



**Evaluation of Selected Bio-rational and Synthetic Insecticides Against
Onion Thrips (*Thrips tabaci* L.) (Thysanoptera: Thripidae) on Onion
(*Allium cepa* L.) in the Central Rift Valley of Ethiopia**

MSc. THESIS

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**HAWASSA UNIVERSITY
COLLEGE OF AGRICULTURE**

Hawassa, Ethiopia

October 2021

**Evaluation of Selected Bio-rational and Synthetic Insecticides Against
Onion Thrips (*Thrips tabaci* L.) (Thysanoptera: Thripidae) on Onion
(*Allium cepa* L.) in the Central Rift Valley of Ethiopia**

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**A THESIS SUBMITTED TO SCHOOL OF PLANT AND
HORTICULTURAL SCIENCES, HAWASSA UNIVERSITY, COLLEGE
OF AGRICULTURE, SCHOOL OF GRADUATE STUDIES**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF THE MASTER OF SCIENCE IN PLANT SCIENCE
(SPECIALIZATION: CROP PROTECTION)**

HAWASSA, ETHIOPIA

October 2021

COLLEGE OF AGRICULTURE
SCHOOL OF PLANT AND HORTICULTURAL SCIENCES
ADVISORS APPROVAL SHEET
(Submission sheet 1)

This is to certify that the thesis entitled” **Evaluation of Selected Bio-rational and Synthetic Insecticides against Onion Thrips (*Thrips tabaci* L.) (Thysanoptera: Thripidae) on Onion (*Allium cepa* L.) in the Central Rift Valley of Ethiopia**” submitted in partial fulfillment of the requirements for the degree of **Master of Science** with specialization in **Crop Protection** to graduate program of the School of **Plant and Horticultural Sciences**, college of Agriculture, and is a record of original research carried out by Tamene Getahun Bariso, under my supervision, and no part of thesis has been submitted for any other degree or diploma.

The assistance and help received during this investigation have been duly acknowledged. Therefore, I recommend that it accepted as fulfilling the thesis requirements.

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We, the undersigned, members of the Board of Examiners of the final open defense by **Tamene Getahun Bariso** have read and evaluate his thesis entitled” **Evaluation of Selected Bio-rational and Synthetic Insecticides Against Onion Thrips (*Thrips tabaci* L.) (Thysanoptera: Thripidae) on Onion (*Allium cepa* L.) in the Central Rift Valley of Ethiopia**” and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of **Master of Science** in plant sciences with specialization in **Crop Protection**.

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DEDICATION

I dedicated this thesis manuscript to my father Getahun Bariso and mother Chamo Meniso for their support, encouragement, and prayer.

STATEMENT OF THE AUTHOR

I declare that this thesis is my real work and all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the master science at Hawassa University and is deposited at the university library to be made available to borrowers under rule of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Date of submission _____

ACKNOWLEDGMENTS

First, I would like to thank the almighty God, for helping me in all circumstances. Next, I am grateful to my major advisor, Mr. Beniam Tilahun for support, immediate feedback, excellent guidance, valuable criticism and directing from the proposal development, field supervision, constructive comments and guidance that made this research works a success.

I also thank my co-advisor Dr. Ferdu Azerefegne for his valuable comments, encouragement, and field supervision during my study. Also, I would like to express my sincere gratitude to VEGETABLE IPM project for the research grant.

I have deep gratitude and respect to my family for their passion, motivation, prayer, support, and encouragement.

Moreover, I have a sincere gratitude to the school of plant and horticultural sciences staff of Hawassa University.

LIST OF ACRONYMS AND ABBREVIATIONS

A.i	Active ingredient
ANOVA	Analysis of Variance
ATARC	Adami Tulu Agricultural Research Center
CRV	Central Rift Valley
CSA	Central Statistical Authority
CV	Coefficient of Variance
EC	Emulsifiable Concentrates
FAO	Food and Agriculture Organization
HSD	Honestly Significant difference
INSV	Impatiens Necrotic Spot Virus
IPM	Integrated Pest Management
IYSV	Iris Yellow Spot Virus
PAN	Pesticides Action Network
RCBD	Randomized Completely Block Design
SAS	Statistical Analysis Software
SC	Suspension Concentrate
TSWV	Tomato Spotted Wilt virus
TYFRV	Tomato Yellow Fruit Ring Virus

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Evaluation of Selected Bio-rational and Synthetic Insecticides against Onion Thrips (*Thrips tabaci* L.) (Thysanoptera: Thripidae) on Onion (*Allium cepa* L.) in the Central Rift Valley of Ethiopia

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ABSTRACT

Onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae) is a key insect pest of onion. Onion growers at Meki and Batu locations rely on synthetic insecticides to control onion thrips. This practice encourages the development of insecticide resistance. Therefore, the search for alternative measures has become increasingly important. The present study was designed to evaluate the efficacy of selected bio-rational insecticides and the efficacy of selected synthetic and bio-rational insecticides in rotation against onion thrips. Field experiments were conducted in two locations at Meki and Batu, Eastern Shewa of Oromiya Regional state of Ethiopia during the dry season of 2019/2020. Two experiments were laid out in a randomized complete block design (RCBD) with four replications. Experiment one evaluated the efficacy of bio-rational insecticides (nimbecidine, spinosad, spinetoram, mixture of natural plant extracts and phytoenzyme, *Sophora flavescens* plant extract 25% + emamectin benzoate 1% SL, *Milletia ferruginea*, profenofos (as a standard check) and untreated plots). Experiment two evaluated efficacy of selected bio-rational and synthetic insecticides in rotation (nimbecidine + profenofos, nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + profenofos, mixture of natural plant extracts and phytoenzyme + imidacloprid, imidacloprid, profenofos (as a standard check) and untreated plots). The study showed that all the biorational insecticides reduced thrips population when compared with the untreated plots. Spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme effectively controlled thrips on onion and were comparable to the standard check insecticide (profenofos) and gave significantly higher yield than the untreated. Nimbecidine + profenofos and mixture of natural plant extracts and phytoenzyme + profenofos in rotation treatments effectively controlled thrips on onion and were comparable with the standard insecticide (profenofos). The highest yield (29.75, 31.22 ton/ha) was obtained from nimbecidine + profenofos in rotation treatment and the lowest (13.93, 14.36 ton/ha) from the untreated. Thus, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme as a sole application or nimbecidine + profenofos and mixture of natural plant extracts and phytoenzyme + profenofos in rotation can be used to control onion thrips on onion.

Key words: Bio-rational, efficacy, onion thrips, synthetic insecticides, rotation

1. INTRODUCTION

1.1. Background and Justification

Onion (*Allium cepa* L.) belongs to the genus *Allium* of the family Alliaceae and its origin Central Asia (Grubben and Denton, 2004). It is introduced to Ethiopia from Sudan and then distributed to different parts of the country and became important vegetable crop (Nikus and Mulugeta, 2010). Ethiopia, the third-biggest producer of onion in the African continent next to Egypt and South Africa, contribute 2.7% to the total world production (FAOSTAT, 2019).

Onion is food and cash crop in Ethiopia (Shiberu *et al.*, 2013). It is produced under irrigated, and rain fed conditions by small scale farmers, private investors, and state enterprises mainly in the Awash Valley and Rift Valley Lake Regions where the bulk of dry bulbs and seeds are produced. Onion is one of the major economically important vegetable crops grown in the central region of the country; mainly in the upper Awash and Lake Ziway areas (Lemma and Shimelis, 2003). The best growing altitude for onion under Ethiopian condition is between 700 and 1800 meter above sea level (Lemma, 2004).

Onion can be grown under a wide range of climatic conditions. However, their production is more successful under mild climate without extremes of heat or cold and excessive rainfall (Lemma, 2004). Ethiopia's diversified agro-climatic conditions suitable to produce a broad range of fruits, vegetables and flowers also allow successful production of onion (Lemma *et al.*, 2006).

The production and productivity of onion in Ethiopia is very low compared to world average onion yield. Averaged over the period of 2010 – 2018, the onion yield is 11.70 ton/ha (CSA, 2019; FAOSTAT, 2019), which is far below the world average of 19.7 ton/ha (Megersa,

2017). Low quality of cultivars, in appropriate agronomic practices, weak extension system, diseases and insect pests, and fluctuation of climatic conditions are the major constraints for the onion production and productivity in Ethiopia (Megersa, 2017; Melese *et al.*, 2018). Insect pests such as onion thrips (*Thrips tabaci*) and cut worms (*Agrotis* spp.), diseases such as downy mildew (*Peronospora destructor*), purple blotch (*Alternaria porri*), white rot (*Sclerotium cepivorum*), leaf spots and onion smudge (*Colletotrichum circinans*) are among the major constraints of onion production and quality (Rabinowitch and Currah, 2002).

Onion thrips, *T. tabaci* Lindeman; (Thysanoptera: Thripidae) is economically important pests of onion worldwide (Gachu *et al.*, 2012; Gill *et al.*, 2015). Onion thrips is a key pest of onion and their control is vital to the production and profitability of this crop (Shiberu and Negeri, 2014). Onion thrips affect 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 (Abate, 1985). Areas of leaf injury can occur as patches and streaks (Diane, 2008). When damage is severe, these small patches can occupy most of the surface of the leaf and the plant cannot adequately photosynthesize and nutrient transportation to the bulb (Cranshaw, 2004).

Onion thrips is polyphagous nature, high reproductive rate, short generation time, high survival of cryptic (nonfeeding prepupa and pupa) instars, ability to reproduce without mating (parthenogenesis), ability to transmit plant pathogens, and development of resistance to insecticides (Morse and Hoddle, 2006; Diaz-Montano *et al.*, 2011). onion thrips highly feeding results not only results in plant stunting and reduced bulb weight, but also predisposes onion plants to various fungal and bacterial pathogens that further decrease yield. Onion thrips is a principal vector of Iris yellow spot virus (IYSV) (Bunyaviridae: Tosspovirus) that can cause

100% crop losses (Morse and Hoddle, 2006; Nault .and Shelton, 2010; Diaz-Montano *et al.*, 2012).

In Ethiopia, *T. tabaci* is an important onion insect pest that destroys onion fields, especially in the dry seasons (Shiberu *et al.*, 2013). Level of infestation and extent of yield losses due to thrips on onion were reported by various researchers differently; Abate (1985) and Merene (2005) reported that onion bulb yield losses of 33% and 26-57%, respectively, due to onion thrips in Ethiopia. Upper Awash Agro Industry Enterprises revealed yield losses due to onion thrips ranged between 10 - 85% in Ethiopia (Bekele *et al.*, 2006). In Toke Kutaye district, West Shoa, Ethiopia the yield losses due to onion thrips reached up to 36.44% were recorded (Shiberu *et al.*, 2013).

Onion producers tend to apply effective single classes of insecticide repeatedly to control onion thrips. The most applied insecticide classes include carbamate, organophosphate, organochlorine and pyrethroids often applied repeatedly and indiscriminately in the Central Rift Valley of Ethiopia (Belay *et al.*, 2017). Indiscriminate application of insecticides against onion thrips in onion is a common practice in the Rift Valley of Ethiopia (Banchiamlak *et al.*, 2012). This practice has made insecticidal control ineffective, encouraged development of insecticide resistance and decimated natural controlling factors such as parasitoids (Lebedev *et al.*, 2013). The repeated application of the same group of insecticides could have led to the development of resistance to insecticides (Shitole *et al.*, 2002; Banchiamlak *et al.*, 2012; Belay *et al.*, 2017). Farmers have intensively used insecticides which are usually used in the area to control this pest on onion crops, however insecticides applied without adequate knowledge of the pest and the identity of the insecticides including dosage and frequency (Mohammed *et al.*, 2006; Belay *et al.*, 2017); such application of insecticides are conducive to increasing

insecticide resistance. Tebkew and Getachew (2015) reported that all small-scale vegetable growers in East Shewa Zone, Ethiopia, rely solely on insecticides and spray insecticides frequently to control pests.

Several insecticides from different classes are registered for control of thrips on onion in Ethiopia (MoANR, 2017). Moreover, most insecticides are ineffective because many thrips are protected between the inner leaves of the onion plant and the pupal stage is spent in the soil (Nault and Shelton, 2010). Alternative non-chemical insecticides, such as botanicals are found to be the best option for smallholder vegetable production (Ayalew, 2005; Shiberu *et al.*, 2013). According to Ibrahim *et al* (2015) application of botanicals (Neem, Mexican marigold, tobacco, and Jimson weeds against onion thrips provides 60% suppression of onion thrips. Therefore, the present study was designed the following objectives:

1.2. Objectives of the Study

1.2.1 General objective

- To evaluate the efficacy of bio-rational insecticides and possible use in rotation with synthetic insecticides as alternative means to control onion thrips in the Central Rift Valley of Ethiopia.

1.2.2. Specific objectives

- To evaluate the efficacy of selected bio-rational insecticides against onion thrips.
- To test the efficacy of selected bio-rational and synthetic insecticides in rotation against onion thrips.

2. LITERATURE REVIEW

2.1. Geographical Distribution of Onion Thrips

Onion thrips, *T. tabaci* is considered as the most economically important pests of onion worldwide (Gachu *et al.*, 2012; Gill *et al.*, 2015). The onion thrips is originated in the Mediterranean region. It was first found in Hawaii in 1915, it is found all over the world where onion is grown (Brian, 2006). Thrips are distributed all over the world including the cool arctic region (Lewis, 1997). In the tropics, thrips population on annual crops are possibly affected more by immigration than in north temperate regions, due to the north-south movement of inter tropical convergence zone. Thrips can colonize crops from sea level up to 2000 m.a.s.l (Mishra *et al.*, 2014). In Ethiopia, onion thrips distributed throughout the country, particularly in onion growing areas (Tadele and Amin, 2014). High temperature and lack of rainfall have been associated with increase in onion thrips population, while high relative humidity and rainfall reduce thrips population (Murai, 2000). Severe damage to various crops has been reported in Africa, Asia, Europe, North and South America and Australasia (Boateng *et al.*, 2014).

2.2. Economic Importance of Onion Thrips

Thrips of vegetable crops are known to be serious pests on a wide range of fruit, vegetable, flower, and agronomic crops. Thrips are members of the order Thysanoptera, which contains several genera and species. Among species of thrips that attack onions are onion thrips (*T. tabaci*) and western flower thrips (*Frankliniella occidentalis* Pergande). The major insect pest of onion is the onion thrips. Onion thrips, *T. tabaci* is considered as the most economically

important pests of onion worldwide (Gachu *et al.*, 2012; Gill *et al.*, 2015). In Ethiopia, *T. tabaci* is an important onion insect pest that destroys onion fields, especially in the dry seasons (Shiberu *et al.*, 2013). Onion thrips is important especially in areas where onions are grown under irrigation (Abate, 1985). Onion thrips, *T. tabaci* is a key pest of onion and their control is vital to the production and profitability of this crop (Shiberu and Negeri, 2014). Onion thrips are polyphagous, high reproductive rate, short generation time, high survival of cryptic (nonfeeding prepupa and pupa) instars, ability to reproduce without mating (parthenogenesis), ability to transmit plant pathogens, and development of resistance to insecticides (Morse and Hoddle, 2006; Diaz-Montano *et al.*, 2011). Onion thrips, *T. tabaci* is a global pest of onion, *A. cepa* L., and the principal vector of Iris yellow spot virus (IYSV) (Bunyaviridae: Tospovirus), that can cause 100% crop losses (Morse and Hoddle, 2006; Nault and Shelton, 2010; Diaz-Montano *et al.*, 2012).

Onion thrips cause considerable onion yield losses in Ethiopia. In Toke Kutaye district, West Shoa, Ethiopia the yield losses due to onion thrips up to 36.44% (Shiberu *et al.*, 2013). Abate (1985) and Merene (2005) reported that onion bulb yield losses of 33% and 26-57% respectively, due to onion thrips in Ethiopia. Similar studies at Upper Awash Agro Industry Enterprises revealed yield losses of 10 - 85% due to onion thrips in Ethiopia (Bekele *et al.*, 2006).

2.3. Biology of Onion Thrips

Onion thrips can reproduce asexually (parthenogenesis) and sexually. The most common reproductive mode is thelytoky, a parthenogenesis in which females are produced from unfertilized eggs. Onion thrips also reproduce via arrhenotoky, a parthenogenesis in which males are produced from unfertilized eggs; females are produced from fertilized eggs. Onion

thrips that reproduce via thelytoky differ genetically from those that reproduce via arrhenotoky (Toda and Murai, 2007; Kobayashi and Hasegawa, 2012; Gill *et al.*, 2015).

There are biological differences between onion thrips populations that reproduce via arrhenotoky and thelytoky. For example, when arrhenotokous and thelytokous onion thrips populations developed on either onion or cabbage, the arrhenotokous population performed better on onion than on cabbage, whereas the opposite was true for the thelytokous population (Li *et al.*, 2014). Arrhenotokous onion thrips that developed on onion produced more progeny and the population developed significantly faster on onion than on cabbage (Li *et al.*, 2014). Another difference observed between arrhenotokous and thelytokous populations of onion thrips was the ability to transmit Tomato spotted wilt virus (TSWV), Tospovirus closely related to Iris yellow spot virus (IYSV) (Chatzivassiliou *et al.*, 2002). Arrhenotokous onion thrips populations successfully transmitted TSWV (Chatzivassiliou *et al.*, 2002).

Adults often fly to and land on clothes or exposed skin because of the thrips attraction to white and yellow colors (Rueda and Shelton, 1995). Adults are elongated with body color varying with temperature from yellow to brown. The forewings and hind wings are fringed and pale in color. Mouthparts are piercing-sucking, antennae are 7-segmented, and eyes are gray (Patel *et al.*, 2013). Adult females are 1.0–1.3mm in length and males are 0.7mm in length. Adult longevity varies from 16–42 days on garlic and 28–30 days on onion (Patel *et al.*, 2013). Onion thrips adults emerge from overwintering sites in the spring and may fly to colonize weed hosts and volunteer onion plants before subsequent generations infest onion crops (Smith *et al.*, 2011). There are six to eight generations per season (Hoffmann *et al.*, 1996).

Females lay eggs singly by inserting them into leaf tissue. Only one end of the egg is in proximity to the tissue surface to allow emergence of immature. Eggs are microscopic, white or yellow, and kidney shaped. On onion, the average length and width of eggs are 0.23mm and 0.08 mm, respectively (Patel *et al.*, 2013). Incubation period is 4–5 days on onion, hatching occurs in 2–3 days under laboratory conditions (Pourian *et al.*, 2009).

Larvae the first and second instars are active feeding stages. The first instar is small, 0.35–0.38mm in length, semitransparent and dull white, changing later to yellowish white. The second instar is larger and yellow (Patel *et al.*, 2013). Larvae are 0.7–0.9mm in length with red eyes. The abdomen is divided into eight distinct segments and has a large posterior segment that is conical in shape. Duration of the first instar varies from 2- 3 days, and the second instar can range from 3 - 4 days (Pourian *et al.*, 2009).

The prepupa and pupa (1.0–1.2mm in length) are relatively inactive, nonfeeding stages. There are two non-feeding stages (instars III and IV), called the pre pupa and pupa. Pupation normally takes place at the base of the onion's apical meristem or within the soil (Rueda and Shelton, 1995). The average length of the prepupa is 0.9mm and the width is 0.23 mm. The prepupa is whitish-yellow and lasts for 1–3 days. In completely formed pupae, the antennae are folded back over the head and wing pads are well developed. The pupae are yellowish white, changing to yellow before adult emergence. The pupal period varies from 3–10 days among different geographical regions (Patel *et al.*, 2013). A complete generation requires 3-4 weeks during the summer months and 5-8 generations may occur each year (Diane, 2008).

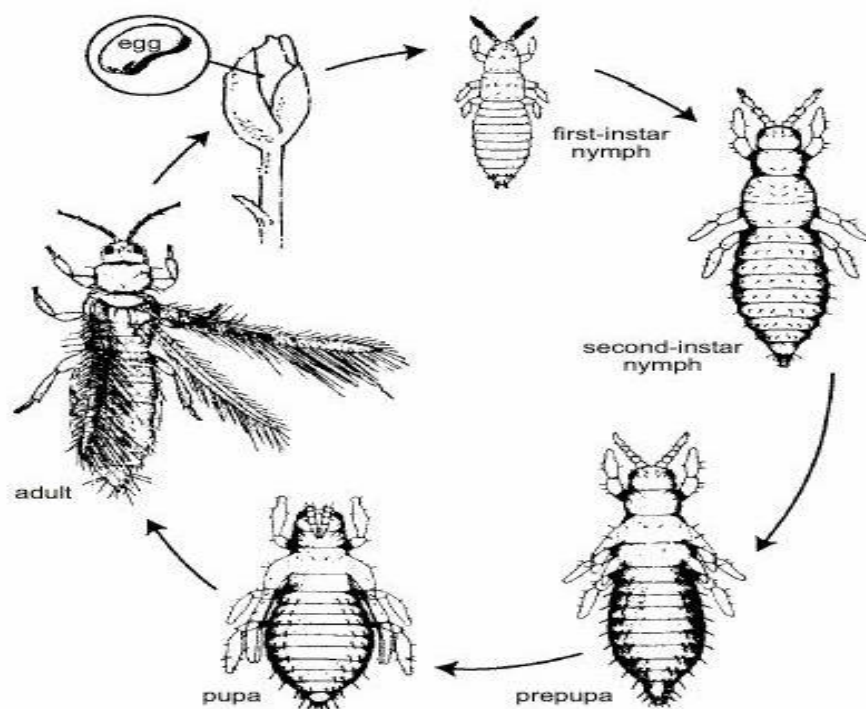


Figure 1. The life cycle of onion thrips (source University of California, 2004)

2.4. Host Range of Onion Thrips

Onion thrips have an extremely wide host range compared with other thrips species. Reports of their host range vary from more than 140 plant species in over 40 families (Ananthakrishnan, 1973) to more than 355 species of flowering plants (Morison, 1957). Some onion thrips populations exclusively utilize a single plant species like tobacco (Brunner *et al.*, 2004). According to Abate (1995) was 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. Onion thrips also can reproduce on cultivated crops and weedy plants (Diaz-Montano *et al.*, 2011). In addition to onion, onion thrips may attack the following: alfalfa (*Medicago sativa*), asparagus (*Asparagus officinalis*), bean (*Phaseolus vulgaris*), beet (*Beta vulgaris*), blackberry (*Rubus fruticosus*), cabbage (*Brassica*

oleracea), carrot (*Daucus carota*), cauliflower (*Brassica oleracea* L. var. *botrytis* L.), celery (*Apium graveolens*), cotton (*Gossypium* spp.), cucumber (*Cucumis sativus*), garlic (*Allium sativum*), kale (*Brassica alboglabra* L.H. Bailey), leek (*Allium ampeloprasum* var. *porrum*), lettuce (*Lactuca sativa*), parsley (*Petroselinum crispum*), pea (*Pisum sativum*), pineapple (*Ananas comosus*), potato (*Solanum tuberosum*), pumpkin (*Cucurbita maxima*), squash (*Cucurbita* spp.), strawberry (*Fragaria ananassa*), sweet potato (*Ipomoea batatas*), turnip (*Brassica rapa* var. *rapa*), tomato (*Solanum lycopersicum*) and practically all small grains (Pergande, 1895; Parella and Lewis, 1997; Cranshaw, 2004; Shelton *et al.*, 2008). Notably, the extent and frequency by which onion thrips damage crops varies across plant species. Onion is its preferred host and onion is one of the crops it damages the most. Weed species supported reproductive populations of onion thrips, especially *Brassica* weed species such as *Barbarea vulgaris* Ait. f., *Sinapis arvensis* L. and *Thalspi arvense* L. (Smith *et al.*, 2011).

2.5. Damage

Onion thrips have very distinctive feeding behaviors by punching through the leaf surface and then extracting sap from plant cells. During this process, thrips release substances that help predigest the tissue. After this, they siphon off the plant contents and consume mesophyll cells, which eventually results in a loss of chlorophyll and reduced photosynthetic efficiency (Boateng *et al.*, 2014). Damage appears as silvery patches or streaks on the leaves (Rueda and Shelton, 1995). Severe feeding injury by onion thrips is also associated with tiny black “tar” spots, which is excrement from thrips (Cranshaw, 2004).

Onions are most sensitive to thrips injury during the rapid bulb enlargement phase that occurs in dry season, particularly during irrigation season in Ethiopia (Abate, 1985). Accelerated

plant maturity and senescence due to thrips injury may truncate the bulb growth period. Thrips also may feed on onion bulbs following harvest and during storage, and this can cause scars that reduce the aesthetic appearance and quality of bulbs (Mayer *et al.*, 1987).

Thrips are the only vectors of tospovirus, and onion thrips is the principal vector of the tospovirus, Iris yellow spot virus (IYSV) in onion (Diaz-Montano *et al.*, 2012). IYSV is not transmitted via onion seeds, nor is it successfully transmitted mechanically (Gent *et al.*, 2004; Gent *et al.*, 2006). First instars can acquire the virus from an infected plant and the acquisition rate decreases as the larva matures. Viruliferous adult thrips are capable of transmitting IYSV for life. IYSV causes straw- to tan-colored lesions on onion leaves and spindle-to diamond-shaped lesions on the scapes. In severe cases, IYSV may cause leaves to become necrotic and plants to mature prematurely. In such situations, bulb size and yield losses onion in fields 60% (Gent *et al.*, 2006) and even up to 100% (Diaz-Montano *et al.*, 2012). Onion thrips is also known to transmit tomato spotted wilt virus (TSWV) (Wijkamp *et al.*, 1996), tomato yellow fruit ring virus (TYFRV) (Golnaraghi *et al.*, 2007), and impatiens necrotic spot virus (INSV) in other crops. Onion thrips may serve as a vector of *Alternaria porri*, the fungus that causes purple blotch. *A. porri* typically enters onion leaves through stomata and the epidermal cell layer, but fungal penetration becomes easier when the leaf surface has been damaged by onion thrips. Onion thrips was shown to transmit a bacterial pathogen, *Pantoea ananatis*, to onion (Dutta *et al.*, 2014). *P. ananatis* causes center rot in onion and has caused substantial economic losses.

2.6. Economic Threshold Level (ETL)

An action threshold for onion thrips is defined as the average thrips number per plant that will cause economic yield loss if the infestation is not controlled (Nault and Shelton, 2010). Knowledge of action thresholds for onion thrips can help onion growers optimize insecticide applications and other management tactics. Action thresholds for Insect pests may vary depending on geographic region, variety, plant stage, plant architecture, and insecticide efficacy. In California, a threshold of 30 thrips/plant at mid-season has been used successfully for bulb, fresh market, and drying onions, using conventional, synthetic pesticides. This number would be adjusted downward for very young plants and upward for larger, mature plants. In New York State a conservative action threshold 3 thrips/leaf has been suggested, and 1 thrips/leaf for Spanish and green bunching onions (Hoffmann *et al.*, 1996). In Ethiopia, the economic threshold level of onion thrips was 5-10 thrips/plant (Abate, 1985). In onions, thrips must be controlled before the crop reaches the early bulbing stage, so that populations do not exceed manageable levels (Coviello *et al.*, 1993). Plant architecture can also influence thrips population levels. In onions, cultivars with flat-sided leaves and a compact growth point (where the leaves are closely compressed) protect thrips from natural enemies, weather, and insecticides. Conversely, round, openly spaced leaves reduce thrips' hiding places (Fournier *et al.*, 1995).

2.7. Management of Onion Thrips

2.7.1. Cultural control

Plant health adherence through removal of volunteer onion plants and weeds around the cultivated fields and crop rotation would be useful in minimizing thrips populations in an

onion field. The intercropping onion with spider plant and carrot reduced thrips population 45.2% and 21.6% (Gachu *et al.*, 2012). 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 has also been investigated to compare reductions in colonization rates of onion thrips and overall reductions in yield (Trdan *et al.*, 2006). Mulching has also been reported to reduce thrips infestation considerably (Jensen *et al.*, 2001).

According to Ellis and Bradley (1992) reported that blue sticky traps are good for monitoring thrips population and reported the pest could be well controlled, if the crop debris is destroying properly. Rateaver and Rateaver (1999) reported that soil fertility management affects thrips infestation and damage. Lack of adequate soil calcium may invite higher population of thrips (Mishra *et al.*, 2014). The use of cover crops can affect the number of overwintering thrips. Oats is a better choice but requires later fall planting than rye or wheat a factor that constrains its use as a cover crop in colder regions. Drought stress increases the susceptibility of onions to thrips damage (Fournier *et al.*, 1995). The fact that thrips are color-sensitive suggests that colored mulches may be effective in their control. Louisiana researchers conducted a study to see whether aluminum-coated mulch would repel the pest (Quarles, 1990). The reflective mulch repelled 33- 68% of the thrips. Ultraviolet-absorbing plastics used to build walk-in field tunnels have proved effective in protecting crops from western flower thrips (Antignus *et al.*, 1996).

2.7.2. Host plant resistance

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). The resistance in onion to *thrips tabaci* was discovered first in 1934 in U.S.A. Onion “White pertains” cultivar was found to possess factors, which reduced the buildup of thrips population on its leaves and found to be tolerant. A study in New York identified several cultivars considered partially thrips resistant (OLYS05N5, Tioga, Peso, Calibra, Vaquero, Cometa, Medeo, NMSU 03-52-1, Delgado, T-433, Colorado 6, Arcero, Mesquite, White Wing, and Granero). Onion cultivars with yellow-green, glossy to semi-glossy leaf surfaces and an open neck were less attractive to onion thrips compared with cultivars with blue green, waxy leaves, and tight necks (Diaz-Montano *et al.*, 2012).

On the other hand, Mambo, Early Red and Stockton cultivar have leaves, which are tightly bundled together, which can provide thrips hiding niche from natural enemies and pesticides and hence these varieties were highly infested by thrips (Fournier *et al.*, 1995). Besides, morphological characters such as thickness of epidermis leaf structure and glossy foliage has been reported as resistance of onion to thrips (Doederlein and Sites, 1993).

2.7.3. Biological control

There are many beneficial organisms’ prey to harm onion thrips. Some of these include ladybird beetles, minute pirate bugs, ground beetles, lacewings, hover flies, predatory thrips, predatory mites, and spiders (Hoffmann *et al.*, 1996). Anthocoridae bugs and Phytoseiidae mites were successfully managing thrips in the greenhouses (Riudavets and Castane, 1998). Some species of the *Aeolothrips*, *Haplothrips*, *Scolothrips*, *Franklinothrips*, *Karnyothrips*

genera as well as those of the *Aleurodothrips*, *Allelothrips*, *Androthrips*, *Apterygothrips*, *Desmidothrips*, *Erythrothrips*, *Leptothrips*, *Mymarothrips*, *Parascolothrips*, *Podothrips*, *Stictothrips*, *Stomatothrips*, *Symphyothrips*, *Trichinothrips*, *Veerabahuthrips*, *Xylaplothrips* and *Andrewarthaia* genera were well known predators of thrips (Sabelis and Vanriijn, 1997; Trdan *et al.*, 2003).

According to Kakimoto *et al* (2006) evaluated the predation potential of *Haplothrips brevitubus* (Karny) for thrips; when second stage larvae of *Pseudodendrothrips mori* (Niwa) were presented to an adult *H. brevitubus* at densities of 10, 20, 30, and 40 larvae per cage at 25°C over 24hrs, the number of larvae consumed per day increased with an increasing density up to 30. One *H. brevitubus* larvae consumed 41.6 *P. mori* larvae on average during the total larval period. These results indicated that *H. brevitubus* had good potential as a predator of *P. mori* and is likely to be useful for controlling thrips. Thus *H. brevitubus* seems to have higher predatory and reproductive ability as a natural enemy of thrips than do other predatory thrips, such as *A. intermedius* and *F. vespiformis*. *Amblyseius barkeri* female adult consumes 3 *T. tabaci* larvae daily (Bonde, 1989).

Thrips in the greenhouse in Southern California up to 50% of its eggs were killed by a tiny wasp, *Megaphragmamy maripenne*. After feeding inside during its larval stage then pupating, the emerging adult parasite leaves a relatively large round hole in the tiny thrips egg. *Thripobiuss emiluteus* parasitizes greenhouse thrips larvae. Thrips parasitized by this wasp's larvae become swollen around the head and turn black in contrast to the pale color of parasitized greenhouse thrips larvae (Bethke *et al.*, 2014). The occurrence of parasitoids was well synchronized with onion thrips population and it as a positive density dependent relationship. In Ethiopia, *Adonia variegata* and *Orius* spp were found to be the most important

natural enemies of thrips found in many onion-growing areas (Abate, 1986). Different species of entomopathogenic nematodes (*Steinernema carpocapsae*, *S. feltiae*, *Heterorhabditis bacteriophora*) were evaluated for the management of onion thrips in a laboratory study and one with onion and green bean plants grown in a controlled environment. Onion thrips prepupal and pupal mortality was high (>90%) in the high nematode concentration treatments in the laboratory, there was no effect of nematodes on thrips mortality on plants grown in the controlled environment (Kashkouli *et al.*, 2014). Entomopathogenic fungi, *Beauveria* and *Metarhizium* caused 46.18 and 26.09% mortality of onion thrips, respectively at the 3rd day of application (Shiberu *et al.*, 2013). *Beauveria bassiana* was most effective when used early at economic threshold level, before large thrips populations have built up. *B. bassiana* were successful in reducing onion thrips populations and increasing onion yield (Singh *et al.*, 2011). The influence of temperature on the infection process is very important. *Metarhizium* infecting adult thrips at about 23 °C and decreases in temperature of 3 to 5 °C increase the time to death of the insect about a day. *B. bassiana* is used as a contact myco-insecticide but survives a relatively short period when exposed on a leaf surface. The killing capacity of the fungus at 3rd, 5th and 7th day was 46.18, 54.31 and 60.67%, respectively (Shiberu *et al.*, 2013).

2.7.4. Botanical control

Botanicals control against onion thrips, especially when combined with other management tactics. Neem (*Azadirachta indica*) extracts used to control thrips (Hazara *et al.*, 1999). The efficacy of botanicals *Phytolacca dodecandra*, *Chrysanthemum cinerariaefolium*, *Nicotiana tabacum* and *Azadirachta indica* for the controlling the onion thrips reported (Stoll, 2000). The botanicals that extract of neem seed powder evaluated against onion thrips, reduced thrips population under field condition (Ayalew, 2005). The *Bidens pilosa* was effective control

against aphid, cutworm, and termites (PAN, 2008). Likely, in this study, *B. pilosa* was minimized the number of onion thrips population but exhibited low mortality rate percentage when compared to other treatments. *Securidaca longepedunculata* showed a better performance than commonly used botanicals, *A. indica* and *C. cinerariaefolium*. *S. longepedunculata* is a toxic plant and its root bark contains “Chamana’e” which is commonly used for washing clothes as well as medicinal value against snake attack in areas where the plant is grown. Under Ethiopian condition there is a study made on the use and toxicity potential of the plant against any insect pest. Shiberu *et al* (2013) reported that *A. indica* and *C. cinerariaefolium* performance better than *C. citratus* was at 1st, 3rd, 5th, and 7th day scored efficacy percent against onion thrips under field condition. Stoll (2000) also reported that lemongrass, and the whole plant extract was very effective against rice pest. *Parthenium hysterophorous* root extract was minimized onion thrips at 1st day but prolonged to decline within 7 days (Shiberu *et al.*, 2013).

2.7.5. Biorational insecticides

Biorational insecticides are active against pest populations, but relatively innocuous to nontarget organisms and therefore, non-disruptive to biological control. Bio-rational insecticides are effective against target pest insects and cause negligible harm to non-target organisms when used properly. They are effective control pests and are derived from biological or natural origins (Stansly *et al.*, 1996). Bio-rational insecticides include oils, soaps, and botanicals (Schuster and Stansly, 2005). It is being low risk, are also used to keep fruits and vegetables free of harmful insecticide residues, safeguard the health of agricultural workers and reduce the environmental impact.

Several bio-rational insecticides used for control onion thrips. Spinosad and spinetoram have been widely used for the control of thrips (including western flower thrips, onion thrips, and chill thrips) on fruit and leafy vegetables, tree fruits and ornamentals globally (Dripps *et al.*, 2011). Nault and Shelton (2010) reported that abamectin, cyantraniliprole, spinetoram, spinosad and spirotetramat have consistently demonstrated management of onion thrips. Workman and Martin (2002) reported that spinosad reduced thrips populations on onion crop comparable to imidacloprid. Abdul *et al* (2014) reported that the botanicals (neem, datura and bitter apple) and insecticides (acephate, spirotetramat and spinetoram) tested caused significant reductions (45-70%) in thrips populations; the botanicals gave not more than 60% control of thrips.

2.7.6. Chemical insecticides

Insecticides are the most common practices for onion thrips management. The out breaks of onion thrips in onion fields, insecticides have been the primary mode to manage this pest (Morse and Hoddle, 2006; Nault and Shelton, 2010). Despite their use and availability of numerous classes or modes of action, rapid development of resistance to insecticides has been a key problem. Many of the earlier registered products for the management of onion thrips are losing management efficacy. The most applied insecticide classes in the Central Rift Valley of Ethiopia are carbamate, organophosphate, organochlorine and pyrethroids, often applied repeatedly and indiscriminately (Belay *et al.*, 2017). Indiscriminate application of insecticides against onion thrips in onion is a common practice in the Rift Valley of Ethiopia (Banchiamlak *et al.*, 2012). This practice has made insecticidal control ineffective, encouraged development of pest resistance and decimated natural controlling factors such as parasitoids; because thrips have developed resistance to various groups of insecticides (Lebedev *et al.*,

2013). The main reasons lie in the life history characteristics of onion thrips reproduction by parthenogenesis (eggs develop without male fertilization so females pass all their genes to their offspring), high reproductive potential, short generation (Morse and Hoddle, 2006; Diaz-Montano *et al.*, 2011). Due to the rapid development of the onion thrips and the presence of protected, non-feeding stages of this pest, several insecticide applications may be required to achieve adequate control (Tilm and Carrie, 2014). Pre pupa and pupa (Instars III and IV) are non-feeding and seek protection in the soil or at the base of onion plants, escaping contact by most insecticides (Tilm and Carrie, 2014).

Development of resistance by onion thrips to most used insecticides has been reported by many authors. Nazemi *et al.* (2015) concluded that most of *T. tabaci* populations in onion fields developed resistance to the conventional organophosphate and pyrethroid insecticides. Due to the polyphagous nature of thrips species and their need to detoxify allelo chemicals, metabolic detoxification plays an important role in insecticide resistance development (Gao *et al.*, 2012). Diaz-Montano *et al.* (2011) reported that *T. tabaci* becomes a global pest of increasing concern in commercial onion fields because of its development of resistance to insecticides, ability to transmit plant pathogens and frequency of producing more generations at high temperatures. Resistance can be mitigated by limiting the frequency of insecticide applications, rotating insecticides used in a sequence (based on groups or modes of action) and prolong the effectiveness of insecticides (Gill and Garg, 2014).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiments were conducted at Meki and Batu areas in the Central Rift Valley (CRV) of Ethiopia. The experiment sites were about 130 km (Meki) and 160 km (Batu) South of Addis Ababa, East Shewa Zone of Oromiya Regional State, Ethiopia. Meki is located at 8° 10'N latitude and 38° 50'E longitude with an altitude range between 1500 - 2300 m.a.s.l and annual temperature ranged between 22 - 28°C. The average annual rainfall was 750 mm per annum (DWOA, 2014). Batu is located 7° 9'N latitude and 38° 7'E longitude at, an altitude of 1650 m.a.s.l. and with bimodal unevenly distributed average annual rainfall of 760.9 mm per annum. The long-term mean temperature ranged 12.6 - 27°C (ATARC, 1998).

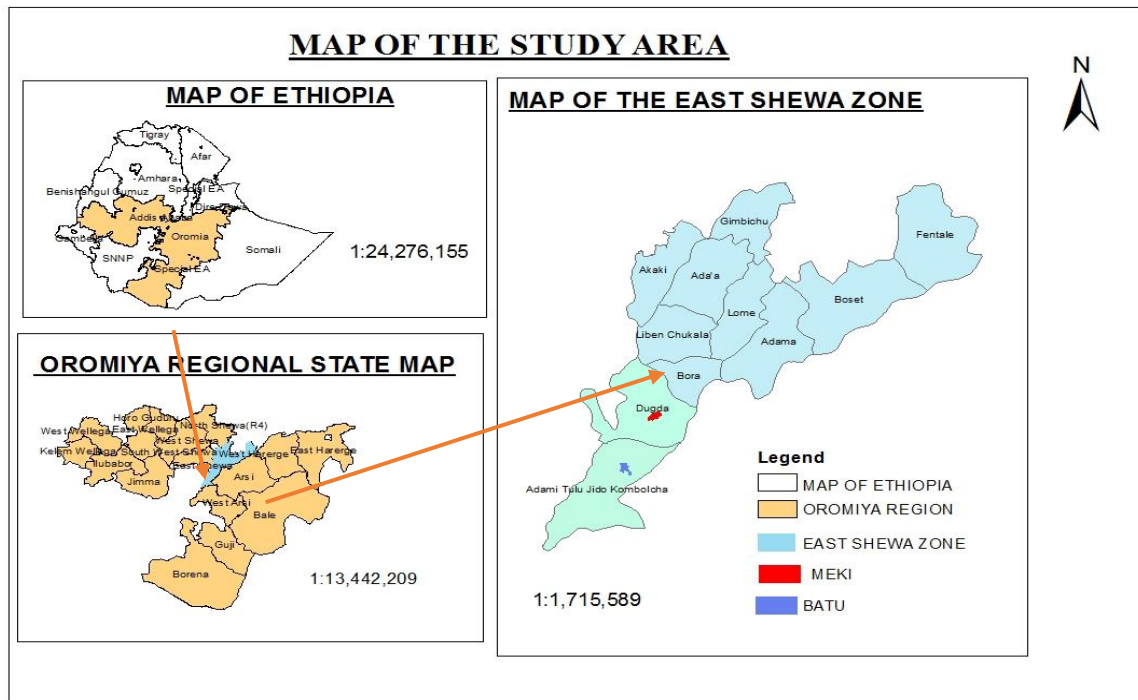


Figure 2: Map of the study area

3.2. Planting Material

Onion variety ‘Bombay red’ was used for the study. The variety was released by Melkassa Agricultural Research Center in 1980 (EARO, 2004). It has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color (EARO, 2004). Bombay red is one of the commonly and widely used variety in Meki and Batu areas.

3.3. Experimental Procedure and Field Management

Nursery managements: Seeds of Bombay red were sown at the rate of 4.0 kg/ha (EARO, 2004) on 1mx5m raised seedbed in November 5/2019. Onion seeds were sown with a spacing of 2cm and 10cm between and within rows, respectively. Seedlings were managed in the nursery for 45 days. All nursery management practices, such as mulching, watering, fertilizer application and weeding were executed to raise vigorous and healthy seedlings.

Transplanting: Seedlings were transplanted to the main experimental field when they attained 3-4 true leaves on December 19/2019. One day before transplanting, the nursery beds were irrigated to ease uprooting of the seedlings. During transplanting healthy, vigorous, and uniform seedlings were transplanted.

Field management and procedures: The field was ploughed using oxen and harrowed manually to bring the soil to fine tilth. The seedlings were transplanted to well prepared and irrigated experimental field. Irrigation was applied for the first two weeks after transplanting at four days interval. The experimental plots were irrigated in every six days using furrow irrigation system (Lemma and Shimeles, 2003). Fertilizer di-ammonium phosphate (DAP) was applied during transplanting at the rate of 100 kg/ha (18% N: 46% P₂O₅). Urea was applied at the rate of 100kg/ha (46% N) in split applications at transplanting and a month after

transplanting (EARO, 2004). Cultivation, weeding and all other agronomic practices, except insecticides application, were followed for all plots uniformly.

3.3.1. Experiment one: Efficacy of selected bio-rational insecticides against onion thrips

The experiment was conducted in the dry season where there was a high level of thrips population. The experiment was set in a randomized complete block design (RCBD) with four replications. The plot size was 25m² (5m x 5m). Onion seedlings were planted in double row spacing. The spacing between furrows were 40 cm, double rows in a furrow 30 cm and between plants 10cm (Lemma and Shimeles, 2003). The experiment had eight treatments, i.e., nimbecidine, spinosad, spinetoram, mixture of natural plant extracts and phytoenzyme, *Sophora flavescens* plant extract 25% + emamectin benzoate 1% SL, *Milletia ferruginea*, synthetic insecticide (profenofos as a standard check) and untreated plots (Table 1). The insecticides were applied using a manual knapsack sprayer of 15 liters capacity. Onion thrips infestation started to appear within the first two weeks after transplanting. Prior to each spray the number of thrips were counted from ten randomly selected plants from the middle rows in each plot with the aid of 10x magnifying hand lens and when the onion thrips population reached the economic threshold level of 5-10 thrips/plants (Abate, 1985) insecticides were applied. The experimental plots were sprayed four times within ten days interval. The first spray was applied (38 days at Batu and 40 days at Meki) after transplanting. Three days after each insecticide spray, the number of thrips per plant in each plot was counted using the sampling procedure described above.

3.3.1.1. Method of milletia seed extraction

Seeds of *M. ferruginea* were collected from mature trees in Hawassa. Milletia seeds were dried in well-ventilated area under shade and then grounded to a fine powder. The powdered seed material was soaked in distilled water at 50g/L and left 24hrs as described by Keshav and Singh (2013). The mixture was filtered with cheese cloth and made ready for spraying (Bekele, 2002).

Table 1: Experimental treatments

Trt No	Trade name	Common name	Rate of application	Rate of water	Formulation
1	Azadirachitin0.03%	Nimbecidine	3L/ha	600L/ha	EC
2	Tracer480SC	Spinosad	0.15L/ha	200L/ha	SC
3	Radiant120SC	Spinetoram	0.15L/ha	200L/ha	SC
4	Gomite	Mixture of natural plant extracts and phytoenzyme	1L/ha	300L/ha	EC
5	Aketchi 260SL	<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	0.5L/ha	300L/ha	SL
6	<i>M. ferruginea</i>	Birbira	50g/L	300L/ha with 5% aqueous Milletia seed powder suspension	SP
7	Ajanta72%EC	Profenofos	0.7L/ha	300L/ha	EC
8	Untreated				

The efficacy of the insecticides was calculated using Henderson Tilton's (1955) formula

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

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

3.3.2. Experiment two: Efficacy of selected synthetic and bio-rational insecticides in rotation against onion thrips

The experiments were laid out in a randomized complete block design (RCBD) with four replications. The plot size was 25m² (5m x 5m). Onion seedlings were planted in double row spacing. The spacing between furrows was 40cm, double rows in a furrow 30cm and between plants 10cm (Lemma and Shimeles, 2003). The experiment had seven treatments i.e., nimbecidine + profenofos, nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + profenofos, mixture of natural plant extracts and phytoenzyme + imidacloprid, imidacloprid, profenofos and untreated plots (Table 2). Prior to each spray the number of thrips were counted from ten randomly selected plants from the middle rows in each plot with the aid of 10x magnifying hand lens and when the onion thrips population reached the economic threshold level of 5-10 thrips/plants insecticides were applied (Abate, 1985). The plots were sprayed four times at ten days interval using a manual knapsack spray. In the insecticide rotation experiment with bio-rational and synthetic insecticides; the first and fourth sprays were bio-rationals and the second and third applications were synthetic insecticides (Table 2). The first spray was applied (38days at Batu and 40 days at Meki) after transplanting. Three days after each insecticide spray, the number of thrips per plant in each plot was counted using the sampling procedure described above.

Table 2: Experimental treatments and spray sequence

Trt. No	Trt. Code	Sequence of spray			
		1 st spray	2 nd spray	3 rd spray	4 th spray
1	A	Nimbecidine	Profenofos	Profenofos	Nimbecidine
2	B	Nimbecidine	Imidacloprid	Imidacloprid	Nimbecidine
3	C	Mixture of natural plant extracts and phytoenzyme	Profenofos	Profenofos	Mixture of natural plant extracts and phytoenzyme
4	D	Mixture of natural plant extracts and phytoenzyme	Imidacloprid	Imidacloprid	Mixture of natural plant extracts and phytoenzyme
5	E	Imidacloprid	Imidacloprid	Imidacloprid	Imidacloprid
6	F	Profenofos	Profenofos	Profenofos	Profenofos
7	G	Untreated	Untreated	Untreated	Untreated

Nimbecidine was sprayed with a rate of 3L/ha diluted in 600L/ha of water, mixture of natural plant extracts and phytoenzyme in 1L/ha diluted in 300L/ha of water, profenofos in 0.7L/ha diluted in 300L/ha of water and imidacloprid 0.4L/ha diluted in 200L/ha of water.

The efficacy of the insecticides was calculated using Henderson Tilton's (1955) formula

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

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

3.4. Data Collected

3.4.1. Number of thrips per plant

Data on number of thrips were recorded by counting onion thrips randomly selected ten plants from middle rows. When the onion thrips population reached economic threshold level of 5-10 thrips/plant the insecticides were sprayed (Abate, 1985). Thrips was counted by examination of the randomly selected plants with the aid of 10x magnifying hand lens. Counting of thrips was during wind free time of the day early in the morning and late afternoon. The numbers of thrips were counted pre- and post-spray of insecticides. Three days after each insecticide spray, the number of thrips per plant in each plot was counted.

3.4.2. Growth and yield parameters

Leaf length (cm): The longest leaves of ten randomly selected plants at physiological maturity was measured from the point of their emergence using ruler and expressed as a mean value in centimeter (cm) and used for further analysis.

Average bulb weight (gm): The average bulb weight of ten randomly selected plants were harvested from each plot at the middle row (Guesh, 2015).

Bulb yield (ton/ha): The bulb yield obtained from the net plot area of each plot was measured in kilogram and expressed as ton per hectare (Lemma and Shimeles, 2003).

3.4.3. Crop yield gain

Crop yields gain due to protection of onion thrips was calculated in percent (%) by using the following formula

$$\text{Yield gain \%} = \frac{(\text{Protected treatment} - \text{Untreated treatment})}{\text{Untreated treatment}} * 100$$

3.4.4. Partial budget Analysis

Cost of treatments (ETB/ha): Price of the insecticides and application costs were recorded.

Gross returns (ETB/ha): The bulb yield was converted into gross return in birr based on the prevailing market prices.

Net return (ETB/ha): The treatments of net returns were obtained by subtracting the cost of treatments from the gross returns.

Cost benefit ratio (C: B) = cost of treatments (ETB)/Net return (ETB).

3.5. Data Analysis

Data were subjected to analysis of variance (ANOVA) using the PROC-GLM procedure of SAS (Statistical Analysis System) version 9.0 (SAS Institute Inc., 2005) software. Differences among treatment means were separated using Tukey's honestly range significant difference (HSD) at 5% independent level of significance (Gomez and Gomez, 1984).

4. RESULTS AND DISCUSSION

4.1. Efficacy of Selected Bio-rational Insecticides against Onion Thrips

4.1.1. Population of onion thrips

The mean number of thrips per onion plant in the experimental field was 10.90 at Meki and 8.75 at Batu before the first application of insecticides. The first application of insecticides significantly reduced the number of thrips compared with untreated plots at Meki and Batu locations. Few thrips survived on onion treated with profenofos (0.47, 0.25 thrips/plant), spinosad (0.87, 0.45 thrips/plant), nimbecidine (0.95, 0.55 thrips/plant) and mixture of natural plant extracts and phytoenzyme (0.99, 0.92 thrips/plant), whereas, the number of thrips were significantly higher on spinetoram (2.15, 1.57 thrips/plant), *S. flavescens* plant extract 25% + emamectin benzoate 1% SL (3.05, 2.02 thrips/plant) and *M. ferruginea* (4.60, 3.89 thrips/plant) at Meki and Batu, respectively (Table 3 and 4). Spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme effectively controlled thrips on onion and were comparable to the standard check profenofos; followed by spinetoram and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas *M. ferruginea* caused the least mortality on onion thrips population in both locations (Table 3 and 4).

Similar trends of performance were observed during the second-round spray which was conducted ten days after the first spray. All the insecticide treatments significantly reduced onion thrips population compared to the untreated plots. The post-spray population densities of thrips (thrips/plant) on the profenofos, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme sprayed plots were the lowest; followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* in descending

order compared with the untreated plots. The thrips population on spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme treated plots were comparable with the standard check (profenofos); followed by spinetoram and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas *M. ferruginea* caused the least thrips mortality in both locations (Table 3 and 4).

Successive application of the insecticides profenofos, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme in the third and fourth spray reduced the population of thrips significantly to very low levels; followed by spinetoram and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL. Application of *M. ferruginea* caused the lowest onion thrips mortality compared to other treatments in both locations but was significantly higher than the untreated plots (Table 3 and 4).

More than 90% efficacies were obtained from profenofos, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme treatments during the four successive sprays which indicated that they were highly equally effective. The bio-rational insecticides; spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme had also >90% field efficacy comparable to standard insecticide profenofos at Meki and Batu. During the four successive sprays the lowest and highest efficacy of spinetoram (83.4 – 87.6%), *S. flavescens* plant extract 25% + emamectin benzoate 1% SL (76.5 – 84.0%) and *M. ferruginea* (61.4 – 69.3%) was recorded. These efficacy percentages were less than 90% and not comparable to standard insecticide profenofos at both Meki and Batu (Table 5).

Table 3: Effect of insecticides applications on the population density of thrips at Meki during 2019/2020

Treatments	First spray	Second spray		Third spray		Fourth spray	
	Post	Pre	Post	Pre	Post	Pre	Post
	spray	spray	spray	spray	spray	spray	spray
	Mean number of thrips per plant						
Nimbecidine	0.95 ^d	9.00 ^{de}	0.69 ^d	7.60 ^{cd}	0.46 ^e	7.02 ^b	0.45 ^d
Spinosad	0.87 ^d	8.10 ^{de}	0.57 ^d	7.15 ^{cd}	0.32 ^e	6.82 ^b	0.41 ^d
Mixture of natural plant extracts and phytoenzyme	0.99 ^d	9.65 ^{cd}	0.98 ^d	9.22 ^{bc}	0.95 ^{de}	8.97 ^b	0.88 ^d
Spinetoram	2.15 ^c	10.30 ^{bcd}	1.85 ^{cd}	9.50 ^{bc}	1.67 ^{cd}	9.52 ^b	1.60 ^{cd}
<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	3.05 ^c	11.30 ^{bc}	2.95 ^{bc}	11.40 ^b	2.50 ^c	10.95 ^b	2.60 ^c
<i>M. ferruginea</i>	4.60 ^b	12.17 ^b	4.40 ^b	11.80 ^b	4.37 ^b	11.50 ^b	4.50 ^b
Profenofos	0.47 ^d	7.02 ^e	0.34 ^d	6.47 ^d	0.22 ^e	5.40 ^b	0.18 ^d
Untreated	13.50 ^a	18.15 ^a	21.32 ^a	29.30 ^a	31.50 ^a	47.86 ^a	48.52 ^a
Tukey/HSD (0.05)	1.11	2.52	1.53	2.74	0.99	7.92	1.51
SE(m)	0.47	1.07	0.65	1.17	0.42	3.38	0.64
CV (%)	14.21	9.94	15.86	10.12	8.12	25.06	8.68

Means followed by the same letter(s) with in a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference at $P \leq 0.05$, CV = Coefficient of variance, SE (m) = standard error of the mean.

Table 4: Effect of insecticides applications on the population density of thrips at Batu during 2019/2020

	First spray	Second spray	Third spray	Fourth spray			
Treatments	Post spray	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
Mean number of thrips per plant							
Nimbecidine	0.55 ^{de}	9.02 ^{cd}	0.60 ^d	9.42 ^c	0.71 ^e	8.97 ^c	0.50 ^c
Spinosad	0.45 ^{de}	8.52 ^d	0.52 ^d	9.32 ^c	0.69 ^{ef}	8.88 ^c	0.46 ^c
Mixture of natural plant extracts and phytoenzyme	0.92 ^{cde}	9.17 ^{cd}	0.90 ^d	9.88 ^{bc}	1.00 ^e	9.10 ^c	0.90 ^c
Spinetoram	1.57 ^{cd}	10.85 ^{bc}	1.86 ^c	10.07 ^b	1.65 ^c	9.55 ^{bc}	1.42 ^c
<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	2.02 ^c	10.97 ^b	2.35 ^c	11.02 ^b	2.51 ^c	10.37 ^{bc}	2.36 ^{bc}
<i>M. ferruginea</i>	3.89 ^b	11.57 ^b	4.05 ^b	11.12 ^b	3.75 ^b	11.60 ^b	3.87 ^b
Profenofos	0.25 ^e	6.05 ^e	0.20 ^d	5.85 ^d	0.19 ^f	5.52 ^d	0.12 ^c
Untreated	12.65 ^a	21.47 ^a	22.80 ^a	29.95 ^a	31.75 ^a	39.35 ^a	39.87 ^a
Tukey/HSD (0.05)	1.16	1.99	0.75	1.37	0.48	2.07	2.31
SE(m)	0.49	0.85	0.34	0.58	0.20	0.88	0.98
CV (%)	17.86	7.79	7.78	4.86	3.93	6.85	15.98

Means followed by the same letter(s) with in a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference at $P \leq 0.05$, CV = Coefficient of variance, SE (m) = standard error of the mean.

Table 5: Efficacy of bio-rational insecticides against onion thrips at Meki and Batu

	Locations							
	Meki				Batu			
	First spray	Second spray	Third spray	Fourth spray	First spray	Second spray	Third spray	Fourth spray
Treatments	Percent Efficacy							
Nimbecidine	92.9	93.4	94.3	93.6	95.6	94.0	93.0	94.7
Spinosad	93.5	94.0	95.8	94.1	96.4	94.3	93.9	95.0
Mixture of natural plant extracts and phytoenzyme	92.6	91.3	90.4	90.3	92.7	91.0	90.5	90.2
Spinetoram	84.1	85.0	83.6	83.4	87.6	84.0	85.0	85.3
<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	77.4	78.0	79.6	76.5	84.0	79.8	78.6	77.6
<i>M. ferruginea</i>	65.9	69.2	65.5	61.4	69.3	67.0	68.2	67.1
Profenofos	96.5	95.7	97.2	96.7	98.0	96.8	96.9	97.8

Spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme proved to be the best insecticides for the control of thrips, they were comparable with standard synthetic insecticide (profenofos); followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas *M. ferruginea* had least efficacy against onion thrips. The current results were similar with findings by Barakat and Kordy (2013) that among tested insecticides efficacy percentage of nimbecidine and spinosad against onion thrips was 94.88% and 94.34%, respectively. Shaikh (2013) reported that the profenofos and spinosad treatments were effective against thrips on onion. Vanisree *et al* (2013) conducted field experiments during 2008-09 and 2009-10 and spinosad was found effective in reducing the population of Chilli thrips (*Scirtothrips dorsalis*) and resulted in high yield. Shelton *et al* (2008) reported that acetamiprid, dimethioate and spinosad performed better control against thrips on cabbage. According to Shankar *et al* (2008), from different insecticides evaluated against chilli thrips,

acephate and profenofos were effective in reducing the population of chilli thrips. According to Mahmoud and Osman (2007) spinosad, emamectin benzoate, azadirachtin and *Beauveria bassiana* gave the best control and continued to give significant reduction in onion thrips population. Spinosad and spinetoram have been widely used for the control of thrips (including western flower thrips, onion thrips and chill thrips) on fruit and leafy vegetables, tree fruits and ornamentals globally (Dripps *et al.*, 2011). In the current study, *M. ferruginea* caused the least mortality to onion thrips similar with findings of Abdul *et al* (2014), the botanicals (neem, datura and bitter apple) gave not more than 60% control of thrips.

4.1.2. Growth and yield parameters

4.1.2.1. Leaf length (cm)

The longest leaf length was recorded from profenofos treated plots 47.50 and 43.67cm at Meki and Batu locations, respectively. However, it was not statistically different from spinosad, nimbecidine, mixture of natural plant extracts and phytoenzyme, spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL treatments. Significantly the shortest leaf length was recorded from untreated plots 29.12 and 30.57cm at Meki and Batu, respectively (Table 6).

4.1.2.2. Average bulb weight (g)

The highest bulb weight was recorded from profenofos treated plots 87.45 and 94.29g at Meki and Batu locations, respectively, which were statistically comparable with spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme; followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea*. On the other

hand, lowest bulb weight was recorded from untreated plots 43.77 and 58.26g in both locations (Table 6).

4.1.2.3. Bulb yield (ton/ha)

The highest bulb yield was recorded from profenofos treated plots, 27.34 and 29.83 ton/ha at Meki and Batu, respectively, which was statistically equal to spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme; followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea*. On the other hand, lowest bulb yield was recorded from untreated plots 12.42 and 14.43 ton/ha at Meki and Batu, respectively (Table 6).

4.1.3. Yield gain (%)

The highest yield gain was recorded from profenofos treated plots at Meki (120.12%) and Batu (106.72%) which were also not significantly different from spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme treated plots; followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas *M. ferruginea* treated plots had lowest yield gain of 47.18% and 36.38% at Meki and Batu, respectively (Table 6).

Table 6: Effect of insecticides on growth and yield parameters and yield gain

Treatments	Locations							
	Meki				Batu			
	Leaf length	Bulb weight/plant (g)	Bulb yield (ton/ha)	Yield gain (%)	Leaf length	Bulb weight/plant (g)	Bulb yield (ton/ha)	Yield gain (%)
Nimbecidine	45.52 ^{ab}	85.95 ^{ab}	26.06 ^a	109.82	43.02 ^a	91.51 ^{ab}	29.09 ^a	101.59
Spinosad	47.47 ^a	86.85 ^{ab}	27.18 ^a	118.84	43.59 ^a	92.39 ^{ab}	29.38 ^a	103.60
Mixture of natural plant extracts and phytoenzyme	43.32 ^{ab}	85.40 ^{ab}	25.76 ^{ab}	107.40	42.49 ^a	90.77 ^{ab}	28.54 ^a	97.78
Spinetoram	43.27 ^{ab}	80.60 ^{bc}	23.58 ^{bc}	89.85	40.94 ^{ab}	85.85 ^{bc}	26.90 ^b	86.41
<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	40.27 ^{ab}	75.95 ^c	21.84 ^c	75.84	40.39 ^{ab}	82.24 ^c	25.41 ^c	76.09
<i>M. ferruginea</i>	38.07 ^b	73.99 ^c	18.28 ^d	47.18	36.09 ^{bc}	78.94 ^c	19.68 ^d	36.38
Profenofos	47.50 ^a	87.45 ^a	27.34 ^a	120.12	43.67 ^a	94.29 ^a	29.83 ^a	106.72
Untreated	29.12 ^c	43.77 ^d	12.42 ^e		30.57 ^c	58.26 ^d	14.43 ^e	
Tukey/HSD (0.05)	8.34	7.15	2.27		6.5	7.95	1.36	
SE(m)	3.56	3.05	0.96		2.47	3.39	0.58	
CV (%)	8.51	3.94	4.25		6.13	4.02	2.29	

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference, CV = Coefficient of variance, SE(m) = standard error of the mean.

The profenofos, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme treatments effectively controlled onion thrips and gave significantly higher yield and yield gain in both locations; followed by spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea*. Hossain *et al* (2014) reported similar findings of lowest thrips population and highest onion yield on plots protected with spinosad and nimbecidine.

According to Kalola *et al* (2017) garlic thrips were effectively controlled and gave higher yield in plots treated with cypermethrin, fipronil, lambda cyhalothrin, profenofos, profenofos + cypermethrin, spinosad and imidacloprid. Similarly, Patil *et al* (2009) reported that treatment with spinosad and deltamethrin + triazophos resulted in higher onion yield.

4.1.4. Partial budget analysis

4.1.4.1. Cost of treatment (ETB/ha)

The highest cost of treatment was recorded from spinosad (8000 birr/ha) followed by spinetoram, nimbecidine, mixture of natural plant extracts and phytoenzyme, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and profenofos, whereas the lowest cost of treatment was recorded from *M. ferruginea* treated plots (3000 birr/ha) in both locations (Table 7).

4.1.4.2. Gross return (ETB/ha)

The highest gross return was recorded from profenofos, 273400 birr/ha at Meki and 298300 birr/ha Batu; followed by spinosad, nimbecidine, mixture of natural plant extracts and phytoenzyme, spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea*. The lowest gross return was recorded from untreated plots 124300 birr/ha and 144300 birr/ha in Meki and Batu, respectively (Table 7).

4.1.4.3. Net return (ETB/ha)

The highest net return was obtained from profenofos treated plots, 269440 birr/ha at Meki and 294340 birr/ha Batu; followed by spinosad, nimbecidine, mixture of natural plant extracts and

phytoenzyme, spinetoram and *S. flavescens* plant extract 25% + emamectin benzoate 1% SL whereas the lowest net return was recorded from *M. ferruginea* treated plots 179800 birr/ha and 193800 birr/ha at Meki and Batu, respectively (Table 7).

4.1.4.4. Cost benefit ratio (C: B)

The highest cost benefit ratio was recorded from profenofos treated plots 1:68 and 1:74 at Meki and Batu locations, respectively; followed by mixture of natural plant extracts and phytoenzyme, *M. ferruginea*, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL, nimbecidine, spinosad and spinetoram in both locations (Table 7).

Table 7: Partial budget analysis of different treatments

Treatments	Bulb yield (ton/ha)		Gross return (birr/ha)		Cost of treatment (birr/ha)		Net return (birr/ha)		Cost benefit ratio	
	Meki	Batu	Meki	Batu	Meki	Batu	Meki	Batu	Meki	Batu
Nimbecidine	26.06	29.09	260600	290900	5000	5000	255600	285900	1:51	1:57
Spinosad	27.18	29.38	271800	293800	8000	8000	263800	285800	1:32	1:35
Mixture of natural plant extracts and phytoenzyme	25.76	28.54	257600	285400	4000	4000	253600	281400	1:63	1:70
Spinetoram	23.58	26.90	235800	269000	7520	7520	228280	261480	1:30	1:34
<i>S. flavescens</i> plant extract 25% + emamectin benzoate 1% SL	21.84	25.41	218400	254100	4000	4000	214400	250100	1:53	1:62
<i>M. ferruginea</i>	18.28	19.68	182800	196800	3000	3000	179800	193800	1:59	1:64
Profenofos	27.34	29.83	273400	298300	3960	3960	269440	294340	1:68	1:74
Untreated	12.43	14.43	124300	144300	-	-	-	-	-	-

Market price of onion bulbs 10 birr/Kg, cost of treatments also included application charges 500 birr/ha/spray

4.2. Efficacy of Selected Bio-rational and Synthetic Insecticides in Rotation against Onion Thrips

4.2.1. Population of onion thrips

The number of thrips per onion plant in the experimental field was 10.64 at Meki and 9.02 at Batu before the first application of insecticides. The first application of insecticides significantly reduced the number of thrips compared with untreated plots at Meki and Batu locations. Few thrips (0.45 - 1.15 thrips/plant at Meki) and (0.12 - 0.97 thrips/plant at Batu) survived on profenofos, nimbecidine and mixture of natural plant extracts and phytoenzyme whereas imidacloprid significant different among the treatments. Mixture of natural plant extracts and phytoenzyme and nimbecidine effectively controlled thrips on onion and were comparable to the standard check profenofos, whereas imidacloprid caused the least mortality onion thrips population in both locations (Table 8 and 9).

During the second and third spray low thrips/plant count (0.27 - 0.57 thrips/plant at Meki and 0.05 - 0.32 thrips/plant at Batu) were recorded on profenofos sprayed plots, whereas in imidacloprid treated plots higher number of thrips (2.60 - 3.83 thrips/plant at Meki and 2.62 - 3.95 thrips/plant at Batu) survived compared with standard check profenofos. There was significant different between profenofos and imidacloprid treatments (Table 8 and 9).

Similar trends to the first spray were observed during the fourth spray. Few thrips survived on profenofos, nimbecidine and mixture of natural plant extracts and phytoenzyme treated plots, whereas imidacloprid significant different among the treatments. Mixture of natural plant extracts and phytoenzyme and nimbecidine effectively controlled thrips on onion crop and

were comparable to the standard check insecticide profenofos whereas imidacloprid caused the least mortality on onion thrips in both locations (Table 8 and 9).

Efficacy of profenofos, nimbecidine and mixture of natural plant extracts and phytoenzyme was more than 90% which indicated that they were equally effective. Mixture of natural plant extracts and phytoenzyme and nimbecidine had desirable field efficacy (>90%) comparable to standard insecticide profenofos at Meki and Batu locations. During the four sequential sprays the low efficacy was recorded from imidacloprid (70.2 – 78.3%) treated plots. The efficacy percentage obtained from imidacloprid treatments were less than 90% and not equally effective with standard insecticide profenofos at Meki and Batu, respectively (Table 10).

Low efficacy of imidacloprid insecticide might be due to resistance development. According to Nault and Shelton (2010) different classes of insecticides have different performances because of their different inherent toxicities to insects as well as evolving resistance due to over dependence on a single insecticide product. According to Belay *et al* (2017) vegetable growers in Ethiopia like farmers in several African countries rely on one effective product for the control of a particular pest. This practice may result in the development of pesticide resistant population nullifying the controlling capacity of the product. According to Gholam and Sadeghi (2016) 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. Verma *et al* (2012) reported that imidacloprid treatment on garlic resulted in minimum number of thrips followed by fipronil, which clearly elustrates that thrips were susceptible or resistant groups were few.

Table 8: Effect of insecticides application on the population density of thrips at Meki during 2019/2020

	First spray	Second spray		Third spray		Fourth spray	
Treatments	Post spray	Pre spray	Post spray	Pre spray	Post spray	Pre spray	Post spray
Mean number of thrips per plant							
N-P-P-N	0.92 ^c	8.00 ^{de}	0.40 ^c	6.02 ^d	0.27 ^c	5.82 ^c	0.41 ^C
N-I-I-N	0.97 ^c	8.95 ^{cd}	2.60 ^b	10.00 ^c	2.65 ^b	11.20 ^b	0.87 ^C
M-P-P-M	1.07 ^c	9.45 ^{cd}	0.57 ^c	6.40 ^d	0.37 ^c	5.12 ^c	0.42 ^C
M-I-I-M	1.15 ^c	9.60 ^c	3.12 ^b	11.35 ^{bc}	3.40 ^b	11.10 ^b	1.00 ^c
I-I-I-I	3.62 ^b	12.15 ^b	3.75 ^b	12.60 ^b	3.83 ^b	11.55 ^b	3.30 ^b
P-P-P-P	0.45 ^c	6.82 ^e	0.35 ^c	6.38 ^d	0.28 ^c	5.65 ^c	0.30 ^d
U	16.70 ^a	23.15 ^a	25.62 ^a	30.27 ^a	32.87 ^a	37.57 ^a	38.20 ^a
Tukey/HSD (0.05)	1.59	1.46	1.73	1.89	1.46	1.15	0.79
SE(m)	0.69	0.63	0.75	0.82	0.64	0.50	0.78
CV (%)	19.42	5.69	14.48	6.94	10.28	3.92	11.76

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference at $P \leq 0.05$, CV = Coefficient of variance, SE(m) = standard error of the mean, N = nimbecidine, M = mixture of natural plant extracts and phytoenzyme, I = imidacloprid, P = profenofos and U = untreated.

Table 9: Effect of insecticides application on the population density of thrips at Batu during 2019/2020

	First spray	Second spray		Third spray		Fourth spray	
Treatments	Post spray	Pre	Post	Pre	Post	Pre	Post
		spray	spray	spray	spray	spray	spray
Mean number of thrips per plant							
N-P-P-N	0.78 ^{cd}	9.32 ^c	0.22 ^d	5.02 ^d	0.12 ^c	5.00 ^c	0.34 ^c
N-I-I-N	0.70 ^{cd}	9.28 ^c	2.62 ^c	9.52 ^c	2.95 ^b	9.80 ^b	0.82 ^c
M-P-P-M	0.90 ^{cd}	9.60 ^c	0.32 ^d	5.85 ^d	0.16 ^c	5.27 ^c	0.40 ^c
M-I-I-M	0.97 ^c	9.82 ^c	3.10 ^{bc}	11.50 ^{bc}	3.37 ^b	11.62 ^b	0.98 ^c
I-I-I-I	3.20 ^b	12.05 ^b	3.60 ^b	12.57 ^b	3.95 ^b	12.62 ^b	3.77 ^b
P-P-P-P	0.12 ^d	5.27 ^d	0.07 ^d	5.05 ^d	0.05 ^c	4.45 ^c	0.02 ^c
U	12.92 ^a	20.20 ^a	21.42 ^a	28.05 ^a	29.77 ^a	38.30 ^a	39.50 ^a
Tukey/HSD (0.05)	0.80	1.43	0.65	3.04	0.99	3.55	1.97
SE(m)	0.34	0.62	0.28	1.34	0.47	1.54	0.86
CV (%)	12.71	5.83	6.25	11.96	8.28	12.41	13.05

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference at $P \leq 0.05$, CV= Coefficient of variance, SE(m) = standard error of the mean, N = nimbecidine, M = mixture of natural plant extracts and phytoenzyme, I = imidacloprid, P = profenofos and U = untreated.

Table 10: Efficacy of tested insecticides on onion thrips at Meki and Batu

Locations								
Meki					Batu			
Percent Efficacy								
Treatments	First	Second	Third	Fourth	First	Second	Third	Fourth
	spray	spray	spray	spray	spray	spray	spray	spray
N-P-P-N	94.5	95.4	96.0	93.5	93.9	97.8	97.7	93.4
N-I-I-N	94.2	73.5	75.6	93.0	94.6	73.0	70.8	92.0
M-P-P-M	93.6	95.0	95.6	92.0	93.0	96.8	97.4	92.7
M-I-I-M	93.1	71.0	72.4	91.1	92.4	70.2	72.3	92.0
I-I-I-I	78.3	72.1	72.0	71.9	75.2	72.0	70.3	71.0
P-P-P-P	97.3	95.3	96.0	95.0	99.0	98.7	99.1	97.4

N = nimbecidine, M = mixture of natural plant extracts and phytoenzyme, I = imidacloprid and P = profenofos.

4.2.2. Growth and yield parameters

4.2.2.1 Leaf length (cm)

The longest leaf length was recorded from nimbecidine + profenofos treated plots at Meki (52.92cm) and Batu (48.83cm), respectively. Nimbecidine + profenofos and mixture of natural plant extracts and phytoenzyme + profenofos treatments were comparable with profenofos and followed by nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + imidacloprid and imidacloprid treatments. Significantly the shortest leaf length was recorded from untreated plots at Meki (23.62cm) and Batu (36.13cm), respectively (Table 11).

4.2.2.2. Average bulb weight (g)

The highest bulb weight was recorded from nimbecidine + profenofos treated plots at Meki (100.45g) and Batu (114.60g). Mean bulb weight from nimbecidine + profenofos and mixture

of natural plant extracts and phytoenzyme + profenofos treatments were statistically equivalent with profenofos treated plots. Nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + imidacloprid and imidacloprid treatments significantly lower mean bulb weight. Significantly the lowest bulb weight was recorded from untreated plots at Meki (64.15g) and Batu (56.03g) (Table 11).

4.2.2.3. Bulb yield (ton/ha)

The highest bulb yield was from nimbecidine + profenofos treated plots at Meki (29.75 ton/ha) and Batu (31.22 ton/ha) which is statistically equal to the treatments of mixture of natural plant extracts and phytoenzyme + profenofos and profenofos and followed by nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + imidacloprid treatments. Plots protected with imidacloprid resulted the lowest bulb yield (19.15 and 22.71 ton/ha at Meki and Batu, respectively) compared with the rest of insecticide treatments. Significantly the lowest bulb yield was recorded from untreated plots 13.93 and 14.36 ton/ha at Meki and Batu, respectively (Table 11).

4.2.3. Yield gain (%)

The highest yield gain was recorded from nimbecidine + profenofos treated plots at Meki (113.56%) and Batu (117.40%), respectively. Higher yield gains were also obtained from nimbecidine + profenofos, mixture of natural plant extracts and phytoenzyme + profenofos and profenofos treated plots; followed by nimbecidine + imidacloprid and mixture of natural plant extracts and phytoenzyme + imidacloprid. On the other hand, imidacloprid treated plots recorded lowest yield gain, 37.47% and 58.14% at Meki and Batu, respectively (Table 11).

Table 11: Effect of insecticides on growth and yield parameters and yield gain

Treatments	Locations							
	Meki				Batu			
	Leaf length	Bulb weight/pl ant (g)	Bulb yield(to ns/ha)	Yield gain (%)	Leaf length	Bulb weight/ plant (g)	Bulb yield (t/ha)	Yield gain (%)
N-P-P-N	52.92 ^a	100.45 ^a	29.75 ^a	113.56	48.83 ^a	114.60 ^a	31.22 ^a	117.40
N-I-I-N	44.45 ^{bc}	82.10 ^b	26.18 ^{bc}	87.93	44.01 ^{bc}	91.98 ^b	29.16 ^{cd}	103.06
M-P-P-M	50.72 ^{ab}	89.35 ^{ab}	28.35 ^{ab}	103.51	47.55 ^{ab}	107.31 ^a	30.41 ^a	111.76
M-I-I-M	43.22 ^{bc}	80.70 ^b	24.50 ^c	75.87	42.02 ^c	90.00 ^{bc}	28.18 ^d	96.23
I-I-I-I	40.15 ^c	75.57 ^{bc}	19.15 ^d	37.47	40.34 ^{cd}	81.52 ^c	22.71 ^e	58.14
P-P-P-P	48.75 ^{ab}	86.96 ^{ab}	27.89 ^{ab}	100.21	47.40 ^{ab}	106.59 ^a	30.34 ^a	111.28
U	23.62 ^d	64.15 ^c	13.93 ^e		36.13 ^d	56.03 ^d	14.36 ^f	
Tukey/HSD (0.05)	8.07	14.18	2.29		4.22	8.95	1.02	
SE(m)	3.51	6.16	0.99		1.83	3.89	0.48	
CV (%)	8.09	7.45	4.11		4.19	4.20	1.87	

Means followed by the same letter(s) within a column are not significantly different from each other at 5% level of significance using Tukey's honestly significant difference test, HSD = honestly significant difference, CV = Coefficient of variance, SE(m) = standard error of the mean, N = nimbecidine, M = mixture of natural plant extracts and phytoenzyme, I = imidacloprid, P = profenofos and U = untreated.

Low yield was obtained from untreated plots due to high onion thrips infestation. Mayer *et al* (1987) reported that onion thrips do not reduce onion yield unless the pest infestation above economic threshold level. Malik *et al* (2003) reported that thrips population densities have an indirect effect on yield. Shiberu *et al* (2013) also reported a negative relationship between thrips population and onion bulb yield when the population densities of thrips above economic threshold level.

4.2. 4. Partial budget analysis

4.2.4.1. Cost of treatment (ETB/ha)

The highest cost of treatment was recorded from nimbecidine + profenofos treated plots, (4480 birr/ha) in both locations; followed by nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + profenofos, mixture of natural plant extracts and phytoenzyme + imidacloprid and profenofos, whereas the lowest cost of treatment was from imidacloprid treated plots (3920 birr/ha) at Meki and Batu locations (Table 12).

4.2.4.2 Gross return (ETB/ha)

The highest gross return was recorded from nimbecidine + profenofos at Meki (297500 birr/ha) and Batu (312200 birr/ha), respectively; followed by mixture of natural plant extracts and phytoenzyme + profenofos, profenofos, nimbecidine + imidacloprid, mixture of natural plant extracts and phytoenzyme + imidacloprid and imidacloprid. The lowest gross return was from untreated plots, 139300 birr/ha and 143600 birr/ha at Meki and Batu, respectively (Table 12).

4.2.4.3. Net return (ETB/ha)

The highest net return was obtained from nimbecidine + profenofos treated plots at Meki (293020 birr/ha) and Batu (307720 birr/ha); followed by mixture of natural plant extracts and phytoenzyme + profenofos, profenofos, nimbecidine + imidacloprid and mixture of natural plant extracts and phytoenzyme + imidacloprid whereas the lowest net return was recorded from imidacloprid treated plots 187580 birr/ha and 223180 birr/ha at Meki and Batu, respectively (Table12).

4.2.4.4. Cost benefit ratio (C: B)

The highest cost benefit ratio was recorded from mixture of natural plant extracts and phytoenzyme + profenofos treated plots 1:70 and 1:75 at Meki and Batu, respectively; followed by profenofos, nimbecidine + profenofos, mixture of natural plant extracts and phytoenzyme + imidacloprid, nimbecidine + imidacloprid and imidacloprid (Table 12).

Table 12: Partial budget analysis of different treatments

Treatments	Bulb yield (tons/ha)		Gross return (birr/ha)		Cost of treatment (birr/ha)		Net return (birr/ha)		Cost benefit ratio	
	Meki	Batu	Meki	Batu	Meki	Batu	Meki	Batu	Meki	Batu
N-P-P-N	29.75	31.22	297500	312200	4480	4480	293020	307720	1:65	1:68
N-I-I-N	26.18	29.16	261800	291600	4460	4460	257340	287140	1:57	1:64
M-P-P-M	28.35	30.41	283500	304100	3980	3980	279520	300120	1:70	1:75
M-I-I-M	24.50	28.18	245000	281800	3960	3960	241040	277840	1:60	1:70
I-I-I-I	19.15	22.71	191500	227100	3920	3920	187580	223180	1:47	1:56
P-P-P-P	27.89	30.34	278900	303400	3960	3960	274940	299440	1:69	1:74
U	13.93	14.36	139300	143600	-	-	-	-	-	-

Market price of onion bulbs 10 birr/Kg, cost of insecticides also included application charges 500 birr/ha/spray.

5. CONCLUSION AND RECOMMENDATIONS

Onion producers in the study areas heavily rely on synthetic insecticides for the control of onion thrips. Therefore, the present study was conducted to test the efficacy of biorational insecticides and their use in rotation with selected synthetic insecticides against onion thrips on onion in Meki and Batu locations during dry season.

Bio-rational insecticides; spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme effectively controlled thrips on onion crop and resulted in high yield which were comparable to the standard insecticide profenofos. Spinetoram, *S. flavescens* plant extract 25% + emamectin benzoate 1% SL and *M. ferruginea* showed lower efficacy (<90%) and less yield compared with spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme and the standard insecticide (profenofos). Therefore, spinosad, nimbecidine and mixture of natural plant extracts and phytoenzyme are recommended to control the onion thrips and can be used as an alternative means of onion thrips control.

Biorational insecticides can also be used in rotation with synthetic insecticides. A mixture of natural plant extracts and phytoenzyme + profenofos and nimbecidine + profenofos applied in rotation effectively controlled onion thrips and resulted in high yield which were comparable to standard insecticide (profenofos). Therefore, nimbecidine + profenofos and mixture of natural plant extracts and phytoenzyme + profenofos insecticides sprayed at recommended rates in every ten days interval can be used to control the onion thrips. However, nimbecidine and mixture of natural plant extracts and phytoenzyme sprayed in rotation with imidacloprid resulted lower yield compared with standard insecticide (profenofos). This was mainly due to low efficacy of imidacloprid insecticide in research areas. The study suggests that

imidacloprid insecticide is less effective and should not be used alone in Meki and Batu areas. However, similar research is required in many areas before terminating the use of this insecticide.

Both experiments showed that all the insecticides significantly reduced onion thrips population compared with untreated plots. Use of insecticides in rotation gave better control of onion thrips population and yield. However, results of the current experiments are based on only two locations with few biorational insecticides and synthetic insecticides were tested. Therefore, studies on the use of biorational insecticides in sole and in rotation with synthetic insecticides should be conducted across different agro ecological zones and in different seasons. Future studies and interventions should be designed to investigate insecticide resistance and devise resistance management solutions.

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7. APPENDICES

Appendix Table 1: Experiment one, Mean square values post-spray count thrips first spray at Meki and Batu

Source of variation	Meki		Batu
	D.F	Post spray means	Post spray means
Treatment	7	75.3717***	105.1583 ***
Replication	3	0.4369	0.1037
Error	21	0.2221	0.0713

*** = highly significant at $p < 0.0001$ and D.F = degree of freedom.

Appendix Table 2: Experiment one, Mean square values of pre- and post-spray count thrips during second spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	7	47.1171 ^{ns}	200.4869***	17.0892 ^{ns}	149.9245***
Replication	3	0.3737	0.4503	0.9469	0.1136
Error	21	1.1614	0.4320	0.7191	0.1024

*** = highly significant at $p < 0.0001$, ns = non- significant and D. F= degree of freedom.

Appendix Table 3: Experiment one, Mean square values of pre- and post-spray count thrips during third spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	7	92.0006 ^{ns}	306.3669***	88.2433 ^{ns}	316.665***
Replication	3	0.3828	0.0170	0.3312	0.3103
Error	21	0.7316	0.2142	0.3481	0.1436

*** = highly significant at $p < 0.0001$, ns = non- significant and D. F= degree of freedom.

Appendix Table 4: Experiment one: Mean square values of pre- and post-spray count thrips during fourth spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray mean	Post spray means
Treatment	7	190.7385 ^{ns}	630.1217 ^{***}	246.0370 ^{ns}	523.5749 ^{***}
Replication	3	0.1661	0.9328	1.5053	1.1178
Error	21	0.5009	0.8282	0.6788	0.9187

*** = highly significant at $p < 0.0001$, ns = non- significant and D. F= degree of freedom.

Appendix Table 5: Experiment one, Mean square of analysis of variance for growth and yield parameters at Meki and Batu

Source of variation	D.F	Meki			Batu		
		LL	ABW	BY	LL	ABW	BY
Treatment	7	147.6 ^{***}	785.7 ^{***}	98.4 ^{***}	81.4 ^{***}	528.2 ^{***}	113.2 ^{***}
Replication	3	7.5	20.7	0.3	14.7	51.3	0.2
Error	21	13.5	11.8	1.1	6.9	5.8	0.3

ABW=Average bulb weight, BY = Bulb yield, LL= leaf length, D. F= Degree of freedom, *** = highly significant at ($p < 0.0001$).

Appendix Table 6: Experiment two; Mean square values of post-spray count of thrips first spray at Meki and Batu

Source of variation	Meki		Batu
	D.F	Post spray means	Post spray means
Treatment	6	108.3476720 ^{***}	59.4948545 ^{***}
Replication	3	0.1471296	0.1232143
Error	18	0.0896296	0.0602513

*** = highly significant at $p < 0.0001$ and D. F= degree of freedom.

Appendix Table 7: Experiment two, Mean square values of pre- and post-spray count of thrips during second spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	6	43.9022619 ^{ns}	222.811389 ^{***}	31.5815476 ^{ns}	161.7998148 ^{***}
Replication	3	0.1838095	0.526878	0.7566667	0.0333730
Error	18	0.4468651	0.400119	0.2613889	0.0590212

*** = highly significant at $p < 0.0001$, ns = non- significant and D.F = degree of freedom.

Appendix Table 8: Experiment two, Mean square values of pre- and post-spray count of thrips during third spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray means	Post spray means
Treatment	6	137.7707143 ^{ns}	414.910225 ^{***}	106.9703571 ^{ns}	346.290595 ^{***}
Replication	3	0.6879762	0.021852	1.4695238	0.309471
Error	18	0.2610317	0.046080	0.8048016	0.237280

*** = highly significant at $p < 0.0001$, ns = non- significant and D.F = degree of freedom.

Appendix Table 9: Experiment two, Mean square values of pre- and post-spray count of thrips during fourth spray at Meki and Batu

Source of variation	Meki			Batu	
	D.F	Pre spray means	Post spray means	Pre spray mean	Post spray means
Treatment	6	218.934524 ^{ns}	479.687116 ^{***}	219.690714 ^{ns}	529.352910 ^{***}
Replication	3	0.061310	0.028082	1.433690	0.823757
Error	18	0.189921	0.088668	1.931190	0.389929

*** = significant at $p < 0.0001$, ns = non- significant and D.F = degree of freedom.

Appendix Table 10: Experiment two, Mean square of analysis of variance for growth and yield parameters at Meki and Batu

Source of variation	D.F	Meki			Batu		
		LL	ABW	BY	LL	ABW	BY
Treatment	6	389.937***	517.7***	131.1***	84.229***	1575.2***	171.2***
Replication	3	11.381	42.5	0.3	2.760	42.4	0.4
Error	18	12.506	37.3	1.0	3.472	10.6	0.2

ABW= Average bulb weight, BY = Bulb yield, LL= leaf length, D.F = Degree of freedom,

*** = highly significant at ($p < 0.0001$)

Appendix figure 1. Field supervision, data recording and spray insecticides



SKETCH OF BIOGRAPHY

The author was born in 1994 at Sidama regional state, Loka Abaya woreda. He attended Elementary education at Gorbe Sala (1 - 6) and junior secondary education (7 - 8) at Ras Desta School. After completion of his junior secondary class, He joined Yirgalem Secondary and preparatory school (9 - 12) at Yirgalem town. Then, He joined Wolaita Sodo University, College of Agriculture in 2011G.C and graduated with the degree of Bachelor of Science in plant science in June 2014G.C. After graduation he was employed Sidama Region, Loka Abaya woreda Agriculture office as a crop expert for one-year 2015 and then joined Youth and Sport sector under the department of rural job opportunity creation as a specific crop expert for two years (2016 – 2017G.C). Then in October 2018 he joined Hawassa University, school of Graduate studies and his Master of Science study in crop protection program.