



**ECOLOGY AND INSECTICIDE RESISTANCE MANAGEMENT OF THRIPS
(THYSANOPTERA: THIRIPIDAE) ON ONION (*Allium cepa* L.) IN THE RIFT
VALLEY OF ETHIOPIA**

PhD DISSERTATION

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HAWASSA, ETHIOPIA

JULY 2020

Ecology and Insecticide Resistance Management of Thrips (Thysanoptera:
Thripidae) on Onion (*Allium cepa* L.) in the Rift Valley of Ethiopia.

PhD Dissertation

Submitted to the School of Plant and Horticultural Sciences, College of
Agriculture Hawassa University

In Partial Fulfillment of the Requirement for the Degree of Doctor of Philosophy
in Agricultural Entomology

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JULY 2020

SCHOOL OF AGRICULTURE STUDIES

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STATEMENT OF THE AUTHOR

I declare that this dissertation is my genuine work and that all sources of materials used for this dissertation were duly acknowledged. This dissertation was submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Agricultural Entomology at Hawassa University and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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DEDICATION

I dedicate this dissertation to my families for nursing me with affection and love and for their dedicated partnership in the success of my life.

ACKNOWLEDGEMENTS

First, my gratitude belongs to the supreme Almighty God for providing me the health, patience and endurance to complete the study and to achieve this level of education. I would like to express my deepest and heartfelt thanks to my major advisor Dr. Ferdu Azerefegne for his keen interest, critical review of dissertation and consistent guidance throughout my graduate studies. My deepest gratitude goes to my co-advisor Dr. Gashawbeza Ayalew for his permission to carry out the research at Melkassa, his interest in the work, frequent supervising the field research with genuine comments, and critical review and commenting starting from preparation of the proposal up to the final dissertation write up.

The Ministry of Education is highly acknowledged for offering me with financial assistance to undertake my dissertation work. I acknowledge Melkassa Agricultural Research Center, Ethiopia, for providing all the required facilities for laboratory and field studies. My special thanks go to technical staffs of the Melkassa Agricultural Research Center, Department of Entomology for their unreserved technical support during the study. I would like to thank the Department of Horticulture Research Divisions the Melkassa Agricultural Research Center for providing me with the seed of the onion varieties Bombay red for my research.

I am thankful of Mr. Damitew Getu and Buta Urigessa for their valuable support in the field works. It is my great pleasure to extend my appreciation to Mr. Eshetu Gebre for mapping the study sites. I am also very grateful to Yohannes Fekadu, researcher at Ethiopian Institute of Agricultural Research, for his assisted in data analysis. Finally, I would like to express my appreciation to all of my families, in particular my wife Eskedar Mekibib and to all of my friends and other relatives who have always inspired me and helped me in building my academic career.

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
cm	Cent meter
CRV	Central Rift Valley
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Diammonium Phosphate
DAT	Days after transplanting
EARO	Ethiopian Agricultural Research Organization
EHDA	Ethiopian Horticulture Development Agency
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization
GPS	Global Positioning System
ha	Hectare
ICIPE	International center of insect physiology and ecology
IPM	Integrated Pest Management
IRM	Insecticides resistance management
km	Kilometer
LC ₅₀	Lethal concentration which killed 50% of tested population
m.a.s.l	Meter above sea level
MARC	Melkassa Agricultural Research Center
MoA	Ministry of Agriculture
MOARD	Ministry and Agriculture and Rural development

MOWR	Ministry of Water Resources
RCBD	Randomized Complete Block Design
RR	Resistance ratio
SAS	Statistical analysis software
SPSS	Statistical Package for the Social Sciences
USD	United State Dollar

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Dissertation outline

The dissertation is presented in seven chapters;

Chapter 1: Provides a general introduction, general and specific objectives, literature review and over all description of the research methodology including description of the study areas, experimental design, data collection and analysis.

Chapter 2: Presents the study on Seasonal abundance of thrips (Thysanoptera: Thripidae) and effect on onion yield in the Central Rift Valley of Ethiopia. To be submitted

Chapter 3: Presents the study on Farmers' insecticide use practices and species composition and abundance of thrips species (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia. Published on African journal of agricultural research

Chapter 4: Presents the study on Field evaluation of commonly used synthetic insecticides against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia. Published on pest management journal of Ethiopia

Chapter 5: Presents the study on Insecticides resistance of Thrips (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia. Under review in the International Journal of Tropical Insect Science

Chapter 6: Presents the study on Insecticide resistance management against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia. Published on the International Journal of Tropical Insect Science

Chapter 7: Gives general summary, conclusion and recommendation for future research work.

Papers/manuscripts

This dissertation consists of the following manuscripts in the chapter formats

Chapter 2

Seasonal abundance of thrips (Thysanoptera: Thripidae) and effect on onion yield in the Central Rift Valley of Ethiopia. To be submitted

Chapter 3

Farmers' insecticide use practices and species composition and abundance of thrips species (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia.

Belete Negash, Ferdu Azerefegne and Gashawbeza Ayalew. 2019. Farmers' insecticide use practices and species composition and abundance of thrips species (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia. African journal of agricultural research 14(32):1537-1543.

Chapter 4:

Field evaluation of commonly used synthetic insecticides against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia.

Belete Negash, Ferdu Azerefegne and Gashawbeza Ayalew. 2019. Field evaluation of commonly used synthetic insecticides against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia. Pest management journal of Ethiopia 21:24-34

Chapter 5

Insecticides resistance of Thrips (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia. Under review in the International Journal of Tropical Insect Science

Chapter 6

Insecticide resistance management against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia. Published in the International Journal of Tropical Insect Sciences

**Ecology and Insecticide Resistance Management of Thrips (Thysanoptera: Thripidae) on
Onion (*Allium cepa* L.) in the Rift Valley of Ethiopia**

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ABSTRACT

Decline in efficacy of registered insecticides to control thrips (Thysanoptera: Thripidae) on onion in Ethiopia stimulated studies on insecticide resistance, ecology and management of thrips on onion in the major onion production belt of the Central Rift Valley of Ethiopia (CRV). Several studies including farmers' insecticide use practices against thrips on onion, species composition and abundance, seasonal abundance of thrips and their effect on yield, insecticides resistance detection and management were conducted from 2015 to 2017. Diazinon, dimethoate, profenofos, lambda-cyhalothrin and spinetoram were widely used for thrips control on onion in the surveyed areas. Type and frequency application of insecticides use were different among the locations. Insecticide application frequencies were higher at Meki and Melkassa than in Werer areas. All the onion fields visited during the survey were infested by two thrips species namely, the western flower thrips, *Frankliniella occidentalis* (Pergande) and the onion thrips, *Thrips tabaci* (Lindeman). Thrips species compositions vary with locations. While, *T. tabaci* was dominant in Werer and Melkassa areas. The *F. occidentalis* thrips species was dominant at Meki location. Thrips population was higher during mid-growth stage of onion, 50 to 64 days after transplanting, than early and late growth stages in cool dry (October–January), hot dry (February – may) and rainy (June – September) growing seasons. Significantly lower thrips population recorded in the rainy season than the cool dry and hot dry seasons. Onion growth stage, growing seasons and sunshine hours were important factors for predicting thrips numbers. Cool and rainfall seasons significantly negative correlated with thrips numbers, while it was positively correlated with the onion growth stage, maximum temperature and sunshine hours. Thrips number was significantly greater on untreated plots than insecticide treated plots except in the rainy season. Higher percent yield losses were recorded on planting made in cool dry and hot dry

seasons in both years than rainy season with 8.24 to 40.17% yield losses. Commonly used insecticides on thrips were evaluated for their efficacy both in field and laboratory condition. Plots treated with spinosad, spinetoram, and imidacloprid resulted in better control, which was comparable higher marketable yield of onion both in cool and hot dry seasons. While, alpha-cypermethrin, diazinon, neem and λ -cyhalothrin insecticides treated plots poorly performed in both seasons and had lower marketable yield. Performances of dimethoate and profenofos were intermediate with the intermediate yield gains over the control under field condition. Laboratory bioassay confirmed that the poor efficacy of λ -cyhalothrin and diazinon under field conditions was due to thrips resistance to these insecticides. Higher level of resistance was recorded to λ -cyhalothrin and diazinon in Meki and Melkassa collected thrips populations, whereas no resistances to profenofos, dimethoate and spinetoram insecticides in all tested thrips populations were found. From insecticides resistance management studies, the sequential application of the more effective insecticides, imidacloprid and spinetoram, followed by less effective insecticide λ -cyhalothrin resulted in better control with higher economic return. Adding a penetrating surfactant improved the efficacy of insecticides compared to those without a penetrating surfactant in both seasons. Onion growers will continue to rely on insecticides as part of thrips management. Hence screening of new molecules periodically to identify effective insecticides and deploying a resistance management strategy through, among others, rotational application should form integral component in the integrated management of thrips (IPM) on onion. Studies on non-chemical control methods including cultural such as intercropping with other vegetables, host plant resistance should be conducted with the aim of strengthen thrips IPM.

Key words: Onion, Species Composition, Yield loss, Insecticides Resistance, Bioassay, Thrips, Management, Ethiopia

CHAPTER 1. GENERAL

1.1. INTRODUCTION

Onion (*Allium cepa* L.) is an important vegetable produced in a wide range of latitudes in Africa, Asia, Europe and North America (Rabinowitch and Currah, 2002). From the total cultivated vegetable crops, onion ranks third, after tomatoes and potatoes worldwide (FAOSTAT, 2012). It is a widely grown vegetable by small and large-scale farmers in Ethiopia covering an area of 48,443.36 hectares with the total production of 37,470.38 ton (CSA, 2016). In Ethiopia, especially in the Central Rift Valley, it ranks first among vegetables and is followed by tomato (Tebkew and Getachew, 2015). It is produce for home consumption and as income sources for many small-scale farmers and commercial growers. Consumption of onions has been increasing significantly in the world partly due to the health benefits (Havey *et al.*, 2004; Wang *et al.*, 2006). It is the richest sources of flavonoids in the human diet and flavonoid consumption has been associated with a reduced risk of cancer, heart disease and diabetes and they possess anti-bacterial, antiviral, and anti-allergenic (Javadzedah *et al.*, 2009). It is used in the daily diet, mostly used as seasonings or as vegetables in stews in Ethiopia (Weldemariam *et al.*, 2015).

Onion production area is increasing from time to time, mainly due to its high profitability per unit area, ease of production, and the increases in small-scale irrigation areas (FAO, 2010). It is produced rain fed in the meher season and under irrigation in the off-season. In many areas of the country, the off-season crop constitutes much of the area under onion production (FAO, 2010). Onion has great contribution both in economic and health issues, but its production and productivity is not scaled up to the required level. In Ethiopia, the national average productivity of onion is low (7.734 t ha⁻¹) (CSA, 2016) as compared to the world average productivity (19.49 t ha⁻¹) (FAOSTAT, 2013). A poor cropping system, lack of resistant varieties, disease and insect

pests contribute to the lower productivity of onion in Ethiopia (Yemane *et al.*, 2013; Tadele and Amin, 2014).

Thrips are serious pests of onions. Western flower thrips, *Frankliniella occidentalis* (Pergand) and Onion thrips, *Thrips tabaci* (Lindeman) are two common species of thrips that attack onions (Kuepper, 2004). Although both species have similar biology and management, *F. occidentalis* is reported to have developed resistance to a number of insecticides (Lorbeer *et al.*, 2002; Murphy *et al.*, 2003). Both species are present in onion in the Central Rift Valley of Ethiopia with different composition. *T. tabaci* is an important insect pest of onion throughout the world (Diaz-Montano *et al.* 2011) and in Ethiopia (Tebkew and Getachew, 2015). Unless properly managed, thrips can destroy an entire onion field, especially in dry seasons. Yeshitla (2015) reported 26-57% bulb yield losses in the absence of thrips control.

Thrips abundance is affected significantly by local weather patterns, which generally plays a major role in determining the survival and growth of insect populations because of its direct impact on them and on their food supply (John *et al.*, 2011). Components of weather, mainly temperature, rainfall and relative humidity strongly affect the survival, development, fecundity and behavior of individual insects (Wilstermann and Vidal, 2013). Understanding the effects of weather on thrips population is important to predicting thrips populations and developing an integrated thrips control strategy in a given climatic trend (Waiganjo *et al.*, 2008). In addition, thrips abundance and distribution in onion fields are affected by agricultural practices (Diaz-Montano *et al.*, 2011). The misuse of insecticides lead to increased incidence of pest resurgence and appearance of pest species resistant to pesticides (Kaur and Garg, 2014).

The use of insecticides is the major control strategy of onion thrips infestations in commercial onion production (Gill *et al.*, 2015), but this approach allows the evolution and spread of insecticide resistance (Foster *et al.*, 2010). In the CRV of Ethiopia, vegetable growers heavily rely on the use of synthetic insecticides to control pests. The insecticides in use are often old types, and broad-spectrum such as organochlorines, organophosphates and pyrethroids (Gashawbeza, 2011). Moreover, they are applied indiscriminately (Banchiamlak *et al.*, 2012). But, these groups of insecticide have induced resistance in onion thrips in numerous countries (Bielza *et al.*, 2007; Herron *et al.*, 2008; Nault *et al.*, 2013). In Ethiopia, thrips in onion are suspected to have developed resistance to the earlier registered insecticides (Tadele and Amin, 2014). Thrips has greater potential to develop rapid insecticide resistance due to their cryptic feeding habit, short developmental period, rapid reproduction nature, eggs protected under leaf tissues, prepupae and pupae reside in soil or remain in inner spaces between leaves, and some adults may take niche in the inner leaf spaces and escape control (Diaz-montano *et al.*, 2011).

Insecticides resistance is the most important issue facing agricultural production, because pesticides are integral part of high-yielding production agriculture (Miller *et al.*, 2010). Therefore, insecticide resistance management (IRM) practices are needed to prevent rapid insecticide resistance development in onion fields. Considering the ecological factors, which promote the outbreak of onion thrips, knowing the overall insecticide use in the production system, monitoring thrips populations for changes in susceptibility to insecticides, establishing rotations for insecticide with different modes of action, proper application timing and insecticide delivery are important considerations while developing insecticide resistance management plan (Canas, 2015; Sparks and Nauen, 2015).

In Ethiopia, the effect of farmers insecticides use practice on species composition and abundance of thrips, seasonal abundance of thrips and their effect on yield, extent of thrips resistance to insecticides, and effectiveness of insecticides to control of thrips on onion are not well studied. Besides, integrated pest management an important approach to reduce insecticide use, lower control costs, slowdown development of resistance to insecticides in the thrips population, and encourage biological control through preservation of natural enemies has received little attention. Hence, understanding of the ecology and insecticides resistance management practice is essential towards the development of effective, economical, safe, sustainable and ecologically acceptable management methods.

1.1.1. General objective of the study

To contribute to the overall management of thrips (Thysanoptera: Thripidae) on onion in the Rift Valley of Ethiopia through studying the thrips ecology and insecticides resistance.

1.1.2. Specific objectives

1. To study seasonal abundance of thrips and determine their effect on onion yield
2. To assess the effect of insecticides use practices on species composition and abundance of thrips on onion
3. To evaluate insecticides for thrips control and to quantify yield gain due to use of insecticides
4. To assess thrips resistance to various insecticides in different onion growing areas
5. To evaluate the effects of rotational applications of insecticides and use of surfactant against thrips on onion

1.2. LITERATURE REVIEWS

1.2.1. Onion (*Allium cepa* L.); Origin and importance

Onions, (*Allium cepa* Linnaeus) belongs to the family Alliaceae and thought to have originated in Central Asia. Dry bulb onions are the second most important horticultural crop after tomatoes and consumed worldwide for their unique flavor and health-related properties (Griffiths *et al.*, 2002). Onion is considerably important in the daily Ethiopian diet. Onion can grow from 500-2400 meter above sea level, but the best growing altitude so far known is from 700 to 1800 meter above sea level (Desalegne and Shimeles, 2003). The main production regions are Amhara, Oromia, Tigray, Benishngule-gumuz, Gambella and South Nations Nationalities and People's Region, but predominantly produced in Oromia (64%) and Amhara Regional States (30%) (EHDA, 2011).

The Ethiopian Central Rift Valley region is an area of great economic importance to the national food security and foreign exchange earnings of the country through production of export crops (Joosten *et al.*, 2011). A lion's share of 95% of the vegetables and fruits produced in the country comes from the smallholder sector (Joosten *et al.*, 2011). Onion production practices in the region is increasing from time to time, mainly due to the introduction of new cultural practices such as high density planting and intensive use of inputs (fertilizers, fungicides and other chemicals) (Edossa, 2014). The crop is consumed more intensively than any other vegetable crop. All the plant parts are edible, but the bulbs and the lower stem sections are the most popular as seasonings or as vegetables in stews (MoARD, 2009). This crop extensively used as precursor of the flavor compounds in food processing industries and used as a medicine to prevent heart disease, Cancer, diabetes and other ailments in humans (Yemane *et al.*, 2013).

Fresh onions used for their flavor, aroma, and taste, being prepared domestically or forming raw materials for a variety of food manufacturing processes.

Onion (*Allium cepa*) is a recently introduced crop to Ethiopia. The release of a variety from introduced materials (from Sudan) has marked the beginning of extensive production of onion in the country (FAO, 2010). There are eight onion varieties in production in Ethiopia: Adama Red, Melkam, Red Creole, Bombay Red, Nasik red (Dereselegn), Nafis, Nasika Red and Neptune (Beshir and Nishikawa, 2012). However, 'Bombay Red' is the preferred cultivar by growers due to its early maturing character and in anticipation of a reduction of production cost and time than the rest of cultivars (Nega and Menamo, 2015).

1.2.2. Biology of onion thrips

Thrips (Thysanoptera: Thripidae) are minute, slender insects, usually a few millimeters long, which vary from 0.5 to 1.2mm. Adult female have fully developed wings but males are wingless. The wings are very different from other insects. They have a single longitudinal vein in which there is several hairs connected perpendicular to the vein. The wing appears as fringe with hairs and pale yellow to dark brown colors in adult, white to pale yellow in immature stage (Rueda and Shelton, 2003).

Stages in the developmental life cycle are the egg, first larval stage, second larval stage, pre pupa, pupa, and adult (Nault, 2006). Female adult may live for about 20 days and lay two to four eggs per day. They have a saw-like ovipositor that helps to make an incision in plant tissue for egg laying. Eggs placed singly under the epidermis of succulent leaf, flowers, stem or bulb tissue (Hamid *et al.*, 2009). Only one end of the eggs will be near the surface of the tissue to allow the

immature to emerge. The eggs hatch four to 10 days later and the larva feeds for about five days before it pupates in the soil or litter of plant. About four days later, new adults emerge from the soil. Their life cycle may complete in 14 to 30 days. Developmental life cycle is highly dependent upon environmental conditions and nutrient quality of their food source (Waiganjo *et al.*, 2008). When temperatures go over 30 °C, the life cycle can be shortened to 10 or 11 days. The feeding larva remains protected in the tender growth of the host plants, but pupation may occur in the loose of the plant neck or in the soil (Rueda and Shelton, 2003). Onion thrips do not necessarily need to mate for reproduction. Females that do not mate will produce only female progeny. Sometimes the entire population of the thrips is composed of female. Each of this female can produce up to 80 eggs. Therefore, thrips population can generate from a single thrips in very short time especially during hot and dry period (Hammon, 2002; Rueda and Shelton, 2003). In heated glasshouses, generations (up to 14 per year) succeed at a rapid rate (Bagheri *et al.*, 2002). However when the conditions are unfavorable thrips undergo diapauses either as fully-grown larva or as adult and the numbers of generation is reduced during these time. Diapausing may occur in the cervices of soil, leaf litter and in bulbs (Capinera, 2000).

1.2.3. Distribution and Host range of onion thrips

The onion thrips, *T. tabaci* is cosmopolitan in distribution. *T. tabaci*, originated from eastern Mediterranean region, although now cosmopolitan and important pest of onions at an elevation range from sea level to 2000 meters above sea level in Africa, Asia, Australia, North and South America and Europe. It is found all over the world where onion is grown (Nault, 2006). Onion thrips distributed throughout the country particularly in all onion-growing areas of Ethiopia (Tadele and Amin, 2014). Thrips is a polyphagous insect. They feed on many cultivated crops as

well as uncultivated plants belonging to at least 25 families. However, the principal hosts include beans, broccoli, cabbages, carrot, cauliflower, Chinese broccoli, cotton, cucumber, garlic, head cabbage, leek, melon, onion, orchids, papaya, peas, pineapple, rose, squash, tobacco and tomato (Hammon, 2000). Tsedeke (1985) recorded *T. tabaci* on cultivated and wild plants in the upper and middle awash areas on tomato, hot pepper, cabbage, haricot bean, nut sedge (*Cyperus* spp) and wild sorghum in Ethiopia.

1.2.4. Onion yield losses due to thrips on onion

Onion Thrips is a key insect pest of onion in Ethiopia, that affects onion yield by direct feeding as well as reducing the quality and quantity by rasping the leaves and other tissues of onion crops to release the nutrients (Tadele *et al.*, 2013). Onion fields can be destroyed by onion thrips, especially in dry seasons and are the major problem on onion crops (Alston and Drost, 2008). Onions are most sensitive to thrips injury during the rapid bulb enlargement phase that occurs in dry season particularly during irrigation season from November to early June in Ethiopia. Yield reduction due to reduced bulb size is the primary crop loss caused by onion thrips. The level of infestation and extent of yield losses due to thrips on onion reported by various researchers was vary. Yeshitila (2015) reported that onion bulb yield losses of 26-57% due to onion thrips. Moreover, *T. tabaci* is identified as the main vector of an emerging *tospovirus*, the Iris Yellow Spot Virus (IYSV), which negatively correlated with bulb size reduction in western states (Gent *et al.*, 2004).

1.2.5. Effects of weather on outbreak of thrips on onion

Weather variables included rainfall, temperature, relative humidity and wind are affecting the occurrence of thrips in onion fields. Dry weather (30.3 mm rainfall) with moderately high

temperatures (15.6-28.2°C) increases seasonal thrips numbers, while wet season (391mm rainfall) with moderately high relative humidity negatively correlates with thrips numbers (Waiganjo *et al.*, 2008). Haider *et al.* (2014) reported that thrips colonization is negative correlation with heavy rainfall and low temperature. Thrips populations is positively correlated with max temperature, but negatively with relative humidity and rainfall (Hossain *et al.*, 2015). In addition to their effect on thrips activity, temperature and relative humidity further influence the intrinsic rate of natural increase of the thrips (Murai, 2000). Hot and dry weather can lead to an increase in onion thrips populations and the severity of thrips injury to onion. The reason behind this is likely a combination of factors including a shorter generation time and a reduction in mortality from rain (Rueda *et al.*, 2007).

1.2.6. Insecticides resistance detection

Bioassays are important to select newer insecticides and appropriate doses that affect insects, as well as to test for pest resistance presence and the pesticide selectivity to natural enemies. The bioassay methods should closely simulate field conditions to ensure predictability of control efficacy in the field from data obtained through lab-measured resistance. Important factors that influence bioassays are stage of the insects, choice of insecticide bioassay response, method of application, bioassay environment, diet, sample size, sampling, health of the test organism and operator's skill. In addition to choosing the correct bioassay technique equally important is data that correlates with expected field efficacy of the pesticide (Kranthi, 2005). There are different laboratory bioassay methods available to evaluate pesticide toxicity against insect pests. Over the past two decades, bioassay methods based on leaf-dip, larval dip, topical application and vial-residue developed as viable alternatives to simulated field conditions.

1.2.7. Insecticides resistance management against thrips

The most common method of thrips control is the use of foliar insecticides, but control of thrips is difficult due to the development of resistance to insecticides in several parts of the world (Martin *et al.*, 2003; Shelton *et al.*, 2003; Herron *et al.*, 2008;). There are different strategies that need to be considered when developing insecticide resistance management plans. These are insect outbreak prevention and insecticide management. Non-chemical control methods including cultural control, biological control and use of resistant variety are among insect outbreak prevention strategies (Gao *et al.*, 2012). Assessment of overall insecticide use on the production system, monitoring populations for changes in susceptibility to insecticides, establishing insecticide rotations employing products from a different mode of action groups, proper application timing and insecticide delivery are common strategies in insecticides management (Canas, 2015).

1.2.7.1. Monitoring of thrips

Monitoring to identify when thrips arrive and determine population levels is helpful in designing an appropriate control strategy. Knowledge of action thresholds for onion thrips can help onion growers optimize insecticide applications and other management tactics. Benefits include making fewer applications, saving time and money, and potentially mitigating insecticide resistance development (Kuepper, 2004). Early detection of a pest problem is a key element for designing integrated pest management strategies. In onions, thrips generally migrate into a field when plants in surrounding areas begin to dry, so monitoring efforts should be timed accordingly (Kuepper, 2004). In many cases, infestation of onion thrips begins along field edges rather than other parts of the field (Nault and Shelton, 2012). Action thresholds for onion thrips may vary

depending on geographic region, cultivar, plant stage, plant architecture, and insecticide efficacy. For example, an action threshold of 30 thrips per plant during mid-season has been effective in California for dry bulb, fresh-market onion (Kuepper, 2004). An action threshold level of 30 or more thrips per plant is suggested for the thrips-tolerant varieties, whereas a lower level of 15–30 thrips per plant is suggested for susceptible cultivars (Cranshaw, 2004) whereas Hatfield, 2003 suggests an initial treatment threshold of one thrips per plant and then waiting until they have reached five thrips per plant for a second treatment. In Ethiopia, the economic threshold level of onion thrips was reported 5 to 10 thrips per plant (Tsedeke, 1985).

1.2.7.2. Cultural control methods

Cultural control is the oldest pest control practice. Crop management practices that keep onion plants healthy and non-stressed will increase the crops immunity to onion thrips feeding injury. Cultural practices should be the first line of defense against onion thrips (Alston and Drost, 2008). Under this sub-topic, various non-chemical management options of thrips such as intercropping onion with other crops, irrigation system and mulching are used as alternative thrips control measures.

1.2.7.2.1. Intercropping

Insect infestations are often lower per plant on intercrops than on monocrops and this association may arise in many ways. These are visual or olfactory disruption of the host finding behavior of the pest. Gachu *et al.* (2012) reported that intercropping onion with spider plant and carrot reduced thrips population by up to 45.2% and 21.6%, respectively. Other intercropping systems, which have significantly reduced thrips population and plant infestation, include leek with clover (Belder *et al.*, 2000); leek with carrot, and clover with French bean (Kucharczyk and

Legutowska, 2002). Intercropping of various plant species was investigated to compare reductions in colonization rates of onion thrips (Trdan *et al.*, 2006). Furthermore, vegetation diversity encourages insect natural enemies by providing alternative prey, nectar, pollen and or breeding site. As the result, populations of the beneficial insects increase whereas the pest insects are reduced either due to limited food resource or due to the impacts of the natural enemies.

1.2.7.2.2. Mulching

Mulching has long history with agricultural practice in crop production to conserve moisture and regulate the soil temperature. However, currently it is used as alternative pest control measure especially in vegetable crops in both nursery and production fields. Capinera (2000) reported that organic and plastic (white and black) mulches effectively reduced winged thrips landing on chili. Kuepper (2004) in America reported that 3 to 68% of the thrips populations were repelled from landing on crop mulched with reflective plastic sheets. However, the effect of reflective mulch ceased to repel insects when the plant canopy covers more than 60% of the soil surface. It is most effective only at early growth stages of the crop when the plants are small (Dreistadt and Phillip, 2005).

There are two possible explanations on how mulching control thrips. First, the light reflection from mulch disrupt the host finding cue of thrips, so that winged thrips may be unable to recognize their host plants. Second, mulch covers topsoil, which is a pupation site for thrips. In addition to, direct effect on thrips, plastic and straw mulch results in yield increment and natural enemies' abundance. According to Vavrina and Roka (2000) in plastic mulch improved the net return from onions by increasing bulb weight and marketable yield by delaying of virus incidence and enhancing faster growth and the development of crop.

1.2.7.2.3. Irrigation

The use of overhead sprinkler irrigation is an alternative tactic for thrips control on onion. The action of overhead sprinklers may simulate rainfall on a crop, which is widely believed to reduce insect numbers (Gill *et al.*, 2015). The physical action of water washing thrips off the plants and water droplets standing on leaf surfaces are inhibitory to thrips. In addition, sprinklers used for water application may promote a crust on the soil surface, which reduces the access of pre-pupae and pupae to seek shelter in the soil (Gill *et al.*, 2015). Frequent irrigation by flooding of the onion field at the soil surface reduced the density of thrips on the crops as prepupae and pupa killed in the soil (Cranshaw, 1994).

1.2.7.3. Use of resistance varieties

The use of resistant onion variety is importance practice for sustainable production of onion. Many onion varieties having different levels of resistance to onion thrips have been released regularly form the research centers in Ethiopia. However, there are no cultivated onion varieties with known “true resistance to onion thrips in Ethiopia. Nevertheless, some onion varieties can tolerate effects of thrips feeding with only mild yield loss. Varieties with tolerance to thrips require fewer rounds of insecticide application and reduced insecticide use lowers control costs, slows development of resistance to insecticides in the thrips population, and may encourage biological control through preservation of natural enemies (Tadele and Amin, 2014). Onion varieties with an open neck growth and dark, glossy leaves are less attractive to thrips than varieties with tight necks and lighter green leaves (Cranshaw, 2004).

1.2.7.4. Biological control

Many beneficial organisms work to suppress thrips on onion. These include predators of onion thrips; such as, *Aelothrips* spp., green lacewing (*Chrysoperla* spp.) larvae, coccinellids (e.g. *Coleomegilla maculata*), big-eyed bug (*Geocrois* spp.) and minute pirate bug (*Orius* spp.), which usually do not reach high population until late in a growing season, i.e., after the majority of feeding has occurred (Fok *et al.*, 2014).

1.2.7.5. Biopesticides

Biopesticides derived from living microorganisms or natural products, marketed as “green chemicals”, have earned some market share as an alternative tactic for pest control and for insecticide resistance management of urban pests. Use of botanical insecticides is ideal for organic farming and is safe for both the environment and human health, and is affordable where the materials are locally available. Ibrahim *et al.* (2015) indicated that application of tree tobacco and neem seed reduced the thrips population from 6.4 to 23.13 and 2.57 to 25.5 as compared to control, respectively. Tadele *et al.* (2013) evaluated the effectiveness of different botanical extracts (*Artemisia annua*, *Azadirachta indica*, *Bidens pilosa*, *Chrysanthemum cinerariaefolium*, *Cymbopogon citratus*, *Nicotiana tabacum*, *Nicotiana* spp.,(local var.), *Parthenium hysterophorous*, *Phytolacca dodecandra*, and *Securidaca longepedunculata*) insecticides against onion thrips (*Thrips tabaci*). Of these botanical extracts, *Nicotiana* spp., *P. dodecandra*, *S. longepedunculata* and *N. tabacum* exhibited high mortality rate (69.65, 68.99, 63.85 and 63.56%, respectively), whereas in *C. cinerariaefolium*, *A. indica* and *P. hysterophorous* showed intermediate mortality rate (60.79, 56.89 and 52.06 respectively) and the rest were the lowest mortality rate.

The effect of Entomopathogenic fungal (EPF) was evaluated in experimental field against onion thrips. The result showed that *Beauveria* and *Metarhizium* were caused 46.18% and 26.09% mortality of onion thrips at the 3rd day of application, respectively. It was observed that the effect of *Beauveria* against the onion thrips was significantly increased after 3 days whereas the effect of *Metarhizium* against the onion thrips was prolonged unlikely decreasing trend resulting unsatisfactory control of the pest in Ethiopia (Tadele *et al.*, 2013).

1.2.7.6. Insecticides rotation

Synthetic insecticides are still the mainstay of agricultural pest control due to ease of use and availability of numerous classes of insecticides (Paramasivam and Selvi, 2017), however, rapid development of resistance to insecticides has been a key problem (Diaz-Montano *et al.*, 2011). The rotation of several classes of insecticides (with different modes of action) within a growing season practiced in many agricultural cropping systems as insecticide resistance management (IRM) in their pest control programs. Compounds within the same chemical class (such as carbamates, OPs, or pyrethroids) will all have the same mode of action. Rotating from one pyrethroid compound to another simply exposes the population to a single mode of action, and has no value in resistance management. Theoretically, rotation within a chemical class or mode of action could take place in a situation where a single compound was unaffected by a resistance mechanism that affected all other compounds in that class or mode of action (McCaffery and Nauen, 2006). The key to managing insecticide resistance is to reduce selection pressure by rotating between insecticides with different modes of action and reducing the number of insecticide applications. In addition, applying insecticides to onion using a high spray volume will provide better coverage of the foliage and better thrips control. Inclusion of a penetrating

surfactant is critical for improving the efficacy of insecticides that have systemic and translaminar movement within onion plants to control onion thrips (Nault *et al.*, 2013).

The development of insecticide resistance is a dynamic and complex process, depending directly on genetic, physiological, behavioral and ecological factors of the arthropod pests, and depending indirectly on operational factors including categories of insecticides used as well as the application timing, rate, coverage and method (Denholm and Rowland, 1992). Insecticide resistance management (IRM) strategies in urban ecosystems consist of understanding the status and mechanisms of insecticide resistance, overcoming or delaying resistance to existing compounds and preventing the development of resistance to new pesticides through reducing the insecticide selection pressure (Georghiou, 1994).

1.2.7.7. Integrated pest management

Integrated pest management (IPM) was initially developed in the 1950s to promote a concerted use of chemical and biological approaches for pest control. The concept of IPM was subsequently expanded to include the integration of biological, cultural and chemical tactics in a compatible manner to achieve favorable economic and environmental consequences. IPM aims to minimize the input of pesticides and reduce harmful effects of pesticides on non-target organisms and the environment. Today, IPM has become a fundamental strategy of sustainable agricultural arthropod pest management to maintain the abundance of pests below an established economic injury level (Peshin *et al.*, 2009). The use of natural enemies in combination with selected insecticides, which have no effect on them, is effective in depressing the population density of the pest. The integration of chemical and biological control is often critical to the

success of an integrated pest management (IPM) program for arthropod pests (Wakeil *et al.*, 2006).

Integrated pest management of onion thrips should improve profitability and sustainability of onion production. Promising management approaches include reducing nitrogen application rates, using thrips resistant cultivars and implementing action threshold-based insecticide programs (Leach *et al.*, 2017). Combinations of entomopathogenic fungus *Paecilomyces lilacinus* with nonconventional agents such as *Azadirachta indica* and diatomaceous earth formulations may be effective for controlling onion thrips (Wakil *et al.*, 2012).

1.3. GENERAL MATERIALS AND METHODS

1.3.1. Description of the study area

The studies were conducted in the major vegetable growing areas in the Central Rift Valley of Ethiopia. The survey areas varied in elevations, pest control measures, type and frequency of insecticide application. All field experiments conducted at Melkassa Agricultural Research center (MARC) from 2015 to 2017. Melkassa is located (8^o24' N, 30^o21'E, 1550 m.a.s.l) and characterized by low and erratic rainfall with an average of 771 mm rainfall per year over 80% of which falls between April and October, with the peak is in July and August. The soils are mainly sandy with pH of 6.9-7.9 and mean temperature of 21^oc (Desalegne and Shimeles, 2003).

1.3.2. Seasonal abundance of thrips and their effect on yield

Field experiments conducted in three consecutive onions growing seasons in rainy, cool dry and hot dry season at Melkassa Agricultural Research center (MARC) from 2015 to 2017. Seasonal abundance of thrips and their effect on onion was assessed on insecticide treated and untreated plots. Standard insecticide spinetoram (Radiant 120 SC) was applied at the rate of 130 ml per hectare (ml/ha) using a manual knapsack sprayer of 15 liter capacity.

1.3.3. Assessment of farmers insecticide use practices and species

composition of thrips on onion

A survey was carried out in farmers' fields to assess farmers' insecticides use practices and species composition of thrips and their abundance on onion. Eighty onion grower farmers were systematically selected along the irrigated areas of each surveyed district. Data were collected using local language by face-to-face interviews in the farmers' field using a structured questionnaire. The questionnaires focused on insecticides use practices, types of insecticides and

frequency of insecticide application for thrips control on onion. Adult thrips collected from each farmer's field were mounted on slides and later identified using a compound microscope in the laboratory at the Melkassa Agricultural Research Center. In addition, thrips abundance was measured visually on ten randomly selected plants in each field.

1.3.4. Insecticides resistance detection

Based on the survey data the extent of insecticide resistance of thrips in the survey areas were tested using Thrips Insecticide Bioassay System (TIBS) (Rueda and Shelton, 2003). Thrips were collected from heavy pesticide use areas in Melkassa and Meki, moderate pesticide use areas in Werer and low pesticide use areas in Minjar. The selected insecticides are widely used to thrips control on onion in CRV including Spinetoram, λ -cyhalothrin, Diazinon, Dimethoate and Profenofos. For each insecticide, seven concentrations and a control were prepared. Concentrations of insecticides were chosen to estimates of mortality above and below the expected LC50. A standard of 0.5-ml microcentrifuge vial with a flexible plastic caps were used

1.3.5. Insecticides resistance management

Nine insecticides were screened against thrips on onion at Melkassa Agriculture Research Center in 2015/16 growing season. The tested insecticides are registered for thrips control on onion in Ethiopia and are widely used in (CRV). Among the tested insecticides, four selected insecticides each representing a specific class of insecticides namely Profenofos (Organophosphates), Imidacloprid (Neonicotinoids), λ -cyhalothrin (Pyrethoids) and Spinetoram (Spinosyn) were applied in sequences as insecticides resistance management. In addition, the efficacy of Imidacloprid, Spinetoram and Dimethoate with and without a penetrating surfactant (Silwet gold (0.1% v/v) were evaluated. All experiments laid in a Randomized Complete Block Design (RCBD). Insecticides applied weekly and the first application made when thrips populations

reached five per plant confirmed by random sampling of ten plants. All treatments were applied using manually operated knapsack sprayer of 15-liter capacity.

1.3.6. Agronomic practices

Onion variety Bombay red was raised on nursery bed and transplanted at 2-3 leaf stage in all field experiments. The experimental fields irrigated twice per week for the first three weeks after transplanting and weekly thereafter. The fields fertilized with Di-ammonium phosphate (DAP) and urea at the rate of 200 kg and 150 kg per hectare, respectively. The DAP was applied during transplanting and urea was applied split into two times; the first half was applied during transplanting and the remaining 30 days after transplanting. All other agronomic practice done as recommended for onion production (FAO, 2010).

1.3.7. Data collection

Thrips population (Adult and larval) was counted weekly on randomly selected plant from the central rows of each plot by visually examining the entire plant parts. At maturity, onion bulbs harvested from the middle rows in each plot and then sorted out into marketable and unmarketable bulbs. Healthy bulb weighing between 20 and 160 g considered as marketable (Desalegne and Shimelis, 2003).

1.3.8. Statistical analysis

Survey data summarized and analyzed using (SPSS software version 16.0). Correlation and linear regression analysis performed between weekly mean thrips count with weekly mean rainfall, minimum and maximum temperature, sunshine hour and wind speed. The influence of predicting variable on thrips population was estimated using stepwise regression analysis. Thrips population and yields data analyzed using the general linear model of statistical analysis using

SAS software (SAS, 2003 version). When significant differences observed in the ANOVA, mean separation was performed using Student-Newman-Keuls (SNK) test. The LC_{50} (Lethal Concentrations), slope, and the 95% Confidence Limits (CL) were estimated by probit analysis using SAS software (SAS, 2003) after corrected the natural mortality using Abbott's formula (Abbott, 1925). The resistance ratio (RR) was calculated at the LC_{50} level to compare LC_{50} values between locations.

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CHAPTER 2.

Seasonal abundance of thrips (Thysanoptera: Thripidae) and effect on onion yield in the Central Rift Valley of Ethiopia

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ABSTRACT

Seasonal abundance of thrips (Thysanoptera: Thripidae) and their effect on yield was studied on onion for three consecutive seasons, hot dry, cold dry and rainy between 2015 to 2017 in the Central Rift Valley of Ethiopia. Two plots each measuring 100 m² were established in each season and one of the plots was treated with the insecticide Spinetoram and the other was left untreated. The numbers of thrips were counted on five plants sampled from the central rows at weekly interval starting from 15 days after transplanting and continued until the crop matured. At harvest, yield data were collected from the entire plot by excluding the border rows. Thrips population was higher during mid-vegetative growth stage, 50 to 64 days after transplanting, than early and late growth stages in all the three seasons. Significantly lower thrips population was observed from onion planted in the rainy season than both cool dry and hot dry seasons. Thrips population was influenced by crop growth stage, production season, and weather, sunshine hours. Thrips number was significantly higher on untreated plots than insecticide treated plots except in the rainy season. Percent yield losses recorded on planting made in cool dry, hot dry and rainy seasons were 36.0, 29.1 and 8.2, respectively in 2015/16. This corresponds to 2016/17 yield losses of 38.5, 40.1 and 17.3, respectively. Efforts on the control of thrips affecting onion should consider the growth stage and season of production.

Key words: Onion, Yield loss, Growth stage, Season, weather

2.1. INTRODUCTION

Onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae) is a key insect pest of onion worldwide (Diaz-Montano *et al.*, 2011) and in Ethiopia (Tebkew and Getachew, 2015). Earlier reports in Ethiopia indicated that onion yield loss due to thrips could range from 10 to 85% (Bekele *et al.*, 2006). Recent studies also reported similar extent of losses (Tadele and Mulugeta, 2014; Yeshitla, 2015). Thrips effect on onion was reported to be highest in the dry seasons (Ibrahim and Adesiyun, 2009, Yeshitla, 2015). Weather variables such as temperature, rainfall and relative humidity strongly affect the survival, development, fecundity and behavior of individual insects (Wilstermann and Vidal, 2013). In the Central Rift Valley of Ethiopia, onion is cultivated throughout the year. However, most onion growers produce onion two times and few farmers produce once per year (Tebkew and Getachew, 2015).

The main method of controlling thrips is using insecticides and onion growers apply insecticides against the pest without considering growing seasons and monitoring thrips population (Yeshitla, 2015). However, understanding the interactions between pests and weather is the first step to select the right pest control measure at the right time. Waiganjo *et al.* (2008) reported that understanding the relationship between weather variables and thrips population is important to develop integrated thrips control in specific weather condition. Added to this, predictive seasonal pest dynamics model is important to apply insecticides at the proper time and critical stage of plant growth (Haider *et al.*, 2014). No information was available prior to this study on the effect of season of production, crop growth stage and weather variables on thrips infestation level and yield loss from the central rift valley region. Hence, the objectives of the study were to

investigate seasonal fluctuation of thrips population and assess yield loss caused by thrips on onion planted in different seasons.

2.2. MATERIALS AND METHODS

2. 2. 1. Descriptions of the study area

Field experiments were conducted in three consecutive onions growing seasons rainy season (June – September), cool dry season (October–January) and hot dry season (February – May) at Melkassa Agricultural Research Center (MARC) from 2015 to 2017. Melkassa is located (8⁰ 24' N, 30⁰ 21'E, 1550 m.a.s.l) and characterized by low and erratic rainfall with an average of 771 mm rainfall per year over 80% of which falls between April and October, with the peak in July and August. The soils are mainly sandy with pH of 6.9 -7.9 and mean temperature of 21⁰c (Desalegne and Shimeles, 2003).

2.2.2. Treatments and sampling procedure

Seasonal abundance of thrips and effect on yield of onion was assessed on insecticide treated and untreated plots. Individual plots had a size of 10m by 10m (100m²) accommodating sixteen double rows of onion with 0.2m spaced apart in rows. Spaces between block and plants were 2 m and 0.1m, respectively. Seeds of the onion variety “Bombay Red” were obtained from the Melkassa Agricultural Research Center (MARC). Seeds were seeded on nursery bed and transplanted at 2-3 leaf stage for all experiments. Plots were divided into three at about 3 meter interval and five plants from each section of the plot were randomly picked for counting live thrips per sampling occasion. Standard insecticide spinetoram (Radiant 120 SC) was applied at the rate of 130 ml per hectare (ml/ha) using a manual knapsack sprayer of 15 liter capacity in the insecticide treatment plot. Frequency of pesticide application was based on economic threshold established which is 5 to 10 thrips/ plant (Tsedeke, 1983). Based on this, there were four, eight and eight applications in the rainy, dry cold and hot dry seasons, respectively in both years. All

other agronomic practices were followed as per the recommendation of the vegetable improvement program at Melkassa.

2.2.3. Data collection

Thrips population was counted at weekly interval starting from 15 days after transplanting (DAT) and continued until the crop matured. Five plants were sampled from the inner rows of each section of the plot by visually examining the whole plant, including the center leaves and the base of the plant. Marketable and unmarketable onion yields were measured from the entire plot by excluding the border rows. Marketable bulb yield refers to the weight of healthy bulbs ranging from 20 g to 160 g in weight (Desalegne and Shimeles, 2003). Undersized, diseased, decayed and physiologically disordered bulbs were considered as unmarketable bulbs. Meteorological data (rainfall, minimum and maximum atmospheric temperature, relative humidity, sunshine hour and wind speed) were taken from Melkassa Agricultural Research Center Meteorological station.

2.2.4. Data analysis

Thrips count data were checked for normality before analyses and square root ($\sqrt{x+0.5}$) transformed. Thrips populations were analyzed using SAS version 9.0 (SAS, 2003). Pairwise comparisons were made at 5% level of significance to determine mean difference between seasons or insecticide treated and untreated plot with linear estimates and contrasts. Pearson correlation analysis (SAS, 2003) was used to estimate the correlation between thrips population and weather variables. The influence of predicting variable on thrips population was estimated using stepwise regression analysis (SAS, 2003).

Thrips population was expected to be influenced by growth stage (D1= early growth stages, D2= bulb enlargement stages, D3= maturation growth stages) and season (D1= cool dry planting, D2 = hot dry planting and D3= rainy planting). Seasonal and growth stage effects captured by creating dummy variables for each of the seasons and growth stage.

$$pt = B0 + x1 + x2 + x3 + x4 + x5 + x6 + x7 + x8 + e \dots \dots \dots (1)$$

Where Pt thrips population, x_1 is the season ($D_1 = 1$ if cool dry, 0 otherwise, $D_2 = 1$ if hot dry, 0 otherwise and $D_3 = 1$ if rainy, 0 otherwise), x_2 is growth ($D_1 = 1$ if early growth stages, 0 otherwise, $D_2 = 1$ if bulb enlargement stages, 0 otherwise and $D_3 = 1$ if maturation growth stages, 0 otherwise), x_3 is weekly total rainfall (mm), x_4 is weekly average daily minimum temperature, x_5 is weekly average daily maximum temperature, x_6 weekly average relative humidity (%), x_7 weekly average sunshine hours, and x_8 is weekly average wind speed. Yield loss was calculated using the following formula.

$$yield\ loss\ (\%) = \frac{yield\ on\ treated - yield\ on\ untreated}{yield\ on\ treated} * 100$$

2.3. RESULTS

2.3.1. Abundance of thrips related to the growth stage of onion

The thrips population was low until 29 days after transplanting (DAT) and increased rapidly starting from the 36 DAT and peaked with 140 thrips/plant at 57 DAT in the dry cool season, 167 thrips/plant at 50 DAT in the dry hot season, and 52 thrips/plant in the rainy season during 2015/2016 (Fig. 2.1). In 2016/2017, highest thrips number 140 thrips/plants at 64 DAT, 205 thrips/plant at 43 DAT and 79 thrips/plant at 57 DAT in dry cool, dry hot and rainy season were recorded, respectively. In all seasons, the thrips population declined during the mature growth stages (Fig. 2.2).

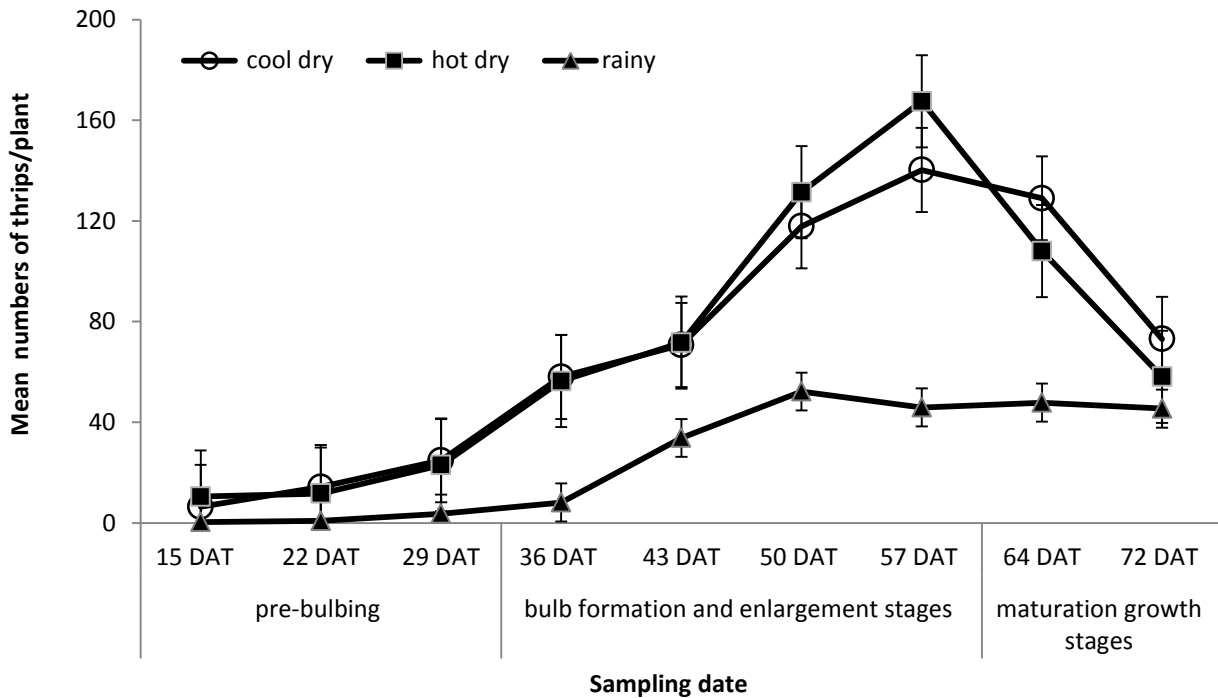


Figure 2. 1. Mean number of thrips per plant in cool dry, hot dry and rainy season on unprotected plot in 2015/2016. Error bars show SEs

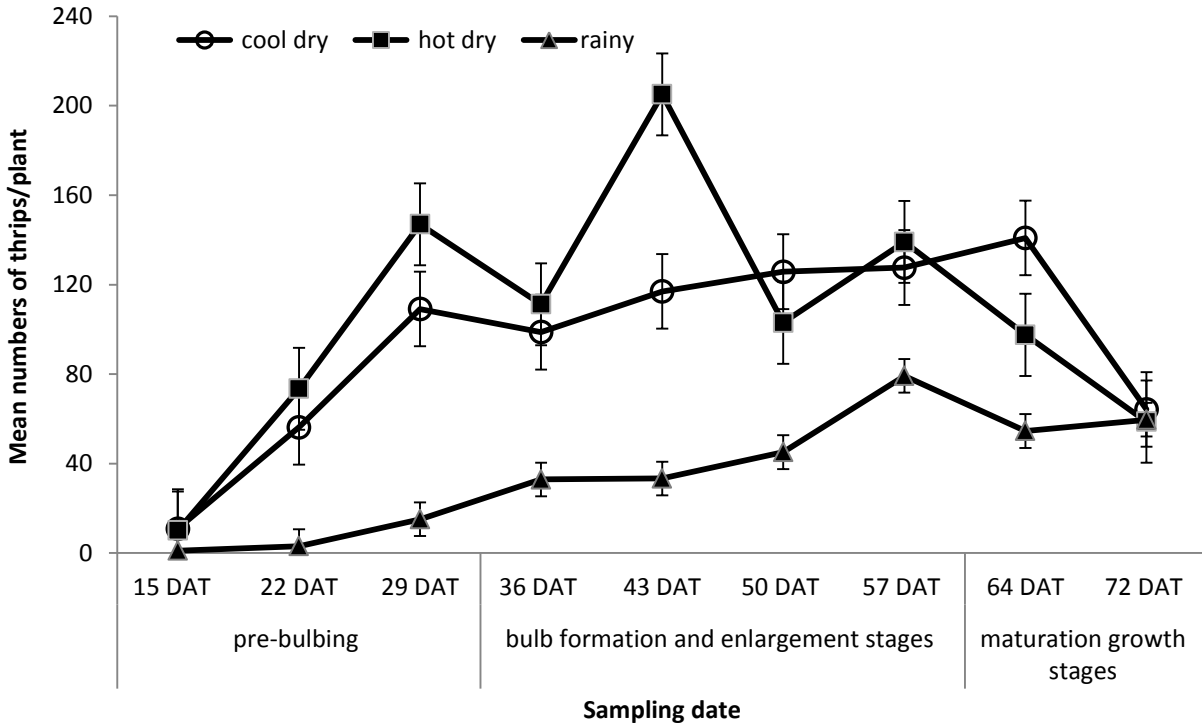


Figure 2.2. Mean number of thrips per plant in cool dry, hot dry and rainy seasons on unprotected plot in 2016/2017. Error bars show SEs

2.3.2. Effect of production season on thrips population

Thrips population was significantly affected by seasons ($F = 8.9$, $p = 0.0005$) on untreated plots. The pairwise comparisons analyses indicated that there were significant differences between cool dry and rainy ($t = 2.18$, $p < 0.038$) and hot dry and rainy season ($t = 2.17$, $p = 0.04$). Differences between cool dry and hot dry seasons, however, were not significant ($t = 0.01$, $p = 0.99$) in 2015/2016 cropping season. Similar relationship was observed in the 2016/17 cropping season. Differences were significant between cool dry and rainy season ($t = 2.91$, $p = 0.0076$) and hot dry and rainy season ($t = -3.23$, $p = 0.0037$); and insignificant between cool dry and hot dry seasons ($t = -0.32$, $p = 0.75$) on the untreated check plot.

2.3.3. Weather variables in different season

The weather pattern during the three seasons was variable. The dry hot (February – May) planting period, experienced higher maximum daily mean temperature and the dry cool period (November- January) the lowest minimum temperature in both years. Mean rainfall and relative humidity were higher during the rainy season (August -September) in both years. The highest daily sunshine and wind speed were recorded during the dry cold (November- January) season in both years (appendix 2.1 and 2.2).

2.3.4. Correlation Analysis

Rainfall and relative humidity showed significant negative relationship with thrips population was observed. On the other hand, maximum temperature and sunshine hours showed significantly positive relationship with thrips population. No correlation was observed between thrips population and Minimum temperature as well as wind speed (Table 2.1).

Table 2. 1. Relationship between thrips population and weather variables (Mean of two years)

	Rainfall	Temperature		Relative humidity	Sunshine hours	Wind speed
		Min-	Max-			
Rain fall	1.00					
Min- temperature	0.35**	1.00				
Max- temperature	-0.35**	0.25ns	1.00			
Relative humidity	0.62**	0.57**	-0.55**	1.00		
Sunshine hours	-0.66**	-0.45**	0.51**	-0.79**	1.00	
Wind speed	-0.47**	-0.44**	0.09ns	-0.60**	0.54**	1.00
Thrips number	-0.34*	-0.19ns	0.34**	-0.36**	0.49**	0.17ns

*. Correlation is significant at the 0.05 level.

**. Correlation is significant at the 0.01 level.

ns. Correlation is non-significant.

2.3.5. Regression Analysis

The regression analysis results showed that growth stage, season and sunshine hours significantly affected thrips abundance in the selected model at (P=0.15) (Table 2.2). Rainfall, minimum and maximum temperature, relative humidity and wind speed were dropped in the selected model. Sixty-nine percent of the total variation of thrips number were explained in the selected model included growth stage, season, and sunshine hours as independent variables (Table 2.2).

$$pt = 5.54 - 4.39 \text{ stage} - 2.63 \text{ season} + 0.52 \text{ sunshine} + 3.79 \dots \dots \dots (2)$$

Table 2. 2. The regression statistics for populations of thrips related to season, stage, max temperature and sunshine hours

Variable	Slope	F value	P value	Model R ²
Stage (early)	-2.63	60.75	<0.0001	0.39
season (rainy)	-4.39	15.44	<0.0003	0.64
Sunshine hours	0.52	7.57	0.0093	0.69

2.3.6. The effect of insecticide on thrips population

Thrips population between treated and untreated plots differed significantly both in the cool dry (t = -3.74; P = 0.0018) and hot dry (t = -3.95; P =0.0011) seasons of 2015/16, while no significant difference was observed in the rainy season in the same year (t = -1.26; P =0.0.224). Similar trends were observed in 2016/17 cropping season. Differences were significant between treated and untreated check in cool dry (t = -5.51; P < 0.0001) and hot dry (t = -4.84; P = 0.0002) seasons of 1016/17 but not in the rainy season (t = -1.54; P = 0.144).

2.3.7. Yield loss

The highest onion bulb yield loss was recorded in dry production season in both years. The highest onion bulb yield loss was recorded in cool dry, hot dry and rainy season in 2015/16 were 36.0, 29.1 and 8.2, respectively. Similarly, in 2016/17, onion bulb yield loss was recorded in cool dry, hot dry and rainy season were 38.5, 40.1 and 17.3 respectively (Table 2.3). The regression of thrips population on level of yield loss pooled from all production seasons and both years showed a strong and significant positive linear relationship ($R^2=0.90$; $p=0.0029$) (Fig 2.3).

Table 2. 3. Onion bulb yield loss due to thrips infestation

Years	Seasons	Mean onion bulb yield (t/ha)				% yield loss	
		Treated		Untreated		Marketable	Total
		Marketable	Total	Marketable	Total		
2015/16	Cool dry	29.88	30.80	19.38	19.69	35.12	36.07
	Hot dry	25.50	26.33	18.33	18.66	28.1	29.11
	Rainy	13.33	13.47	12.36	12.36	7.29	8.24
2016/17	Cool dry	28.33	28.47	17.29	17.50	38.97	38.53
	Hot dry	28.33	28.88	16.91	17.28	40.3	40.17
	Rainy	16.32	16.45	13.40	13.61	17.87	17.29

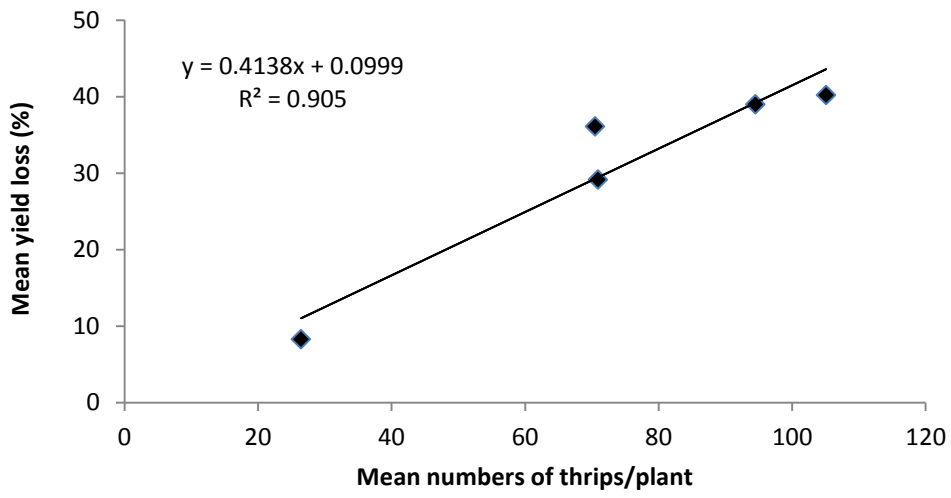


Figure 2. 3. Relationship between mean numbers of thrips per plant and yield loss in onion

2.4. DISCUSSION

Size of thrips population varied between years, seasons, and growth stages. Lower thrips population was found in early growth stages of onion (15 - 36 days after transplanting), while population was higher at bulbing stage (43 -64 days after transplanting) and declined thereafter in all the three seasons. Similar to this study, Waiganjo (2004) found that the highest population was observed during the bulb formation and enlargement stages (35 to 84 DAT), while the lowest occurred during pre-bulbing (0 to 28 DAT) and maturation growth stages (91 to 105 DAT). Previous studies also described that thrips populations are low during the early growth stage, gradually increase and peak during the vegetative stage of the crop, followed by an abrupt decline in numbers with physiological maturity of onion (Gachu *et al.*, 2012; Nyasani *et al.*, 2012; Neergude *et al.*, 2014). Haider *et al.* (2014) attributed the high thrips population during the vegetative stage to vigorous flesh green, high sap content, and maximum hiding places for thrips suitable for continuous breeding. When the crop matures, thrips population declines because the leaf nutritional status declines and becomes tougher and lignified making it difficult for thrips to rasp (Yeshitla, 2015). Hossain *et al.* (2015) observed that the thrips population suddenly decline due to maturation of the crop, leaf hardening and migration of thrips to other crops.

Thrips population was significantly affected by season in this study. Thrips were high in numbers in the dry seasons compared to the rainy seasons in both years. This may be due to higher rainfall in the rainy season affecting thrips populations. Liu (2004) reported that rainfall tends to negatively affects thrips populations because it can temporarily wash off thrips from the plant. Rueda and Shelton (2003) also observed that heavy rains maintain thrips population at low levels. On the other hand, the number of thrips was higher during the dry season with higher

maximum temperature in both years. Thrips population increase in hot and dry weather conditions, because of shorter generation time and higher number of generations (Rueda *et al.*, 2007). Thrips infestation is magnified with increased temperature, which enhances the multiplication rate of thrips (Bergant *et al.*, 2005; Waiganjo *et al.*, 2008).

Other weather variables are also important in limiting thrips abundance. A sunshine hour was important variables for predicting thrips population size. A positive slope of sunshine hours indicated that thrips population increased with increased sunshine hours. In disagreement to this result, Chhatrola (2003) reported that mean bright sunshine hours did not significantly affect the population of *T. tabaci* on onion. Wind speed had weak relationship with thrips population. On contrary, Waiganjo *et al.* (2008) indicated that wind speed had a positive correlation with thrips count on sticky traps and plant samples. According to the developed regression model, growth stage, season, maximum temperature and sunshine hours accounted for sixty-three percent of the variation in thrips population.

Yield losses of onion varied depending on the season and thrips population. Losses were higher in plantings made in the hot dry seasons. Desalegne and Shimeles (2003) also observed differences in yield and quality of dry bulbs between production seasons due to the variations in weather conditions prevailing in the areas. The seasonal abundance and level of thrips infestation are related with weather conditions. A significant positive relationship was observed between onion bulb yield loss and thrips population in this study. Increase in population of thrips impacts negatively the onion bulb yield (Wang *et al.*, 2006). In this study onion bulb yield loses ranged from 40 to 8.2. Diaz-Montano *et al.*(2011) reported higher than 50% yield losses from America

and Haider *et al.*, (2014) 57% yield loss from Pakistan. Studies in Kenya by Waiganjo *et al.*, (2008) reported yield loss of 18 to 60%.

2.5. CONCLUSION AND RECOMMENDATION

Thrips population is significantly higher in hot dry and cool dry production seasons than rainy production season in both years on untreated plot. Growth stage, season and sunshine hours are responsible factors for regulating in thrips abundance on onion plants in different season. Sixty-nine percent of the total variation of thrips number was explained by growth stage, season, maximum temperature and sunshine hours. The remains thirty-one percent of variations of thrips population could be due other weather variables. Thrips can cause up to 40% bulb yield losses in onion on untreated plots in dry production season. Application of Spinetoram insecticide for thrips control can reduced thrips infestation and increase yield of onion specifically in dry production season where infestation is high. Therefore, onion growers in the CRV should be advised to control thrips effectively using IPM specifically in dry production season.

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CHAPTER 3

Relative Abundance of Thrips Species (Thysanoptera: Thripidae) on Onion and Farmers' Insecticide Use Practices in the Rift Valley of Ethiopia

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ABSTRACT

A survey was conducted in 2016 in the major onion producing areas of the Ethiopian Central Rift Valley. A structured questionnaire was used to assess farmers' management practices with a focus on the use of insecticides. Plant samples were collected to assess species composition of thrips and their relative abundance. The results showed that insecticides were the only control option available for onion growers to control thrips infesting onion. The insecticides Diazinon, Dimethoate, Profenofos, Lambda-cyhalothrin and Spinetoram were commonly in use. Level of insecticide use was higher in Meki than Melkassa and Werer. Despite increase in the volume of insecticide use for thrips control the thrips population was on the increase over the years. *Frankliniella occidentalis* and *Thrips tabaci* were present in all the surveyed areas with *T. tabaci* accounting for a higher proportion. The relative species composition varied significantly with location. The highest proportion of *T. tabaci* was recorded at Werer, where insecticide use on onion was relatively minimal. On the other hand, *F. occidentalis* was highest at Meki where insecticide use was also higher. The reduced efficacy of insecticides and the increase frequency of application mainly in Meki suggests that thrips infesting onion might have been developing resistance to the commonly used insecticides. Further studies are required to confirm and develop a thrips resistance management programs in the area.

Key words: *Frankliniella occidentalis*, *Thrips tabaci*, onion, species composition

3.1. INTRODUCTION

Ethiopia has great potential to produce various vegetable crops including onion (*Allium cepa* L.) year-round for both local consumption and export. Onion has become popular among vegetable growers because of its high yield potential, availability of desirable cultivars and ease of propagation. Additionally, high domestic and export markets in fresh and processed forms (Selamawit *et al.*, 2013) and increasing worldwide consumption due to their numerous health benefits (Wang *et al.*, 2006). However, its production and productivity is low, with average production in Ethiopia reaching 7.73 t ha⁻¹ (CSA, 2016). This low productivity in Ethiopia is attributed partly to high infestation of thrips (Daniels and Fors, 2015).

In Ethiopia Thrips (Thysanoptera: Thripidae) are a well-known onion pest worldwide (Gill *et al.*, 2015) and the only insect pest that significantly reduces yield of onion and warrants interventions (FAO, 2010). Two thrips species: onion thrips, *Thrips tabaci* (Lindeman) and western flower thrips, *Frankliniella occidentalis* (Pergande) are highly invasive and damaging throughout the world (Stuart *et al.*, 2011). These two species are also present on onion in Ethiopia. When the species co-occur, one species tends to eventually predominate the other. The use of insecticides in cropping systems is one possible factor that can mitigate the competitive interaction (Zhao *et al.*, 2017). Western flower thrips, *F. occidentalis* is known to develop resistance rapidly to many standard insecticides used for thrips control (Zhao *et al.*, 2017) than the onion thrips, *Thrips tabaci*. Variable susceptibility to insecticides may increase the likelihood of one species being replaced by another, thus driving changes in population demographics (Gao *et al.*, 2012).

Insecticides are commonly used to control thrips on onion and the most common are: Carbamate, Organophosphate, Organochlorine, and synthetic Pyrethroids. They are often applied repeatedly and indiscriminately in the central rift valley of Ethiopia (Belay *et al.*, 2017) with recorded variable efficacy. The impact insecticide use on thrips species composition and relative abundance has not been assessed in onions producing areas of Ethiopia. This lack of information is cause for concern because growers have been making management decisions without knowledge of the thrips species present and their populations. Hence, this research was carried out to assess the species composition and relative abundance of thrips under different management approaches on onion in the central rift valley of Ethiopia.

3.2. MATERIALS AND METHODS

3.2.1. Description of the study area

The study was conducted from February to March 2016 in the major onion growing areas (Melkassa, Meki, and Werer) in the central rift valley region of Ethiopia (Fig 3.1). The study districts were purposely selected because of the intensive vegetable production taking place, access to irrigation water and proximity to attractive local markets. In these area farmers can produce vegetables in three cycles within the same year, but two-cycle of production is the most common (Tebkew and Getachew, 2015). The survey areas had different in elevations, practices of pest control measures, and type and frequency of insecticide application. Other vegetable crops like tomatoes and cabbage were also cultivated along with onion.

3.2.2. Assessment of farmers insecticide use

The survey was carried out to assess farmers' insecticides use practices to control thrips on onion. A total of 80 onion farmers, 25, 25 and 30 from Werer, Melkassa and Meki districts, respectively, were systematically selected along the irrigated areas of each district. The selected farmers' fields had similar growth stage and were free from insecticides for at least three days in each district. Data were collected using the local language in a face-to-face interview, often conducted in the farmers' field using a structured questionnaire. The questionnaires focused on insecticide use practices, types of insecticides and frequency of their application for thrips control on onion.

3.2.3. Assessment of thrips species composition and their abundance

A thrips sample was taken from ten randomly selected plants within each farmer field. The selected plant was covered with a plastic bag and then gently shaken to dislodge the thrips into the bag. The sampled thrips were transferred into vials that contain 70% ethyl alcohol and taken to the laboratory at the Melkassa Agricultural Research Center for species identification. Adult thrips were mounted on microscope slides and identified using a compound microscope. Adult thrips were identified using taxonomic keys, digital images and species descriptions (Sparks and Liu, 1914; Reed *et al.*, 2003). Mature onion thrips, *T. tabaci* is slightly smaller than western flower thrips, *F. occidentalis*. *T. tabaci* has ocellar pigment which is usually grey, has 7-segmented antennae and wings fringed with at least one row of incomplete setae whereas mature *F. occidentalis* have fringed wings with two complete rows of setae, pronotal anteromarginal setae are equal in length to anteroangular setae, ocellar pigment usually red and the antennae have 8-segments. Well-developed hairs or setae are present on the anterior part of the thorax for all *Frankliniella* species and absent in *Thrips* species, including onion thrips (Sparks and Liu, 1914; Reed *et al.*, 2003). In addition, thrips abundance was assessed visually by counting thrips on ten randomly selected plants from within each field. The coordinates of the study areas were recorded by (GPS) then using Arc view version 3.2a (GIS) software the study sites were mapped.

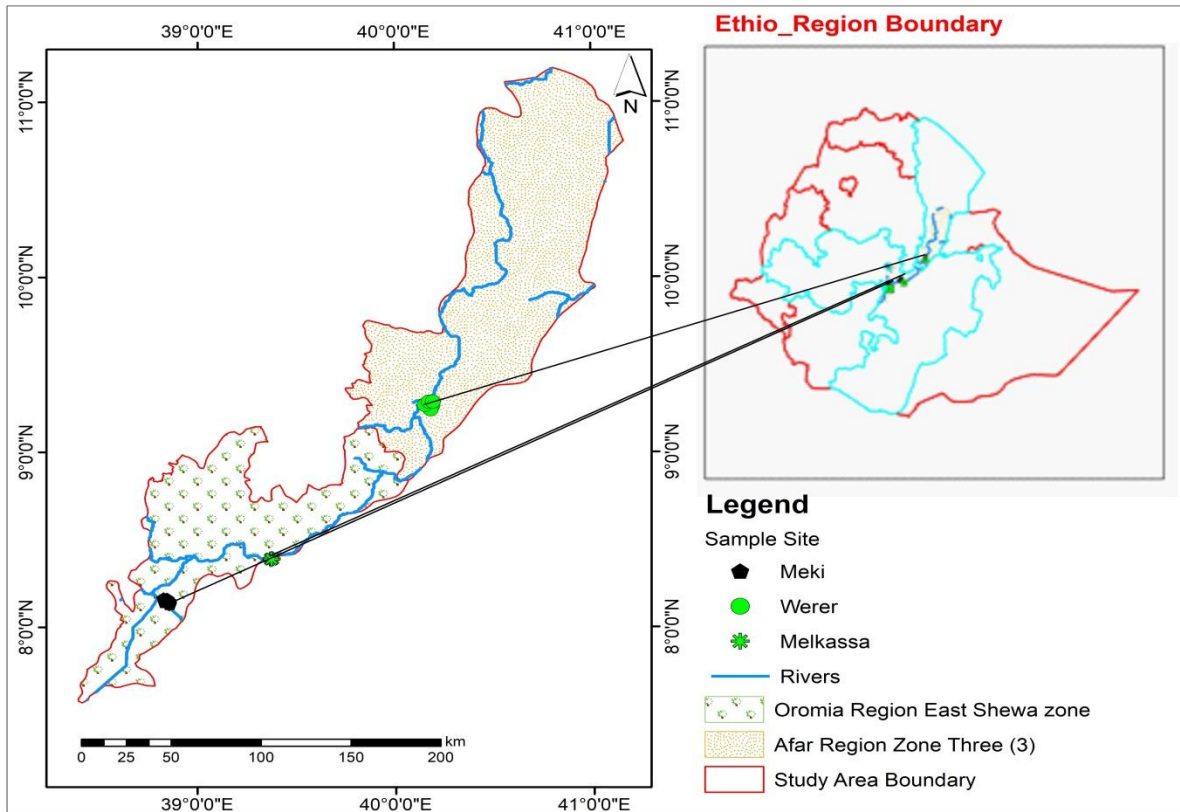


Figure 3. 1. Map of the surveyed onion growing areas in the central rift valley, 2016

3.2.4. Data analysis

Survey data were summarized and analyzed using (SPSS software version 16.0). Descriptive statistics were used to analyze the collected data. Associations of species composition with different region and insecticide application intervals were examined using chi-square (χ^2) test. Correlation between mean numbers of thrips per plant, thrips counts for each farmers and insecticide application interval was analyzed.

3.3. RESULTS

3.3.1. Insecticide type and frequency of application

All onion growers surveyed control thrips using synthetic insecticides. A total of seven insecticides are in use in the surveyed onion farming areas. The most frequently used classes is the organophosphates Profenofos available in different trade names (Girgit-Plus, Profit and Selecron). Besides this, Dimethoate and Diazinon are in use in the three survey areas. Less than 20% of the farmers in Melkassa and Meki use Lambda cyhalothrin. The use of new generation insecticide Spinetoram is reported by 20% of the farmers in Meki and to a much lesser extent in Melkassa (Fig 3.2).

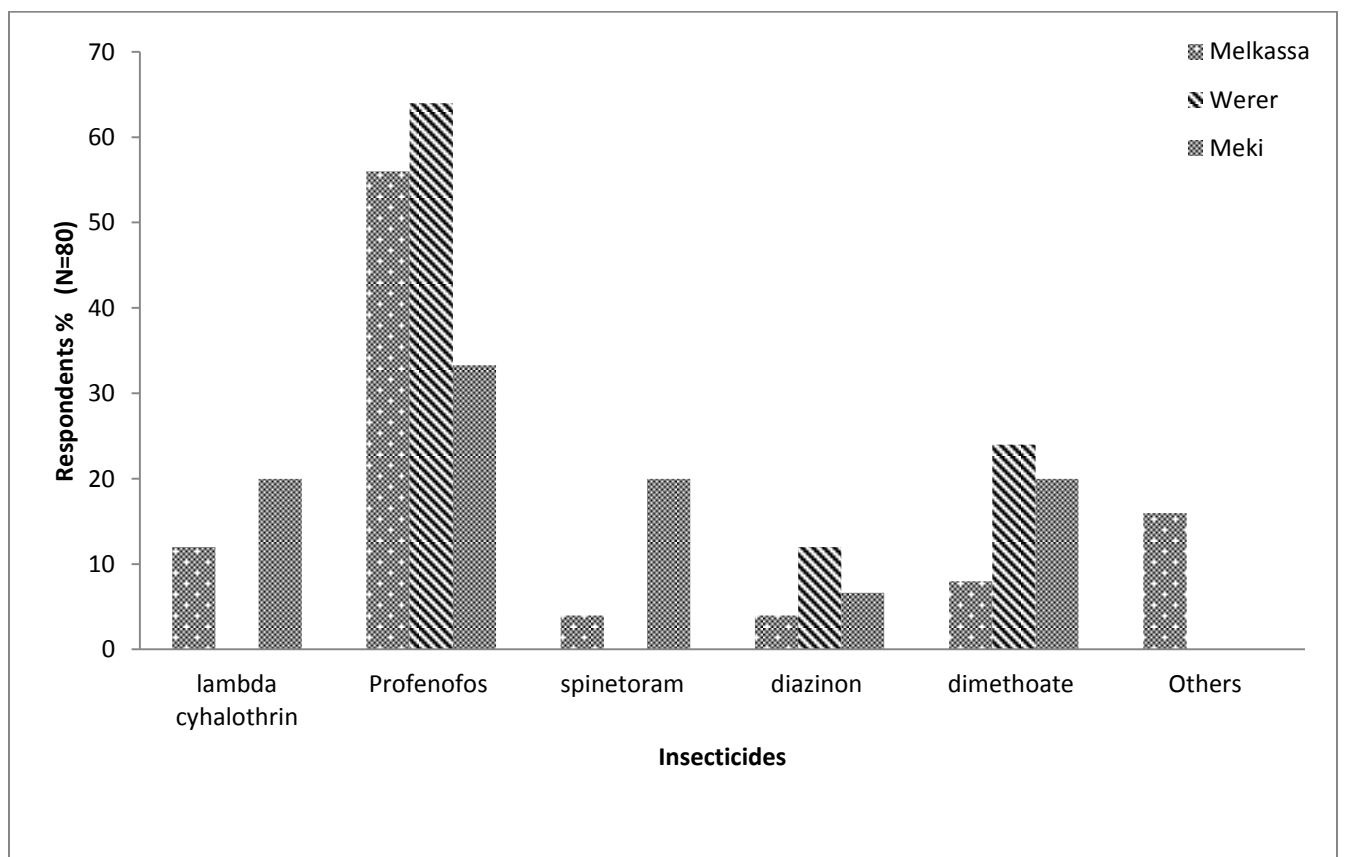


Figure 3. 2.Types of insecticides used on onion by farmers in Melkassa, Werer and Meki, districts, Ethiopia, 2016

A significant difference was found between regions with respect to the insecticide spraying interval ($\chi^2 = 19.56$, $P = 0.001$). The total number of applications per season ranged from 3 to 15 times. The numbers of sprays per crop season varied significantly between locations ($\chi^2 = 56.46$, $P = 0.001$). On the average, about 50% of the respondents sprayed insecticides in less than seven day interval, 43% of them at the seven day interval and the remaining 8% sprayed as necessary (Table 3.1). Regarding the practice of insecticide use, about 93.8% of the respondent observed that it has increased year-to-year; only 6.2% of farmers were of the opinion that there was not much change (Table 3.1).

Table 3. 1. Percentage of survey respondents, with in each location, reporting their frequency of insecticide use to control thrips on onion

No	Variables	Locations and percent of respondents (N=80)			
		Melkassa (%)	Werer (%)	Meki (%)	Total (%)
1	Management methods				
	Chemicals	100	100	100	100
2	Spraying interval				
	< 7 days	56	24	66.6	50
	7 days	44	52	33.4	42.5
	As necessary	0	24	0	7.5
3	Spraying frequency per cropping season				
	<5 times	12	44	0	17.5
	7 times	56	56	13.3	40
	8 times	24	0	16.7	13.8
	> 10 times	8	0	70	28.8
4	Quantity of yearly insecticides use				
	Increase	80	100	100	93.75
	Decrease	0	0	0	0
	No change	20	0	0	6.25

3.3.2. Farmers' perceptions of insecticides use in onion production

The majority of farmers (97.5%) were of the opinion that thrips on onion can be effectively controlled with the use of insecticides, while only a few of them (2.5%) perceived that insecticides did not solve their thrips problem. About 92.5% of respondents attributed the increase in productivity of onion to the use of insecticides. Although farmers believed that the insecticides were effective against thrips, about 81.2% of the respondents stated that the abundance of onion thrips increased year to year, while the remaining respondents indicated that the abundance of thrips decreased or did not change much (Table 3.2).

Table 3. 2. Percentage of survey respondents describing their perception of insecticide use in onion production in Ethiopia

No	Variables	Locations and percent of respondents (N=80)			
		Melkassa (%)	Werer (%)	Meki (%)	Total (%)
1	Effect of insecticides on onion production				
	Increase	88	88	100	92.5
	No change	6	6	0	3.75
	I don't know	6	6	0	3.75
2	Effectiveness of insecticides				
	Effective	92	100	100	97.5
	Not effective	0	0	0	0
	No change	8	0	0	2.5
3	Yearly change in thrips pressure				
	Increase	52	88	100	81.2
	Decrease	24	0	0	7.5
	No change	24	12	0	11.2

3.3.3. Species composition and abundance of thrips on onion

Two thrips species: onion thrips, *Thrips tabaci* and western flower thrips, *Frankliniella occidentalis* were present in all sampled areas but in different proportions. Pooling across all regions and field sites, 70.9% of the identified thrips were *T. tabaci* and the remaining 29.1% were *F. occidentalis* (Fig. 3.3). Thrips composition was statistically different between locations ($\chi^2 = 69.45$, $P = 0.001$). *T. tabaci* was the dominant species in Werer (88.2%) and in Melkassa (74%), while the two thrips species were present in equal proportion at Meki (Fig.3.3). Composition of thrips species was significantly affected by the insecticide application interval ($\chi^2 = 151$; $P = 0.001$) and number of insecticide sprays per one crop periods ($\chi^2 = 18.39$, $P = 0.001$). The abundance of total number of thrips was significantly different between the three locations (F-value? And P-value?). The highest number of thrips per plant was recorded at Meki followed by Melkassa and Werer (Fig. 3.4). Insecticide use was relatively higher at Meki and Melkassa. At the field level, the mean number of thrips per plant was not significantly correlated with the reported insecticide application intervals (Pearsons 2-tailed, $r = -0.072$).

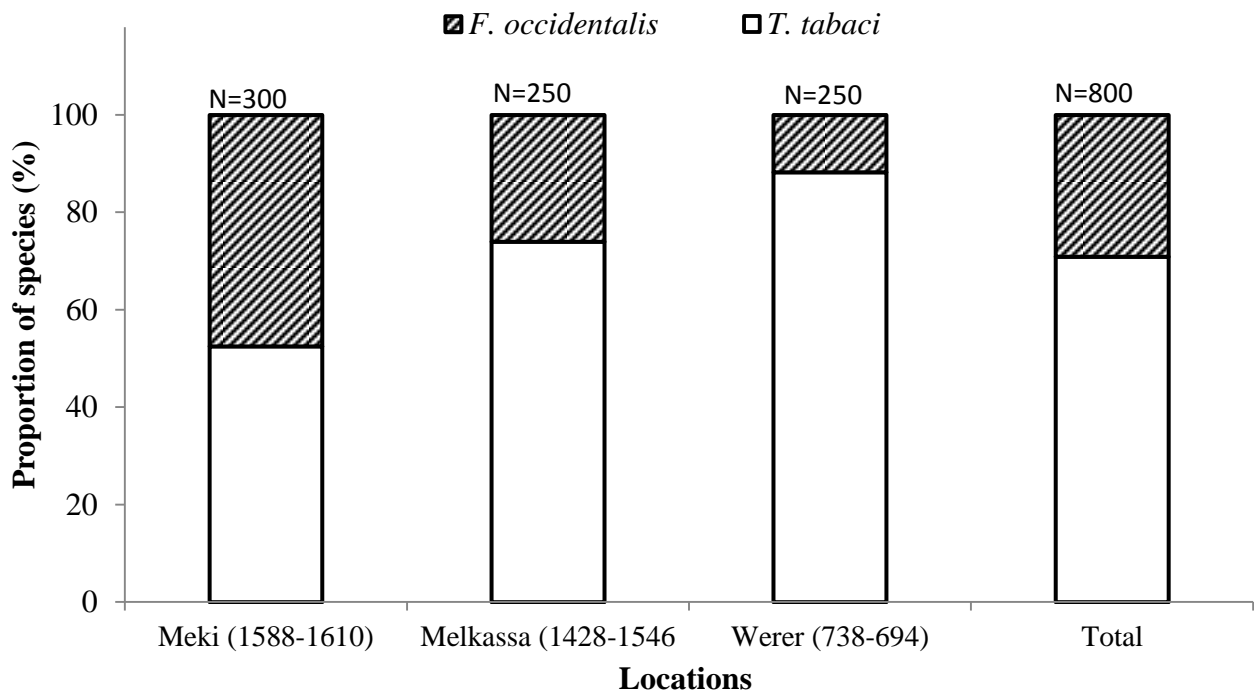


Figure 3. 3. Species composition of thrips (within brackets indicate the altitude in m.a.s.l) in onion fields

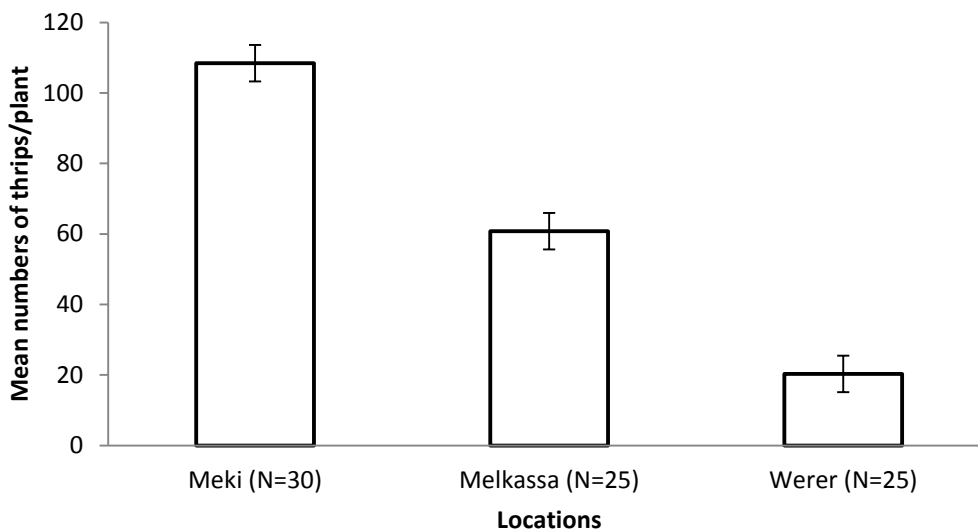


Figure 3. 4. Mean number of thrips/plant from the total of 80 onion grower farms fields visited at Meki, Melkassa and Werer, 2016. Error bars show SEs

3.4. DISCUSSION

Onion farmers routinely apply second generation synthetic organic insecticides (organophosphates and pyrethroids) at varying spray intervals and sprays frequencies per crop season to control thrips on onion. Only very few farmers used new generation insecticides (Spinetoram) and applied when necessary. Similar studies by Belay *et al.* (2017) reported that vegetable grower used different types of commercial pesticides with different chemical composition and applied indiscriminately and often in violation of the recommendations. Tebkew and Getachew (2015) reported that all small-scale vegetable growers in East Shewa Zone, Ethiopia, rely solely on pesticides and spray pesticides frequently to control pest. However, such intensive application of insecticides is conducive to increasing insecticide resistance. Adilakshmi *et al.* (2008) has reported that frequent insecticide use contributes to the reduction of beneficial and natural enemies and increases the development of insecticide resistance. Khaliq and Tahir (2015) indicated that the frequent use of synthetic chemical insecticides leads to resistance development in *T. tabaci*.

Most of farmers believed that increment of insecticide use solved their thrips problems and increased onion yield. This misperception about insecticides use lead to increase the volume of insecticide use every year, in parallel the intensity of onion thrips was increased every year. This misuse and misperception of insecticides use is aggravating the problem of thrips in onion production, because large quantity and frequently applied pesticide have posed increased incidence of pest through resurgence and appearance of pest species that are resistant to pesticides (Kaur and Garg, 2014).

T. tabaci was the most abundant species, especially at Werer. The highest proportion of *F. occidentalis* was recorded where the frequency and amount of insecticide use was high. This clearly shows that farmers' insecticide use affects the species composition of thrips in onion fields. When two species co-occur, one species dominated over the other due to the use of insecticides in cropping systems, because *F. occidentalis* was known significantly more tolerant to insecticides than *T. tabaci* (Zhao *et al.*, 2017). In another study by Bielza (2008) *F. occidentalis* was reported less susceptible to many insecticides and to develop resistance quickly. However, altitude is an important factor that may also contribute to species composition. A survey conducted in East Africa indicated that *F. occidentalis* was more abundant in the high altitude zones as compared to the low altitude zones (ICIPE, 2009). Mound and Azidah (2009) also found *F. occidentalis* to be abundant in highland areas. Farmers' insecticide use also affected thrips abundance, where by the highest thrips counts occurred in frequently sprayed locations as compared with less frequently sprayed locations. However, Ssemwogerere *et al.*(2013) found that the highest thrips occurrence was recorded where farmers that applied one pesticide spray per week as compared to those using two sprays a week.

3.5. CONCLUSION AND RECOMMENDATION

The trend of insecticides use for control of thrips on onion is increasing from year to year. The survey has shown that the frequency of insecticide spray per crop season ranged from 3 to 15 times. However, it is known that extensive use of insecticides has adverse effects on thrips population that lead to develop resistance to insecticides. This indiscriminate use of insecticides could be the reason for the increased volume of insecticides used every year. These farmers insecticide use affected the species composition and abundance of thrips on onion. From these results concerning the insecticides used to control thrips in onion, onion farmers should reduce

their reliance on insecticides. Finally, understanding the compositions of thrips species in farmers' fields is needed to control thrips effectively using IPM.

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CHAPTER 4

Field evaluation of commonly used synthetic insecticides against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia

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ABSTRACT

Thrips are responsible for high onion yield losses and mainly controlled with the use of insecticides. There is a demand for new products against thrips due to failure of commonly used insecticides. Thus, commonly used insecticides are periodically evaluated to avoid total failure of thrips control on onion. The efficacy of nine insecticides from classes of pyrethroids, organophosphates, spinosyns, neonicotinoid and botanical were evaluated against thrips on onion using a randomized complete block design in four replications in two seasons in 2015 and 2016. The lowest thrips infestations were observed in plots treated with spinosad, spinetoram, and imidacloprid, which resulted in higher marketable yield of onion both in cool and hot dry seasons. Whereas, alpha-cypermethrin, diazinon, neem and λ -cyhalothrin insecticides performed poorly in all the seasons with lower marketable yields. Performance of dimethoate and profenofos was intermediate with the intermediate yield gain over the control. Rotational application of the most effective neonicotinoid and spinosyns with less effective pyrethroids and organophosphates should be practiced in order to safeguard their long-term efficacy and utility to thrips control. Future research on the management of this pest should focus on insecticide resistance management and other effective IPM options.

Key words: onion thrips, resistance, pyrethroids, organophosphates, neonicotinoids, spinosyns

4.1. INTRODUCTION

Onion (*Allium cepa* L.) is the most widely grown vegetable crop by small and large-scale producers in Ethiopia, especially in the central rift valley. It ranks first among vegetables (Tebkew and Getachew, 2015). The area under onion is increasing from time to time, because it is highly profitable, easily propagated by seed, and the increase in small-scale irrigation areas (FAO, 2010). However, productivity is affected by several biotic and abiotic factors. Among biotic factors onion thrips, *Thrips tabaci* (Lindeman) is a key insect pest in most onion production regions of Ethiopia (Tebkew and Getachew, 2015). In addition to *T. tabaci*, western flower thrips *Frankliniella occidentalis* (Pergande) has become equally important in many Central Rift Valley areas of Ethiopia (Personal observation). According to Diaz-Montano *et al.* (2011), onion thrips is a global pest of onion, and the principal vector of Iris yellow spot virus (IYSV) that can cause 100% crop losses. This pest is responsible for a significant yield loss in Ethiopia with the range of 23-85% in different seasons (Yeshitla, 2015).

Control of thrips is a major concern to the production and profitability of onion (Nault *et al.*, 2013). Management methods including host plant resistance, cultural, biological and chemicals are used for thrips control on onion. However, use of chemical insecticides remains the major control strategy of onion thrips in commercial onion production in several countries including Ethiopia (Gill *et al.*, 2015). Experiences in the Central Rift Valley of Ethiopia show that vegetable growers heavily rely on the use of old and broad-spectrum synthetic insecticides (Gashawbeza, 2011). Moreover, rate and frequency of applications are not as per the recommendations for thrips control on onion (Belay *et al.*, 2017). Extensive and frequent use of broad-spectrum chemical insecticides in agriculture often leads to the development of genetically

resistant pest populations that are no longer affected by some commonly used pesticides (Gameel, 2004). In addition, the indiscriminate use of insecticides without taking into consideration the efficacy of insecticides is economically wasteful, and destroys natural enemies (Bommarco *et al.*, 2011).

Several synthetic insecticides have been tested for thrips control in Ethiopia (Tadele *et al.*, 2013; Tadele and Mulugeta, 2014; Ibrahim *et al.*, 2015), but most of them are pyrethroids and organophosphate. However, there are also other groups of insecticides in use elsewhere and available in the local market with different chemistry and reported them little effect on non-target organisms including natural enemies, and also have minimal adverse effects on human health. In addition, most of the registered insecticides available in the local market are old and broad-spectrum. Consequently, onion growers widely use these broad spectrums insecticides and apply them indiscriminately. Therefore, periodic screening of the insecticides in use is required to find which ones are still effective and provide information for insecticides resistance management of thrips on onion. Hence, this research was designed to evaluate the efficacy of different insecticides for the control of thrips on onion and bulb yield of onion.

4.2. MATERIALS AND METHODS

4.2.1. Descriptions of the study area

The study was conducted at Melkassa Agricultural Research center (MARC). It is located (8⁰ 24' N, 30⁰ 21'E, 1550 m above sea level) and characterized by low and erratic rainfall with an average of 771 mm rainfall per year over 80% of which falls between April and October, with the peak in July and August. The soils are mainly sandy with PH of 6.9-7.9 and mean temperature of 21⁰c (Lemma and Shimeles, 2003)

4.2.2. Treatments and Experimental Designs

The performance of different insecticides against onion thrips was evaluated for two seasons in 2015 and 2016. The first experiment was conducted between October 2015 and January 2016 (cool dry) and the second between March 2016 and June 2016 (hot dry) under irrigation at Melkassa Agriculture Research Center. Nine insecticides and untreated check were considered for the study. The test insecticides were one botanical formulation (neem-oil-based botanical insecticide), two natural products Spinosyns (spinetoram, spinosad), one Neonicotinoid (imidacloprid), two synthetic Pyrethroids (λ -cyhalothrin, alpha-cypermethrin), and three Organophosphates (diazinon, dimethoate, profenofos) (Table 4.1). The tested insecticides were registered for thrips control on onion in Ethiopia (MoANR, 2018) and are widely used by vegetable growers in the Central Rift Valley (CRV). A randomized complete block design in four replications was used. The plot size was 3 m by 3 m with five double rows and each row with 30 plants making a total of 300 plants in a plot. Spacing between water furrows, plant rows and plants were 40 cm, 20 cm and 10 cm, respectively. Spacing between plots and blocks were 1.5 m each. Seedlings of the onion variety “Bombay Red” was raised in nursery bed and transplanted at 2-3 leaf stage. The experimental field was irrigated twice per week for the first

three weeks after transplanting and weekly afterwards. The field was fertilized with Diammonium phosphate (DAP) and UREA at the rate of 200 kg and 150 kg per hectare, respectively. DAP was applied during transplanting and UREA was applied in two splits; the first half during transplanting and the remaining half 30 days after. Other recommended agronomic practices were carried out as required. Application of Insecticides was started when thrips population reached 5-10 thrips per plant (Tsedeke, 1983) and applied weekly for seven weeks period using manufacturers recommendation and manual operated knapsack sprayer of 15 liter capacity.

4.2.3. Data collection

Starting from 15 days after transplanting the insecticides were applied at seven days interval and the post spray data were taken on the same date prior to each insecticide application. Thrips population was counted on five randomly selected plants from the central rows of each plot by visually examining the entire plant parts. At maturity, onion bulbs were harvested from the middle three double rows in each plot and then sorted out into marketable and unmarketable bulbs. Healthy bulbs weighing between 20 and 160 g were considered as marketable, while undersized, oversized, diseased, decayed and physiologically disordered bulbs were considered as unmarketable (Lemma and Shimeles, 2003).

4.2.4. Data analyses

Thrips population and yield data were analyzed using the general linear model of statistical analysis using SAS version 9.0 (SAS, 2003) at 5% level of significance. Significant means ($p < 0.05$) were separated using Student-Newman-Keuls (SNK) test. Corrected efficacy was calculated using Abbott's formula (Abbott, 1925).

$$\text{Corrected \%} = \left(1 - \frac{n \text{ in T after treatment}}{n \text{ in Co after treatment}}\right) * 100$$

Where: n= insect population, T= treated, Co= control

Table 4. 1. List of insecticides tested and their application rate against thrips on onion at Melkassa Ethiopia, 2015/16

Trade Name	Common Name	Class	Rate (ml/ha)
Diazinon 60% EC	diazinon	Organophosphate	1500 ml
Agro-thoate 40% EC	dimethoate	Organophosphate	1000 ml
Con-fidence 350 SC	imidacloprid	Neonicotinoid	400 ml
Karate 5% EC	λ -cyhalothrin	Pyrethroid	300 ml
Fstac 10% EC	alpha-cypermethrin	Pyrethroid	300ml
Girgit-Plus 72% EC	profenofos	Organophosphate	600 ml
Nimbicidine	azadirachtin	Botanical	3000 ml
Radiant 120 SC	Spinetoram	Spinosyn	130 ml
Tracer 480 SC	spinosad	Spinosyn	200 ml

4.3. RESULTS

4.3.1. Thrips population

Applications of spinetoram, spinosad and imidacloprid resulted in significantly lower number of thrips: 9.55, 11.30 and 17.72 thrips/plant, respectively, than the rest of the treatments during the cool dry season (Table 4.2). The number of thrips was significantly higher in plots treated with diazinon, neem, alpha-cypermethrin and λ -cyhalothrin insecticides: 76, 73.5, 69.2 and 65.6 thrips/plant respectively, than the rest of the treatments except the untreated check (Tables 4.2). Performance of dimethoate and profenofos was intermediate between the best performing treatments (spinetoram, spinosad and imidacloprid) and the rest of the treatments. Similar trends in the performance of the insecticides were observed in the hot dry planting season of 2016 (Table 4.3)

Table 4. 2. Mean number (\pm SE) of thrips /plant on onion treated with different insecticides in cool dry season, Melkassa, 2015/16

Insecticides	Sampling dates							Season mean	% efficacy
	16-Nov	23-Nov	30-Nov	7-Dec	14-Dec	21-Dec	28-Dec		
diazinon	21.9 \pm 4.01a	13.1 \pm 2.46c	42.6 \pm 5.36bc	110.9 \pm 8.43a	99.4 \pm 5.36ab	123.9 \pm 8.28a	120.6 \pm 7.90ab	76.1 \pm 2.40ab	2.27
dimethoate	20.9 \pm 2.46a	11.6 \pm 1.91c	13.4 \pm 2.59e	50.8 \pm 4.11cd	43.1 \pm 2.07d	41.7 \pm 5.17cd	39.0 \pm 3.96cd	31.5 \pm 2.59c	59.52
imidacloprid	11.2 \pm 1.17bc	7.9 \pm 1.83c	15.4 \pm 2.26e	25.2 \pm 3.01e	19.0 \pm 1.32e	24.3 \pm 2.93de	21.2 \pm 3.06de	17.7 \pm 1.17d	77.23
alpha-cypermethrin	18.9 \pm 1.72ab	50.4 \pm 4.88a	48.2 \pm 6.11b	83.4 \pm 1.56b	96.6 \pm 4.78b	94.9 \pm 2.75b	92.2 \pm 2.84b	69.2 \pm 1.29ab	11.08
profenofos	7.2 \pm 1.74c	7.6 \pm 1.20c	19.7 \pm 3.27de	43.2 \pm 7.03cd	69.3 \pm 5.34c	52.9 \pm 5.88c	49.6 \pm 5.62c	35.6 \pm 1.91c	54.24
λ -cyhalothrin	12.9 \pm 2.85abc	25.2 \pm 3.49b	30.8 \pm 2.73cd	75.3 \pm 3.16b	93.0 \pm 6.22b	112.3 \pm 9.75ab	109.9 \pm 9.54ab	65.6 \pm 3.06b	15.68
Neem	21.8 \pm 3.82a	29.7 \pm 4.56b	45.5 \pm 3.21bc	82.3 \pm 5.44b	106.4 \pm 6.78ab	115.9 \pm 8.64ab	113.0 \pm 8.62ab	73.5 \pm 1.45ab	5.56
spinetoram	10.7 \pm 2.07bc	3.4 \pm 0.92c	7.3 \pm 1.59e	11.7 \pm 2.04f	6.8 \pm 1.57e	17.5 \pm 6.25de	9.7 \pm 2.66de	9.6 \pm 1.94d	87.73
Spinosad	11.2 \pm 1.7bc	2.1 \pm 0.2c	6.5 \pm 1.6e	31.3 \pm 3.7de	14.3 \pm 2.99e	8.4 \pm 1.5de	5.5 \pm 1.45e	11.3 \pm 1.32d	85.48
Control	16.8 \pm 2.7ab	23.7 \pm 2.6b	62.0 \pm 7.7a	72.4 \pm 5.4b	114.6 \pm 5.8a	132.3 \pm 10.9a	123.0 \pm 10.5a	77.8 \pm 4.9a	
SE	1.69	4.72	6.16	9.85	13.2	15.10	15.37	8.96	
CV	28.4	29.9	29.5	15.5	15.3	18.5	18.36	10.57	

Means followed by the same letter(s) in a column are not significantly different at 5% SNK. SE= Standard error, CV= Coefficient of Variability.

Table 4. 3. Mean number of thrips/plant on onion treated with different insecticides in the hot dry season, Melkassa, 2016.

Insecticides	Sampling dates							Season Mean	% efficacy
	11-Apr	18-Apr	25-Apr	2-May	9-May	16-May	23-May		
diazinon	21.5±1.81a	32.7±3.02ab	43.4±7.95b	76.1±6.76b	147.2±12.41a	121.1±8.93b	74.4±2.73b	73.8±1.40bc	16.64
dimethoate	16.3±2.75ab	30.2±4.48ab	39.9±5.32b	69.7±9.55b	111.3±14.02ab	92.4±7.30bc	39.8±6.32cd	57.0±2.64d	35.56
Imidacloprid	10.5±0.80b	26.1±4.58ab	6.5±0.93c	14.9±3.89c	9.7±2.07d	30.9±10.01d	8.6±0.51e	15.3±1.41f	82.72
alpha-cypermethrin	10.4±2.16b	25.9±5.23ab	52.2±1.69ab	114.2±6.05a	122.2±11.89ab	176.2±16.02a	95.5±0.88b	85.2±3.20ab	3.7
Profenofos	11.2±2.38b	28.7±3.58ab	11.1±2.58c	62.8±7.21b	54.0±3.67c	77.9±9.73c	42.1±10.73cd	41.1±1.68e	53.55
λ-cyhalothrin	15.7±1.48ab	27.0±4.34ab	36.1±2.32b	78.1±10.95b	98.6±13.61b	119.0±11.74b	123.0±12.96a	71.1±6.16c	19.69
Neem	15.7±2.05ab	40.8±3.74a	39.1±5.72b	133.1±15.32a	121.1±8.48ab	187.2±9.90a	47.9±3.55c	83.5±5.03ab	5.58
Spinetoram	8.2±0.69b	15.9±2.10b	7.9±1.00c	17.2±4.29c	21.2±4.85d	15.9±5.33d	6.5±1.62e	13.3±1.26f	85.02
Spinosad	8.0±1.6.b	17.7±5.33b	19.3±2.35c	37.1±7.17c	7.9±1.34d	25.7±6.42d	16.5±4.78de	18.9±2.19f	78.68
Control	13.2±4.50b	27.4±5.60ab	60.1±8.33a	118.3±9.15a	140.1±10.92a	168.5±11.74a	91.9±18.39b	88.5±4.04a	
SE	1.34	2.22	6.04	13.03	17.34	20.21	12.66	9.59	
CV	28.4	29.6	27.6	21.3	22.9	18.7	29.3	12.1	

Means followed by the same letter(s) in a column are not significantly different at 5% SNK. SE= Standard error, CV= Coefficient of Variability.

4.3.2. Onion bulb yield

Marketable yield varied significantly between treatments in both seasons (Table 4.4). Higher marketable yields were obtained from plots treated with spinosad (28.88 t/ha) and spinetoram (27.77 t/ha) than the rest of the treatments. Marketable onion bulb yields were low for λ -cyhalothrin (15.18 t/ha), diazinon (18.05t/ha), and neem (19.35t/ha) treated plots in the cool dry season (Table 4.4). Similar trend was observed in marketable yield in the hot dry season. The total bulb yield was negatively associated with thrips number in cool dry ($R^2=0.785$; $p = 0.0012$) and hot dry ($R^2=0.90$; $p = 0.0001$) seasons (Figs. 4.1 and 4.2).

4.3.3. Yield increase over control

The highest mean marketable bulb yield increment was recorded from spinosad (8.87 t/ha) and spinetoram (8.38 t/ha) treated plots which accounted for 46.86 and 44.26% increment over control, respectively. Subsequent higher bulb yield increment was obtained from onion treated with imidacloprid, profenofos and dimethoate with 7.66, 4.31 and 3.33 t/ha bulb yield with 40.46, 22.76 and 17.59% increase over control, respectively (Table 4.4). The yield increase obtained by spraying the pyrethroids alpha- cypermethrin was low (1.2%). On the other hand, onion yield from the plots treated with λ -cyhalothrin and diazinon were lower than the untreated check and resulted in negative gain.

Table 4. 4. Marketable bulb yield of onion treated with different insecticides against thrips in cool and hot dry seasons, Ethiopia, 2015/16.

Insecticides	Marketable yield (tons/ha) and percent of yield gain over control						
	Cool season	dry	Hot season	dry	Mean	Increment of yield gain over control (t/ha)	% yield gain over control
	Marketable		Marketable		Marketable		
diazinon	18.1±1.12bc		18.8±0.92c		18.4±0.75d	-0.51	-2.69
dimethoate	23.3±2.90ab		21.2±1.42c		22.3±1.76bc	3.33	17.59
imidacloprid	23.5±1.84ab		29.67±2.55a		26.6±1.51a	7.66	40.46
alpha-cypermethrin	20.5±0.76bc		17.9±0.48c		19.2±0.55bcd	0.23	1.21
profenofos	24.3±1.48ab		22.2±1.38bc		23.2±0.66b	4.31	22.76
λ-cyhalothrin	15.2±1.10c		17.8±0.50c		16.5±0.67d	-2.45	-12.94
Neem	19.4±1.10bc		19.3±1.48c		19.3±0.78bcd	0.37	1.95
spinetoram	27.8±2.59a		26.9±1.38ab		27.3±1.27a	8.38	44.26
Spinosad	28.9±2.49a		26.7±1.55ab		27.8±1.98a	8.87	46.86
Control	19.7±0.66bc		18.1±1.27c		18.9±0.69bcd	-	-
CV	13.9		13.34		14.59		
SE	0.76		0.78		0.73		

Means followed by the same letter(s) in a column are not significantly different at 5% SNK. SE= Standard error, CV= Coefficient of Variability.

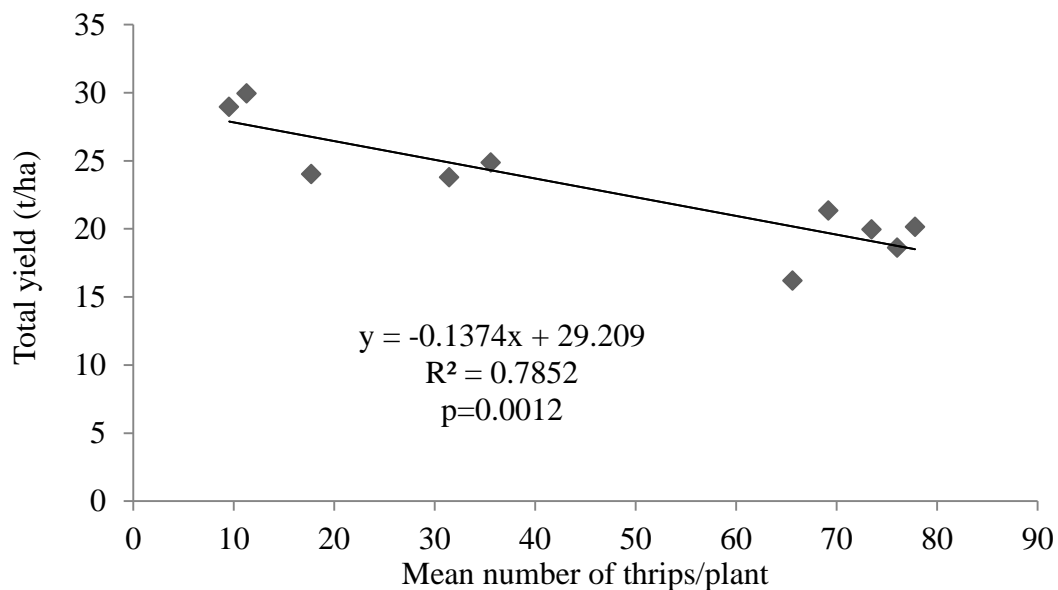


Figure 4. 1. Relationship between mean number of thrips and total onion bulb yield (t/ha.) in cool dry season, 2015/16

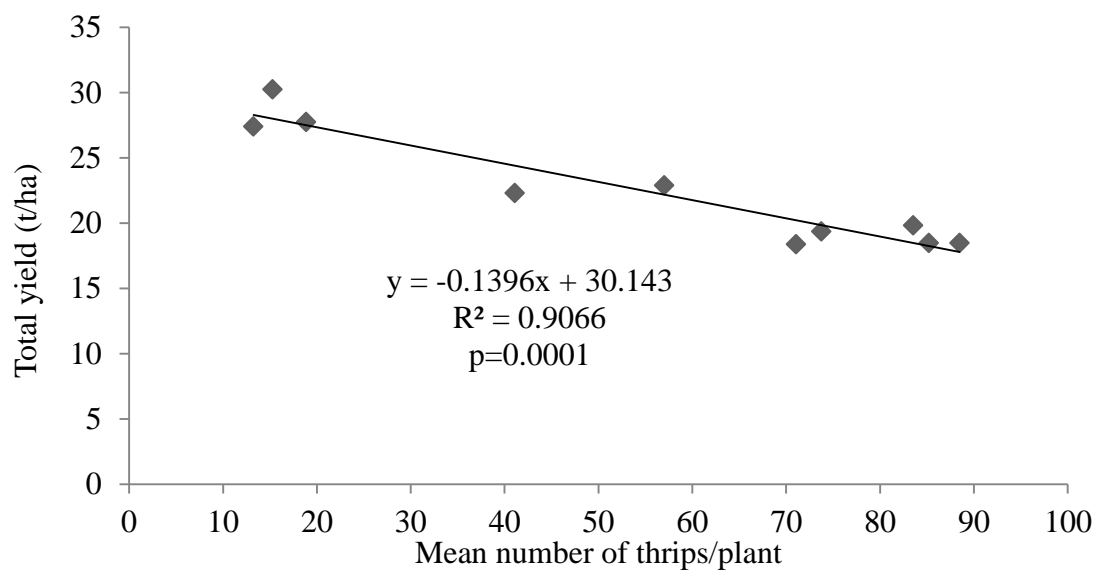


Figure 4. 2. Relationship between mean number of thrips and total onion bulb yield (t/ha.) in hot dry season, 2016

4.4. DISCUSSION

Among the insecticides tested, spinosad and spinetoram effectively controlled onion thrips as compared to other insecticides. These insecticides were recently registered in Ethiopia. The newer spinosyns derived products, specifically the spinosad (Tracer) and spinetoram (Radiant) showed great promise for *T. tabaci* control in onions with low lethal dose values in the USA (Greenberg *et al.*, 2012). Spinosad and spinetoram are new selective insecticides belonging to novel classes of chemistry that have shown excellent control of *T. tabaci* infestations (Diaz-Montano *et al.*, 2011). In addition, spinosad, a natural reduced-risk insecticide derived from an actinomycete bacterium, is compatible with natural enemies and currently provides the most effective chemical control of western flower thrips (Mouden *et al.*, 2017). Spinosyns, the active ingredient of spinetoram and spinosad, act as nicotinic acetylcholine receptor (nAChR) allosteric modulators (IRAC, 2018). Furthermore, these products have translaminar and/or systemic activity so that they are able to penetrate into areas of the plant where thrips are located (Reitz, 2014). Spinosyns act on insects that come in contact with treated leaf surface or ingest the treated tissue (Siebert *et al.*, 2016). Insecticides with systemic mode of action have high efficacy against sucking insect pests (Ahmed *et al.*, 2014). Therefore, the result of our insecticide performance evaluation against onion thrips agrees with the result of the above mentioned scientists. But, most of the vegetable growers in the CRV largely rely on less expensive and older insecticides (Belay *et al.*, 2017) which are readily available and supplied by many dealers (Gashawbeza, 2011).

The insecticides λ -cyhalothrin, alpha-cypermethrin, neem and diazinon failed to control thrips on onion in this study. Earlier report by Banchiamlak *et al.* (2012) showed that λ -cyhalothrin, diazinon, profenofos and spinosad were effective against thrips on onion in the Rift Valley of

Ethiopia. Pyrethroids, carbamates, and organophosphates groups of insecticides have been used to control insect pests on vegetables for many years in Ethiopia (Yalemtehay and Agonafir, 2002) and are still widely used. These insecticides are applied indiscriminately in higher frequencies and doses (Tebkew and Getachew, 2015; Belay *et al.*, 2017). It is a common practice to sprays mixes of insecticides at times when sole insecticide applications become less effective. Failure in the efficacy of insecticides to control onion thrips could be due to the development of resistance. Several studies have indicated that *T. tabaci* has developed resistance to commonly used insecticides. Nault and Shelton (2010) and Shelton *et al.* (2003, 2006) documented resistance in thrips populations to the pyrethroid (λ -cyhalothrin), organophosphates and carbamates in many New York onion fields. Broughton and Herron (2009) also reported that resistance to insecticides by western flower thrips is common.

The present study showed that the yield reduction due to onion thrips infestation was very high and protection with the most effective insecticides, spinosad, spinetoram and imidacloprid increased yield of onion. Several researchers have reported higher yields when onion is protected from thrips with best performing insecticides. Acephate and fipronil insecticides protected from thrips with higher yield (Moorthy *et al.*, 2013). Khaliq and Muhammad (2015) also reported higher yields of onion from plots treated with insecticides as well as botanicals compared to untreated controls. In the current study, lower marketable bulb yields were obtained from plots treated with diazinon, λ -cyhalothrin, alpha-cypermethrin and botanical formulation (neem) insecticides. On the contrary, Ibrahim *et al.* (2015) reported significantly higher onion yield from λ -cyhalothrin (23.3%) sprayed plots as compared to the control in Tigray, Ethiopia. Anomalies in the performance of insecticides could be explained by the variation on the level of resistance by different population of the thrips found in different parts of the country.

4.5. CONCLUSION AND RECOMMENDATIONS

Onion thrips have become a serious problem, especially in the Central Rift Valley of Ethiopia, and the continuous use of insecticides might have resulted in resistant populations to commonly used insecticides. The insecticides spinosad, spinetoram and imidacloprid reduced number of thrips and increased onion bulb yield. On the other hand, λ -cyhalothrin, alpha-cypermethrin, diazinon and neem were less effective. Variations in the performance of insecticides in the field could be due to other factors, such as the chemistry of the insecticide, higher populations of thrips, inappropriate application in terms of timing, rate and coverage. Therefore, studies are needed to detect and monitor thrips resistance to commonly used insecticides. Onion growers in the CRV should be advised to rotate the old class insecticides with the new during a season to delay development of resistance and prolong the life of these insecticides.

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CHAPTER 5

Thrips (Thysanoptera: Thripidae) resistance to insecticides on onion in the Rift Valley of Ethiopia

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ABSTRACT

The responses of thrips populations collected from onion fields to commonly used insecticides were studied with the aim of detecting presence or absence of insecticides resistance thrips in the central rift valley of Ethiopia (CRV). Thrips populations were collected from area with heavy pesticide use history Meki and Melkassa and less use areas of Werer and Minjar. Minjar collected thrips population was considered as susceptible thrips population. Collected adult thrips population were exposed to various concentrations of λ -cyhalothrin, dimethoate, profenofos, diazinon and spinetoram treated vial and thrips mortality was assessed after 24 hours. The percent mortality was significantly lower in Meki and Melkassa collected thrips populations than in Minjar and Werer populations to λ -cyhalothrin and diazinon at recommended field rate. On the other hand, differences were insignificant for the insecticides spinetoram and profenofos at recommended field rate. Of the five tested insecticides λ -cyhalothrin and diazinon had higher resistance ratio (RR) to Meki and Melkassa collected thrips population, whereas spinetoram, dimethoate and profenofos had lower resistance ratios. The resistance ratios of λ -cyhalothrin was very high, ranging from 10.8-fold to 6.78-fold. Field collected thrips resistance to dimethoate and profenofos were comparatively low, with the RR values ranging from 3.2-fold at Meki to 3.1-fold at Melkassa. Results of this study suggest that thrips affecting onion in Meki and Melkassa areas have developed resistance to λ -cyhalothrin and diazinon insecticides. Periodic assessment of efficacy of registered insecticides and deploying a pesticides resistance management strategy are useful for sustainable use of pesticides in integrated thrips management program.

Key words: Onion, Thrips, Resistance, λ -cyhalothrin, diazinon, spinetoram, dimethoate, profenofos

5.1. INTRODUCTION

Onion thrips, *Thrips tabaci* (Lindeman) and western flower thrips, *Frankliniella occidentalis* (Pergande) are highly invasive and damaging thrips species throughout the world (Stuart *et al.*, 2011) and these species are present in onion in the Rift Valley of Ethiopia with different composition (Chapter 3). Onion thrips, *T. tabaci* is a key insect pest of onion in most onion production regions of Ethiopia (Tebkew and Getachew, 2015). Onion thrips cause both direct and indirect damage to onion by feeding and ovipositing on leaves that may cause green onions to be unmarketable and dry bulb onion size to be reduced (Gill *et al.*, 2015). Onion growers in Ethiopia control thrips using a variety of insecticides available in the market. These groups of insecticides are usually organophosphates and synthetic pyrethroids and applied up to 15 times per growing season.

Insecticides resistance is the most important issues facing agricultural production, because pesticides are an integral part of high-yielding production agriculture (Miller *et al.*, 2010). The challenges in insecticide resistance and its management are exemplified by thrips (Thysanoptera: Thripidae). This highly invasive pest has a great propensity for developing insecticide resistance because of its biological attributes (short generation time, high fecundity), and cases of resistance to most classes of insecticides used for its management have been detected (Diaz-Montano *et al.*, 2011).

Insecticide resistance has been a major factor for insect pest control failure for more than half a century (Sparks and Nauen, 2015) and it has been reported in many parts of the world (Nault *et al.*, 2013). Although studies are scanty, resistance to insecticides by some insect pests is suspect in Ethiopia due to the rampant misuse of insecticides and farmers' claim that some of the

insecticides are no more effective. Insecticides performance can also be affected by environmental factors and poor coverage of the crop (Shelton *et al.*, 2003).

Assessment of pesticide susceptibility in pest populations is a proactive approach to detect any shift in insecticide performance and provide an early warning to modify chemical control strategies (Miller *et al.*, 2010). Early detection of insecticides resistance provides a basis for the management of resistant pest populations (Osorio *et al.*, 2008). Besides, resistance detection and monitoring in onion thrips are lacking, eventhough some registered insecticides are losing their field performance in Ethiopia. A Field study combined with a bioassay is important to measure changes in phenotypic response to an insecticide (Rueda and Shelton, 2003). Moreover, resistance monitoring is important to quickly remove from use before complete failures of insecticides and ensure sustainable thrips management. Hence, this study was conducted to assess susceptibility of thrips on onion in farmers' fields to commonly used insecticides in the Central Rift Valley of Ethiopia (CRV).

5. 2. MATERIALS AND METHODS

5.2.1. Collection sites

Thrips populations were collected from four different onion-growing regions in the CRV of Ethiopia 2017. Thrips were collected from heavy pesticide use areas of Melkassa and Meki, moderate pesticide use areas of Werer and low pesticide use area of Minjar. Minjar collected thrips population was expected to be susceptible to insecticides, where thrips populations are less problem. In all locations, thrips populations were collected from fields that were not sprayed with insecticides at least in the previous seven days.

5.2.2. Insecticides

Five widely used insecticides for thrips control on onion in the CRV were used in the laboratory bioassays (Table 5.1). The tested insecticides were spinosyn (spinetoram), pyrethroid (λ -cyhalothrin), and organophosphates (diazinon, dimethoate, and profenofos).

5.2.3. Bioassay Procedure

Thrips Insecticide Bioassay System (TIBS) (Rueda and Shelton, 2003) was used. For each insecticide, seven concentrations and a control were prepared. Concentrations of insecticides were chosen to estimate mortality above and below the expected LC_{50} . A standard 0.5-ml microcentrifuge vial with a flexible plastic cap was used. For each insecticide concentration, coat vials were prepared. The vials were coated from inside with a solution containing one of the insecticides diluted with water. To coat the microcentrifuge vial, the insecticide solutions were poured into each microcentrifuge vial and allowed to remain for 4 h. The vials were allowed to dry at room temperature for at least 8 h. Coated vials can be stored up to 3 weeks in a refrigerator (4°C) (Rueda, 2000). On the inside of the cap a 10% sugar solution was used as the food source

for thrips because it helps to prolong thrips survival (Rueda, 2000). Approximately 10-25 live adult onion thrips were introduced into each vial and replicated five times for each insecticide.

5.2.4. Data collection and Analysis

Thrips mortality was assessed after 24 hours of exposure. Thrips were considered dead if they failed to move when probed with a fine hairbrush. For each vial, the numbers of dead and live adults were counted. Statistical analysis was performed by analysis of variance (ANOVA), and comparisons of the means were made using Student-Newman-Keuls (SNK) test at the 5% significance level. The LC₅₀ (Lethal Concentrations), slope, and the 95% Confidence Limits (CL) were estimated by probit analysis using SAS software (SAS, 2003) after correcting the natural mortality using Abbott's formula (Abbott, 1925). The resistance ratio (RR) was calculated by dividing the LC₅₀ of thrips population from each area of Melkassa, Meki and Werer by LC₅₀ of thrips population from Minjar assumed to be susceptible.

$$\text{corrected mortality} = \frac{\text{mortality in test bottles}(\%) - \text{mortality in a control bottle}(\%)}{100\% - \text{mortality in control bottle}(\%)} * 100$$

Table 5. 1. Insecticides and their recommended application (label) rates for field crop based on 500 litres of insecticide solution per ha of onion.

Common name and recommended cone,(mg a.i./litre)	Product and formulation	Recommended application rate (product)
lambda-cyhaltrin (30)	Karate 5% EC	60ml/100L
diazinon (720)	Diazinon 60% EC	150ml/100L
profenofos (720)	Selecron 720 EC	150ml/100L
spinetoram (31.2)	Radiant 120 SC	26ml/100L
dimethoate (400)	Agro-Thoate 40% EC	100ml/100L

5.3. RESULTS

5.3.1. Insecticides resistance in thrips population

High level of resistance was detected for both Meki and Melkassa areas thrips population to λ – cyhalothrin and diazinon insecticides. Meki thrips population was more resistant to the λ – cyhalothrin and diazinon than Melkassa and Werer collected population, while all collected thrips population were susceptible dimethoate, profenofos, diazinon and spinetoram.

5.3.2. Thrips response to λ –cyhalothrin

The highest level of variability in thrips susceptibility to λ –cyhalothrin in four different field populations with the range of 30.5 to 94.5% (Fig.5.1). The percent mortality was significantly lower for Meki and Melkassa thrips populations compared to Minjar and Werer thrips populations (Fig.5.1). The higher level of resistance ratios (RR) was also found in Meki thrips populations with 10.9- fold, while lower resistance ratios (RR) was found in Werer thrips populations with 4.7 -fold as comparison to Minjar thrips population (Table 5.2) .

Table 5. 2. Efficacy of λ -cyhalothrin on thrips collected from the different areas with different pesticide use history in the rift valley of Ethiopia

Population	Slope (\pm SE)	LC ₅₀ (mg a.i./litre)	(95% CL) (mg a.i./litre)	χ^2	RR	Mortality
Meki	1.25+0.142	37.64	(27.85 -51.55)	50.68 s	10.9	35.5c
Melkassa	1.65+0.146	23.17	(18.66-28.94)	49.5s	6.7	30.7c
Werer	1.51+0.122	16.13	(13.09-19.93)	35.4ns	4.67	65.5b
Minjar	1.79+0.22	3.45	(2.31-4.54)	21.13ns		94.5a

LC50 = the lethal concentration which killed 50% of tested population, 95% CL= the lower and higher limits at which the LC50 value can fall at 95% probability, SE=standard error, χ^2 =chi square, RR= resistance ratio

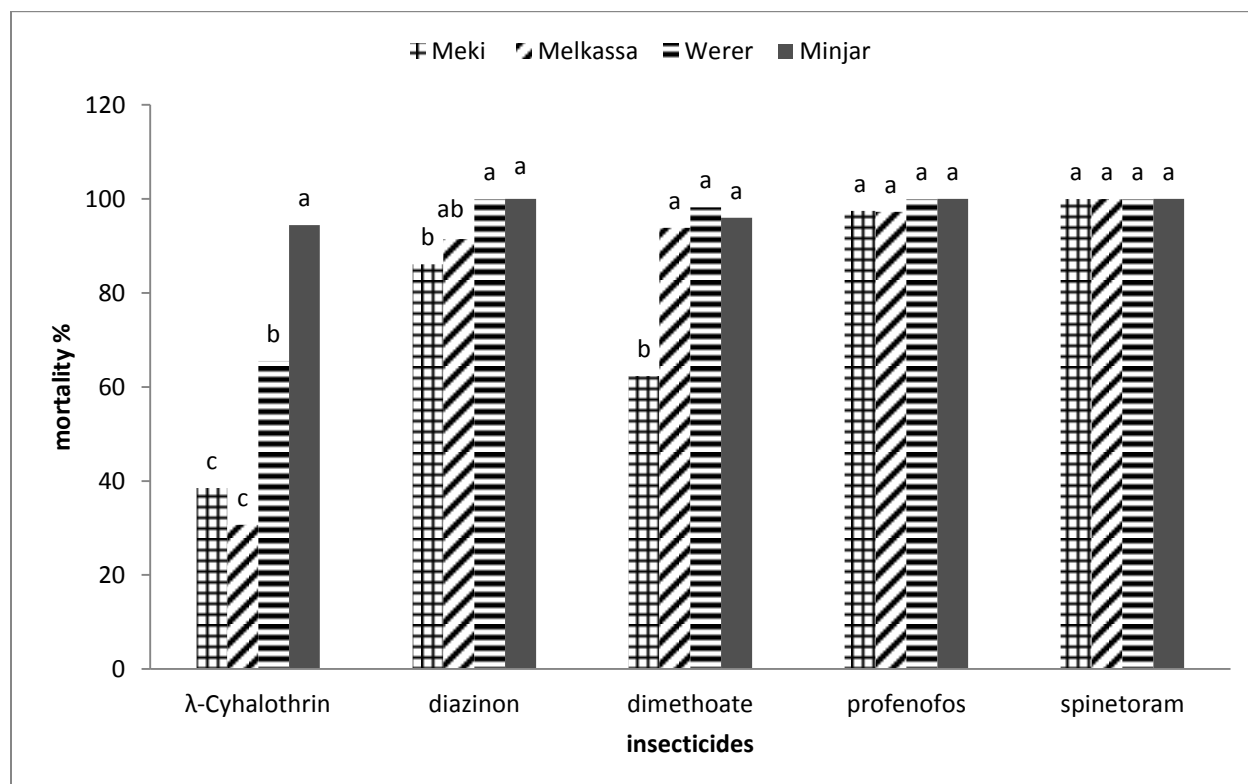


Figure 5. 1. Percentage mortality of field-collected thrips population and exposed to field spray rate to λ -cyhalothrin, dimethoate, profenofos, diazinon and spinetoram.

5.3.3. Thrips response to profenofos

Thrips mortality caused by profenofos did not vary significantly among the four thrips populations (Fig.5.1). Werer and Minjar thrips population died completely, while lower mortality was recorded from Meki and Melkassa thrips populations. Higher resistance ratio was observed in Meki and Melkassa thrips populations to profenofos insecticide with a RR of 1.86 and 1.4-fold, respectively (Table 5.3).

Table 5. 3. Efficacy of Profenofos on thrips collected from the different areas with different pesticide use history in the Rift Valley of Ethiopia.

Population	Slope (\pm SE)	LC ₅₀ (mg a.i./litre)	(95% CL) (mg a.i./litre)	χ^2	RR	Mortality
Meki	2.46+0.251	146.24	(118-173.76)	15.26ns	1.86	97.5a
Melkassa	2.67+0.311	111.32	(89.4-131.78)	19.04ns	1.42	97.3a
Werer	2.68+0.342	92.92	(70.47-112.7)	11.32ns	1.19	100a
Minjar	2.01+0.241	78.13	(55.53-98.98)	12.54ns		100a

LC50 = the lethal concentration which killed 50% of tested population, 95% CL= the lower and higher limits at which the LC50 value can fall at 95% probability, SE=standard error, χ^2 =chi square, RR= resistance ratio.

5.3.4. Thrips response to diazinon

Percent mortality differences to diazinon were significant (Fig.5.1). The lowest (86.1%) was recorded from Meki population followed by Melkassa thrips population (91.5%). Mortality in Werer and Minjar populations was high (Fig.5.1). Higher resistance ratios were recorded from Meki (3.3 fold) and Melkassa (2.9 fold) locations (Table 5.4).

Table 5. 4. Efficacy of diazinon to thrips collected from the different areas with different pesticide use history in the Rift Valley of Ethiopia.

Population	Slope (\pm SE)	LC ₅₀ (mg a.i./litre)	(95% CL) (mg a.i./litre)	χ^2	RR	Mortality
Meki	1.54+0.14	199.6	(151.1- 251.34)	27.15ns	3.33	86.16
Melkassa	2.26+0.22	176.64	(143.4-212.1)	44.9ns	2.95	91.5ab
Werer	2.38+0.35	67.53	(45.1-86.3)	19.84ns	1.12	100a
Minjar	1.74+0.23	59.83	(35.95- 82.75)	29.45ns		100a

LC50 = the lethal concentration which killed 50% of tested population, 95% CL= the lower and higher limits at which the LC50 value can fall at 95% probability, SE=standard error, χ^2 =chi square, RR= resistance ratio

5.3.5. Thrips response to dimethoate

The percent mortality in the Meki thrips population was significantly lower compared to Melkassa, Minjar and Werer thrips populations (Fig.5.1). The higher level of resistance ratios (RR) was recorded in Meki thrips populations with 2.3- fold, while lower resistance ratios (RR) was recorded at Melkassa thrips populations with 1.3 –fold (Table 5.5).

Table 5. 5. Efficacy of dimethoate to thrips collected from the different areas with different pesticide use history in the Rift Valley of Ethiopia

Population	Slope (\pm SE)	LC ₅₀ (mg a.i./litre)	(95% CL) (mg a.i./litre)	χ^2	RR	Mortality
Meki	1.99+0.20	179.9	(139.4-227.4)	60.1s	2.25	62.4b
Melkassa	2.45+0.206	106.59	(90.48-123.3)	17.14ns	1.33	93.8a
Werer	2.04+0.229	59.89	(45.4-73.75)	22.9ns		98.2a
Minjar	2.4+0.24	79.89	(64.48-94.92)	29.66ns		96.0a

LC50 = the lethal concentration which killed 50% of tested population, 95% CL= the lower and higher limits at which the LC50 value can fall at 95% probability, SE=standard error, χ^2 =chi square, RR= resistance ratio

5.3.6. Thrips response to spinetoram

Thrips mortality caused by spinetoram did not vary significantly among the four thrips populations (Fig.5.1). All collected thrips population had 100% mortality. Relatively high level of RR were found at Meki and Melkassa collected thrips populations with 1.4 and 1.3-fold, respectively as compared to the susceptible population of Minjar (Table 5.6)

Table 5. 6. Efficacy of spinetoram to thrips collected from the different areas with different pesticide use history in the rift valley of Ethiopia.

Population	Slope (\pm SE)	LC ₅₀ (mg a.i./litre)	(95% CL) (mg a.i./litre)	χ^2	RR	Mortality
Meki	2.88+0.294	6.69	(5.63-7.74)	20.5ns	1.42	100a
Melkassa	3.41+0.348	6.03	(5.22-6.83)	17.02ns	1.29	100a
Werer	2.19+0.382	2.15	(1.18-2.96)	12.57ns		100a
Minjar	2.43 \pm 0.273	4.68	(3.8-5.6)	15.6ns		100a

LC50 = the lethal concentration which killed 50% of tested population, 95% CL= the lower and higher limits at which the LC50 value can fall at 95% probability, SE=standard error, χ^2 =chi square, RR= resistance ratio

5.4. DISCUSSION

Thrips mortality was observed to vary significantly between locations to λ -cyhalothrin and diazinon. Significantly lower mortalities were recorded in both Meki and Melkassa field collected thrips population to λ -cyhalothrin and diazinon when applied at recommended field rates compared to the susceptible population, indicating presence of resistance. Differences were also observed in LC50. Minjar and Werer collected population had lower LC50 than Melkassa and Meki sampled populations. These differences in susceptibility to insecticides tested could be attributed to differences in insecticide use including type, rate and application frequencies. The survey result (Chapter 3) indicated that the amount and frequency of insecticide use was higher in Meki and Melkassa than Werer. Several studies showed higher propensity of pesticide resistance to increased frequency of insecticide application (Adilakshmi *et al.*, 2008). High selection pressure due to excessive insecticides use coupled with multiple insect generations per year increases the possibility of development of resistance to specific insecticides (Loughner *et al.*, 2005).

Pesticide use is increasing in horticultural farms of Ethiopia (Negatu *et al.*, 2016). Currently there are several insecticides registered for control of thrips on onion, but most are old and broad-spectrum. A wide variety of insecticides including carbamates, organophosphates and synthetic pyrethroids are used for the control of thrips in onion in Ethiopia. This reliance on old and broad-spectrum insecticide groups could result in a rapid development of resistance among local thrips populations. The existence of resistance to these insecticides has not been reported in Ethiopia. Earlier reports by Banchiamlak *et al.* (2012) did not indicate occurrence of resistance to λ -cyhalothrin, diazinon, profenofos and spinosad insecticides.

High levels of resistance were detected both in Melkassa and Meki sampled thrips populations to λ -cyhalothrin and diazinon insecticides. Variable responses of thrips collected from different locations to the same insecticide could be due to insecticides resistance in the thrips populations. In a field experiment conducted at Melkassa center of the Ethiopian Institute of Agricultural Research (IAR), the efficacy of λ -cyhalothrin and diazinon was poor compared to profenofos, dimethoate and spinetoram in controlling thrips on onion (Chapter 4). The poor performance of λ -cyhalothrin and diazinon could be due to insecticides resistance, but these insecticides are still effective in some parts of Ethiopia (Ibrahim *et al.*, 2015). Numerous studies have reported that organophosphate, carbamate, and pyrethroid classes of insecticides has been reported to induce resistance in onion thrips (Shelton *et al.*, 2003, 2006; Nault and Shelton, 2010), New Zealand (Martin *et al.*, 2003), and Australia (Herron *et al.*, 2008; Broughton and Herron, 2009). Thus, it can be said that there is apparent insecticide resistance developed in Meki and Melkassa for onion thrips.

The percent mortality was similar for spinetoram, profenofos and dimethoate at the recommended field rate in all tested population, suggesting absence of resistance to these insecticides. It could be partly due to this absence of resistance that three insecticides showed better performance than λ -cyhalothrin and diazinon. Of course, the insecticide spinetoram that belongs to the spinosyn class is a newer molecule and registered for use in Ethiopia very recently. Resistance development to this insecticide at this time seems unlikely.

5.5. CONCLUSIONS AND RECOMMENDATIONS

Decline in efficacy of some registered insecticides for thrips control has become a common phenomenon. This was hypothesized to be due to development of resistance in thrips populations. Results of this study indicated, presence of insecticides resistances in Meki and Melkassa collected thrips populations to λ -cyhalothrin and diazinon insecticides. Early monitoring of thrips susceptibility to commonly use insecticides and implementing insecticides resistance management through rotating different classes of insecticide and diversifying thrips control strategies are needed for sustainable insecticide resistance management (IRM).

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CHAPTER 6

Insecticide resistance management against thrips (Thysanoptera: Thripidae) on onion in the Central Rift Valley of Ethiopia

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ABSTRACT

Two field experiments were conducted in the Central Rift Valley of Ethiopia in the hot and cool dry seasons of 2016/2017 with the objective to develop an insecticide resistance management program on thrips infesting onion. The first experiment dealt with the evaluation of four different insecticides namely profenofos, λ -cyhalothrin, imidacloprid, and spinetoram in different sequences on thrips population and their effect on yield. The second experiment examined the effect of admixing the surfactant organosilicone with imidacloprid, spinetoram and dimethoate. A Randomized Complete Block Design with three replications was used for both experiments. Data on number of thrips, bulb yield and economic returns were collected. The insecticides imidacloprid and spinetoram gave the highest thrips control and higher yields than profenofos and λ -cyhalothrin. Application of the more effective insecticides when the thrips population was high followed by less effective insecticides resulted in better control and higher economic return. Surfactant added on insecticides controlled thrips by than when the same insecticide was applied without a surfactant and higher yields were obtained in plots that received insecticide+surfactant. The application of spinetoram or imidacloprid followed by λ -cyhalothrin or profenofos by adding surfactant are recommended for thrips control as an integral component of thrips management in the Central Rift Valley of Ethiopia.

Key words: Thrips, resistance, management, insecticides, rotation, surfactant.

6.1. INTRODUCTION

Onion (*Allium cepa* L.) is a widely grown vegetable by small and large-scale farmers in Ethiopia covering an area of 48,443.36 hectares with the total production of 374,704 tons (CSA, 2016). The national average productivity of onion in Ethiopia is 7.734 t ha⁻¹ (CSA, 2016) which is low compared to the world average of 19.49 t ha⁻¹ (FAOSTAT, 2012). This low productivity could be attributed to poor agronomic practices and pests damage (Tadele and Amin, 2014). Onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae) is considered the most economically important pests of onion worldwide (Gachu *et al.*, 2012). Thrips are major pests in all onion-growing areas of Ethiopia and can routinely reduce bulb yields by 23-85% (Tadele and Mulugeta, 2014). Bekele *et al.* (2006) reported 10 to 85% onion bulb yield losses due to onion thrips at Upper Awash Agro Industry areas in Central Ethiopia.

The use of insecticides is the most common management tactic against onion thrips infestations in onions Ethiopia as it is elsewhere (Reitz, 2014; Gill *et al.*, 2015). Indiscriminate application of insecticides against onion thrips in onion is a common practice in the Rift Valley of Ethiopia (Banchiamlak *et al.*, 2012). Such misuse of insecticides could lead to the development of insecticide resistant biotypes. Many targeted pests species in the world have developed resistant due to intensive use of pesticides (Tabashnik *et al.*, 2009). Moreover, most insecticides are ineffective because a large number of thrips always protected between the inner leaves of the onion plant and the pupal stage spent in the soil (Shelton *et al.*, 2003, 2006; Nault and Shelton, 2010).

Thrips can rapidly develop resistant to insecticides which results in the rapid loss of effectiveness of new insecticides (Reitz *et al.*, 2014). Insecticides resistance have been documented in a

number of chemical classes, including the organochlorines, organophosphates, carbamates, pyrethroids and spinosyns (Bielza *et al.*, 2007; Herron *et al.*, 2008; Nault *et al.*, 2013). Resistance of onion thrips to some synthetic insecticides is suspected in Ethiopia because many of the earlier registered products for control of the pests are losing efficacy (Tadele and Amin, 2014).

Several insecticides from different classes have been registered for control of thrips on onion in Ethiopia (MoANR, 2017). Sustainable use of these insecticides entails a pesticide resistance management program, which can be achieved, among others, by rotational application from different insecticide classes (Gill and Garg, 2014). Another important tactic to improve insecticides efficacy in thrips control on onion is to prevent or slow down insect resistance to insecticides with a penetrating surfactant. Surfactants could improve deposition of sprays applied to the onion leaves and the efficacy of insecticides against onion thrips (Gangwar *et al.*, 2016). Nault *et al.* (2013) reported that inclusion of a penetrating surfactant is critical for improving the efficacy of insecticides that have systemic and translaminar movement within onion plants to control onion thrips. Insecticides use for thrips control will continue, but this strategy must be used carefully and in a manner that will prevent or slow down the ability of thrips to develop resistance (Nault *et al.*, 2013).

In Ethiopia, there has not been any known comprehensive study on the effects of penetrating surfactant to enhance insecticide efficacy and rotational application of insecticides with different modes of action for thrips control in onion. Thus, this research was designed to evaluate effects of rotational application of insecticides with different modes of action and use of surfactant to improve control of thrips on onion.

6.2. MATERIALS AND METHODS

6.2.1. Effect of rotational application of insecticides

The efficacy of rotational application of four selected insecticides in different sequences against thrips on onion was conducted at Melkassa Agricultural Research Center, East Shewa, Ethiopia. Melkassa is located at (8⁰24' N and 30⁰21' E). The elevation of the center is 1550 m.a.s.l. The area is characterized by low and erratic rainfall with an average of 771 mm per year over 80% of which falls between April and October, with a peak in July and August. The soil is mainly sandy with pH of 6.9-7.9 and the mean air temperature is 21 °c (Desalegne and Shimeles, 2003).

The experiment was conducted for two seasons during the cool dry period (November 2016 - February 2017) and hot dry period (March 2017 - June 2017). Four selected insecticides each representing a specific insecticide class and registered for thrips control on onion in Ethiopia were applied as sole and in rotation using different sequences (Table 6.1). The insecticides were profenofos (Organophosphates), imidacloprid (Neonicotinoids), λ-cyhalothrin (Pyrethroids) and spinetoram (Spinosyn). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Treatments were applied using a manually operated knapsack sprayer of 15 L capacity. Insecticides were applied weekly for eight weeks and the first applications were made on 12-Dec in cool dry and 30-Mar in hot dry seasons when thrips populations reached five per plant from a random sample of ten plants.

Table 6. 1. Details of treatments in the insecticide rotation experiment at MARC, 2016/17

No	Treatment	Application period and sequence			
		Weeks 1 and 2	Weeks 3 and 4	Weeks 5 and 6	Weeks 7 and 8
1	I- I-I-I	imidacloprid	imidacloprid	Imidacloprid	imidacloprid
2	L-L-L-L	λ -cyhalothrin	λ -cyhalothrin	λ -cyhalothrin	λ -cyhalothrin
3	P-P-P-P	profenofos	Profenofos	profenofos	profenofos
4	S –S-S-S	spinetoram	spinetoram	spinetoram	spinetoram
5	L- S- P- I	λ -cyhalothrin	spinetoram	profenofos	imidacloprid
6	I- P- S- L	imidacloprid	profenofos	spinetoram	λ -cyhalothrin
7	I -S –L- p	imidacloprid	spinetoram	λ -cyhalothrin	profenofos
8	P-L- I- S	profenofos	λ -cyhalothrin	imidacloprid	spinetoram
9	S- I -P –L	spinetoram	imidacloprid	profenofos	λ -cyhalothrin
10	Untreated	untreated check	untreated check	untreated check	untreated check

L= λ -cyhalothrin (Karate 5 EC at 300ml/ha), I= imidacloprid (Con-fidence 350 SC at 400ml/ha), P= profenofos72% EC (Girgit-Plus at 600ml/ha), and S=spinetoram (Radiant 120 SC at 130ml/ha).

6.2.2. Effect of surfactant on efficacy of selected insecticides

The effects of a penetrating surfactant organosilicone (Silwet gold) on insecticides efficacy against thrips on onion was evaluated in both the hot dry period (March 2016 - June 2016) and cool dry (October 2016 – February 2017) as described in the experiment on rotational application. The experiment consisted of eight treatments; imidacloprid (Confidence 350 SC applied at 400 ml/ha), spinetoram (Radiant 120 SC applied at 130 ml/ha) and dimethoate (Agro-Thoate 40% EC applied at 1 L/ha) with and without surfactant (Silwet gold (0.1% v/v). Untreated check and application of surfactant alone were included for comparison. The tested insecticides were selected based on their mode of action (systemic and translaminar). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Treatments were applied using manually operated knapsack sprayer of 15 liter capacity. Treatments were applied weekly for seven weeks period. The first application was made when thrips populations reached five per plant from a random sample of ten plants.

6.2.3 Agronomic practices

Onion seedlings of Bombay red variety was raised on nursery bed and transplanted at 2-3 leaf stage. Each plot was 9m² (3 m x 3 m) with five double rows spaced 0.2m apart. Spaces between blocks, plots, and plants were 1.5 m, 1.5 m, and 0.1m, respectively. The experimental fields were irrigated twice per week for the first three weeks after transplanting and weekly thereafter. The fields were fertilized with Di-ammonium phosphate (DAP) and urea at the rate of 200 kg and 150 kg per hectare, respectively. The DAP was applied during transplanting and urea was applied split into two times; the first half was applied during transplanting and the remaining half 30 days after transplanting. Weeding was carried out as required.

6.2.4. Data collection and analysis

6.2.4.1 Data Collection

The post spray data were taken at seven-day interval prior to the next application. Thrips population was counted on five randomly selected plants from the central rows of each plot by visually examining the entire plant parts. At maturity, onion bulbs were harvested from the middle three double rows in each plot and then sorted out into marketable and unmarketable bulbs. Healthy bulb weighing between 20 and 160 g was considered marketable (Desalegne and Shimeles, 2003)

6.2.4.2. Statistical analysis

Thrips count data were square root ($\sqrt{x+0.5}$) transformed before analysis to stabilize the variance and normalize the data. Thrips population and yield were analyzed using the general linear model of statistical analysis using SAS software (SAS, 2003 version). When significant differences were observed in the ANOVA, mean separation was performed using Student-Newman-Keuls (SNK) test.

6.2.4.3. Economic analysis

The relative economic returns of the treatments were calculated by subtracting the cost of insecticides and their application cost from the gross return. The price of onion bulb was estimated based on the farm gate price at US\$ 350.87 per ton. The application cost in the first experiment was estimated at USD 140.32 per ha (32 mandays per ha; 4.385 USD per manday) and in the second season at 122.78 USD (28 mandays per ha; 4.385 per manday). The price of imidacloprid, profenofos, λ -cyhalothrin, spinetoram, dimethoate and organosilicone per L were estimated at USD 35.08, 35.83, 43.84, 245.6, 16.66 and 35.08, respectively.

6.3. RESULTS

6.3.1. Effect of insecticides rotations

6.3.1.1. Thrips population

The number of thrips/plant varied significantly among the treatments both in cool dry ($P < 0.0001$, $F = 520.26$, $df = 9, 18$) and hot dry ($P < 0.0001$, $F = 375.7$, $df = 9, 18$) seasons. The interaction between seasons and treatments also varied significantly ($P < 0.0001$, $F = 31.89$, $df = 9, 36$). Numbers of thrips were lower at the early growth stage and increased as the season progressed during the cool dry season. During the hot dry season, this trend was not observed as the populations were generally variable. Among the sole applied insecticides, fewer numbers of thrips were counted on imidacloprid and spinetoram treatments, both in cool dry (Fig. 6.1) and hot dry seasons (Fig. 6. 2). Numbers of thrips were significantly higher on the untreated check and λ -cyhalothrin treatment in both cool dry (Fig. 6. 1) and hot dry seasons (Fig. 6. 2).

Insecticides applied in different sequences resulted in varied number of thrips. The lowest number of thrips was recorded from imidachloprid-profenofos-spinetoram- λ -cyhalothrin(I-P-S-L) treatment followed by spinetoram-imidacloprid-profenofos- λ -cyhalothrin(S-I-P-L) and profenofos- λ -cyhalothrin-imidacloprid-spinetoram (P-L-I-S) treatments in cool dry and hot dry seasons, respectively (Fig. 6.1 and 6.2). On the other hand, the highest number of thrips was recorded on profenofos- λ -cyhalothrin-imidacloprid-spinetoram (P-L-I-S) and imidacloprid-spinetoram- λ -cyhalothrin-profenofos (I-S-L-P) in cool dry and hot dry seasons, respectively (Figs. 6.1 and 6.2).

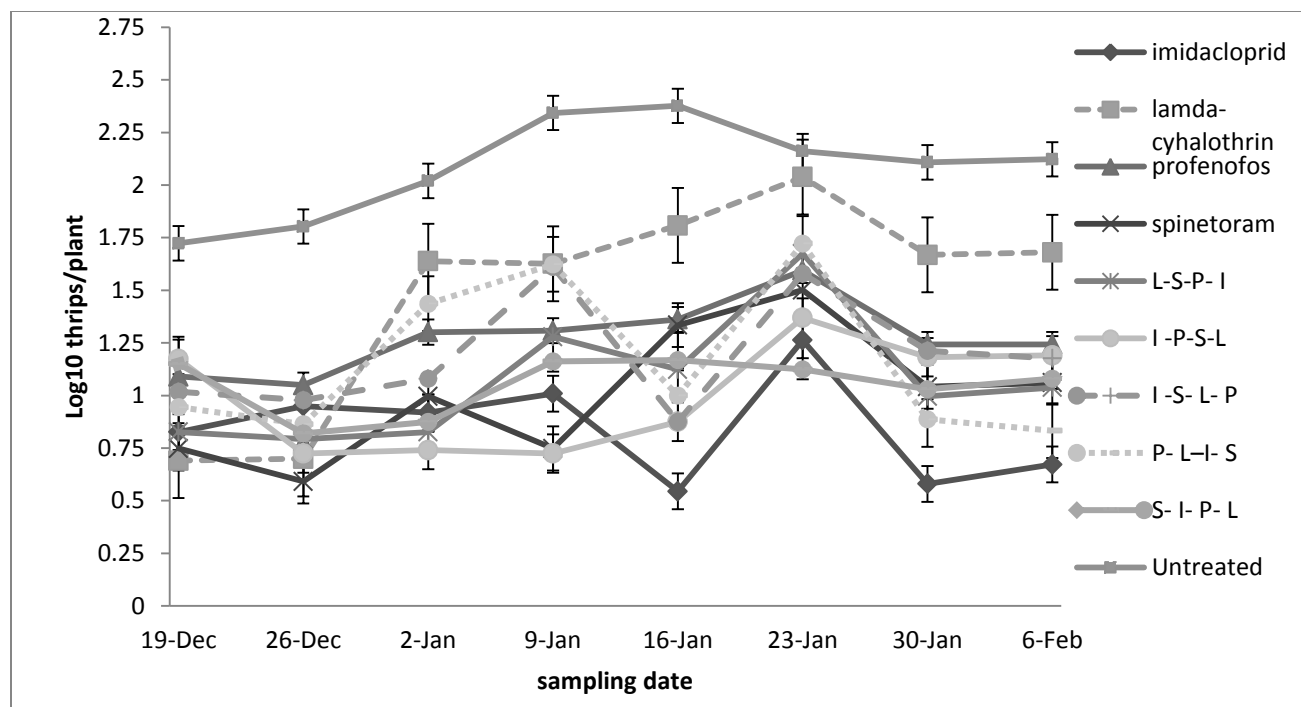


Figure 6. 1. Number of thrips on onion treated with selected insecticides as sole and in rotations during the cool dry season at Melkassa, Ethiopia, 2016/17. Error bars show SEs. L= λ -cyhalothrin, I= Imidacloprid, P= Profenofos, S=Spinetoram.

6.3.1.2. Yield

All the tested insecticides, except lambda cyhalothrin, applied as sole or in rotation gave significantly higher marketable yields than the untreated check in both cool dry ($P < 0.0001$, $F = 13.7$, $df = 9, 18$) and hot dry ($P = 0.0002$, $F = 7.33$, $df = 9, 18$) seasons. The highest marketable yield was obtained from sole applied of imidacloprid in both cool dry and hot dry seasons, while the lowest yield across seasons was obtained in lambda cyhalothrin and untreated control (Table 6.2).

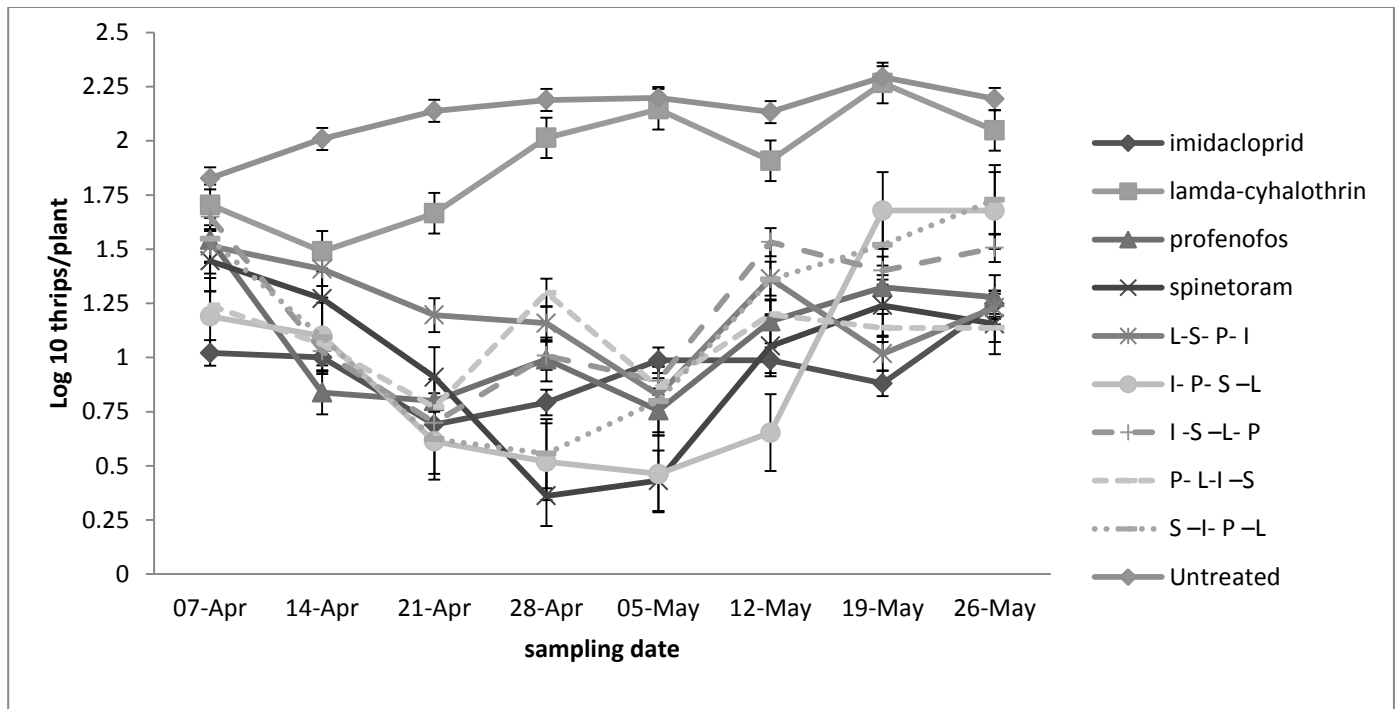


Figure 6. 2. Number of thrips on onion treated with selected insecticides as sole and in rotations during the hot dry season at Melkassa, 2017. Error bars show SEs. L= λ -cyhalothrin, I= Imidacloprid, P= Profenofos, S=Spinetoram.

6.3.1.3. Economic returns

The highest net return was obtained from sole applied imidacloprid (US\$ 9,856.87) followed by the rotational application of imidacloprid-profenofos-spinetoram- λ -cyhalothrin treatment (I-P-S-L) (US\$ 8,679.3), while lowest net return was obtained from λ -cyhalothrin and untreated control (US\$ 6,486.1) (Table 6.2)

Table 6. 2. Marketable onion bulb yield and partial economic analysis of onion treated with selected insecticides as sole and in rotations during the cool dry and hot dry seasons at Melkassa Research Center, Ethiopia, 2016/17.

Treatment	Marketable yield(tons/ha)			Partial economic analysis		
	Cool dry Marketable	Hot dry Marketable	Mean Marketable	Gross Return (US\$/ha)	Cost of plant Protection (US\$/ha)	Net return (US\$/ha)
Imidacloprid	30.00 ^a	27.65 ^a	28.99 ^a	10,109.47	252.60	9,856.87
λ-cyhalothrin	19.38 ^d	19.01 ^{bc}	19.19 ^d	6,731.46	245.56	6,486.10
Profenofos	25.30 ^{bc}	22.09 ^b	23.70 ^{bc}	8,313.48	308.75	8,004.73
Spinetoram	26.29 ^b	22.71 ^{ab}	24.50 ^{bc}	8,594.11	395.77	8,198.34
L- S –P- I	23.33 ^{bc}	22.22 ^b	22.78 ^{bc}	7,990.76	300.66	7,690.10
I- P- S –L	26.79 ^b	24.44 ^{ab}	25.60 ^b	8,979.96	300.66	8,679.30
I- S- L- p	21.60 ^{cd}	21.35 ^b	21.40 ^c	7,506.69	300.66	7,206.03
P- L-I- S	24.32 ^{bc}	23.64 ^{ab}	23.98 ^{bc}	8,411.70	300.66	8,111.04
S- I -P –L	23.15 ^{bc}	24.32 ^{ab}	23.74 ^{bc}	8,327.50	300.66	8,026.85
Untreated	18.89 ^d	15.92 ^c	17.4 ^d	6,103.57	0	6,103.57

In a column, means followed by the same letter(s) are not significantly difference at 5% level of probability by Student Newmans Keul's (SNK) test. L= λ-cyhalothrin, I= Imidacloprid, P= Profenofos, S=Spinetoram, Ha=hectare, Kg=kilogram.

6.3.2. Effect of surfactant on efficacy of selected insecticides

6.3.2.1. Thrips population

The thrips populations were significantly different among the treatments both in hot dry ($P < 0.0001$, $F = 35.2$, $df = 7, 16$) and cool dry ($P < 0.0001$, $F = 278.7$, $df = 7, 16$) seasons. The interaction between seasons and treatments varied significantly ($P < 0.0001$, $F = 14.04$, $df 7, 28$). A significantly higher number of thrips was counted on untreated check and surfactant alone treatments, both in hot dry and cool dry seasons (Figs. 6.3 and 6.4). The insecticide dimethoate applied with surfactant resulted in a significantly lower number of thrips than without surfactant in both seasons (Figs. 6.3 and 6.4). On the other hand, differences between with and without surfactant in spinetoram and imidacloprid treated plots were not significant. In both situations, the number of thrips present was very low (Figs. 6.3 and 6.4). The combined analysis of the two seasons indicated that the interaction between surfactant and insecticides is significant ($P < 0.0001$, $F = 15.35$, $df = 3, 30$).

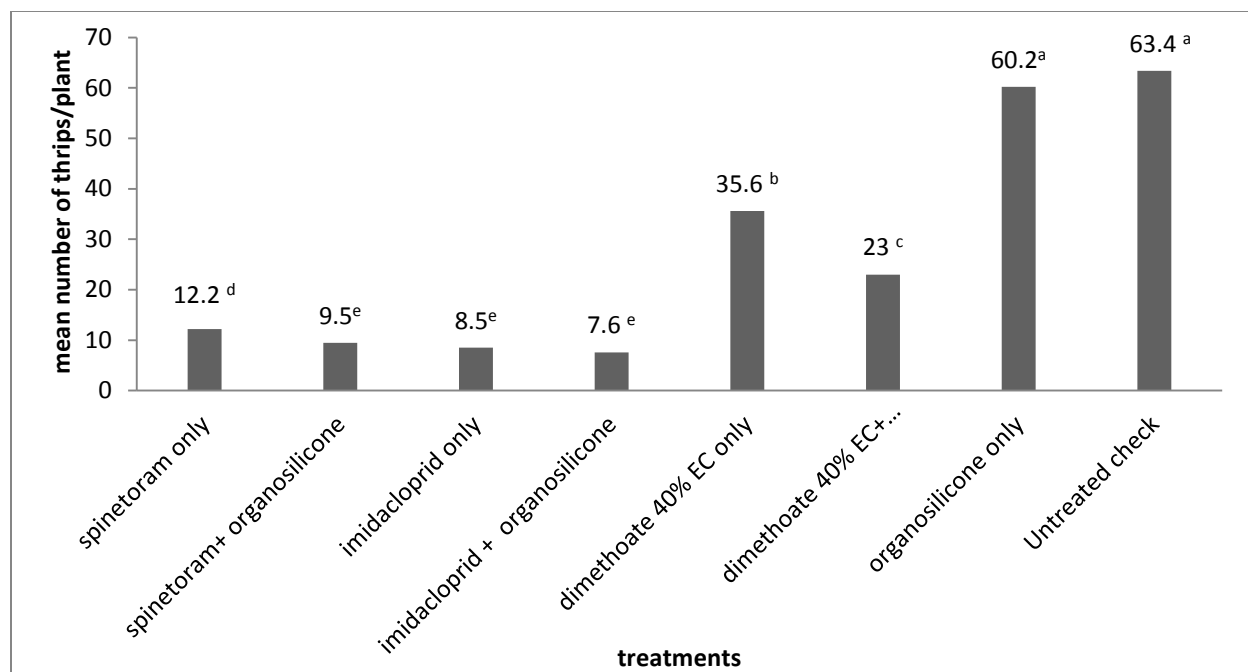


Figure 6. 3. Number of thrips per plant on onion treated with selected insecticides with and without surfactant in hot dry seasons, 2016. Different letters above bars denote significant differences between treatments at 5% level of probability by Student Newman-Keuls (SNK)

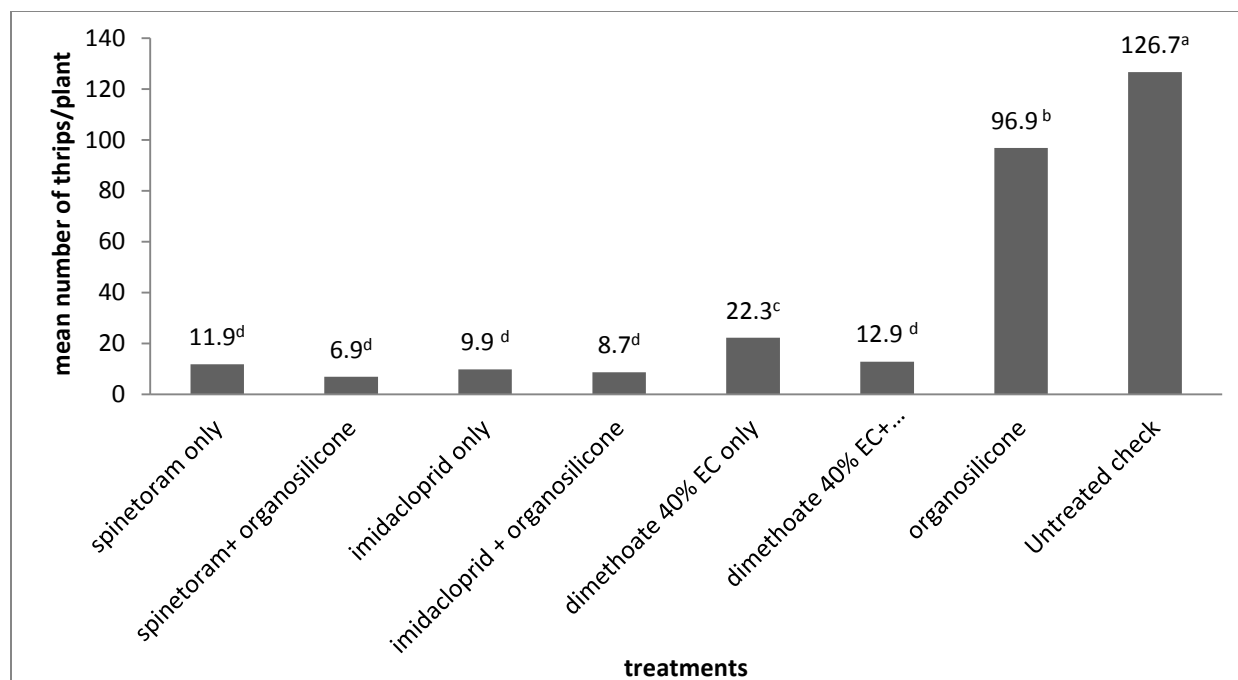


Figure 6. 4. Number of thrips per plant on onion treated with selected insecticides with and without surfactant in cool dry seasons, 2016/2017. Different letters above bars denote significant differences between treatments at 5% level of probability by Student Newman-Keuls (SNK)

6.3.2.2. Yield

Significantly lower yield was obtained from the untreated check and surfactant alone treatments than the rest of the treatments both in hot dry ($P = 0.0002$, $F = 9.46$, $df = 7, 14$) and cool dry ($P < 0.0001$, $F = 11.33$, $df = 7, 14$) seasons (Table 6.3). Higher marketable bulb yield was obtained from insecticides applied with surfactant than without. Surfactant added imidacloprid followed by spinetoram resulted in the highest yields (Table 6.3).

6.3.2.3. Economic returns

Higher net returns were obtained from insecticides applied with surfactant than without. The maximum net return was obtained from surfactant added imidacloprid (US\$ 9,513.1). The lowest net returns were obtained from surfactant alone treatment (US\$ 6,619.17) and untreated control (US\$ 6,640.26) (Table 6. 3).

Table 6. 3. Marketable yield and partial economic analysis of onion treated with selected insecticides with and without surfactant in hot dry and cool dry seasons, 2016/17

Treatments	Marketable yield(tons/ha)			Partial economic analysis		
	Hot dry	Cool dry	Mean	Gross	Plant Protection	Net
	Marketable	Marketable	Marketable	Return (US\$/ha)	Cost (US\$/ha)	Profit(US\$/ha)
spinetoram only	23.29 ^{abc}	26.54 ^{ab}	24.92 ^{bcd}	8,741.43	346.296	8,395.14
spinetoram+ organosilicone	25.80 ^{ab}	29.259 ^a	27.53 ^{ab}	9,656.97	591.85	9,065.12
imidacloprid only	22.67 ^c	23.33 ^{bc}	23.00 ^d	8,067.94	221.02	7,846.92
imidacloprid + organosilicone	26.74 ^a	30.25 ^a	28.45 ^a	9,979.69	466.58	9,513.11
dimethoate only	23.69 ^{abc}	24.94 ^{ab}	24.11 ^{cd}	8,457.3	239.42	8,217.88
dimethoate + organosilicone	24.98 ^{ab}	28.39 ^{ab}	26.68 ^{abc}	9,358.81	484.98	8,873.83
organosilicone only	20.21 ^{cd}	19.63 ^{cd}	19.92 ^e	6,987.53	368.36	6,619.17
Untreated check	19.59 ^d	18.27 ^d	18.93 ^e	6,640.26	0	6,640.26

In a column, means followed by the same letter(s) are not significantly different at 5% level of probability by Student Newmans Keul's (SNK) test.

6.4. DISCUSSION

Different classes of insecticides have different performances because of their different inherent toxicities to insect as well as evolving resistance due to over dependence on a single insecticide product (Nault and Shelton, 2010). Most of the ineffective insecticides are broad spectrum and have been in use in Ethiopia for over three decades. Vegetable growers in Ethiopia, similar to farmers in several African countries, rely on one effective product for the control of a particular pest (Tebkew and Getachew, 2015; Belay *et al.*, 2017). This practice poses a high selection pressure, which may result in the development of pesticide resistant population. Several examples of such cases have been reported (Tabashnik *et al.*, 2009; Gao *et al.*, 2012).

The study showed that sole application of the systemic insecticide imidacloprid and the translaminar insecticide spinetoram were more effective than sole applied contact insecticides profenofos and λ -cyhalothrin. This could be due to the differences in the mode of action and /or possible presence of resistant thrips populations to one or more of the insecticides. Because of their translocation to all tissues of the treated plant (Sanchez Bayo, 2013) systemic insecticides such as imidacloprid effectively control sucking insect compared with contact insecticides such as profenofos 50EC and λ -cyhalothrin 2.5EC on cotton (Ahmed *et al.*, 2014).

Deploying resistance management program, among others, by sequential application of insecticides with different mode of action is useful for sustainable use of insecticides in the IPM of thrips on onion (Gholam and Sadeghi, 2016). The sequential application of different insecticides resulted in a lower number of thrips per plant than the sole application of a particular insecticide. The insecticides spinetoram and imidacloprid were very effective in reducing thrips number when the infestation was heavier during 5th and 6th application times. The less effective

insecticide λ -cyhalothrin appeared to perform better when applied during low infestation level in the early and late crop growth stage. Nault and Shelton (2012) reported effective control of thrips with the insecticide Radiant (spinetoram) when applied during periods of high thrips population in sequential insecticides application program. In a different study, Reitz (2014) also found effective control of thrips with the insecticide carbamate (Lannate) when applied at an early growth stage and with the insecticide Radiant (spinetoram) when applied at 3rd through the 8th application periods.

The tendency of thrips to congregate between new onion leaves, deep within the onion leaf axils, provides them with protection from spray coverage. In addition to this, the leaf surface of the onion is waxy and smooth which is barrier to adhere and spread the insecticide properly in the target group (Gangwar *et al.*, 2016). This problem can be minimized by using surfactants (adjuvants) with insecticides as they could improve crop leaf penetration, and/or modify droplet sizes (Nansen *et al.*, 2013). The current study showed that adding a penetrating surfactant improved the efficacy of all tested insecticides compared to those without a penetrating surfactant in both seasons. However, surfactants added small improvements to spinetoram and imidacloprid, which were also very effective when applied alone. Earlier studies have shown that use of surfactant with insecticides significantly increased the efficacy of insecticides and reduced the number of thrips per plant (Nault *et al.*, 2013; Gangwar *et al.*, 2016; Siebert *et al.*, 2016).

In both experiments, treatments that effectively reduced the populations of thrips increased marketable yield compared to the untreated check. The mean marketable yield from the best performing treatments, which had the greatest effect in reducing the thrips population, increased the yield of onion with higher profitability. Many studies have reported that higher bulb yields

were obtained with insecticides that reduced the density of thrips (Gachu *et al.*, 2012; Pandey *et al.*, 2013; Reitz, 2014). Yield obtained from λ -cyhalothrin was similar to untreated control in both seasons, which had little effect on thrips population in this study. This is in agreement with reports of Nault and Shelton (2010) who reported similar thrips damage ratings in λ -cyhalothrin and untreated control. Similar to results from this study, Gangwar *et al.* (2016) found that the insecticides applied with surfactant reduced the severity of thrips damage and increased the bulb yield in when compared with the insecticides without surfactant.

The partial economic analysis of thrips controls using insecticides indicated that the highest net returns were found in plots sprayed with imidacloprid alone insecticides followed by the rotational application of imidacloprid-profenofos-spinetoram- λ -cyhalothrin treatment (I-P-S-L) (Table 6.2). Similar performance was observed in surfactant added insecticides treatment. In all cases, the most effective treatments gave highest yields and gross returns. Ullah *et al.* (2010) reported higher net returns from more effective insecticides Confidor200SL against *T. tabaci* on onion.

6.5. CONCLUSION AND RECOMMENDATIONS

Performance of sole applied λ -cyhalothrin was similar to the untreated control in both seasons with the minimum net return. On the other hand, imidacloprid was effective in reducing thrips numbers and increased profits as compared to other effective insecticides such as spinetoram. However, sole application of one effective insecticide is not recommended due to the risks of resistance development to the insecticide in thrips population. The sequential application of spinetoram and imidacloprid with less effective λ -cyhalothrin and profenofos by mixing with adjuvants is recommended for control of thrips as an integral component of thrips IPM in the

CRV of Ethiopia. Further research with the purpose of assessing the effect of different adjuvants on improving the efficacy of registered insecticides for the control of thrips in Ethiopia is suggested.

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CHAPTER 7

GENERAL SUMMARY AND CONCLUSIONS

Ethiopia has great potential to produce onion (*Allium cepa* L.) throughout the year for both local consumption and export. Onion is cultivated in a wide range of climatic conditions and forms an important component of diets in Ethiopia. The Central Rift Valley of Ethiopia is one of the major onion producing areas in Ethiopia and has seen an increase in onion productivity due to the intensification of agricultural practice including irrigation schemes.

Thrips can cause significant yield losses in onion crops worldwide. In Ethiopia, thrips is serious insect pest of onion in the major onion growing areas especially in dry growing seasons. Weather has direct/indirect influence on the survival, development, fecundity and behavior of thrips. In addition, thrips abundance in onion fields is affected by insecticides use practices. The current study investigated the effect of farmers' insecticides use practice on species composition and abundance of thrips, seasonal abundance of thrips and their effect on yield, insecticides resistance detection and management.

The survey results showed that diazinon, dimethoate, profenofos, lambda-cyhalothrin and spinetoram were commonly used insecticides for thrips control on onion in the study areas. Amount and frequencies of insecticides use were higher in Meki and Melkassa than Werer. The species composition of thrips was different among locations. Onion thrips, *Thrips tabaci* has been considered as the single thrips species in onion crops in Ethiopia until recently. Recent studies including this one confirmed the occurrence of the western flower thrips, *F. occidentalis* concurrently with onion thrips, *Thrips tabaci*. Onion thrips, is more prevalent in

lower insecticides use areas where as proportion of western flower thrips, *F. occidentalis* tended to be higher in heavy insecticides use areas.

Thrips population and their damage peaked during the dry hot periods. Weather and onion growth stage appeared to influence thrips abundance. Population of thrips increased during the dry season at mid- growth stage of onion. Their number was low in the rainy season. The stepwise regression analyses showed that growth stage, season and sunshine hours significantly affected thrips abundance, while rainfall, minimum temperature and wind speed were not important in the selected model. Thrips resulted in up to 40% bulb yield losses on untreated plots in dry production seasons. The insecticide spinetoram gave effective control of the pest and reduced yield losses in the cool dry and hot dry production season.

Results from insecticides screening under field condition showed that performances of some the tested insecticides like λ -cyhalothrin and diazinon were poor. Results of the laboratory bioassay suggested that the poor performance of λ -cyhalothrin and diazinon in field trial could be due to insecticides resistance. The percent mortality was significantly lower in Meki and Melkassa collected thrips populations than in Minjar and Werer collected populations to λ -cyhalothrin and diazinon, while there were no significant differences among locations to spinetoram, dimethoate and profenofos insecticides at recommended field rate.

The sequential application of different insecticides resulted in a lower number of thrips per plant than the sole application of a particular insecticide. The insecticides spinetoram and imidacloprid were more effective in reducing thrips number the rest of the insecticides when applied during mid-growth stage of onion. The less effective insecticide λ -cyhalothrin appeared to perform better when applied during low infestation level in the early and late crop growth stages. The

sequential application of insecticides proved to minimize insecticide resistance problems and reduced losses from the thrips attack on onion. The insecticide dimethoate applied with surfactant resulted in a significantly lower number of thrips than without surfactant in both seasons. This was not the case when used with the insecticides spinetoram and imidacloprid, which performed well with sole application.

Generally, season-long management of thrips is important to reduce thrips infestation and increased bulb yield of onion particular in dry seasons. Onion growers depend on the use synthetic insecticides to control pests, which are old, broad-spectrum insecticides. However, controlling thrips using these insecticides is becoming difficult in the Central Rift Valley of Ethiopia due to buildup of resistance, shift in the species composition of thrips and lack of alternative non-chemical control methods. Due attention needs to be given to Insecticide Resistance Management strategy (IRM). Assessment of the insecticide use practice, monitoring thrips response to insecticides, improving existing insecticides efficacy, introducing new insecticide chemistry through periodic evaluation of new insecticides, establishing insecticide rotations programs and developing non-chemical alternative control measures are important components of insecticides resistance management program.

SUGGESTIONS FOR FUTURE RESEARCH

This study elucidated the problem of insecticide resistance to some of the registered insecticides for the control of thrips on onion in Ethiopia. In the absence of other non-chemical control options, reliance on insecticides for controlling the pest will continue. Hence, due emphasis should be given in the development of IPM options along with judicious use of insecticides. The followings are suggested for future research.

1. Country-wide survey on thrips species associated with onion using conventional and molecular method
2. Studies on cultural control such as intercropping onion with vegetables such as carrot and other vegetables
3. Studies on natural enemies associated with thrips with the purpose of strengthening biological control
4. Country-wide survey on occurrence of insecticide resistance to a range of insecticides registered insecticides
5. Periodic evaluation of new insecticides for their efficacy and use
6. Screening of available genotypes of onion for their resistance to the pest
7. Development of integrated thrips management program that combines cultural practices, host plant resistance, biological control, and selective insecticides is needed

BIOGRAPHICAL SKETCH

The author was born on April, 1984 in North Shewa administrative Zone, Minjar Shenkora Woreda, Ethiopia. He completed his Elementary and Secondary School Education from 1994 to 2001 at Arerti Elementary School and Goro Secondary School, respectively. His Secondary Education completed at Adama, Hawas Secondary School from 2002-2005. In 2006, he joined Haramaya University, Collage of Agriculture and graduated in July 2008 with the Degree of Bachelor of Science in Plant Production and Protection. In March 2009, he was joined Hawassa University, Collage of Agriculture for pursued his MSc and graduated in July 2011 with the Degree of Master of Science in Plant protection. He employed by the Ministry of Education in July 2011 and served as an instructor at Debre Markos University, Collage of Agriculture. After two years of service, he joined the School of Graduate Studies, Hawassa University in September 2013, to pursue his Degree of Doctor of Philosophy with specialization in Agricultural Entomology.

APPENDIX 2.1

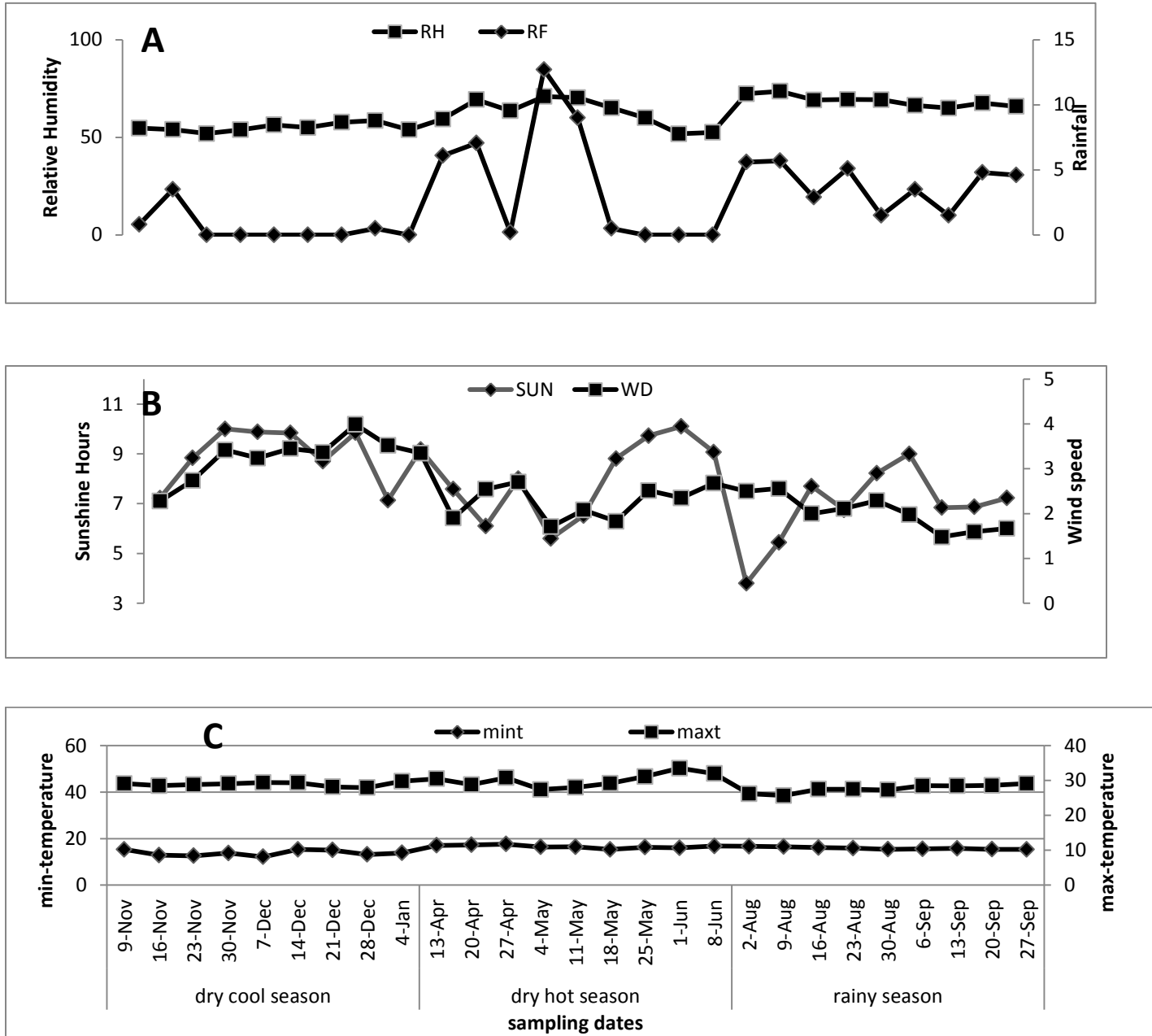


Figure 2.1. Weekly average rainfall (mm) and relative humidity (%) (A), weekly average sunshine hours(h) and wind speed (km/h)(B) and weekly average minimum and maximum temperature (°C) in dry cool, dry hot and rainy season in the consecutive sampling dates on unprotected plot in 2015/2016.

APPENDIX 2.2

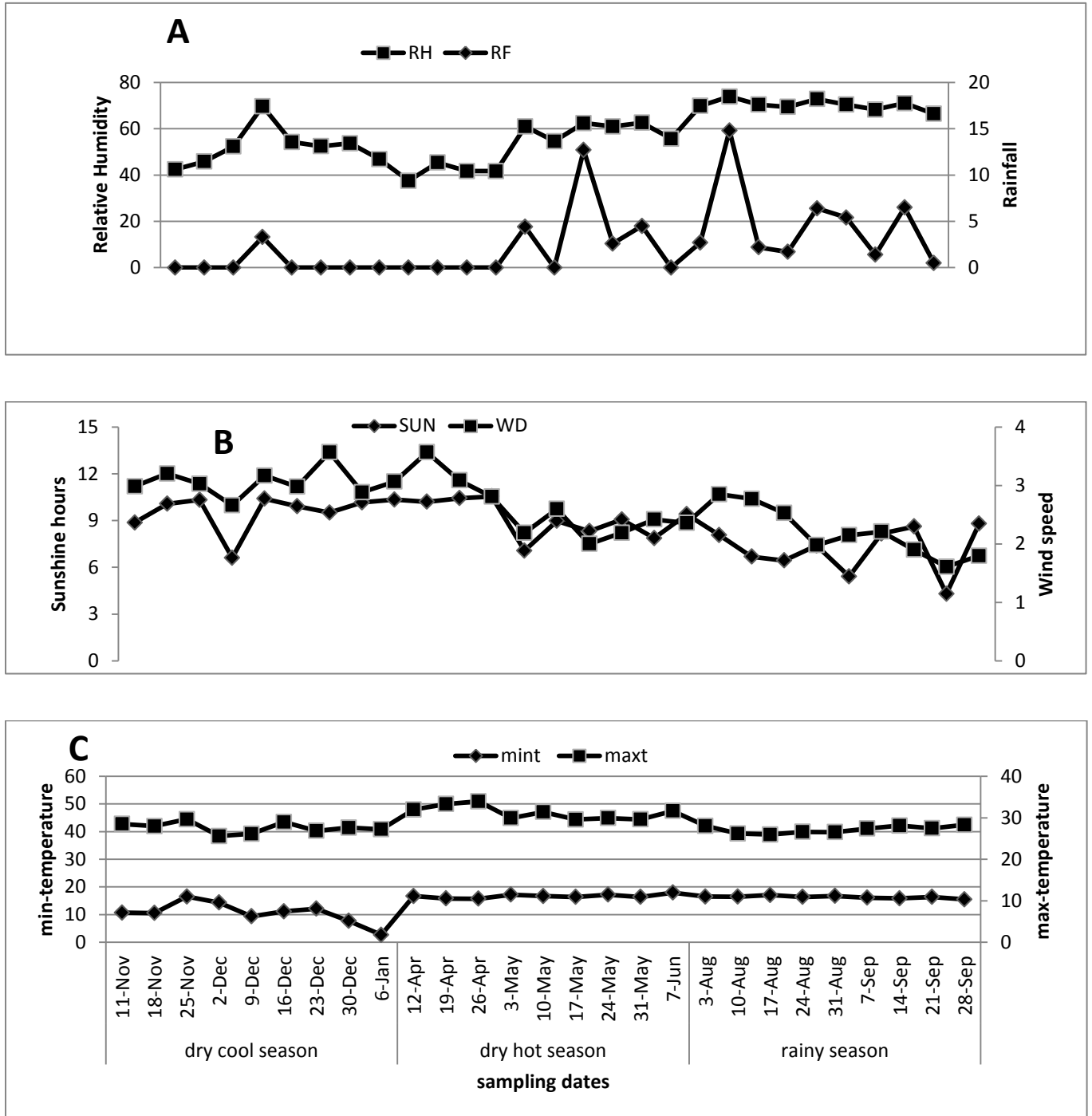


Figure 2.2. Weekly average rainfall (mm) and relative humidity (%) (A), weekly average sunshine hours(h) and wind speed (km/h) (B) and weekly average minimum and maximum temperature (°C) in cool dry, in hot dry and rainy season in the consecutive sampling dates on unprotected plots in 2016/2017.