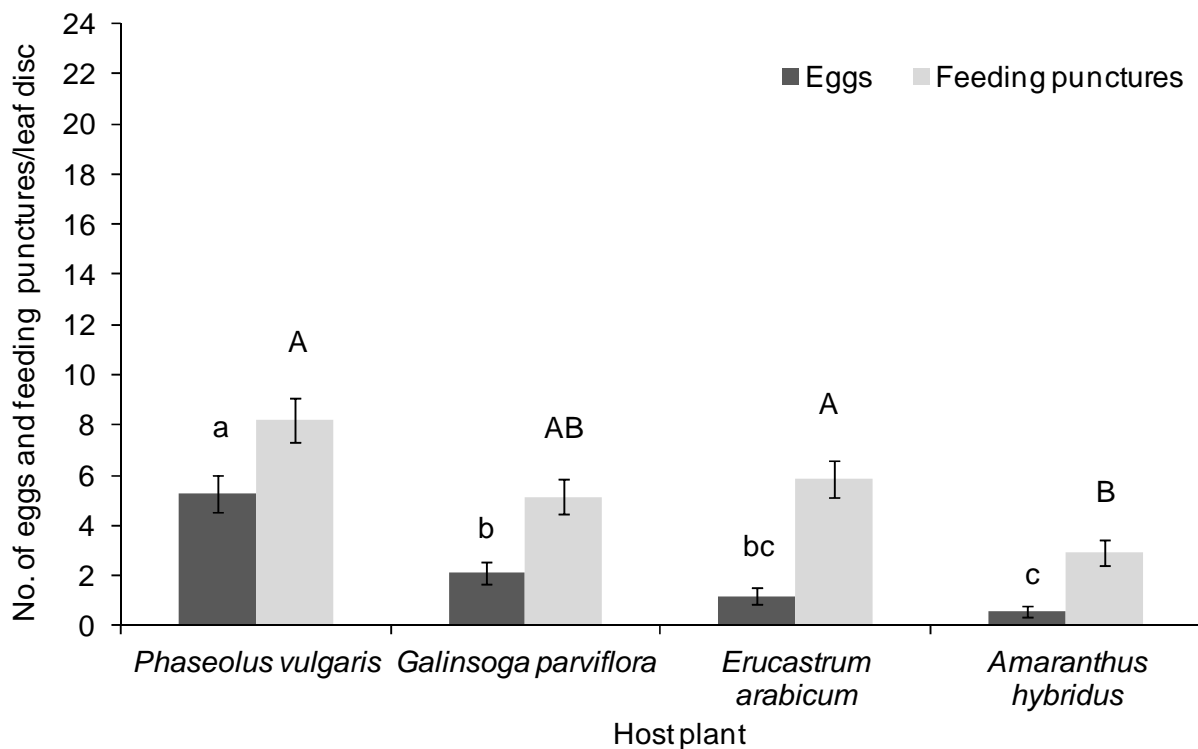


Figure 5: Choice test effect of host plant on feeding damage and oviposition of *Frankliniella occidentalis* on *Phaseolus vulgaris*, *Galinsoga parviflora*, *Erucastrum arabicum* and *Amaranthus hybridus* leaf discs. Bars indicate means \pm SE. Means followed by the same upper or lower case letters within each case indicate no significant differences between host plants for feeding damage and oviposition, respectively, by *post hoc* comparisons using chi-square test. Data represents the number of punctures and number of eggs recorded on leaf discs within 48 hours of exposure.

4.4 Discussion

This is the first laboratory study on feeding and oviposition of *F. occidentalis* on crop and weed plants commonly encountered in French bean agroecosystem in Kenya. Thrips are able to distinguish among plants as suitable feeding and/or oviposition sites to ensure fitness of their progeny (Scott-Brown et al., 2002). Studies by de Kogel et al. (1997) showed that number of hatched larvae is strongly correlated ($r = 0.99$) with oviposition rate of *F. occidentalis* on cucumber leaves, because egg mortality is very low. Similar studies by Rahman et al. (2010) reported that the preferred strawberry cultivar for feeding and oviposition by *F. occidentalis* was also the most optimum cultivar for larval development.

In the present study the relative the potential of selected crop and weed plants as feeding and oviposition sites for *F. occidentalis* is reported. Among the crop plants tested, *C. pepo* and *P. vulgaris* leaves received most feeding punctures and eggs of *F. occidentalis*. All the other crop plants, *B. vulgaris* and *C. annuum*, were of minor importance for *F. occidentalis* feeding and oviposition. This indicates that *C. pepo* leaves may act as a high quality reproductive site for *F. occidentalis*. *Frankliniella occidentalis* has also been reported to feed and oviposit on *P. vulgaris* leaves by Zhang et al. (2006) and Koschier et al. (2007) in life history and host selection studies using different host plants, respectively. Although feeding and oviposition preference experiments involving *F. occidentalis* and *C. pepo* have not been described, *F. occidentalis* has been reported to feed on squash (Yardimci & Kilic, 2009) and cucumber, *Cucumis sativus* (de Kogel et al., 1997; Kiers et al., 2000; Hulshof et al., 2003; Yardimci & Kilic, 2009) in feeding and oviposition studies. As observed in this study, Zhang et al. (2006) also reported that leaves of cucurbitaceous plants were the most suitable host for oviposition by *F. occidentalis* compared to leaves of cruciferous, solanaceous and fabaceous plants.

Among the weed species tested, *G. parviflora* was the most preferred host for feeding and oviposition by *F. occidentalis* compared to *N. physaloides*, *E. arabicum*, and *A. hybridus*. This may indicate that *G. parviflora* is a potential feeding and oviposition host of *F. occidentalis* under field conditions. Studies by Nyasani et al. (2010) also reported that *F. occidentalis* adults and larvae were present on *G. parviflora* in the field. Results from this study are in agreement with those of Mertelik & Mokra (1998) who also reported *G. parviflora* as a good host of *F. occidentalis* for both feeding and reproduction in glasshouses. *Galinsoga parviflora* is an annual weed commonly found in disturbed habitats and agricultural areas in Kenya. It grows and matures quickly and can have many generations per growing season. Seeds of *G. parviflora* remain viable within the soil for more than two years (Espinosa-García et al., 2003) and therefore, can form a permanent seed bank in the soil. In

our studies, the feeding activity of *F. occidentalis* was least on *N. physaloides*. This may indicate that *N. physaloides* is a poor feeding host for *F. occidentalis*. Previous studies by Andrews-Smith et al. (1991) also reported that *N. physaloides* stops insect feeding due the insect antifeedant steroid that it contains.

In the present choice study involving *P. vulgaris* and important weed species in Petri dishes, *P. vulgaris* was the most preferred host for feeding and oviposition by *F. occidentalis* compared to *E. arabicum*, *G. parviflora* and *A. hybridus*. However, the trend of increased preference for *G. parviflora* in comparison to the other weeds (*E. arabicum* and *A. hybridus*) as observed in the choice tests with weeds alone was not reflected when the focal host plant (*P. vulgaris*) was also provided as a choice. The possible reason could be that *F. occidentalis* prefers a host plant it has already frequently experienced compared to the host plants it occasionally experiences. In the current experiment *F. occidentalis* was originally field-collected from French beans and reared on French bean pods. The phenomenon whereby insects tend to prefer the plant they have already experienced, and whether or not this plant is most appropriate for development has been reported by Szentesi & Jermy (1990). Additionally, thrips are able to distinguish among plants as suitable feeding and/or oviposition sites to ensure fitness of their progeny (Scott-Brown et al., 2002).

These results also indicate that over short distances or when dispersing at random, *F. occidentalis* may be motivated to settle and deposit eggs on *P. vulgaris*. Further, the results indicate that weeds may be ‘source plants’ for immigration of *F. occidentalis* into French bean plants since thrips are highly mobile and are known to migrate into cropping systems at various times throughout the year from non-crop plants (Groves et al., 2002; Northfield et al., 2008; Allsopp, 2010). Studies by Northfield et al. (2008) set to determine potential sources of *Frankliniella* spp. on crops reported that several uncultivated reproductive hosts of *Frankliniella* spp. hosted thrips in different seasons suggesting that they could be a source of

thrips migrating into crops in the following season. Seasonality studies by Allsopp (2010) also reported that more WFT were caught on sticky traps hanging outside the table grapes canopy than on traps hanging under the vine canopy. This suggested a constant influx of thrips into vineyards from alternate host plants in the surrounding area during the growing season.

4.5 Conclusions

This study provides some insight into how *F. occidentalis* can be managed on French beans crops in Kenya. *Cucurbita pepo* and *G. parviflora* have been shown good feeding and oviposition hosts of *F. occidentalis* during the vegetative stage. These results also imply that *P. vulgaris* and *C. pepo* cropping systems might need a rotation scheme to reduce thrips populations, but additional studies involving flowering plants are needed before recommendations can be given. Furthermore, results from this study indicate a need for effective management of weeds such as *G. parviflora*, which may act as potential reservoirs of *F. occidentalis* in French bean fields. However, the role of *C. pepo* and *G. parviflora* as reservoirs of natural enemies and/or potential sources of virus transmission also need to be considered in the development of sustainable management programme. Field studies are required to validate our results. The effect of pollen and/or nectar of the different host plants on reproduction of *F. occidentalis* should also be included because of their impact on thrips feeding and/or reproduction.

CHAPTER 5

GENERAL DISCUSSION

Western flower thrips (WFT), [*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)], is one of the most important pests of French beans in Kenya. Control of WFT is difficult because it has a wide host range (Tommasini & Maini, 1995), high reproduction rate (Weintraub, 2007), cryptic feeding habit (Kirk, 1997), and ability to pupate in soil (Berndt et al., 2004). Western flower thrips has also developed resistance to the commonly used classes of insecticides (Nderitu et al., 2007, 2008). Development of sustainable integrated pest management (IPM) strategies against the WFT requires a sound understanding of its field ecology in terms of colonisation pattern, seasonal abundance, and feeding and oviposition behaviour. However, the above named aspects have not been studied in details within French bean fields in Kenya.

Therefore, to study the seasonal abundance of WFT and its natural enemies in French bean agroecosystems in Kenya, field studies were conducted at two major French bean agroecological zones (mid- and high-altitude zones) in Kenya from January to December 2009. To study the effect of intercrops on thrips species composition and population density on French beans, French bean were planted as a sole crop and as an intercrop with either sunflower, Irish potato, or baby corn, in different combinations. To study the feeding and oviposition preference of WFT for crop and weed plants commonly encountered in French bean fields in Kenya, no-choice and choice experiments were conducted using four important crop (*Phaseolus vulgaris*, *Capsicum annuum*, *Cucurbita pepo* and *Beta vulgaris*) and weed (*Nicandra physaloides*, *Galinsoga parviflora*, *Amaranthus hybridus*, and *Erucastrum arabicum*) plants.

In the seasonality studies, colonisation of French beans with WFT in both small- and large-scale farms in high- and mid-altitude zones started at 2- and 3-leaf stage, respectively. There

was an increase in the number of WFT from budding stage to podding/flowering stage. A decline in population density of WFT was at crop senescence. Two natural enemies of thrips, [*Orius* spp. (Hemiptera: Anthocoridae) and *Ceraninus menes* (Walker) (Hymenoptera: Eulophidae)], were recorded on French beans and their population grew in tandem with the population of WFT. Overall, the population density of WFT was least in the first growing season (January – April) which was in the long rains season. Higher population densities of WFT on French beans in all farm sizes and agroecological zones were recorded in the third growing season (September – December) which was in the short rains season. In studies looking at the effect of intercrops on thrips species composition and population abundance on French bean, a monocrop of French bean hosted more thrips than a French bean intercrop mix. French beans hosted four thrips species, *Megalurothrips sjostedti*, *F. schultzei*, *F. occidentalis*, and *Hydatothrips adolfifriderici* in order of decreasing abundance. Sunflower and Irish potato, hosted mainly *F. schultzei* (>70%), and *F. occidentalis* (>15%). Baby corn did not host the thrips species recorded on French bean. Thrips natural enemies such as *Orius* spp. and *C. menes* were recorded in all crop plants but in especially high numbers on baby corn and French beans, respectively. Plots with French bean alone had about 1.4 times higher yields compared to intercropped plots of French bean with sunflower and French bean with baby corn. However, the percentage of pods that could get rejected on the market due to thrips damage was highest on plots with French bean alone and lowest on plots with French bean and baby corn. Among the crop plants tested for feeding and oviposition preference by WFT, highest feeding and oviposition by WFT was recorded on *C. pepo* and *P. vulgaris*. All the other crop plants, *B. vulgaris* and *C. annuum*, were of minor importance for WFT feeding and oviposition. Among the weeds tested, *G. parviflora* was the most preferred host plant for feeding and oviposition compared to *N. physaloides*, *E. arabicum* and *A. hybridus*. *Phaseolus*

vulgaris was the most preferred host for feeding and oviposition in the presence of *G. parviflora*, *E. arabicum* and *A. hybridus*.

This study clearly shows that thrips population development on French in monocultures and polycultures, small- and large-scale farms, and mid- and high-altitude areas in Kenya is similar. Infestation starts at the 2-leaf stage, a sharp increase in thrips population density is from budding to flowering stage and peak is mainly at podding/flowering stage and a decline is during crop senescence. This implies that neighbouring host plants (crops and weeds) act as a source of infestation to French bean crops at 2-leaf stage. Further, results from this study imply that management strategies targeted at WFT need to start at 3-leaf to budding stage (guided by weekly scouting) to prevent further build-up of thrips population and since it is difficult to control thrips once they are inside flowers. In addition, rainfall and phenological stage of French bean are important factors in determining seasonal dynamics of WFT. The least population densities of WFT are likely to occur during the first growing season (January – April) which coincides with the long rains season whereas the highest population densities of WFT are likely to occur during third growing season (September-December) which coincides with the short rains season. As observed in this study, rainfall has also been reported to affect thrips population both negatively and positively depending on amount and duration (Morsello et al., 2010). It can suppress populations by killing larvae, and thrips populations so affected often recover slowly (Morsello & Kennedy, 2009). However, by maintaining adequate soil moisture, rainfall can positively influence thrips populations by fostering plant growth and enhancing pupal survival (Morsello & Kennedy, 2009). Results from this study also show that intercropping French beans with other crops compromises on French bean yield but reduces damage to the French bean pods, thereby enhancing marketable yield. The slight reduction in French bean yield recorded in polycultures could have been as result of competition for resources between French bean and its intercrops. Further, the enhanced

quality of French bean pods in polycultures could be due to the reduced thrips population densities on French bean in polycultures. As observed in this study, Finckh & Karpenstein-Machan (2002) also reported that intercropping tends to result in lower levels of insect pests than the corresponding monocropping. This study also clearly shows that *C. pepo* and *G. parviflora* are good feeding and oviposition hosts of WFT. This implies that *C. pepo* and *G. parviflora* may act as potential sources of WFT within French bean fields in Kenya.

As an integrated pest management (IPM) strategy based on the research findings from this study, baby corn, sunflower, and Irish potato may be utilised in the IPM package against WFT. The IPM package can be developed in the context of “push and pull strategy”. The best strategy could be to plant baby corn as border crop in order to act as a push plant against WFT, *M. sjostedti*, *F. schultzei*, and *H. adolfifrigerici*. Baby corn also is a good host of *Orius* spp. which are important predators of WFT. In the main farm field, sunflower and Irish potato would need to be planted earlier in respect to French bean so that they come to flowering stage before French beans in order to attract the *Frankliniella* species to the sunflower and Irish potato flowers. The farmer can then spray the sunflower and Irish potato plants to kill the thrips. This strategy would need to be tested in field studies. If crop rotation is adopted as a management strategy against WFT, courgette/zucchini fields should not be side by side with French bean fields or the two crops should not follow one another in a rotation scheme since courgette/zucchini has been shown in this study as potential feeding and oviposition host of WFT. In addition, French bean fields need to be kept weed free of *G. parviflora* which is a good feeding and reproductive host of WFT. The biological reason why *F. occidentalis*, *F. schultzei*, *M. sjostedti*, and *H. adolfifrigerici* seem to reject baby corn also needs to be studied further to understand the role of baby corn in thrips management. Further studies are also needed on the movement of WFT into and out of French beans from neighbouring crops commonly grown side by side or in rotation with French beans in Kenya.

REFERENCES

- Alabi, O.Y., Odebisi, J.A. & Tamò, M. (2004) Effect of host plant resistance in some cowpea (*Vigna unguiculata* {L.} Walp.) cultivars on growth and developmental parameters of the flower bud thrips, *Megalurothrips sjostedti* (Trybom). *Crop Protection*, 23, 83–88.
- Allsopp, E. (2010) Seasonal occurrence of western flower thrips, *Frankliniella occidentalis* (Pergande), on Table grapes in the Hex River Valley, South Africa. *South African Journal of Enology and Viticulture*, 31, 49–57.
- Andrews-Smith, W., Gill, H.K., Smith, R.W. & Whiting, D.A. (1991) Stages in the biosynthesis of the epoxy lactol side chain of Nic-I, insect antifeedant steroid of *Nicandra physaloides*. *Journal of the Chemical Society, Perkin Transactions 1*, 291–296.
- Berndt, O., Meyhöfer, R. & Poehling, H.-M. (2004) The edaphic phase in the ontogenesis of *Frankliniella occidentalis* and comparison of *Hypoaspis miles* and *H. aculeifer* as predators of soil-dwelling thrips stages. *Biological Control*, 30, 17–24.
- Brødsgaard, H.F. (2004) Biological control of thrips – ornamentals. In: *Biocontrol in Protected Culture*, Ball Publishing, Batavia, IL, USA, Ed. by Heinz, K.M., van Driesche, R.G. & Parrella, M.P., pp. 253–264.
- Buitenhuis, R. & Shipp, J.L. (2006) Factors influencing the use of trap plants for the control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on greenhouse potted chrysanthemum. *Environmental Entomology*, 35, 1411–1416.
- Candy, S. (2000) The application of generalized linear mixed models to multi-level sampling for insect population monitoring. *Environmental and Ecological Statistics*, 7, 217–238.

-
- Capinera, J.L., Weissling, T.J. & Schweizer, E.E. (1985) Compatibility of intercropping with mechanized agriculture: effects of strip intercropping of pinto beans and sweet corn on insect abundance in Colorado. *Journal of Economic Entomology*, 78, 354–357.
- Chaisuekul, C. & Riley, D.G. (2005) Host plant, temperature, and photoperiod effects on ovipositional preference of *Frankliniella occidentalis* and *Frankliniella fusca* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 98, 2107–2113.
- Chyzik, R. & Ucko, O. (2002) Seasonal abundance of the western flower thrips *Frankliniella occidentalis* in the Arava Valley of Israel. *Phytoparasitica*, 30, 335–346.
- Delphia, C.M., Mescher, M.C. & De Moraes, C.M. (2007) Induction of plant volatiles by herbivores with different feeding habits and the effects of induced defenses on host-plant selection by thrips. *Journal of Chemical Ecology*, 3, 997–1012.
- Edwards, O. & Singh, K.B. (2006) Resistance to insect pests: What do legumes have to offer? *Euphytica*, 147, 273–285.
- Espinosa-García, F.J., Vázquez-Bravo, R. & Martínez-Ramos, M. (2003) Survival, germinability and fungal colonization of dimorphic achenes of the annual weed *Galinsoga parviflora* buried in the soil. *Weed Research*, 43, 269–275.
- Feller, C., Bleiholder, H., Buhr, L., Hack, H., Hess, M., Klose, R., Meier, U., Stauss, R., Van Den Boom, T. & Weber, E. (1995) Phenological growth stages of vegetables: II. Fruiting vegetables and legumes. *Nachrichtenbl. Deut. Pflanzenschutzd.*, 47, 217–232.
- Finckh, M.R. & Karpenstein-Machan, M. (2002) Intercropping for pest management. In: *Encyclopedia of Pest Management*, Taylor and Francis, Boca Raton, FL, USA, Ed. by Pimentel, D., pp. 423–425.

-
- Gerin, C., Hance Th & van Impe, G. (1999) Impact of flowers on the demography of western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Journal of Applied Entomology*, 123, 569–574.
- Gitonga, L.M. (1999) Bioecology of thrips in French bean growing ecosystem in Kenya. PhD Thesis, Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya.
- Gitonga, L.M., Overholt, W.A., Lohr, B., Magambo, J.K. & Mueke, J.M. (2002) Functional response of *Orius albidipennis* (Hemiptera: Anthocoridae) to *Megalurothrips sjostedti* (Thysanoptera: Thripidae). *Biological Control*, 24, 1–6.
- Gonzalez-Zamora, J.E., Ribes, A., Meseguer, A. & Garcia-Mari, F. (1994) Thrips control in strawberries: use of broad bean plants as a refuge for populations of anthocorids. *Boletin de Sanidad Vegetal*, 20, 57–72.
- Greenberg, S.M., Liu, T.-X. & Adamczyk, J.J. (2009) Thrips (Thysanoptera: Thripidae) on cotton in the Lower Rio Grande Valley of Texas: Species composition, seasonal abundance, damage, and control. *Southwest Entomology*, 34, 417–430.
- Groves, R.L., Walgenbach, J.F., Moyer, J.W. & Kennedy, G.G. (2002) The role of weed hosts and tobacco thrips, *Frankliniella fusca* in the epidemiology of Tomato spotted wilt virus. *Plant Diseases*, 86, 573–582.
- Hansen, E.A., Funderburk, J.E., Reitz, S.R., Ramachandran, S., Eger, J.E. & McAuslane, H. (2003) Within-plant distribution of *Frankliniella* species (Thysanoptera: Thripidae) and *Orius insidiosus* (Heteroptera: Anthocoridae) in field pepper. *Environmental Entomology*, 32, 1035–1044.
- HCDA (Horticultural Crops Development Authority) (2007) Export statistics volumes. http://www.hcda.or.ke/tech/full_site_map.php?p_title=Export%20Statistics
- HCDA (Horticultural Crops Development Authority) (2010) Export statistics volumes. <http://www.hcda.or.ke/Statistics/2010/Volumes,%20Jan%20-%20Dec%20>.

-
- Hirose, Y., Kajita, H., Takagi, M., Okajima, S., Napompeth, B. & Buranapanichpan, S. (1993). Natural enemies of *Thrips palmi* and their effectiveness in the native habitat, Thailand. *Biological Control*, 3, 1–5.
- Hulshof, J., Ketoja, E. & Vänninen, I. (2003) Life history characteristics of *Frankliniella occidentalis* on cucumber leaves with and without supplemental food. *Entomologia Experimentalis et Applicata*, 108, 19–32.
- Jensen, S.E. (2000) Insecticide resistance in the western flower thrips, *Frankliniella occidentalis*. *Integrated Pest Management Review*, 5, 131–146.
- Jiang, X.Q., Meinke, L.J., Wright, R.J., Wilkinson, D.R. & Campell, J.E. (1992) Maize chlorotic mottle virus in Hawaiian-grown maize: vector relations, host range and associated viruses. *Crop Protection*, 11, 248–254.
- KARI (Kenya Agricultural Research Institute) (2005) French (Snap) bean Production Manual. Revised Edition. Kenya Agricultural Research Institute, Thika, Kenya.
- Karungi, J., Adipala, E., Nampala, P., Ogenga-Latigo, M.W. & Kyamanywa, S. (2000) Pest management in cowpea. Part 3. Quantifying the effect of cowpea field pests on grain yields in eastern Uganda. *Crop Protection*, 19, 343–347.
- Kasina, J., Nderitu, J., Nyamasyo, G., Olubayo, F., Waturu, C. et al. (2006a) Evaluation of companion crops for thrips (Thysanoptera: Thripidae) management on French bean *Phaseolus vulgaris* (Fabaceae). *International Journal of Tropical Insect Science*, 26, 121–125.
- Kasina, J., Nderitu, J., Nyamasyo, G., Olubayo, F., Waturu, C., Obudho, E. & Yobera, D. (2006) Diurnal population trends of *Megalurothrips sjostedti* and *Frankliniella occidentalis* (Thysanoptera: Thripidae) and their natural enemies on French bean *Phaseolus vulgaris* (Fabaceae). *International Journal of Tropical Insect Science*, 26, 2–7.

-
- Katayama, H. (1997) Effect of temperature on development and oviposition of western flower thrips *Frankliniella occidentalis* (Pergande). Japanese Journal of Applied Entomology and Zoology, 41, 225–231.
- Kedera, C. & Kuria, B. (2003) Invasive alien species in Kenya: identification of risks and management of invasive alien species using the IPPC framework. Proceedings of a workshop in Braunschweig, Germany, 22–26th September 2003, FAO/IPPC, Rome, Italy, pp. 199–204.
- Kelly, J.F. & Scott, M.K. (1992) The nutritional value of snap beans versus other vegetables. Snap beans in developing world, CIAT, Cali, Columbia, pp. 23–46.
- Kibata, G.N. & Anyango, J.J. (1996) Possibilities of control of flower thrips with insecticides. Proceedings of the Biennial Crop Protection Conference, KARI, Nairobi, Kenya, 27–28th March 1996, pp. 62–68.
- Kiers, E., de Kogel, W.J., Balkema-Boomstra A., Mollema, C. (2000) Flower visitation and oviposition behaviour of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on cucumber plants. Journal of Applied Entomology, 124, 27–32.
- Kirk, W.D.J. (1997) Feeding. In: Thrips as Crop Pests. CAB International, London, UK, Ed. by Lewis, T.L., pp. 119–174.
- Kirk, W.D.J. (2002) The pest and vector from the West: *Frankliniella occidentalis*. Thrips and Tospoviruses. Proceedings of the 7th International Symposium of Thysanoptera, Australian National Insect Collection, Canberra, Australia, Ed. by Marullo, R. & Mound, L., pp. 33–44.
- Kirk, W.D.J. & Terry, L.I. (2003) The spread of the western flower thrips *Frankliniella occidentalis* (Pergande). Agricultural and Forest Entomology, 5, 301–310.

-
- de Kogel, W.J., van der Hoek, M., & Mollema, C. (1997) Oviposition preference of western flower thrips for cucumber leaves from different positions along the plant stem. *Entomologia Experimentalis et Applicata*, 82, 283–288.
- Koschier, E.H., Hoffmann, D. & Reiner, J. (2007) Influence of salicylaldehyde and methylsalicylate on post-landing behaviour of *Frankliniella occidentalis* Pergande. *Journal of Applied Entomology*, 131, 362–367.
- Kyamanywa, S. & Ampofo, J.K. (1988) Effect of cowpea/maize mixed cropping on the incident light at the cowpea canopy and flower thrips (Thysanoptera: Thripidae) population density. *Crop Protection*, 7, 186–189.
- Kyamanywa, S., Baliddawa, C.W. & Omolo, E. (1993) Influence of cowpea/maize mixture on generalist predators and their effect on the population density of legume flower thrips, *Megalurothrips sjostedti* (Trybom) (Thysanoptera: Thripidae). *Insect Science and its Application*, 14, 493–499.
- Lewis, T. (1997) Flight and dispersal. In: *Thrips as Crop Pests*, CABI, Oxon, UK, Ed. by Lewis, T., pp. 175–195.
- Löhr, B. (1996) Integrated pest management in French beans in Kenya. Past achievements and some thoughts about the flower thrips problem. *Proceedings of the Biennial Crop Protection Conference, KARI, Nairobi, Kenya, 27–28th March 1996*, pp. 18–24.
- McDonald, J.R., Bale, J.S. & Walters, K.F.A. (1998) Effect of temperature on development of the western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae). *European Journal of Entomology*, 95, 301–306.
- McKenzie, C.L., Cartwright, B., Miller, M.E. & Edelson, J.V. (1993) Injury to onions by *Thrips tabaci* (Thysanoptera: Thripidae) and its role in the development of purple blotch. *Environmental Entomology*, 22, 1266–1277.

-
- Mertelik, J. & Mokra, V. (1998) Tomato spotted wilt virus in ornamental plants, vegetables and weeds in the Czech Republic. *Acta Virologica*, 42, 347–351.
- Moritz, G., Mound, L.A., Morris, D.C. & Goldarazena, A. (2004) ThripsID–Pest Thrips of the World. An Identification and Information System using Molecular and Microscopical Methods. CD-ROM published by Centre for Pest Information Technology and Transfer, The University of Queensland, Brisbane, Australia.
- Morsello, S.C. & Kennedy, G.G. (2009) Spring temperature and precipitation affect tobacco thrips, *Frankliniella fusca*, population growth and tomato spotted wilt virus spread within patches of the winter annual weed *Stellaria media*. *Entomologia Experimentalis et Applicata*, 13, 138–148.
- Morsello, S.C., Beaudoin, A.L., Groves, R.L., Nault, B.A. & Kennedy, G.G. (2010) The influence of temperature and precipitation on spring dispersal of *Frankliniella fusca* changes as the season progresses. *Entomologia Experimentalis et Applicata*, 134, 260–271.
- Mound, L.A. (2010) Species of the genus Thrips (Thysanoptera, Thripidae) from the Afro-tropical region. *Zootaxa*, 2423, 1–24.
- Munyuli, M.B.T., Luther, G.C. & Kyamanywa, S. (2007) Effects of cowpea cropping systems and insecticides on arthropod predators in Uganda and Democratic Republic of the Congo. *Crop Protection*, 26, 114–126.
- Mwangi, M. (1998) Management of French bean rust by seed treatment and determination of yield loss in relation to stage of infection. MSc. Thesis, University of Nairobi, Kenya.
- Nabirye, J., Nampala, P., Kyamanywa, S., Ogenga-Latigo, M.W., Wilson, H. & Adipala, E. (2003) Determination of damage-yield loss relationships and economic injury levels of flower thrips on cowpea in eastern Uganda. *Crop Protection*, 22, 911–915.

-
- Nderitu, J.H., Anyango, J.J. & Ampofo, J.K. (1997) A survey of insect pests and farmers' control measures on snap beans in Kirinyaga district, Kenya. Occasional publication series, Bean Network Research in Africa. No 23, 1-10.
- Nderitu, J.H., Wambua, E.M, Olubayo, F., Kasina, M.J. & Waturu, C.N. (2007) Management of thrips (Thysanoptera: Thripidae) infestation on French beans (*Phaseolus vulgaris* L.) in Kenya by combination of insecticides and varietal resistance. *Journal of Entomology*, 4, 469–473.
- Nderitu, J.H., Kasina, M.J., Nyamasyo, G.N., Waturu, C.N. & Aura, J. (2008) Management of thrips (Thysanoptera: Thripidae) on French beans (Fabaceae) in Kenya: Economics of insecticide applications. *Journal of Entomology*, 5, 148–155.
- Nderitu, J., Mwangi F., Nyamasyo, G. & Kasina, M. (2009) Evaluation of cropping systems as a strategy for managing snap bean flower thrips in Kenya. *International Journal of Sustainable Crop Production*, 4, 22–25.
- Ngakou, A., Tamò, M., Parh, I.A., Nwaga, D., Ntonifor, N.N., Korie, S. & Nebane, C.L.N. (2008) Management of cowpea flower thrips, *Megalurothrips sjostedti* (Thysanoptera, Thripidae), in Cameroon. *Crop Protection*, 27, 481–488.
- Nihoul, P. & Hance, T. (1994) Implications of intercropping sweet pepper/tomato for the biological control of pests in glasshouses. *Developments in Plant and Soil Science*, 61, 205–211.
- Norris, R.F. & Kogan, M. (2005) Ecology of interactions between weeds and arthropods. *Annual Review of Entomology*, 50, 479–503.
- Northfield, T.D., Pains, D.R., Funderburk, J.E. & Reitz, S.R. (2008) Annual cycles of *Frankliniella* spp. (Thysanoptera: Thripidae) thrips abundance on North Florida uncultivated reproductive hosts: Predicting possible sources of pest outbreaks. *Annals of Entomological Society of America*, 101, 769–788.

-
- Nuessly, G.S., Nagata, R.T., Skiles, E.S., Christenson, J.R. & Elliott, C. (1995) Techniques for differentially staining *Liriomyza trifolii* (Diptera: Agromyzidae) eggs and stipples within cos lettuce leaves. *Florida Entomologist*, 78, 258–264.
- Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2010) Thrips species composition and abundance on French beans, associated crops and weed species in Kenya. IXth International Symposium on Thysanoptera and Tospoviruses, 31 August – 4 September 2009 (ed. by D. Persley, C. Wilson, J. Thomas, M. Sharman and D. Tree). *Journal of Insect Science*, available online: insectscience.org/10.166/abstract62.
- Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2012) Effect of intercrops on thrips species composition and population abundance on French beans in Kenya. *Entomologia Experimentalis et Applicata*, 142, 236–246.
- Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2012) Seasonal abundance of *Frankliniella occidentalis* and its natural enemies in different French bean agroecosystems in Kenya. *Environmental Entomology*, (In press).
- Onkoba, M. (2002) Studies on control of *Uromyces appendiculatus* (Pers.) Unger var. *appendiculatus* using fungal and bacterial metabolites. MSc Thesis, University of Nairobi, Kenya.
- Osekre, E.A., Wright, D.L., Marois, J.J. & Funderburk, J. (2009) Population dynamics and within-plant distribution of *Frankliniella* spp. Thrips (Thysanoptera: Thripidae) in Cotton. *Environmental Entomology*, 38, 1205–1210.
- Paini, D.R., Funderburk, J.E., Jackson, C.T. & Reitz, S.R. (2007) Reproduction of four thrips species (Thysanoptera: Thripidae) on uncultivated hosts. *Journal of Entomological Science*, 42, 610–615.

-
- Park, H.-H., Lee, J.-H. & Uhm, K.-B. (2007) Economic threshold of western flower thrips (Thysanoptera: Thripidae) for unripe red pepper in greenhouse. *Journal of Asia-Pacific Entomology*, 10, 45–53.
- Pearsall, I.A. & Myers, J.H. (2001) Spatial and temporal pattern of dispersal of western flower thrips (Thysanoptera: Thripidae) in nectarine orchards in British Columbia. *Journal of Economic Entomology*, 94, 831–843.
- R Development Core Team (2010) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>.
- Rahman T., Spafford, H. & Broughton, S. (2010) Variation in preference and performance of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on three strawberry cultivars. *Journal of Economic Entomology*, 103, 1744–1753.
- Rämert, B., Lennartsson, M. & Davies, G. (2002) The use of mixed species cropping to manage pests and diseases—theory and practice. Proceedings of the UK Organic Research 2002 Conference, Organic Centre Wales, Institute of Rural Studies, University of Wales, UK, Aberystwyth, 26–28th March 2002, Ed. by Powell, J., Jane. & et al., pp. 207–210.
- Reitz, S.R. (2008) Comparative bionomics of *Frankliniella occidentalis* and *Frankliniella tritici*. *Florida Entomologist*, 91, 474–476.
- Reitz, S.R. (2009) Biology and ecology of the western flower thrips (Thysanoptera: Thripidae): The making of a pest. *Florida Entomologist*, 92, 7–13.
- Rhains, M. & Shipp, L. (2004) Dispersal by adult western flower thrips (Thysanoptera: Thripidae) in greenhouse crops. *Canadian Entomologist*, 136, 241–254.
- SAS Institute (2008) SAS/STAT User's Guide. SAS Institute Inc., Cary, NC, USA.

-
- Schellhorn, N.A., Glatz, R.V. & Wood, G.M. (2010) The risk of exotic and native plants as hosts of four pest thrips (Thysanoptera: Thripidae). *Bulletin of Entomological Research*, 100, 501–510.
- Scott-Brown, A.S., Simmonds, M.S.J. & Blaney, W.M. (2002) Relationship between nutritional composition of plant species and infestation levels of thrips. *Journal of Chemical Ecology*, 28, 2399–2409.
- Songa, J.M., Jiang, N., Schulthess, F. & Omwega, C. (2007) The role of intercropping different cereal species in controlling lepidopteran stemborers on maize in Kenya. *Journal of Applied Entomology*, 131, 40–49.
- Stacey, D.A. & Fellowes, M.D.E. (2002) Temperature and the development rates of thrips: Evidence for a constraint on local adaptation. *European Journal of Entomology*, 99, 399–404.
- Szentesi, A. & Jermy, T. (1990) The role of experience in host plant choice by phytophagous insects. In: *Insect–plant Interactions*, CRC Press, Boca Raton, Florida, Ed. by Bernays, E.A., pp. 39–74.
- Tamò, M., Baumgärtner, J., Delucchi, V. & Herren, H.R. (1993) Assessment of key factors responsible for the status of the bean flower thrips *Megalurothrips sjostedti* (Trybom) (Thysanoptera: Thripidae). *Bulletin of Entomological Research*, 83, 251–258.
- Tommasini, M.G. & Maini, S. (1995) *Frankliniella occidentalis* and other thrips harmful to vegetable and ornamental crops in Europe. In: *Biological Control of Thrips*, Wageningen Agricultural University, the Netherlands, Ed. by Loomans, A.J.L., van Lenteren, J.C., Tommasini, M.G., Maini, S. & Riudavets, J., Papers. 95.1, 1–42.
- Venables, W.N. & Ripley, B.D. (2002) *Modern applied statistics with S* (4th edition). Springer-Verlag, New York. <http://cran.r-project.org/package=MASS>.

-
- Weintraub, P.G. (2007) Integrated control of pest in tropical and subtropical sweet pepper production. *Pest Management Science*, 63, 753–760.
- Yardimci, N. & Kilic, H.C. (2009) Tomato spotted wilt virus in vegetable growing areas in the west mediterranean region of Turkey. *African Journal of Biotechnology*, 8, 4539–4541.
- Yoo, H.J.S., & O’Neil, R.J. (2009) Temporal relationships between the generalist predator, *Orius insidiosus*, and its two major prey in soybean. *Biological Control*, 48, 168–180.
- Yudin, L.S., Cho, J.J. & Mitchell, W.C. (1986) Host range of western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae), with special reference to *Leucaena glauca*. *Environmental Entomology*, 15, 292–295.
- Zhang, Z.-J., Wu, Q.-J., Li, X.-F., Zhang, Y.-J., Xu, B.-Y. & Zhu, G.-R. (2006) Life history of western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), on five different vegetable leaves. *Journal of Applied Entomology*, 131, 347–354.

ACKNOWLEDGEMENTS

This work was made a success through the help and support of a number of people and organisations. I wish to thank the BMZ (Bundesministerium Für Wirtschaftliche Zusammenarbeit) for funding this work through GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) (project no. 07.7860.5-001.00). I am also grateful to the International Centre of Insect Physiology and Ecology (*icipe*), Nairobi, Kenya for providing the research facilities. I wish to thank my supervisors, Prof. Dr. H.-M. Poehling, Dr. R. Meyhöfer and Dr. S. Subramanian, for their guidance and constructive criticisms throughout the study period. I highly appreciate the moral support from my colleagues in the Thrips IPM Project Dr. Saliou Niassy, Ms. Rael Biritia, Mr. Alexander Muvea and Mr. Aduda Siguna. I would also like to thank Dr. Daisy Salifu and Mr. Benedict Orindi for statistical support. I am also indebted to the *icipe* IPM Thrips Project staff (Mr. Bernard Muia, Mr. Bernard Mulwa, Ms Catherine Adongo & Ms Peris Kariuki) for their technical assistance. I express my appreciation to the many contact farmers in the different study sites for allowing me to use their farms for my studies. I thank the KARI Central Training Committee (CTC) for granting me a doctoral study leave. My thanks go to the Centre Director (Dr. Stephen Njoka) and Deputy Centre Director (Dr. Francis Kihanda), KARI-Embu for their invaluable support throughout the study period. I would like to appreciate the logistical support received from Messrs. David Karuri and Fredrick Manyara in co-ordinating the KARI-Embu experiments. My special thanks go to my lovely wife (Terry), daughter (Sandra), parents (Joseck & Josephine), brothers and sisters for their love, patience, and encouragement throughout the study period. Finally, I thank God for granting me good health, patience, and courage throughout the study period.

CURRICULUM VITAE

PERSONAL DATA

Name JOHNSON OUNYA NYASANI
Date of birth 3rd January 1982
Place of birth Nyamira, Kenya
Nationality Kenyan
Language skills Kisii (First language), Kiswahili (Native), English (Fluent)
E-mail nyasanijo@yahoo.com

EDUCATIONAL BACKGROUND

2009 - 2011

PhD Student

Thesis title: **Field ecology of western flower thrips *Frankliniella occidentalis* in French bean agroecosystems in Kenya**

2005 - 2007

Master of Science in Crop Protection

Thesis title: **Potential of using entomopathogenic nematodes in the management of Diamondback moth on kale *Brassica oleracea* var. *acephala***

University of Nairobi, Kenya

2001 - 2005

BSc. Agriculture (**First Class Honours**)

University of Nairobi, Kenya

WORK EXPERIENCE

2008 to present

Kenya Agricultural Research Institute

Position: Research Officer (Agricultural entomologist)

2005 - 2007

Graduate/teaching assistant

University of Nairobi, Kenya

ADDITIONAL SKILLS

1. Experienced in the use of statistical packages such as GenStat, SAS & R.
2. Knowledge in the use of GIS softwares such as Arcview Explorer, Quantum GIS, gvSIG and Map Maker.
3. Experienced in the use of LucID key for thrips identification.
4. Knowledge in the use of CLIMEX/DYMEX software in modelling.

PUBLICATIONS**In refereed journals (from this thesis)**

1. Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2012). Effect of intercrops on thrips species composition and population abundance on French beans in Kenya. *Entomologia Experimentalis et Applicata*. 142, 236–246.
2. Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2012). Feeding and oviposition preference of *Frankliniella occidentalis* for crops and weeds in Kenyan French bean fields. *Journal of Applied Entomology*. DOI: 10.1111/j.1439-0418.2012.01723.x.
3. Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2012). Seasonal abundance of *Frankliniella occidentalis* and its natural enemies in different French bean agroecosystems in Kenya. *Environmental Entomology* (In press).

In refereed journals (from Msc. thesis)

1. Nyasani, J.O., Kimenju, J.W., Olubayo, F.M. & Wilson, M.J. (2008). Laboratory and field investigations using indigenous entomopathogenic nematodes for biological control of *Plutella xylostella* in Kenya. *International Journal of Pest Management*. 54(4), 355–361.
2. Nyasani, J.O., Kimenju, J.W., Olubayo, F.M., Shibairo, S.I. & Mutua, G.K. (2008). Occurrence of entomopathogenic nematodes and their potential in the management of diamondback moth on kale. *Asian Journal of Plant Sciences*. 7(3), 314–318.

In conference proceedings

1. Nyasani, J.O., Meyhöfer, R., Subramanian, S. & Poehling, H.-M. (2010) Thrips species composition and abundance on French beans, associated crops and weed species in Kenya. IXth International Symposium on Thysanoptera and Tospoviruses, 31 August–4 September 2009 (ed. by D. Persley, C. Wilson, J. Thomas, M. Sharman & D. Tree). *Journal of Insect Science*, insectscience.org/10.166/abstract62.

2. Nyasani J.O., Kimenju J.W. & Olubayo F.M. (2008). Occurrence of entomopathogenic nematodes in different agro ecosystems and their potential in the management of diamondback moth on kale. Proceedings of the 5th International Congress of Nematology held at Brisbane Convention and Exhibition Centre 13-18 July 2008, Brisbane, Australia.
3. Nyasani J.O., Kimenju J.W., Olubayo F.M. & Wilson M.J. (2007). Potential of using entomopathogenic nematodes in the management of diamondback moth (*Plutella xylostella*) on kale in Kenya. Proceedings of the 8th African Crop Science Society Conference held in Suzann Mubarak Centre for Arts and Letters 27-31 October 2007, Minia University, El-Minia, Egypt, 7: 1063–1066.

INVITED PRESENTATIONS

1. Techniques in plant nematology for nematode diagnosis and handling (NIESA training at the University of Nairobi 26 - 28 September 2007).
2. Entomopathogenic nematodes in the management of insect pests and plant parasitic nematodes (NIESA training at KEFRI, Kenya 16 July - 3 August 2007).

AWARDS

November 2008

Won a competitive grant for Doctoral studies at the Institute of Plant Diseases and Plant Protection, Leibniz Universität Hannover, Germany through the International Centre of Insect Physiology and Ecology.

November 2007

Won a book prize worth € 125 for the best oral presentation in the 7th Horticultural Association of Kenya Conference held at the University of Nairobi, Kenya. Book prize was sponsored by the University of Hannover.

October 2005

Won a competitive scholarship offered by the University of Nairobi, Kenya for Master of Science (MSc) studies.

DECLARATION

I, Johnson Nyasani Ounya declare that this thesis, entitled 'Field ecology of western flower thrips *Frankliniella occidentalis* in French bean agroecosystems in Kenya' is an original piece of my work conducted by myself and has not been submitted for a degree in any other University.

Johnson Nyasani Ounya

Hannover, 2012

Gottfried Leibniz Universität Hannover