Tomato pest management practices and efficacy of selected botanical pesticides for management of Tomato Leaf miner (*Tuta absoluta*) in Kathiani, Machakos County

BY

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Thesis submitted in partial fulfilment of the requirements for the award of degree of Masters of Science in Crop Protection

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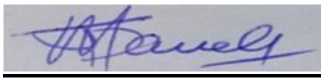
Signature…………  …………Date: 2nd August, 2023

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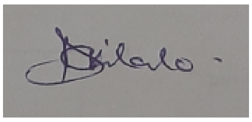
Signature…………..…  …… Date: 15th August, 2023

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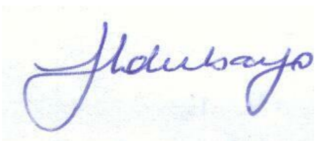
Signature………  …………Date……10th Aug, 2023.

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Dedication

To my dear wife (Agnes Mbeke), my sons (Emmanuel Mutua & Michael Mwendwa), my daughter (Jacinta Koki and my mother (Grace Nduku).

Acknowledgement

First and foremost I would like to thank the Almighty God for granting me good health the entire period of research and thesis compilation. I would also wish to express my sincere thanks and appreciation to my Supervisors Dr. Dora Kilalo and Prof. F.M. Olubayo for the continuous advice, guidance and support. Their patience, motivation, and immense knowledge helped me during my study.

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Acronyms and abbreviation

ANOVA	Analysis of Variance
Bt	*Bacillus thuringiensis*
CAN	Calcium Ammonium Nitrate
CABI	Centre for Agriculture and Bioscience
DAP	Diammonium Phosphate
DDT	Dichlorodiphenyltrichloroethane
HCDA	Horticultural Crops Development Authority
OEPP/EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agricultural Organization
FAOSTAT	Food Agriculture Organization Corporate Statistical Database
GDP	Gross Domestic Product
GOK	Government of Kenya
ICF	International Coaching Federation
IPM	Integrated Pest Management
KARI	Kenya Agricultural Research Institute
KES	Kenya Shillings
KNBS	Kenya National Bureau of Statistics
LSD	Least Significant Difference
MOA	Ministry of Agriculture
MOALFD	Ministry of Agriculture and Livestock and Fisheries Development
MT	Metric Tonnes
NAPPO	North America Plant Protection Organization
NAAIAP	National Accelerated Agricultural Input Access Programme
SPSS	Statistical Package for Social Scientist

Abstract

Tomato in Kenya is the second important vegetable both in production and revenue generation. In recent times, its production and yield has adversely been affected by the recently reported invasive, tomato leaf miner (*Tuta absoluta*). The objectives of the study were to determine farmer management practices of tomato pests and evaluate the bioefficacy of selected biorationals. A survey to determine farmer pest management practices of tomato was conducted by interviewing one hundred tomato small scale growers in Kathiani, Machakos County. A stratified sampling approach was adopted for selecting the sample size of tomato growers from a sampling frame consisting of a list of tomato producers in four administrative wards of Kathiani Sub County. In addition, on-farm experiments were conducted on small holder farms (upper midland four zone -UM 4) in Kathiani for two seasons. The experiments were laid out in a Randomized Complete Block Design (RCBD) in a split plot arrangement with four replications. Two tomato varieties; Rio grande and Tylka F1 were subjected to spray regimes that comprised of Flubendiamide (Belt®); a synthetic pesticide and botanicals; Azadirachtin 0.03% (Nimbecidine), Pyrethrum + Garlic extract (Pyegar) alone and alternate use of Nimbecidine and Pyegar as treatments compared to control.

The study established that significantly ($p<0.05$) more men (75%) grow tomato than women and they use both rainfed and irrigation conditions to produce the crop. Tomato is grown on less than one acre pieces of land out of the 0-5 acres of land that these farmers own. Pests and diseases (43%) and inadequate capital (34%) were the main challenges reported by the growers and *Tuta absoluta* was considered a key pest associated with higher yield loss followed by whitefly and spider mites. Significantly ($p<0.05$) more farmers (93%) had observed Tuta damage in the field but did not know how to identify the pest. The study also established that significantly more farmers (74%) used synthetic pyrethroids mainly alpha cypermethrin and lambda cyhalothrin followed by the use of Flubendiamide in the management of tomato pests, *Tuta absoluta* included. Non chemical management options such as cultural methods intercropping, field hygiene and use of physical barrier were not commonly reported by the farmers indicating low or non-use. Farmers relied on their neighbours and agro-input dealers for agricultural information. The farmer practices are ineffective and there is need for an alternatives to reduce dependency on pesticides.

Efficacy results revealed that there were no differences in leaf damage observed on tomatoes treated with Nimbecidine, Pyegar and Nimbecidine + Pyegar compared to control. However, the percentage leaf damage was much lower in tomatoes treated with either Nimbecidine or Pyegar alone. The lowest percentage leaf damage was recorded in tomatoes treated with Belt®, the standard check; while the highest damage was recorded in the control. The botanicals used and the standard, Belt, significantly ($p<0.05$) reduced tomato leaf miner larva infestation, compared to control. The least recorded was in Belt while highest was recorded in control. The bio pesticides Nimbecidine and Pyegar had the same effect in reducing the larvae infestation but Pyegar achieved slightly higher reduction. The botanicals used and the starndard, Belt, significantly ($p<0.05$) increased the number of tomato fruits compared to untreated control. Belt® recorded the highest number of fruits in both seasons and varieties followed by Pyegar in the second place while control had the least fruits in both seasons and varieties. The combination of Pyrethrum and garlic (Pyegar) and Nimbecidine are effective in reducing leaf damage, Tuta larval infestation on tomato leading to an increase in productivity. Although the botanical extracts were rarely used, the study has demonstrated that they have the potential and are effective for the management of *Tuta absoluta* and can be considered for its management.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tomato (*Lycopersicon esculentum Mill*.) is an important horticultural crop produced all over world. It belongs to the Solanaceae family; other members include tobacco, eggplant (Aubergine), pepper and potato (NAPPO, 2012). According to FAO statistics (2021), production of tomato was approximated to be 189.1 million metric tonnes, of fresh fruit, produced from an approximate 4.8 million ha. In the same year, Africa produced approximately 21.4 million tonnes from about 1,556,547 ha (FAO, 2021). Kenya's tomato production in the same year achieved 702,205 tonnes from acreage of 29,970 ha (FAO, 2021). The area under tomato production has been increasing rapidly over the years because of good returns. Tomato being a short duration crop gives high yields per unit area under good management (Shankara, 2005). However, infestation by pests and diseases continues to hinder tomato production and very recently, it has been affected by an invasive pest; *Tuta absoluta.* It has been reported and proved the most destructive pest (Fatemeh *at al.*, 2018). In Kenya, the pest is threating tomato production (Sabbour and Nayera, 2012).

The Current control strategy of the pest is mainly by use of chemical pesticides, which has shown limited efficacy (Caparros *et al*., 2012). The use of alternative method such as botanicals can be a better option for the management of the pest. They are less toxic to mammals, low persistence to the environment and less adverse effect to non-target organisms (Nabil 2013). Because management of pests cannot be achieved without use of insecticides, there is need therefore to use diverse active ingredients to minimise the pesticides drawbacks (Mohamed and Lobna, 2012). Previous studies have pointed *Tuta absoluta* biology, susceptibility and resistance to pesticides which have been used for its management (Cherif *et* *al.,* 2014). Studies on management of the pest need to focus also on biocontrol strategies; whose adoption reduces the use of synthetic insecticidal compounds (Backer *et al.*, 2014).

Agricultural pest management can be achieved by use of plant extracts and pure compounds isolated of plants. Biopesticides have unique modes of action and target specific pest species (Duke *et al.,* 2003). They have been used in different ways for insect pest management (Salari *et al.,* 2012). They are environmentally friendly, prevent pollution and promote sustainable agricultural production (Leng *et al*., 2011).The active ingredients of these plant extracts have been evaluated in the management of several pest species on acute toxicity, anti-feedant, repellant, and fumigant effects and reproduction inhibitors (Ben *et al.,* 2010). Garlic a horticultural vegetable, belonging to the same genus as onion, has pesticide properties that make it useful to control insect pests. It produces a strong pungent smell and also contains an essential oil with sulphur compound (Duke, 1983). This study aimed at investigating tomato pest management practices by small scale growers and evaluating the bioefficacy of selected botanicals for management of *Tuta absoluta*.

1.2 Problem Statement

Tomato production is a key income earner to farm families in Kenya. Control of pests and diseases is a challenge in tomato production resulting into reduced incomes for the farmer and fair prices for the consumers (Taylor *et al*., 2011). Infestation by pests hinders tomato production and in 2014, the crop was invaded by another pest, *Tuta absoluta*, from other countries in Africa. Its control has been difficult for many farmers due to its challenge in identification and lack of effective control strategy. Currently, it’s being managed mainly by use of synthetic pesticides (Lietti *et al*., 2005). The farmers prefer Alpha Cypermethrin and Lambda cyhalothrin active ingredients which are synthetic pyrethroids. These have not been effective, thereby requiring regular repeated sprays contributing to environmental pollution and killing bee pollinators.

Knowledge and the use of botanical pesticides are low. Previous studies have demonstrated their effectiveness in management *Tuta absoluta.* The current study aims at identifying the pest management practices by small scale growers and evaluating efficacy of selected botanical pesticides for management the pest.

1.3 Justification

Tomato production plays a key role in the Kenyan economy. The tomato industry value chain is faced with various constraints including and not limited to pest and diseases. In tomato pest management, majority of tomato farmers depend on synthetic pesticides as the first option. Non chemical pest management practices such as cultural method, use of pest and disease resistant varieties, field hygiene, crop rotation among other methods are rarely used. Use of synthetic pesticides has increased cost of production of farmers due to high costs of the chemicals, development of pest resistance, destruction of pest natural enemies and build-up of pesticide residue on tomato fruits and the environment. Botanical pesticides have not been given emphasis as alternatives to synthetic pesticides in pest management (Nabil, 2013). They have broad spectrum potential, are inexpensive, accessible, safe to handle and easy to apply (Isirima, 2010). In the management of *Tuta absoluta*, farmers have inadequate knowledge of the pest and its appropriate and effective management options. This has made it difficult to manage the pest. Appropriate identification of Tuta absoluta is key in developing management strategies that are effective. Botanicals come in handy to provide an alternative thereby reduce the dependency on synthetic chemicals in managing *Tuta absoluta.*

1.4 Study objectives

1.4.1 Main objective

The study aimed at increased tomato productivity by evaluating tomato pest management practices by small scale growers and the efficacy of Nimbecidine, pyrethrum and garlic extracts in the management of tomato leaf miner (*Tuta absoluta*).

1.4.2 Specific objectives

The specific objectives were to:

i. Determine the tomato pest management practices by tomato small scale growers in managing *Tuta absoluta* and other pests in Kathiani, Machakos County.

ii. ascertain the efficacy of selected botanical pesticides for Tomato Leaf miner (*Tuta absoluta*) management

1.5 Hypothesis

i. Farmers pest management practices used in Kathiani Machakos County, are not effective for management of Tomato Leaf miner *(Tuta absoluta)*

ii. Use of botanical pesticides is ineffective in managing Tomato Leaf miner (*Tuta absoluta*) infesting Tomato

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview and importance of tomato industry in Kenya

Kenya's land area is approximately 583,000 km^2 and only 17% of this land is arable. Agriculture is a key sector with capacity to deliver 10 % annual economic growth (Ministry of Planning and National Development, 2010). The horticulture sub sector plays an important role in the Kenyan economy and is the most thriving contributing 15-29% growth annually (Government of Kenya, 2012). It employs 4 million people, accounting to 33 per cent in Agriculture GDP and contributes to 38 per cent of Kenya's export (MOA, 2010). It is estimated that 246,000 ha is under horticulture production and among these, vegetable is produced from 99,000 ha (HCDA, 2002).

In Africa tomatoes are widely planted vegetable crop by smallholder and medium scale farmers. They are in high demand both for fresh consumption, processing and acts as food taste enhancers and source of vitamin (Infonet bio vision, 2015). Tomato is ranked second after potato on production and value in Kenya (Lenné *et al*., 2005). In Kenya tomato production provides a source of nutritional requirements, income, employment and foreign exchange earnings (Sigei *et al*., 2014).

Tomato production contributes 14% of the vegetables produced and 6.72% of the sum total of horticultural crops grown in Kenya. It also plays an important role in poverty alleviation (Government of Kenya, 2012). Tomato production is done under greenhouse conditions and in open fields. Production in open fields accounts for 95%, while greenhouse production is approximately 5% of the total tomato produced in the country (Seminis, 2007). In Africa, Kenya is a leading producer of tomato and is ranked 6th (FAO, 2012). The crop was rated first in priority vegetable crops value chains (KARI, 2011). In 2011 it was produced from 19,000 ha, yielding 600,000 MT and with approximate value of KES 14.2 billion (HCDA, 2011) while in the following year 2012 over 18,477 ha were put under tomato production in Kenya giving an estimate of 540,000 tons (FAO, 2013).

Approximately 90% of tomato is composed mainly of water; the rest about 5-7% are vitamins, minerals, citric and other organic acids and soluble and insoluble solids, (Pedro and Ferreira, 2007). Tomato fruit plays an important role in controlling some forms of cancer because of the presence of the antioxidant lycopene in ripe tomatoes (Agarwal and Rao, 2000). Tomatoes have essential nutrients which contribute to good health. Tomato fruit is consumed as vegetable in the world and contains much Iron, vitamin B and C, (Shankara, 2005). They are consumed in a number of ways; fresh or cooked. Hence, tomatoes are produced both as an industrial and cash crop (Babalola, 2010). As an industrial crop tomato is processed into products such as ketchup, juices and purées. It's also processed and marketed as canned and dried tomatoes.

2.2 Constraints to tomato production in Kenya

Tomato production plays a key role in the Kenyan economy contributing as a source of employment, income generation, foreign exchange earnings and nutritional requirements (Sigei et al., 2014). The tomato industry value chain is faced by various constraints (Sigei *et al.,* 2014). Agronomic constraints include pest and diseases and physiological disorders whereas institutional constraints include poor postharvest handling, perishability of tomatoes and poor market infrastructure in rural and urban areas causing price fluctuation (Sigei *et al,* 2014).

A wide range of arthropod insect pests attack tomatoes, they reduce yields and increase the cost of production. The major tomato pests include African bollworm (*Helicoverpa armigera*), whiteflies (*T. vaporarium),* aphids (*Aphis gossypi*), thrips (*Thrips tabaci),* spider mites (*Tetranicus evansi*), leaf miners (*Lyriomyza sativae*), and nematodes *Meloidogyne species* (KARI, 2005). *Tuta absoluta is* a new insect pest of tomato in sub Saharan Africa. It was detected in Kenya in 2014 (Infonet-Bio vision, 2015). In addition, tomatoes are affected by diseases which include early and late blight, fusarium wilt, tomato leaf curl virus, tobacco mosaic virus, septoria leaf spot, powdery mildew, bacterial wilt, bacterial spots and bacterial canker (KARI, 2005).

According to Kelley and Byerlee (2004) most rural population which account approximately 60% in Africa have poor access to markets for their agricultural produce. About 60% of people in Africa live in the rural areas with good arable land for agricultural production but lack access to markets for their produce. In developing countries commercialization of tomato is hindered by high costs of transportation and poor market infrastructure (Sigei *et al*., 2014).

2.3 Background and description of *Tuta absoluta*

Tuta absoluta has become a major tomato pest in Kenya. It has invaded and spread in many countries (Desneux *et al*., 2011). The pest was originally described in 1917 by Meyrick as *Phthorimaea absoluta*. Later it was referred to as *Scrobipalpula absoluta*, *Gnorimoschema absoluta*, (Povolny), or *Scrobipalpuloides absoluta* (Povolny, 1994). Povolny (1994) described the pest in the genus of Tuta and named it *Tuta absoluta* (Muniappan, 2014).

The tomato leaf miner has been described as Neotropical and an oligophagous pest attacking members of solanaceous family plants (Lietti *et al.*, 2005). It originated from South America (Urbaneja *et al*., 2007). The pest exhibits three growth stages, the egg, larva, pupa and the adult. The adults mostly lay their eggs on the underside of leaves, and in some instances on fruits and stem. After hatching the young larvae enter the leaves, stems or fruits where feeding and development takes place. The larva goes through four stages. When the larva is fully developed, it forms silken thread and falls on the ground to pupate. Pupation can also occur on the leaves (Desneux *et al*., 2010).

Tomato leaf miner larvae penetrates young stems, fruits and hallows inside the mesophyll tissues, as it feeds (Lietti *et al.*, 2005). According to Muniappan (2014) the leaf miner deposits eggs on leaves (73%) veins (21%), fruits by (1%), stems and on sepals (5%).The pest gives 10-12 generation per year and does not enter diapause as long as there is adequate food available (EPPO, 2005). It also invades and feeds on other crops and weeds belonging to the Solanaceous family (USDA APHIS, 2011). *Tuta absoluta* larvae attacks tomato crops both in open field and greenhouse conditions, where it feeds on leaves, flowers stems and fruits resulting to 80-100% yield reduction (Desneux *et al.*, 2010).

Under normal circumstance *Tuta absoluta* female lays and deposits the eggs on the foliage of the host plant. Feeding and development of four larval instars takes place in leaf mines inside leaves, between the upper and lower leaf epidermis and inside fruit and stems (Cuthbertson *et al*., 2013). The pupa when formed is greenish in colour and cylindrical in shape. Later the colour becomes dark. The adult is covered with silver grey scales and has filiform antennae and length of about 6-7mm. The females are more voluminous and wider than the males and the anterior wing has a black spot. The pest show nocturnal behaviour, and during the day the adults are difficult to find as they remain hidden (Desneux, 2010).

2.3.1 Host plant and Secondary hosts

The primary host of *Tuta absoluta* is tomato (*Lycopersicon esculentum* Miller) (Desneux, 2010). The pest attacks other cultivated crops of the Solanaceae family. It has been found feeding, developing and reproducing on potato (*Solanum tuberosum L.),* eggplant (*Solanum melongena L.),* Tobacco (*Nicotiana tabacum L)* and sweet pepper (*Solanum muricatum L*.). The pest also has been found attacking uncultivated Solanaceae plants such as *Solanum eleagnifolium,* Solanu*m nigrum L., Solanum bonariense L., Solanum sisymbriifolium Lam., Lycopersicum puberulum Ph saponaceum.* In addition, it attacks host-plants such as *Nicotiana glauca, Datura. stramonium L* and *Datura ferox L* (Desneux, 2010). The pest has been reported to attack Irish potato plants but usually the aerial parts and not the tubers. The attack interferes with plant development thereby drastically reducing tuber yield (Pereira and

Sanchez, 2006). Cape gooseberry (*Physalis peruviana*) is reported as an alternative host of the pest (Tropea, 2009). The pest also attacks *Phaseolus vulgaris* (EPPO, 2005), *Malva sp* and *Lycium sp*. (Desneux *et al*., 2010) that are not in the Solanaceae family. It has high inclination of using various secondary hosts and mostly in the Solanaceae family.

2.3.2 Pest Biology and Dispersal

2.3.2.1 Insect Description and Life Cycle

Tuta absoluta adult is a very small lepidopteran moth with high ability to reproduce under optimal conditions. The female is able to give up to 12 generations within a year. One generation is completed in 28.7 days where it completes three growth stages from the egg hatching, larva, pupa and adult. Its survival is in form of the egg, pupae, or adult stage (EPPO, 2005).

2.3.2.1.1 Eggs

The pest does not lay eggs in batches but singly on all above the ground parts such as leaves, the stem, flowers, and fruits of the host plant. The eggs are very small, creamy white, yellow or orange in colour, cylindrical in shape, and approximately 0.35 mm in length (Estay, 2000). Females prefer laying eggs on lower side of leaves, stems and rarely on fruits. The hatching of the eggs takes place between 4 to 6 days. Young larvae emerge and penetrate all parts of the host plant; the leaves, aerial fruits and the stems where feeding and development occurs (NAPPO, 2012).

2.3.2.1.2 Larvae

The larvae are usually cream in colour. The head is dark and has lateral spot that extend from the ocellus all the way to the posterior margin. The larvae have dark oblique stripe but not covering the dorsal midline, the prothorax lacks a typical dorsal plate (NAPPO, 2012). Before transforming in to pupae stage the insect develops through four larvae stages (Estay, 2000).

The larval instars are very unlikely to enter diapause when there is sufficient food source. As the larvae grow from first instar the colour changes from creamy in first instar to greenish then to light pink between second instar and the fourth instar depending on the food the larvae is feeding on either on the leaflets or ripe fruits and they measure between 1- 8mm in length The larvae stage is completed within 12-15 days and it’s the most damaging period to (NAPPO, 2012)

By attacking the foliage, *Tuta absoluta* larvae hallows the foliage targeting the mesophyll tissues during feeding (OEPP, 2005). Feeding of the larvae causes irregular mines on surfaces of leaves. Consequently, the damaged leaves shrivel, reducing the plants ability to manufacture its food through photosynthesis. It also reduces the plants ability to defend itself against other harmful agents. When plants are severely infested, they exhibit burnt appearance (NAPPO, 2012). The older 3rd and 4th larvae instar usually feed on all above ground plant parts as they leave behind mines, as they move from one part of the plant to the other. The behaviour of the larvae to feed on all plant parts affects growth and development of all stages of plant growth. The larvae manifest on the plant by showing large galleries in leaves, apical buds, plant stalks, and on fruits. When the larva is fully grown, eventually it drops on the ground to pupate on silk thread, mostly on the soil. Occasionally the pupa formation may occur on leaves or in the calyx (NAPPO, 2012).

2.3.2.1.3 Pupae

Mature larvae stop feeding to form a silken cocoon later changing into a pupa. The pupa is cylindrical in shape. When newly formed its greenish in colour and darkens as the adult is about emerge. They are often normally covered with whitish silky bud and are easily reside in and outside the mines, soil and can also be found beneath pots and under the benches in greenhouse (NAPPO, 2012).

2.3.2.1.4 Adult

The adults are 5 mm to 7 mm in length and have a wingspan of 8 to 10 mm. The most distinguishing characteristic is the filiform antenna, silverfish-grey scales and a dark segment on the anterior wings. Females deposit their eggs on foliage of the host plant (NAPPO, 2012). Adult females have a lifespan range of between 10 and 15 days and males it ranges between 6–7 days. The females mate once in a day and mate to a maximum of six times in the lifetime. A single mating bout lasts between 4 - 5 hours. After first mating, females are capable of laying 76% of their eggs in 7 days which is the most prolific oviposition period. The males live only one week and mature female lay approximately 260 eggs before completing its life cycle (Meles *et al.*, 2012). *Tuta absoluta* exhibit nocturnal habit and show greater morning-crepuscular activity as the adults usually remain hidden during the day. Their mode of dispersal within the crop is through flying (NAPPO, 2012). The biological cycle of this moth is dependent on fruit before or after harvest, its survival being limited by low temperature. Depending on environmental conditions the pest can survive as egg, pupae or adult.

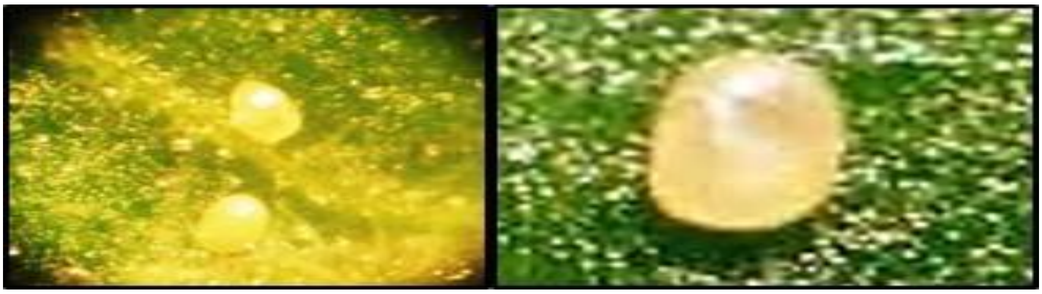

Plate 2.1 Tomato Leaf miner eggs are creamy white to yellow with oval or cylindrical shape approximately 0.35 mm (photo source; Sanjeeva R, 2020).

Plate 2.2 Tomato Leaf miner Larvae; creamy with a dark head, it turns green to light pink in colour between the second and fourth instar (photos source, Daud, J, 2021).

Plate 2.3 Tomato Leaf miner Pupa: Brownish in colour, approximately 6mm long (photo source; Sanjeeva R, 2020).

A B

Plate 2.4 Tomato Leaf miner Adult moth with a filiform antenna, 5 mm to 7 mm in length and approximate wingspan of 8 to 10 mm (A) (photo source; Sanjeeva R, 2020), Adult moth resting on tomato leaf (B photo source; Daud J, 2021).

2.3.1.1 Dispersal mode of *Tuta absoluta*

The moth is capable of spreading in many places and able to survive in fairly harsh conditions. It is capable of reaching long distances, by being drifted by wind currents or by flying as the adult moth. This implies that the insect spread can occur naturally and agricultural trade greatly facilitates the process (NAPPO, 2012). Sometimes the *Tuta absoluta* caterpillars move freely on leaves outside of their hallowed mines. This habit may be influenced by several factors such as accumulation waste faecal material, temperature, and decrease in food material or increase in the mine (Torres *et al*., 2001). Movement of the larvae inside and outside the mines is easily facilitated by silken thread they spin. Sometimes mature larvae leave host plant and move into the soil before pupation (USDA APHIS, 2011).

2.4 Damage and Symptoms caused by *Tuta absoluta*

Damage caused by *Tuta absoluta* larvae are mines on shoots, flowers, leaves, and fruits of tomato but are also found in the leaves and tubers of potato. Hatched *Tuta absoluta* larvae attack and damage the flowers, terminal buds, stems, leaves and fruits (Kaoud, 2014). It is relatively easy to spot *Tuta absoluta* infestation because of developed and numerous irregular mines with dark frass material produced by the larvae during their feeding (USDA APHIS 2011). Newly formed fruits damaged by the larvae and easily are colonized by pathogens causing fruit rot. Young plants are severely damaged by infestation this pest as opposed to older plants (Desneux *et al, 2*010)

2.4.1 Damage on Leaves

After the *Tuta absoluta* larvae are hatched they penetrate the leaf tissue causing winding shaped mines which expanding as the larvae continue feeding and growing (USDA APHIS, 2011). At initial stage of infestation, the mines can easily be confused with mines formed by leaf miner in the Agromyzidae family. Severe attack by the larvae results to leaf surface with skeletonized appearance. Copious amounts of frass are deposited in the foliage, when all the leave tissue is consumed. In most case the larvae in the second and fourth instar spin silken cocoons in leaves and cause leaves roll (USDA APHIS, 2011).

2.4.2 Damage on Shoots

The larvae mine and damage tender shoot by entering through the terminal end or at intercept of petiole and the leaves. The larvae produce silk in their specialized salivary glands and sometimes they cause new shoots to pull together (USDA APHIS, 2011).

2.4.3 Damage on Flowers and Fruit

Developing fruits are not spared by the *Tuta absoluta* Larvae as it mines through the flesh and infested fruits may fall to the ground. Larvae in early instar cause severe damage to flowers and late instars attacks mostly maturing fruits. The larva gain entry to the fruit via the calyx and hallows in the fruit flesh. They leave galleries filled with excrete material resulting to fruit fall down or to decay in its vine. The larvae penetrate the fruit through the terminal by making use the fruit parts in contact with leaves, stem or other fruits and then enter end of terminal end (USDA APHIS, 2011).

2.5 Impact of *Tuta absoluta* and current management

Tuta absoluta is a very destructive pest causing tomato yield loss of approximately 90 to 100% in field where no adequate controls and management of the pest (USDA APHIS, 2011). Plant architecture is negatively affected due to damage to terminal buds resulting in reduced plant growth and reduced fruit yield (USDA APHIS, 2011). The feeding larvae mine the tomato leaves within the leaf mesophyll reducing plant's photosynthetic capacity resulting in low yields. Galleries made in the foliage alter the general plant development and causing the plant burnt appearance. Secondary pathogens causing fruit rot invade tomato fruits destroyed through boring holes and galleries caused by the pest (Desneux *et al,* 2010*).*

Tuta absoluta is multivoltine and attacks flowers, leaves, buds, calyces, tomato fruit and the stems. Direct feeding by the larvae significantly reduces both quality and yield of tomato fruit (Megido *et al*., 2012). The Mining and galleries damage by the pest causes it plant malformation secondary pathogens such as fungal diseases attack fruit before or after harvest causing them to rot (Sabbour and Nayera, 2012). Tomato fruits that are severely attacked lose their economic value because of low returns due to rejection by the buyer. Infestation and damage caused to apical buds badly affects plant architecture, reduces plant growth and depress fruit yield (USDA, APHIS 2011). The pest had can cause extensive economic losses. It has caused severe yield loss of up to 100%, creating high demand and increased tomato prices. It has also resulted in banning trading in fresh tomato and seedling.

Increase in applications of synthetic insecticide has caused environmental pollution, affecting integrated management approach to other tomato pests and increasing cost of crop protection

(USDA APHIS, 2011). Outbreak of *Tuta absoluta* also led to more risks for tomato producers, the end users and the environment as a result of uncontrolled use of chemicals (Zappalà *et al*., 2012). Invasion of *Tuta absoluta* in Africa has reduced tomato grower's livelihood and affected tomato agribusiness. This is because the pest has of high production potential, has ability to withstand harsh environment, diverse climatic conditions and be able to colonize new areas very fast.

2.6 Prevention and management of tomato leaf miner (*Tuta absoluta*

Several management options have been explored in *Tuta absoluta* control. The methods have been categorised as pest detection, pest identification and control methods.

2.6.1 Pest detection and identification

Detection and identification is one of the first steps for successful control and management of any particular pest. Pheromone is one of the reliable methods for detection of the presence of *Tuta absoluta* using traps. The use of pheromone trap data can provide early warning of pest infestation status and provide information before pest populations reach economic threshold (Ghoneim, 2014).

2.6.1.1 Mass trapping

This is a pest strategy for pest management that involves placement traps in various strategic positions in crop fields to remove as many male insects as possible from the pest population (Razek, 2013). When effectively used, it reduces pest pressure and lowers *Tuta absoluta* by reducing sufficient number of male from the population (Witzgall *et al*., 2010). Insect pest monitoring can be achieved by using a variety of traps with different designs. The traps with sticky surface are the most common type that attract and retain the insect. This method works as traps baited with high density pheromone traps large number of males causing sex ratio imbalance, hence interrupting the mating behaviour the pest (USDA APHIS, 2011).

In open fields, the density of pheromone traps should be between 40 to 50 traps/ha (Bolckmans, 2009). Some of the pheromone based traps used in mass trapping are water traps, delta traps and light traps. The most commonly used against *Tuta absoluta* are water traps, which are more advantageous over delta and light traps have easy maintenance, less sensitive to dust and poses larger trapping capacity (USDA APHIS, 2011).

Studies have shown that use mass trapping of male *Tuta absoluta* alone has not effectively resulted in reduction in fruit and leaf damage (Cocco *et al.,* 2012). This is because the traps don't have ability to capture all the male and the fact that female have been shown to reproduce without males (Caparros *et al.,* 2012). The efficiency of mass-trapping depends on pheromone capsule used and regularity of changing the capsules according recommendation of manufacturer (Abbes *et al.,* 2011)'

Pheromone lures are primarily put together with Delta traps in *Tuta absoluta* monitoring (Hassan *et al*., 2010). Delta traps are triangular in shape composed plastic or paper body with opening at ends. A removable sticky insert is placed inside trap floor of the triangle, and a pheromone lure suspension just above it (Rudy *et al*., 2013). Under heavy infestation, the sticky inserts can sometimes be saturated with attracted and trapped males, losing its ability in trapping and retaining *Tuta absoluta* moth (USDA APHIS, 2011). The effectiveness of the trap is also dependent on the colour used. Dark colours such as black, red, green and blue catches more of the male's pest than yellow and white which are lighter colours (Uchôa-Fernandes *et al*., 1994). The traps catch numbers of can be increased by use of completely open traps (Ferrara *et al.*, 2001).

Trap placement are influenced by three important factors; the height of the trap, trap density and its placement technique in the vegetation (Howse, 1998). Capture of male is highly dependent on height positioning of trap in vegetation. In placement of trap, it's important to note that a lot of moths are found in the upper level of the canopy and not more than one metre high and therefore should be adjusted with respect to growth stage of the crop (Laore, 2010). It was noted also irrespective of the stage of plant growth traps located 60 cm had more male moths than traps placed at higher heights. Traps should be placed at 20 cm higher before planting and then adjusted to 60 cm high as the plant grows for monitoring *Tuta absoluta* moth (Rudy *et al*., 2013). In open-field crops recommended trap density per ha is 2-3 traps but two more traps can be put along all four edges of the field for determination of direction of infestation direction of the infestation, (Al-Zaidi, 2009). Trap catches should be counted on weekly basis in order to study the evolution and population and changed every 4–6 weeks (Laore, 2010).

Water traps contains plastic container that holds pheromone lure and water (USDA APHIS, 2011). A wire fixed at both ends of the container can be used for holding the lure above the water. In order to reduce the surface tension, evaporation of the water and frequency of water refills, vegetable oil or soap is added (Chermiti *et al*., 2012). The major advantage of using this kind of trap is its ability to capture large number of adult males and not easily saturated with insects (USDA APHIS, 2011).

2.6.2 Control methods

Tuta absoluta is a serious and very problematic pest to manage. Several methods have been used against this pest. Method used includes physical, chemical, biological, cultural methods and Integrated Pest Management Strategies (Ghoneim, 2014).

2.6.2.1 Physical controls

Physical control is achieved by physical exclusion of pests from the crop under production. Tomatoes grown under controlled environment such as greenhouses, experience some level of physical barrier from entry by tomato pests such as thrips bollworm, and whitefly. Under greenhouse tomato production the pest control can be achieved by screening of vents and sides of greenhouse. It can also be achieved by disciplined and careful use of the double doors at the entry which can prevent entry of pests into the greenhouse. Fans can be placed in double entry porch to blow back incoming pest which might be blown in due thermal currents created by opening and closing greenhouse door (Ghoneim, 2014).

2.6.2.1.1 Aggressive De-Leafing

De-leafing involves the removal and detachment of infested leaves from the plant. Those infested by *Tuta absoluta* can easily be detected because the most obvious symptom is presence of large mines in leaves. The *Tuta absoluta* mainly lays most of the eggs on leaves. To complete its life cycle and depending on the prevailing temperature the pest takes between 3 to 6 weeks. The removal of this infested leaves, breaks down the life cycle of the caterpillar inside the leaf interfering with its development process. This method should also be cautiously done where beneficial insects such as parasitic wasp and *Encarsia formosa* are used in biological control of whitefly. This is because it will interfere with balance as most mature and black parasitized whitefly scales will be found on the lower and older leaves, where most of the pest mines are concentrated (Retta and Berhe, 2015).

2.6.2.2 Cultural methods

Several Cultural control methods have been used in management of *Tuta absoluta*. Some of the methods which have been recommended are; destruction of infested tomato plants, removal of symptomatic leaves, ploughing, manure application, irrigation, crop rotation and soil solarisation (Korycinska and Moran, 2009). It is strongly recommended that during the cropping cycle the removal alternative host such as black nightshade which act as reservoir (USDA APHIS, 2011). Migration of pest population in the open field can be prevented if greenhouses under tomato are kept closed (Plantwise Knowledge bank, 2015). For long term reduction in *Tuta absoluta* population pressure, there is need practice crop rotation by alternating host crops, with non-host plants.

2.6.2.2.1 Use of pest free seedlings

It involves using of transplants that are from free of pests. It's vital to remove any plant part and fruits infested and place them in closed plastic bags especially when the damage is low. Host weed should also be removed and any other plant material either thorough pruning or removing weeds as they harbour pest larvae which can easily leave them to attack new plants. This material should be kept strictly in airtight containers until they are destroyed (Arnó and Gabarra, 2010).

2.6.2.2.2 Destruction of crop residues

Infested plant materials should be removed and destroyed by either burying them or by covering them with transparent plastic film, fermenting them and prevent the pest to escaping. At least a period of six weeks should be observed between successive susceptible crops, which allow soil solarisation to at least kill pupa that remain in the soil (Arnó and Gabarra, 2010). Solanaceous family weeds in close proximity of infested greenhouses should be eradicated to discourage build-up of the pest population which is potential reservoir for new attacks (Koppert, 2009).

2.6.2.3 Host-Plant Resistance

Tomato varieties with high zingiberene and acylsugar contents have been developed and tested to reduce attack on the plant by *Tuta absoluta*. These result in low oviposition rates and reduced feeding by *Tuta absoluta* larvae hence assisting in management of the pest (Maluf *et al*., 2010).

2.6.2.4 Biological Control

The biological control involves use of living organism, normally antagonists or natural enemies such as pathogens, predators, and parasitoids. They are promising solution in addressing *Tuta absoluta* crisis (Desneux *et al*., 2010). This method has proved possible alternative to the use of chemical being more sustainable and less expensive (Bale *et al*., 2008). The tomato leaf miner can be controlled by use of several bio control agents. The mirid bugs *Macrolophus pygmaeus* and *Nesidiocoris tenuis* are most common predators against *Tuta absoluta* (CABI, 2015).

Bacillus thuringiensis (Bt) insecticide has been successfully used in *Tuta absoluta* management. Efficacious use of Bt has been demonstrated by several studies (CABI, 2015). *Bacillus thuringiensis* (Bt) targets the first larval instar which is the most susceptible target (Mollá *et al*., 2011). Biological control method can easily be adopted in development of pest management strategy (Savino *et al*., 2012). The method has worked successfully in management of pest belonging to orders such as Homoptera, Diptera, Hymenoptera, Coleoptera and Lepidoptera. It's being considered in management of *Tuta absoluta* infestation by using control agents such as living antagonists and pest enemies using pathogens, predators, and parasitism (Desneux *et al*., 2010). This method is a less expensive alternative to chemicals and offers a more sustainable approach in pest management.

2.6.2.4.1 Predators

The most promising natural enemies of *Tuta absoluta* are predatory bugs belonging to the species *Macrolophus pygmaeus* which are marketed as *Nesidiocoris tenuis* and *Macrolophus caliginosus*. This species feed on *Tuta absoluta* eggs. The two species are found in Mediterranean production areas naturally colonising tomato crops especially where no broad spectrum insecticides are used. They can also be released for biological control in production of tomatoes in greenhouse. The other predators used in *Tuta absoluta* management include nabid *Nabis pseudoferus ibericus,* the mirid *Dicyphus maroccanus,* and the two phytoseid species *Amblyseius cucumeris* and *Amblyseius swirskii.* The two mites are found inhabiting the eggplant plant (Arnó and Gabarra, 2010).

2.7.2.4.2 Parasitoids

A parasitoid is a living organism that feeds on or within another organism where the relationship is parasitic (Gullan and Cranston, 2010). Parastoids have been used as natural enemies, parasitizing *Tuta absoluta* larvae.

Two potential species of *Necremnus parastoids* have been identified. Some parastoids introduced in other areas and have been found to successfully colonise and adapt in introduced areas. Such species are *Stenomesius spp*. and Braconidae that have been found to occur naturally in infested tomato plots in Spain where they have been and widely used. The parasitoid, *Trichogramma acheae* has been identified as effective biological control agent against *Tuta absoluta* eggs. The other parastoids currently in use include *Steinernema feltiae, Steinernema carpocapsae,* and *Heterorhabditis bacteriophora in* commercial tomato greenhouses (Arnó and Gabarra, 2010).

2.6.2.4.3 Entomopathogens

The use of Entomopathogenic nematodes in both field trials and laboratory has demonstrated high larval mortality of 78.6-100%. Steinernema *feltiae* evaluation against the pest has shown low pupal mortality of 10% (Garcia-del-Pino *et al*., 2013). Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* attack *Tuta absoluta* eggs, larvae and adults of the pest even though their efficiency has not been widely investigated (Pires *et al*., 2010). Studies have revealed *Metarhizium anisopliae to* cause *Tuta absoluta* adults mortality of 54% (Pires *et al*., 2010).

Extensive use of entomopathogens in IPM programmes based on biological control against *Tuta absoluta* has poorly been documented except use of *Bacillus thuringiensis var. kurstaki* (Kaoud, 2014). On the other hand, entomopathogenic nematodes have proved effective in management of late larval instars of *Tuta absoluta* (Arnó and Gabarra, 2010).

2.6.2.4.4 Sterility (sterile males)

In this method, irradiated sterile are released in the pest population such that when they mate with the female they are able to control the population. It is considered as a possible method for *Tuta absoluta* management (Cagnotti *et al*., 2012). The assumption of use of this method is that the amphimixis is the only method of reproduction by the pest (CABI, 2015). However, *Tuta absoluta* has been demonstrated as able to reproduce by use parthenogenesis especially among wild and laboratory-reared strains (CABI, 2015). This phenomenon has created confusion in IPM programmes development and adoption of pheromone-based techniques.

2.6.2.5 Sex pheromone-based control strategies

Sex pheromones control strategies have been used in *Tuta absoluta* management. An organism release sex chemical signals to attract opposite sex in order to mate (Caparros *et al.*, 2012). Most of female sex pheromones are based on a mixture of two or more compounds, which attracts males and elicits courtship behaviour (Linn *et al*., 1987). Sex pheromones have been used widely in monitoring, forecasting and controlling mostly the moth pests (Prasad *et al*., 2012). They have been used successfully in detection the pests and monitoring their population (Witzgall *et al*., 2010). Mass annihilation and mating disruption techniques have for a long time used in controlling insect populations (Witzgall *et al.*, 2010). Management strategies by use of sex pheromone target the sexual reproduction of pest. *Tuta absoluta* females were have been demonstrated to reproduce parthenogenetically i.e. without males (Caparros et al. 2012). Further studies must be considered on efficiency of use sex pheromone as management strategy because of asexual reproduction and polygenic nature of *Tuta absoluta* males (Caparros *et al*., 2012).

Mass annihilation is a technique that involves the attraction of one or both sexes of a pest and it's, achieved lure and kill techniques and mass trapping. It can also involve combination trap large capacity or a trap impregnated with insecticide (Witzgall *et al*., 2010). Mass trapping uses a lure with a physical device to trap insects with a light source or semiochemicals. The device has water bath, an adhesive surface, lure and kill combining use of sterilizing agent or lures laced with semiochemical (Jones, 1998).

Insects use these organic compounds for intra and interspecies communication and for transmission of chemical message (Anonymous, 2015). They use olfactory receptors to detect semiochemicals directly in the air. Use of pheromone based control is a very important recognised technique in against *Tuta absoluta* (Cocco *et al*., 2013). Sex pheromone produced by females attracts the males which are caught in the traps decreasing their mating efficiency (Witzgall *et al.*, 2010). Insects use pheromones are compounds for intraspecies communication.

Tomato leaf miner males mate on average 6.5 times because of their polygenic nature (Silva, 2008); therefore quite a number of males must be removed from the population before eggs are laid on foliage (Witzgall *et al*., 2010). *Tuta absoluta* females have to lay unfertilized eggs influencing the pest population density (Caparros *et al*., 2012. In field of semiochemicals sex pheromones have been used for attracting *Tuta absoluta* male to cope with its menace (Desneux *et al.*, 2010).

There is need to support the potential application of male annihilation because amphimictic nature of *Tuta absoluta* since in its reproduction biology, the males emerge earlier than females affecting mating process (Garzia *et al*., 2012). Monitoring and male annihilation in open fields and in greenhouses tomato production, use of pheromone traps can offer the first protection against *Tuta absoluta* moth (Chermiti *et al*., 2012). Combination of several control techniques are used in most developed IPM strategies or those being developed against *Tuta absoluta.* It utilizes pheromones and other control techniques, including use of mating disruption, male annihilation, pheromone baited traps and lure and kill techniques with *Tuta absoluta* synthetic sex pheromone combined with an insecticide for killing trapped males to reduce their population (Cocco *et al*., 2013).

2.6.2.6 Chemical control

Tuta absoluta has been controlled mainly by application of insecticides, mostly by use of pyrethrin, carbaryl and deltamethrin. In the first years after detection of the *Tuta absoluta* the impact on tomato production in the world led to extensive use of insecticides (Desneux *et al*., 2011. In countries where *Tuta absoluta* has invaded, a number of insecticides have been used in managing the pest. In Brazil, introduction of the pest resulted in increase in number of applications from 10-12 to over 30 applications per cultivation cycle requiring 4 to 6 sprays within week (Guedes and Picanço, 2012). Some of the insecticides that are currently being used against the pest include indoxacarb, spinosin, abamectin, cyromazine and emamectin benzoate (Abbes *et al*., 2012. Despite the pesticides already registered for *Tuta absoluta* management, their effectiveness has been minimal to moderate caused by the cryptic nature of the larvae as it remains hidden and also due its high biotic potential. Insecticide resistance in *Tuta absoluta* has been reported by use of pyrethroids, organophosphates, abamectin, flubendiamide, chlorantraniliprole, spinosad, permethrin and cartap insecticides (Haddi *et al*., 2012).

Control of the pest has not been easy because the larvae reside and hide inside the foliage. *Tuta absoluta* has high reproductive capacity and a very short generation period, increasing the risk of developing resistance to the use of the insecticides (Silva *et al*., .2011) Systematic applications of chemicals should be avoided and use of chemical for management of the pest should be based on recommendation from advisers and also depend on pest population density and crop damage level (Kaoud, 2014).

In order to control pest effectively pesticide active ingredients should be and used when necessary in combination with other methods (Arnó and Gabarra, 2010). There should be judicious use of pesticides because they affect natural enemies, especially predatory bugs, as their establishment rate is very slow. At the early growth stages of the crop, insecticides to be used, in pest control should be carefully selected (Arnó and Gabarra, 2010).

2.7 Botanical pesticides in pest management

Botanical pesticides also referred to as plant based pesticides are pest management agents extracted from plants. They have different modes of action. They act as oviposition deterrents, antifeedants, and repellents and have inhibitory characteristic that interfere with the life cycle of the insects. Plant extracts and pure compounds which are isolated from different plants have the potential of being used in controlling and managing insect pests. They seemingly have no adverse effects on human, animal health and the environment. They have proved to be effective in pest management (Nabil and Sherif, 2014). The following plants described below have different modes of action on insect pests.

2.7.1 Garlic (*Allium sativum* L.) and its mode of action

Garlic is a perennial herb, with pungent smell and a globose bulb. It is also referred to as stinking rose (Ahmad *et al*., 2013). In garlic, the volatile oils constitute allicin, 2-propene thiol

2-propene sulfenic acid, ajoene and propylene, thioacrolein (Gurusubramanian a and Krishna, 1996). It has two major constituents namely; diallyl trisulfide and methyl allyl disulfide (Huang *et al.* 2000). It has been reported by several scientists to possess antifungal and antimicrobial and insecticidal properties (Ahmad et al., 20 13).

A range of pest control products have been formulated from extracts and oils from garlic and marketed as a pesticide against many crop pests (Gareth *et al*., 2015). One of the most serious drawbacks of this product is lack of consistency in pest management. (Gareth *et al*, 2015). Garlic extracts have proved toxic several pest species, in all the growth and most susceptible orders are Lepidoptera, Coleoptera, Diptera and the Heteroptera (Prowse, *et al*., 2006).

In order to manage pests well using Garlic, spraying should be done before plant infestation and for better results to control the pest when it has not become a problem .Garlic produce bad smell which disrupts insects feeding. Garlic is very toxic and kills insects when they feed on it. Garlic works efficiently as the way DDT insecticides worked as it kills anything in the way of insects. The salphone hydroxyl ion found in garlic enters blood brain barrier and produce a specific poison that kill the insect (Meles *et al*., 2012). Garlic controls a wide range of insect pests effectively, targeting all the stages of their life cycle including the eggs, larvae and adult. It has repellent properties and has effectively controlled ants, moths, beetles, termites and ticks (Meles *et al.*, 2012).

Garlic should be used with caution because it's non-Selective effect and has a broad spectrum control and also kill beneficial insects. It is therefore not recommended in control of aphid because it kills its natural enemies (Meles *et al*., 2012). The garlic bulb extract should selectively be used because it affects non-target organism such as bees and also kills other beneficial insects but has no effects to humans (Infonet-Bio vision, 2015).

2.7.2 Neem (*Azadirachta indica*) and its mode of action

Neem (*Azadirachta indica*) is plant in Meliaceae family with wide branches. It is a tropical or semi-tropical drought resistant and evergreen. Neem has been identified a natural product solving problems associated with agriculture, environment and public health in the world (Meles *et al*, 2012). Neem has many different effects on crop pests because of its unique pesticide properties. It It's has broad-spectrum mode of action repellent, insect poison acts as insect growth regulator. Due to its anti-feedant effect neem, reduces insect's appetite and discouraging feeding by making plants unpalatable (Meles *et al*., 2012). In cases where the pest attacks the crop; neem kills insect on contact and also inhibits its ability lay eggs and molt (Meles *et al.*, 2012). The neem extracts enter the insect's system, blocks and interferes with real hormones functioning. Neem oil apart from the simple poison it produces has active ingredients that mimics hormones produced by insects (Meles *et al* 2012).

Naturally neem is not toxic and is very important in plant protection and management. Neem extracts act as effective Insect Growth Regulators (IGR) (Verkerk, 1993) and have been used in controlling quite a number of nematodes and fungi. They also reduce the growth of insects in crops and plants (Lokanadhan, 2012).

The pesticidal and repellent properties of neem extracts are broad spectrum. It repels the insects rather than killing them and affects their growth (Ganguli, 2002). The effectiveness of neem extracts depends on early treatments on early larvae stages rather than the dosage used. They should be used when fresh and not more than three months after preparation (Achio *et al*., 2012). Synergistic effect on the neem product can be enhanced by addition of natural additives such as hot pepper (*Capsicum frutescens*) and garlic (*Allium sativum*) (Achio *et al*., 2012). Studies have also shown that these extracts work effectively when combines or alternatively applied as bio-pesticides (Adu-Acheampong, 1997).

Neem pesticides have widely been used in agriculture in pest management. Neem oil and seed extracts has germicidal and antibacterial properties, very important in protection of the plants from various pests (Lokanadhan, 2012). Neem-based pesticides have advantage in crop protection as they leave no residue on the plants (Lokanadhan, 2012). Natural products or bio insecticides manufactured from neem are environmental friendly and non-toxic to plants and soil (Lokanadhan, 2012).

Azadirachtin the active ingredient from neem tree protects plant by repelling the insects from attacking and inhibiting its feeding (Lokanadhan, 2012). Azadirachtin is in a class of organic molecule refered to as tetranortriterpenoids whose structure resembles the insects hormones, refered to as “ecdysones,” which interferes with metamorphosis process, where the insects passes from larva all the way to adult stages. It acts as ecdysone blocker and interferes with the insect’s ability to molt (EXTOXNET, 1995). Neem products and their extracts generally alter insect’s life process rather than killing (Lokanadhan, 2012).

Neem bio pesticide have mode of actions at different concentrations and in various ways. The Primary mode of action of neem product acts as anti-feedant such that plants are treated with neem product containing azadirachtin, salanin and melandriol and an insect larva is hungry and it wants to feed it will experience an antiperistaltic feeling in the stomach causing vomiting sensation in the insect (Lokanadhan, 2012).

These feelings of vomiting sensation prevent the insect from feeding on the neem treated surface and swallowing is also blocked. Female insect’s eggs oviposition is not allowed as the neem products acts an oviposition deterrent. This comes in handy especially for stored seeds if treated with neem kernel powder or neem oils, insect find it difficult to deposit their eggs. Neem products also act as insect growth regulator (Nabil and Sherif, 2014). This unique nature of neem products works effectively on juvenile hormone of the insect (Lokanadhan, 2012). Neem oil pesticides don’t harm the beneficial insects (Lokanadhan, 2012) and only target the chewing and sucking insects Lokanadhan, 2012).

2.7.3 Pyrethrin and its mode of action

Pyrethrins are composed of six similar natural occurring insecticidal compounds that are in crude pyrethrum flowers. Pyrethrins exhibit quick knockdown for insects that fly and hyperactivity and convulsions for many insects (Nabil and Sherif, 2014). Toxic action to the insects nervous is because pyrethrins block the insect voltage-gated sodium channels in the nerve axons. This resembles DDT and many other synthetic organochlorine pesticides mode of action. The major disadvantage of pyrethrins is their instability in sunlight (Nabil and Sherif, 2014).

Pyrethrins exert their toxic action by interfering with potassium and sodium ion exchange process transmission affecting nerve fibres and interrupting normal nerve impulses transmission of insects. They cause rapid knockdown effect or paralysis in insects as they act very fast (Nabil and Sherif, 2014). Nevertheless, many insects are able to break down pyrethrins very quickly and recover rather than die (Nabil, 2013).

CHAPTER THREE

Evaluation of pest management practices for tomato production by small scale growers

Abstract

Tomato (*Lycopersicon esculentum Mill*.) is an important vegetable crop grown and consumed in Machakos County. It is consumed when cooked, processed or raw. It is has become an important cash crop, source of employment and has improved the living standards of many rural small scale farmers. The study objective was to determine tomato pest management practices in tomato production by small scale farmers. A survey was conducted by interviewing one hundred small scale farmers, who produce tomato, using a structured questionnaire. A stratified sampling approach was adopted for selecting the tomato farmers. The sampling frame consisted of a list of tomato producers from four administrative wards of Kathiani Sub County. The study established that significantly ($p<0.05$) more men (75%) grow tomato than women and that significantly more tomato producers (94%) grow the crop on 0-5 acres compared to 6% who grow on 6 -10acres. Majority farmers had small pieces of land hence a significant ($P<0.05$) proportion (93%) dedicated less than one acre to grow tomato. They mainly used a combination of rain fed and irrigation (72%) whose proportion was significantly ($p<0.05$) higher than production under rain fed conditions or under irrigation alone. Pests and diseases (43%) and lack of capital (34%) were the main challenges facing tomato production in Kathiani and the new pest, (*Tuta absoluta)* was considered the topmost major pest associated with higher yield loss. Significantly ($p<0.05$) more farmers had observed tuta damage in the field. Whitefly and spider mites came second and third, respectively in decreasing order of importance. The study also established that 74% of the farmers used synthetic pesticides and mainly synthetic pyrethroids in the management of tomato pests. Forty two percent of the farmers applied Alpha-cypermethrin while 30% used Lambda-cyhalothrin pesticide as the active ingredients. Non chemical management options such as cultural methods intercropping, field hygiene and use of physical barrier were not commonly reported by the farmers indicating low or non-use. The results also show that, majority of the farmers (64%) apply Belt (Flubendiamide) in management of tomato leaf miner. Farmers rely on their neighbours and agro input dealers for crop growth and management. Inadequate knowledge in pest identification and its development was cited as a hindrance to *Tuta absoluta* management by almost half of the farmer respondents. The farmer practices are ineffective and there is need for an alternative to reduce dependency on pesticides.

3.1 Introduction

Tomato production plays a key role as a source of employment, income generation, foreign exchange earnings and nutritional requirements (Sigei *et al.*, 2014). It is cultivated in almost every part of Kenya, all the year round. A wide range of pests and diseases affect tomatoes, thereby lowering yields and increase the cost of production. The average production stands at about 30 tons/ha in Kenya compare to Egypt's more than 50 tons/ha and other developed countries such as USA and Israel getting 100tons/ha. Kenyan tomato yields are far much below. The main arthropod pests include African bollworm (*Helicoverpa armigera*), whiteflies (*T. vaporarium),* aphids (*Aphis gossypi*), thrips (*Thrips tabaci),* spider mites (*Tetranicus evansi*), leaf miner (*Lyriomyza sativae*) and *Tuta absoluta* a new insect pest of tomato in sub Saharan Africa (MOA, 2014; KARI, 2005).

Tuta absoluta damages the plants by mining on shoots, flowers, leaves, and fruits of tomato. The hatched larvae attack and damage the flowers, terminal buds, stems, leaves and fruits (Kaoud, 2014). It is relatively easy to spot *Tuta absoluta* infestation because of the numerous irregular mines with dark frass material produced by the larvae during the feeding (USDA APHIS 2011). The larvae damages newly formed fruits which are easily colonized by pathogens causing fruit rot and early drop. The pests is severe on young plants compared to the older plants (Desneux *et al, 2*010). It is necessary to understand the farmer practices of Tuta absoluta for effective and sustainable management. The study was undertaken to determine the farmer management practices of *Tuta absoluta* infesting tomato

3.2 Materials and methods

3.2.1 Site selection

The study was conducted in four wards in Kathiani Sub County; one of the eight Sub counties in Machakos County. Kathiani the headquarters of the Sub County is approximately 20 kilometres from Machakos town. The Sub County covers approximately 213 km^2 (21,300Ha) and administratively it is divided into four wards namely Kathiani central, Mitaboni, Lower Kaewa /Kaani and Upper kaewa/Iveti wards. There are five main seasonal rivers of approximate 137 km traversing the Sub County that facilitate production of horticultural crops (Government of Kenya, 2013).

There are six agro climatic zones in the Sub County; lower highland 2, lower highland 3, upper midland 2, upper midland 3, upper midland 4 and upper midland 5. The mean annual rainfall ranges between 400mm-1000mm/year with bimodal pattern distribution in allowing for two rain seasons from March - May and October- December. The altitude ranges between 1450 to 2100m above sea level. The soils are mainly sand loams and vertisols (Government of Kenya, 2014). The sub County has approximate population of 104,217 persons and 24,412 households with population density of 503 persons per km^2 and poverty index stands at 52% (KNBS, 1999).

3.2.2 Study design

The study was a field survey conducted in selected villages in the four wards in Kathiani Sub County. A sample size of 100 tomato producers was selected. In each of the four wards of Kathiani central, Mitaboni, Lower Kaewa and Upper Kaewa 25 respondents were selected. The sample size was computed based on Kothari developed formula (Kothari, 2004); $n= (z^2. p. q)/e^2$,

Where, n represents the sample size, z is the confidence interval (corresponding to the z – is a value from normal distribution tables, p is the expected proportion and the population maximum variability, e is desired level margin of error or precision. Confidence interval of 95% was assumed, with 0.5 expected proportion and margin error of 10%. Ultimately, calculated sample size was as; $n= (1.96)^2 (0.5) (0.5)/ (0.10)^2 =96.04$, approximate 96 households. This minimum sample size of 96 households was adjusted to 100 households adopted in the survey.

3.2.3 Data collection

A structured questionnaire was used for data collection (see Appendix 1). Before the actual survey, the designed questionnaires were first pre-tested to evaluate the relevance of formulated questions, correcting mistakes with aim of verification and adequacy of obtaining the relevant information and improving the standard of the questionnaire to adequately address the objective of the survey. The questionnaire was pre-tested by targeting different respondents who were not part of the study. After the pre-test the questionnaire was modified accordingly and used in face to face interviewing the targeted 100 households. A list of tomato producers available in the study Sub County formed the sampling frame. Stratified random sampling procedure was adopted in the selection of twenty-five farmers from each stratum (administrative ward). The purpose of the survey was first explained to every respondent and consent sought. Farmers were then interviewed individually by the research team comprising of the student and three Agricultural extension agents from the wards using a structured questionnaire. English and Kiswahili languages were used in interviewing farmers although in some cases the research team used local language for clarification of certain terms in the questionnaire. The questionnaire captured information including; basic information on social and economic status, which included farmer's age, gender and educational level. Other information collected included preferred tomato varieties, reasons for their preference, major pests and diseases, pest management strategies, pesticides used in control of pest, pest control challenges, source of extension messages in tomato production and advice in their pest management.

3.2.4 Data analysis

Computer based Microsoft Excel was used in entering collected questionnaires data. Data and information collected entered coded and analyzed using Statistical Package for Social Science (SPSS) version 18.0. Quality checks was maintained during data collection, data entry and data cleaning to ensure data quality. The information obtained was analysed using descriptive statistics and information presented using percentages, mean, standard deviation and correlation coefficient

3.3 Results

The respondents that participated in the study were drawn from the four wards; Kathiani central, Mitaboni, Lower Kaewa/Kaani and Upper Kaewa /Iveti of Kathiani Sub County in Machakos county.

3.3.1 Demographic characteristics of the respondents

Table 3.1 shows the characteristics of tomato producers in Kathiani. The survey revealed that most farmers (80%) have experience in tomato production of between 6 to 20 years. Majority (93%) grew tomatoes on less than one acre piece of land whose proportion was significantly higher than 7% who grew tomatoes on more than 2 acres.

Table 3.1 Demographic characteristics of the respondents

Characteristics	Category	Percentage	Standard deviation
Gender	Male	75.0	0.044
	Female	25.0	
Age	Below 20	2.0	0.110
	21-30	3.0	
	31-40	33.0	
	41-50	31.0	
	51-60	21.0	
	Above 60	10.0	
Household Members	1-3	19.0	0.056
	4-6	71.0	
	7-10	9.0	
	over 10	1.0	
Education level	Primary level	48.0	0.1
	Secondary level	46.0	
	Tertiary level	6.0	
Land size	0-5	94.0	0.0238
	5-10	6.0	

The results also revealed that production system used by farmers was mainly a combination of rain fed and irrigation (72%) whose proportion was significantly higher than production under rain fed conditions and under irrigation alone. The irrigation methods used were overhead, furrow and basin in almost equal proportions. The source of water for irrigation by the farmers was mainly a river or stream, whose proportion was significantly higher than those that depended on rain water for tomato production (Table 3.1).

3.3.2 Tomato production characteristics

Table 3.2 shows the characteristics of tomato production in Kathiani. The survey results revealed that most farmers (80) have experience in tomato production of between 6 to 20 years. Majority (93%) grew tomatoes on less than one acre piece of land whose proportion was significantly higher than 7% who grew tomatoes on more than 2 acres (table 3.2).

Table 3.2 Tomato production in Kathiani Sub County

Characteristics	Category	Percentage	Standard deviation
Years in Production	Less than 1 year	2.0	0.12035
	1-2 years	4.0	
	3-5 years	9.0	
	6-10 years	30.0	
	11-20 years	37.0	
	21-30 years	13.0	
	>30 years	5.0	
Acreage under tomato	0-1	93.0	0.0256
	2-3	7.0	
Production system	Rainfed	2.0	0.05025
	Irrigation	26.0	
	Rain fed and irrigation	72.0	
Method of Irrigation	Overhead	42.0	0.09192
	Basin	25.0	
	Furrow	30.0	
	Drip	3.0	
Source of water	River/Stream	98.0	0.01407
	Rain	2.0	

The results also revealed that the production system used by farmers was mainly a combination of rain fed and irrigation (72%) whose proportion was significantly ($p<0.05$) higher than production under rain fed conditions and under irrigation alone. The irrigation methods used were overhead, furrow and basin in almost equal proportions. The source of water for irrigation by the farmers was mainly river or stream, whose proportion was significantly ($p<0.05$) higher than using rain water for tomato production (Table 3.2).

3.3.3 Tomato varieties planted by farmers and their attributes

Table 3.3 shows tomato varieties grown in Kathiani Sub County. The study established that majority of the farmers (84%) have been growing open pollinated varieties such as Rio grande, Cal J and Oxyl and only 14% were growing hybrid varieties which included Tylka F1, Monica F1, Kilele F1 and Eden F1 (Table 3.3).

Table 3.3 Tomato varieties planted by farmers in Kathiani Sub County

Tomato Variety	Frequency	Percentage	Standard deviation
Tylka F1	1.0	1.0	0.173
Rio grande	46.5	47.0	
Cal j	35.6	36.0	
Oxyl	3.0	3.0	
Monica F1	1.0	1.0	
Money Maker	1.0	1.0	
Kilele F1	5.0	5.0	
Eden F1	5.9	6.0	

Table 3.4 shows tomato variety attributes considered by the tomato growers. The choice of tomato variety to plant depended on various attributes as opined by the surveyed farmers. The farmers cited various tomato qualities they considered when purchasing and growing tomatoes. They included long shelf life, yield potential, resistance to diseases, maturity, fruit quality and marketability of the tomato produce. The findings revealed that long shelf life was the major consideration in choice the tomato variety to plant as reported by almost about half of the farmer respondents (Table 3.4).

Table 3.4: Percentage of farmers who reported various attributes of tomato varieties they considered

Tomato Attributes	Frequency	Percentage	Standard deviation
Resistance To Diseases	13.0	13.0	0.16
Long Harvesting Period	5.0	5.0	
Good Quality Fruits	8.0	8.0	
Long Shelf Life	48.0	4.08	
High Yielding	13.0	13.0	
Highly Marketable	3.0	3.0	
Early Maturing	10.0	10.0±0.16	

3.3.4 Farmers source of extension services

Table 3.5 shows the sources of agricultural information for the farmers growing tomatoes. Farmers who engage in crop production seek advice from various organizations. The findings revealed that majority of the farmers (73%) depend on their fellow farmers and government agricultural extension agents almost equally for source of agricultural information. The study also revealed that some farmers (22%) seek advice from the agro dealers where they purchase agricultural inputs (table 3.5).

Table 3.5: Percentage of farmers seeking extension services from various organizations

Extension Services	Frequency	Percentage	Standard deviation
Fellow Farmers	35	35.0	0.0130
Radio/ TV	5	5.0	
Agro input dealers	22	22.0	
GoK Extension	38	38.0	

3.3.5 Packaging materials and transport methods

Table 3.6 shows the various packaging materials and the means of transporting tomatoes to the market. The study revealed that most farmers (52%) mentioned the use of plastic crates and buckets when handling tomatoes. Majority of the farmers (79%) indicated use of motor cycles (boda boda) as a means of transporting tomatoes to the market (table 3.6).

Table 3.6: Percentage of farmers using various Packaging materials and transport methods

Characteristics	Category	Percentage	Standard deviation
Packaging material	Crate	21.0	0.14247
	Crates, Plastic Buckets	52.0	
	Boxes, Gunny Bags	2.0	
	Crates, Gunny Bags	4.0	
	Crates, Plastic Buckets, Gunny Bags	21.0	
Method of transport	Boda/ Bicycles	79.0	0.08122
	Pick Ups	10.0	
	Ox Cart	6.0	
	Wheelbarrow	5.0	

3.3.6 Challenges facing farmers

Table 3.7 shows challenges faced by farmers in tomato production. They include; pest and diseases, lack of capital, inadequate water for irrigation, drought and poor access to the market. Pest and diseases constraining tomato production were the most reported challenge by just about half (43%) of the interviewed farmers. The constraint that ranked second was lack of capital (34%). Adequate water for irrigation, drought and lack of market somehow took a back stage according to the findings of the surveyed farmers (Table 3.7).

Table 3.7: Challenges facing tomato farmers in Kathiani Sub County

Challenges Facing Farmers	Frequency	Percentage	Standard deviation
Pest and Disease	43	43.0	0.106
Lack of Capital	34	34.0	
Inadequate Water for irrigation	14	14.0	
Drought	5	5.0	
Poor access of Market	4	4.0	

3.3.7 Pests and yield loss associated with most common Tomato pests

Table 3.8 shows the challenges faced by tomato producing farmers. The study established that tomato production was constrained by various pests and diseases.

Table 3.8: Pests and yield loss associated with most common pests identified by farmers

Major Pests	Percentage	Associated Yield loss	Pest Difficult to manage
African bollworm	9.0±0.170	16.0±0.136	0.0±0.099
Aphids	1.0±0.170	1.0±0.136	0.0±0.099
Tuta absoluta	30.0±0.170	40.0±0.136	45.0±0.099
Red Spider mites	17.0±0.170	22.0±0.136	16.0±0.099
White flies	26.0±0.170	15.0±0.136	34.0±0.099
Thrips	6.0±0.170	5.0±0.136	4.0±0.099
Cut Worm	7.0±0.170	1.0±0.136	0.0±0.099
Leaf miner	4.0±0.170	0.0±0.136	1.0±0.099

The tomato leaf miner (*Tuta absoluta)* was considered a major pest as cited by thirty percent of the farmers. Second and third most important tomato pests as reported by farmers were Whitefly and Red spider mite, respectively. The tomato leaf miner was also cited as the pest associated with the highest yield loss (40%) and difficult to control (45%). White flies were the second most difficult to control pest after *Tuta absoluta* (Table 3.8). Various diseases were also reported affecting tomato production. Bacteria wilt was reported by most of the farmers (45%) as the major disease limiting tomato production, followed by late blight and leaf curl virus (table 3.9).

3.3.8 Incidence of *Tuta absoluta* in farmers' fields

Table 3.10 shows the percentage of farmers who reported *Tuta absoluta* in their farms. Regarding the detection of the tomato leaf miner, majority of the farmers (89%) had seen the pest in their tomato fields. The study revealed that *Tuta absoluta* affects the tomato crop at various stages, beginning from the nursery establishment stage, throughout the vegetative, flowering and fruiting stages. The study also revealed that the pest was severely affecting and mostly observed in foliage and fruits than in the stem (table 3.10).

Table 3.9: Major diseases affecting tomato production in Kathiani Sub County

Major Diseases	Frequency	Percentage	Standard deviation
Late blight	21	21.0	0.154
Bacterial wilt	45	45.0	
Leaf curl virus	15	15.0	
Fusarium wilt	8	8.0	
Early blight	5	5.0	
Anthracnose	2	2.0	
Powdery mildew	2	2.0	
Septoria leaf spot	2	2.0	

Table 3.10: Percentage of farmers who reported *Tuta absoluta* in their farms

Characteristics	Category	Percentage	Standard deviation
Tuta absoluta observed	Yes	89.0	0.03145
	No	11.0	
Growth stage seen	Vegetative	21.6	0.155
	Seedling	2.3	
	Flowering	27.3	
	Nursery	21.6	
	Fruiting	27.3	
Plant part seen on	Inflorescence	21.6	0.088
	Foliage	37.5	
	Fruits	37.5	
	Stem	3.4	

3.3.9 Farmer's pest management options

In table 3.11 the farmers reported different management options in the management of pest and diseases in tomatoes. Majority of the farmers (74%) cited use of pesticides in management of tomato pests. Cultural practices and non-chemical management methods; intercropping, field hygiene and use of physical barrier were not commonly reported by the interviewed farmers. For the management of insect pest in tomatoes, majority of the farmer commonly cited Alpha-cypermethrin (42%) and Lambda-cyhalothrin (30%) pesticide active ingredients. In the management of tomato leaf miner (*Tuta absoluta*), majority of the respondents (64%) cited using Belt (Flubendiamide) than the other pesticide active ingredients (table 3.11).

Table 3.11: Percentage of farmers reporting various management options, pesticides and non-chemical in management of pests affecting tomato production

Characteristics	Category	Percentage	Standard deviation
Management option	Pesticides	74.0	0.0838
	Crop Rotation	21.0	
	Intercropping	1.0	
	Field Hygiene	2.0	
	No Action	1.0	
	Physical Barrier	1.0	
Pesticides used for insect pest	Abamectin	3.0	5.56
	Alpha-Cypermethrin	42.0	
	Cypermethrin+Chlorpyrifos	1.0	
	Flubendiamide	4.0	
	Imidacloprid+Betacyfluthrin	1.0	
	Lambda-cyhalothrin	30.0	
	Malathion	1.0	
	Thiamethoxam	12.0	
Pesticide used for *Tuta absoluta*	Alpha-Cypermethrin	11.0	8.71
	Diafenthiuron	1.0	
	Flubendiamide	64.0	
	Imidacloprid	1.0	
	Lambda-cyhalothrin	7.0	
	Thiamethoxam	2.0	
	Profenofos+Cypermethrin	1.0	

3.3.10 Relationship between farmers' demographic characteristics, tomato production characteristics and management types

Table 3.12 shows correlations computed among nine variables of farmers' demographic characteristics, tomato production characteristics and management types on data for 100 respondents. Results indicated no significant association between farmer's education level with source of extension service and tomato pest management types. However, three out of nine tested variables were statistically significant at $p \leq 0.05$. Tomato production was positively and inversely correlated with tomato variety (r 0.233, $p \leq 0.05$) and attendance to trainings r = 0.246, p ≤ 0.05) respectively. The production was also significant and positively correlated with extension service (r= 0.206, p ≤ 0.05). The tomato varieties showed slightly positive correlation and moderate negative correlation with source of extension (r = 0.412, p ≤ 0 .01) and crop rotation (r= 0.243, p ≤ 0.05) respectively. However, correlation coefficient revealed that major diseases were significant and positively correlated with management type (r=0.192, p ≤ 0.05). Management types (r = - 0.184, p ≤ 0 .05) showed negative association with tomato variety grown (Table 3.12)

Table 3.12: Correlation coefficients among farmers' demographic characteristics, tomato production characteristics and management types

	Education level	Tomato production	Variety grown	Extension service	major pests	major diseases	Crop rotation	Management	Attended training
Education level	1.000								
Tomato production	-.162	1.000							
Tomato variety grown	-.139	.233**	1.000						
Extension service	.027	.206*	.412**	1.000					
Major pests	-.067	-.004	.091	.115	1.000				
Major diseases	-.120	.058	.033	.076	-.025	1.000			
Crop rotation	.157	-.129	-.243**	-.112	-.027	-.143	1.000		
Management type	.068	-.114	-.184*	-.024	.025	.192*	-.034	1.000	
Attended training	.074	-.246**	.023	.113	.024	.097	.009	-.010	1.000

**. Correlation is significant at the 0.01 level (1-tailed).
*. Correlation is significant at the 0.05 level (1-tailed).

3.3.11 Challenges facing farmers in pest management

Figure 4.1 and figure 4.2 records the major challenges facing farmers while managing pests in tomatoes with special emphasis on *Tuta absoluta* the invasive species. Results revealed lack of capital as the major challenge in insect pest management as reported by about half of the farmer respondents (Figure 4.1). Management of *Tuta absoluta* is constrained by lack of knowledge in pest identification as is reported as a major challenge by about half of the farmers interviewed. Capital as a constraint followed second as part of the T*uta absoluta* management challenges as reported by the farmer respondents in Kathiani (Figure 4.2).

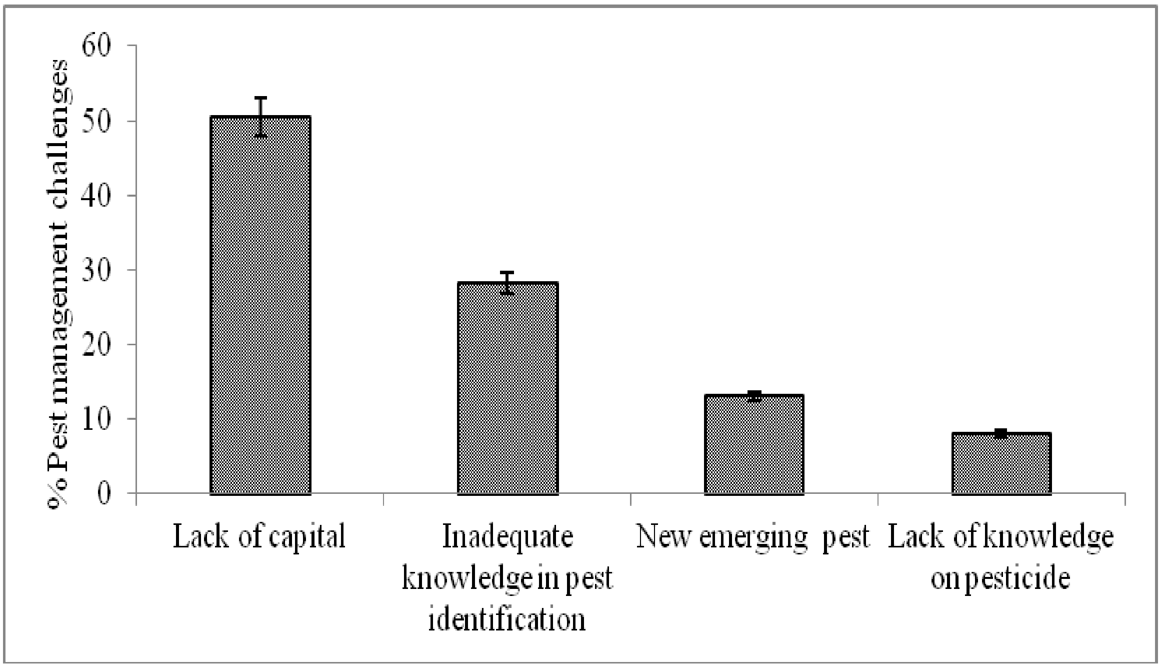

Figure 4.1: Major challenges facing farmers in pest management

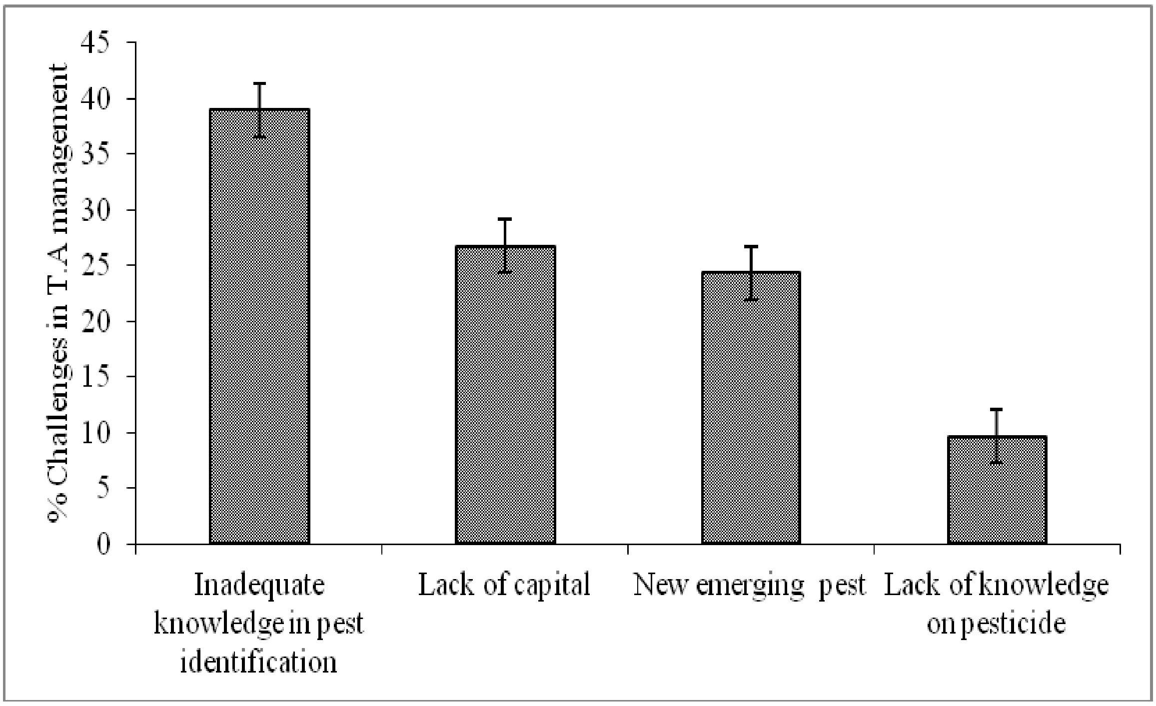

Figure 4.2: Challenges in *Tuta absoluta* management

3.4 Discussion

The survey on determination of farmer's pest management strategies on tomatoes revealed that tomato farming is dominated by men. Possibly because the enterprise is labour intensive and is a source of income. The findings agree with various studies carried out in other parts of the world. According to Waichman *et al.* (2007) and Adjrah *et al.* (2013) farming activities are generally dominated and controlled by men. According to Wachira *et al.* (2014) in a study conducted in Nakuru found over 80% of tomato production is done by men while the rest is done by women. Majority of farmers preferred and were growing Rio Grande and Cal J tomato varieties. This is because of the long shelf life associated with the produce a trait preferred by traders and consumers. Orzolek *et al*. (2006) found out that farmers consider several factors including production potential, market requirement and pest and disease resistance among other factors for choice of tomato varieties to grow. The cost of seeds of Rio Grande and Cal J are affordable to many small-scale farmers. Hybrid varieties such as Kilele F1, Tylka F1, and Eden F1 are high yielding, but the seeds are more expensive and beyond reach of many farmers.

The tomato leaf miner (*Tuta sops*) is a major tomato pest and difficult to control, compared to other tomato pests, according to the farmers. Majority of respondents were able to identify the pest damage in their farms and reported that it affects all the growth stages of the crop from the nursery and throughout the production cycle. Braham and Hajji (2012) stated that tomato crop can be attacked at any developmental stage, from seedlings to mature stage.

Bacteria wilt and late blight were identified as main tomato diseases. Bacterial wilt is a devastating disease of tomato in tropical regions and causes great loss to the production field and under greenhouse cultivation (Singh *et al.,* 2014). Late blight, a fungal disease is a serious problem in Kenya and other tomato growing countries (Waiganjo *et al*., 2006; Tumwine *et al*., 2002; Masinde *et al.,* 2011).

The use of pesticides was a major control method for tomato pests. Farmers used different pesticide active ingredients for general tomato pests. In the management of *T. absoluta* on tomatoes, farmers in the study area relied entirely on synthetic pesticides. Three quarters (74%) of the farmers used synthetic pyrethroids alpha cypermethrin and lambda cyhalothrin and a few farmers applied Flubendiamide insecticide. They are generally available and cheaper compared to other active ingredients. These results are in agreement with those of Momanyi *et al* (2019) who reported a similar trend among Kirinyaga Farmers who use chemicals as a quick way of reducing pest damage and protecting their crops. The Synthetic pyrethroids used are not effective on *T. absoluta* since they do not penetrate into the mines that protect the larvae. Repeated applications are expensive without good outcomes.

Majority of farmers applied Flubendiamide for *T. absoluta* management. They reported some success in reducing *Tuta absoluta* population pressure. According to Straten *et al.* (2011) Flubendiamide has been effective in *T. absoluta* management with no side effects to natural enemies. Preference of Belt® (Flubendiamide) according to the study disagrees with finding by Nderitu *et al*. (2018) who reported that Coragen® (Chlorantraniliprole) was the most preferred and effective insecticide for management of *T. absoluta* in study done in Kirinyaga County in Kenya. Majority of the farmers in the study mainly use synthetic pesticides for pest management. This is in agreement with Balzan and Moonen (2012) findings that Farmers barely consider other strategies such as eco-friendly natural pesticides, field sanitation, tolerant varieties and clean planting material. This could possibly be because of quick results and quality of fruit achieved compared to the other pest management strategies. Non chemical management options such as intercropping, field hygiene and use of physical barrier are rarely used by farmers.

Farmers get advice on tomato production and pest management from various sources but mostly rely on government extension officers. This compares well with findings by Karuku *et* *al.* (2016) who reported that majority of famer rely on extension officer for advice. The study also established that farmers sought advice on pesticide use from fellow famers and to a lesser extent from agro input supplier. This contradicts with studies done in Vietnam (Hoi et al., 2009, Nguyen *et al*., 2018) and in other developing countries (Ngowi *et al*., 2007) which reported that pesticide purchases were highly influenced by Agro input suppliers.

Effective and sustainable pest management require combination of various methods and not relying on one strategy. Knowledge of the pest is an important consideration in management, since poor identification leads to ineffective control. There is need for adoption of Integrated Pest Management strategies by use of non-chemical methods, use of biopesticides and using synthetic pesticides as the last options for sustainable pest management and for improvement of tomato quality and market value. Integrated Pest Management (IPM) as a management strategy needs to be promoted among the farmers. It’s a strategy which combines as many compatible methods as possible to minimize problems caused by pests. It involves various techniques aimed at reducing pest population to avoid economic damage. It is safer, effective offers environmental protection, prevents build-up of pesticide resistance. Single control strategy have limitations.

CHAPTER FOUR

Efficacy of selected botanical pesticides in the management of Tomato Leaf Miner (*Tuta absoluta)*

Abstract

Tomatoes are the second leading vegetable in Kenya in terms of production and revenue generation. In recent times, its production and yields has adversely been affected by the newly introduced, tomato leaf miner (*Tuta absoluta*). The pest was first reported in the county in 2014. The aim of the study was to investigate the efficacy of selected botanicals in management of *Tuta absoluta*. On farm experiments were conducted in smallholder farms in Kathiani Sub County in Machakos County, in upper midland four (UM 4) Agro-Ecological Zone (AEZ). The experiment was laid out in a Randomized Complete Block Design (RCBD) with a split plot arrangement with four replications. Two tomato varieties; Rio Grande and Tylka F1 were subjected to spray regimes that comprised Flubendiamide (Belt®); a synthetic pesticide and botanicals; Azadirachtin 0.03% (Nimbecidine) and Pyrethrin + Garlic extract (Pyegar). The results revealed that there were no differences on leaf damage observed on tomatoes treated with Nimbecidine, Pyegar and Nimbecidine + Pyegar on tomato Rio Grande compared to control. However, the percentage leaf damage was much lower in tomatoes treated with either Nimbecidine or Pyegar alone than treatment with Nimbecidine + Pyegar alternately. The lowest percentage leaf damage was recorded in tomatoes treated with Belt®, the standard check; while the highest damage was recorded in the control treatment where no pesticide was sprayed. Treatments with Pyegar alone generally recorded the lowest leaf damage compared with Nimbecidine treatment alone and the two biopesticides sprayed alternatively on the two tomato varieties. The botanicals used and the standard, Belt, significantly ($p<0.05$) reduced tomato leaf miner larva infestation, compared to control. The least recorded was in Belt while highest was recorded in control. The bio pesticides Nimbecidine and Pyegar had the same effect in reducing the larvae infestation. However, Pyegar showed better performance in reducing larvae infestation compared to Nimbecidine and the alternate use of Nimbecidine and Pyegar. Tylka F1 and Rio Grande cultivars suffered the same effect on leaf damage by *T. absoluta* larvae but Tylka F1 variety showed slight tolerance to leaf damage and *T. absoluta* larvae infestation. The treatments significantly ($p<0.05$) increased the number of tomato fruits compared to untreated control. Treatment with Belt® recorded the highest number of fruits in both seasons and varieties followed by Pyegar in the second place while control had the least fruits in both seasons and varieties.

4.1 Introduction

The use of bio pesticides has been proved effective in control of agricultural pests. The application of bio pesticides on the fields has been shown to be ecologically friendly and mitigating against environmental pollution and promote sustainable agricultural development (Leng *et al*., 2011). Control of insect pests can be achieved by use of plant extracts and pure compounds isolates from different plants. Pesticides from natural products have been shown to have unique mode of action and target specific pest species (Duke *et al.,* 2003). Previous studies on management of *Tuta absoluta* have shown its susceptibility and resistance to pesticides which have been used for its management (Asma *et al*., 2014). The current study investigated insect pest response to different pesticide application regimes in order to identify effective and safe bio pesticides that can be adopted for sustainable crop protection.

4.2 Materials and methods

4.2.1 Experimental site selection

On farm experiments were conducted in a small holder farm in Kauti sub location, Kaewa location, Kathiani Sub County in Machakos County which lies at Latitude, 1° 26' 50.895" and longitude, 37^{o} 21' 53.578". The area is located in Agro-Ecological and Agro-Climate Zone lower midland 3 (LM_3) which is a cotton growing zone and where main enterprises include maize, beans, cow peas, green grams, sorghum and millet. It is characterized by bi-modal rainfall received in month of March to April (long rains) and October to December (short rains). The average rainfall in Machakos is 982 mm per year. The mean minimum temperature in the area ranges between 12 degrees centigrade during the month of June-August to maximum of 22 degrees centigrade during the month of January – March. The coldest month is July and the warmest are October and March prior to the rains. Dry periods are experienced in January to March and August to September (MOA, 2006). Potential evapo-transpiration (PET) for Machakos is 5.6 mm/day. Daily evaporation ranges from 100 mm per month in July to 200 mm per month in March and September. The soil pH ranges from moderately acidic

(5.9) to moderately alkaline (7.62 while soil organic matter content ranges between 0.49%-1.98% total carbons (MOALFD, 2012).

4.2.2 Experimental design and layout

The experiment was carried out in two planting cycles; the first planting was in 2016 and second in 2017. The experiment was laid out in a Randomized Complete Block Design with a split plot arrangement and four replications. There were two main plots and five sub plot in the experimental unit, where the experimental treatments were allocated. The main plots comprised of two tomato variety of (Rio Grande and Tylka F1) and sub plots were allocated to the five spray treatments regimes. The five sub plots were randomly allocated the five treatments with four replications representing four blocks in each of the tomato variety of Rio Grande and Tylka F1.

The main plot measured 20.5M x 2M and the sub plots were measuring 3M x 2M. Tomato variety Rio Grande and Tylka F1 were planted in the main plots. Four weeks old tomato seedlings were transplanted into the plots at inter and intra-row spacing of 60 and 60 cm, respectively. This achieved plant population of 24 tomatoes in each of the five sub plots, totalling to 120 plants in the main plot and established in 4 replicates or blocks. A path of 1M was maintained between the blocks and 0.5M spacing between the sub plots. The experimental area was measuring 42M by 11M.

4.2.3 Crop treatment applications and management practices

Land was ploughed using oxen plough one month before transplanting. Sunken furrows were made using hoes and well decayed manure was applied at a rate of 10 tonnes per hectare. During transplanting the furrows were irrigated and the tomatoes were transplanted in the furrows according to the description given in section 4.2.2 above. The four weeks old tomato seedlings of the two varieties were transplanted in the watered furrows late in the evening. Basal application of Di-ammonium phosphate (DAP) was applied at the rate of 150 kg/ha before planting; mixed thoroughly with the soil before transplanting the tomato seedlings. The tomatoes were top dressed with Calcium Ammonium Nitrate (CAN) at the rate of 200 kg/ha at 5th week after transplanting. Supply of micro-nutrient was done by application of foliar fertilizers alongside the regular pesticide applications. The crop was watered on weekly basis by use of furrow irrigation. Copper-based and sulphur-based fungicides were applied alternatively as a prevent measure against fungal diseases. The following experimental spray regimes (treatments) were evaluated for effectiveness in *Tuta absoluta* management:

1. Azadirachtin 0.03% (Nimbecidine) at rate of 3mls per litre of water, followed by Pyrethrin + Garlic extract (Pyegar) insecticide applications at rate of 3mls per litre of water one week later.
2. Azadirachtin 0.03% (Nimbecidine) insecticide alone applied at rate of 3mls per litre of water on weekly basis
3. Pyrethrin + Garlic extract (Pyegar) insecticide alone, applied at rate of 3mls per litre of water on weekly basis
4. Farmers practice- Flubendiamide (Belt) spray application at rate of 0.2mls per litre of water on weekly basis
5. Control with no pesticide application

All the insecticide applications were done on weekly basis, and the first treatment was done one month after transplanting.

4.2.4 Assessment of parameters (plant height, number of trusses, tomato fruits, Tuta larvae and damage

*Tuta absoluta l*arvae and damage in tomatoes were randomly observed from the inner rows of tomatoes. Four tomato plants were randomly selected assessment and from each plant three leaves were also randomly selected and assessed for presence of *Tuta absoluta* larvae and leaf damage. Pre-treatment assessment was done before application of the treatments. Thereafter, data was collected on a weekly basis, a day before the next scheduled spraying regime. Data on plant height number of trusses and tomato fruits was collected fortnightly

4.2.5 Data Analysis

Data analysis is the process of organising, interpreting, structuring and presenting data to make it more useful in providing important information. Data used for analysis was collected from the field experiment for various Parameters. It was then processed and organized into rows and columns in a table format in Microsoft excel. It was then cleaned to remove errors and checking anomalies in the data set. The data was then subjected to analysis of variance (ANOVA) using GenStat statistical package version 15 and the protected Fisher's least significant difference (LSD) for separation of treatment means at 5% significance level (Lawes Agricultural Trust, 1991).

4.3 Results

4.3.1 Effect of bio pesticides on tomato plant height, number of trusses and tomato fruits

Table 4.1 shows the mean plant height recorded in season one and two. In both season the plant height for the two tomato varieties was not significantly different. However, the height of Tylka F1 was higher than that of Rio Grande variety. Genetically Tylka F1 is indeterminate variety while Rio Grande is determinate (table 4.1).

Table 4.1 Mean plant height recorded in season one and two

	Season one		**Season two**	
Treatments	**Rio Grande**	**Tylka F1**	**Rio Grande**	**Tylka F1**
Nimbecidine® + Pyegar®	28.94 b	44.75 a	26.38 a	38.25 b
Nimbecidine®	25.19 b	40.44 a	27.38 a	37.51 b
Pyegar®	27.06 b	43.06 a	27.69 a	38.47 b
Belt®	26.69 b	43.31 a	26.62 a	40.14 b
Control	26.06 b	40.69 a	26.06 a	39.31 b
Grand Mean	34.62		32.78	
LSD (P≤0.05)	3.18		1.61	
LSD v*t	4.49		2.27	
CV (%)	8.90		4.80	

Means within the same column having a common letter(s) do not differ significantly at P ≤0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, Treatment 1= Azadirachtin (Nimbecidine) + Pyrethrin + Garlic extract (Pyegar), Treatment 2= Azadirachtin (Nimbecidine), Treatment 3= Pyrethrin + Garlic extract (Pyegar), Treatment 4= Farmers practice (Belt), Treatment 5= control

Table 4.2: shows the number of trusses recorded in season one and two. There was no effect of treatments on the number of trusses counted on the two tomato varieties in both season one and two (Table 4.2). Table 4.3 indicates the mean number of fruits recorded in both season one and two. The treatments significantly ($p<0.05$) increased the number of tomato fruits compared to untreated control. Treatment with Belt® recorded the highest number of fruits in season one on Rio grande tomato variety in both season one and two. In season two, Rio Grande treated fruits with Nimbecidine® and Nimbecidine® + Pyegar® alternately did not differ significantly but treatment with Pyegar® alone recorded higher number of fruits (Table 4.3).

Table 4.2: Number of trusses recorded in season one and two

Treatments	**Season one**		**Season two**	
	Variety		**Variety**	
	Rio grande	**Tylka F1**	**Rio grande**	**Tylka F1**
Nimbecidine® + Pyegar®	8.06 a	7.44 a	8.06 a	7.39 a
Nimbecidine®)	8.75 a.	7.87 a	7.96 a	7.69 a
Pyegar®	8.06 a	7.88 a	8.55 a	7.56 a
Belt®	9.19 a	8.19 a	9.49 a	7.78 a
Control	8. 00 a	7.56 a	8.16 a	8.19 a
Grand Mean	8.10		8.44	
LSD	0.80		0.82	
LSD v*t	1.13		1.15	
CV (%)	9.60		9.90	

Means within the same column having a common letter(s) do not differ significantly at $P \leq 0.05$, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, Treatment 1= Azadirachtin (Nimbecidine) + Pyrethrin + Garlic extract (Pyegar), Treatment 2= Azadirachtin (Nimbecidine), Treatment 3= Pyrethrin + Garlic extract (Pyegar), Treatment 4= Farmers practice (Belt), Treatment 5= control

Table 4.3: Mean number of fruits recorded in season one and two

Treatments	Season one		Season two	
	Rio grande	**Tylka F1**	**Rio Grande**	**Tylka F1**
Nimbecidine®) +Pyegar®	22.5 abcd	25.25 cde	22.25 bcd	24.00 bcdef
Nimbecidine®),	24.75 bcde	22.00 abc	23.00 bcde	21.25 bc
Pyegar®	26.00 de	23.00 bcd	26 def	25.00 cdef
Belt®	27.5 e	26.00 de	27.5 f	27.25 ef
Control	21.00 ab	18.75 a	16.25 a	19.75 ab
Grand Mean	23.68		23.23	
LSD (P≤0.05)	1.60		1.89	
LSD v*t	2.26		2.67	
CV (%)	6.60		7.90	

Means within the same column having a common letter(s) do not differ significantly at P ≤0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, Treatment 1= Azadirachtin (Nimbecidine) + Pyrethrin + Garlic extract (Pyegar), Treatment 2= Azadirachtin (Nimbecidine), Treatment 3= Pyrethrin + Garlic extract (Pyegar), Treatment 4= Farmers practice (Belt), Treatment 5= control

Tylka F1 fruits treated with Nimbecidine® were fewer compared to those treated with Nimbecidine®) and Pyegar® combined in both season one and two. However, the results were contrary to treatment with Pyegar® as more fruits were recorded. Nevertheless, these differences were not significant. In season one; slightly lower number of fruits was recorded in Tylka F1 variety treated with Nimbecidine® compared with the control (Table 4.3).

4.3.2 Effect of treatments on tomato leaf damage

Table 4.4 below shows the percentage leaf damage observed in both season one and two. The results show that there was no significant difference on leaf damage between the treatments for the two tomato varieties in both seasons one and two. However, significant differences were recorded with Nimbecidine® and Belt® treatments for Tylka F1 tomato variety compared with Rio Grande variety in the fourth and eighth week in season one and eighth week in season two (Table 4.4). Treatments with Pyegar® alone recorded lower leaf damage for the two tomato varieties compared with Nimbecidine® treatment alone and Pyegar® + Nimbecidine® alternate treatments in both season one and two. Treatment with

Nimbecidine® alone recorded lower leaf damage compared to Pyegar® + Nimbecidine® alternate treatment but slightly higher leaf damage than Pyegar® treatment (Table 4.4). The lowest percentage leaf damage was recorded in tomatoes treated with Belt®, showing the highest efficacy in reducing leaf damage. The highest damage was recorded in the control treatment as no pesticide was sprayed. Treatments with Pyegar® alone generally recorded the lowest leaf damage compared with Nimbecidine® treatment alone and the two bio pesticides sprayed alternatively in the two tomato varieties (table 4.4).

4.3.3 Effect of bio pesticides on tomato leaf miner larvae infestation on tomato leaves

Table 4.5 shows the mean number of larvae recorded in both season one and two. In season one four weeks after transplanting; the mean number of Tuta larva varied from 0.25 (Belt®) to 2.44 (control) for tomato variety Rio Grande. For tomato variety Tylka F1 it varied between 0.19 (Belt®) to 1.88 (Nimbecidine®). Treatment with either Nimbecidine® or Pyegar® for tomato Rio Grande showed significant difference compared with control but was not the case with Tylka F1 variety. Treatment with Belt® showed good performance in reducing the *T. absoluta* larvae compared with other treatments including control for both Rio Grande and Tylka F1 tomato varieties (table 4.5). Treatments significantly reduced larvae infestation, highest being recorded with treatment with Belt® for the two tomato varieties. Treatment with Nimbecidine® and Pyegar® alone reduced the larvae infestation. However, Pyegar® recorded a slightly more reduction of the larvae infestation compared with Nimbecidine®. Treatment with Nimbecidine® and Pyegar® alternately was out performed by each individual product treatment alone (Table 4.5).

Table 4.4: Percentage leaf damage on tomatoes infested by *Tuta absoluta* in season one and two

Treatments	Season one				Season Two			
	Four weeks after transplanting		Eight weeks after transplanting		Four weeks after transplanting		Eight weeks after transplanting	
	Rio grande	Tylka F1	Rio grande	Tylka F1	Rio grande	Tylka F1	Rio Grande	Tylka F1
Nimbecidine®+ Pyegar®	32.64 abc	36.81 bc	34.03 bc	30.56 bc	36.94 bc	34.2 bc	38.32 c	38.06 c
Nimbecidine®,	24.31 abc	25.00 bc	30.56 bc	39.58 c	28.75 bc	27.6 bc	31.11 bc	40.42 bc
Pyegar®	23.61 abc	20.14bc	24.62 bc	23.61 bc	24.9 bc	22.8 bc	22.5 bc	28.33 abc
Belt®	9.72 ab	2.78 a	9.03 ab	2.76 a	8.1 ab	2.5 a	6.94 ab	4.86 a
Control	43.75 c	40.28 bc	40.26 bc	46.53 c	43.16 c	44.9 c	48.06 c	48.35 c
Grand Mean	25.90		28.16		27.38		30.7	
LSD (P≤0.05)	14.27		11.89		20.04		16.36	
LSD v*t	20.19		16.82		28.35		23. 15	
CV (%)	53.70		41.30		50.39		50.07	

Means within the same column having a common letter(s) do not differ significantly at P ≤0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, Treatment 1= Azadirachtin (Nimbecidine) + Pyrethrin + Garlic extract (Pyegar), Treatment 2= Azadirachtin (Nimbecidine), Treatment 3= Pyrethrin + Garlic extract (Pyegar), Treatment 4= Farmers practice (Belt), Treatment 5= control

Table 4.5: Mean number of larvae recorded infesting tomato in season one and two

Treatments	Season one				Season Two			
	Four weeks after treatment application		Eight weeks after treatment application		Four weeks after treatment application		Eight weeks after treatment application	
	Rio Grande	Tylka F1	Rio Grande	Tylka F1	Rio Grande	Tylka F1	Rio Grande	Tylka F1
Nimbecidine® + Pyegar®	1.75 ab	1.56 bc	1.50 bc	1.31 abc	1.06 a	0.69 a	0.38 a	0.50 a
Nimbecidine®	1.75 ab	1.06 ab	1.38 bc	1.19 abc	0.75 a	0.75 a	0.43 a	0.26 a
Pyegar®	1.19 ab	0.88 ab	1.31 abc	1.00 ab	0.69 a	0.74 a	0.44 a	0.25 a
Belt®	0.25 a	0.19 a	0.56 ab	0.13 a	0.63 a	0.44 a	0.19 a	0.19 a
Control	2.44 b	1.88 ab	2.31 c	2.88 b	1.25 a	0.94 a	1.63 a	1.5 a
Grand Mean	1.43		1.23		0.39		0.97	
LSD	0.92		0.51		0.38		0.623	
LSD v*t	1.29		0.71		0.53		0.881	
CV (%)	62.60		40.20		93.40			

Means within the same column having a common letter(s) do not differ significantly at P ≤0.05, LSD=Least Significant Difference, CV (%) =Coefficient of Variation, Treatment 1= Azadirachtin (Nimbecidine) + Pyrethrin + Garlic extract (Pyegar), Treatment 2= Azadirachtin (Nimbecidine), Treatment 3= Pyrethrin + Garlic extract (Pyegar), Treatment 4= Farmers practice (Belt), Treatment 5= control

4.4 Discussion

During the study period various pesticides which included Nimbecidine® (Azadirachtin) Pyegar® (Pyrethrin + Garlic extract) and Belt® (Flubendiamide) were studied for their efficacy in managing tomato leaf miner. Nimbecidine® (Azadirachtin) and Pyegar® (Pyrethrin + Garlic extract) reduced the leaf damage and *T. absoluta* larvae. This indicates that these botanical pesticides have the potential of managing tomato leaf miner and reduce leaf damage. According to Achio *et al*. (2012) use of Neem based insecticides has broad spectrum insecticidal properties effective against some insect pests. This is also in agreement with Hussein *et al*. (2014) who reported that garlic reduced damage of tomatoes by *T. absoluta* larvae and increased yields. The reduced damage on leaves of tomatoes treated with Azadirachtin can be attributed to antifeedant and inhibition on growth of insects (Mohamed and Lobna, 2012). Garlic has volatile oils that constitute allicin, 2-propene sulfenic acid, 2-propene thiol, propylene, thioacrolein and ajoene (Gurusubramaniana and Krishna, 1996). Allicin has two constituents namely; methyl allyl disulfide and diallyl trisulfide (Huang et al. 2000). Apart from being repellent garlic has antifeedant characteristic that affects insects due to presence of essential oils (Ben *et al.*, 2010). Garlic produces a strong pungent smell and also contains essential oils with sulphur compound (Duke, 1983). Neem and garlic have been reported by several researchers to be effective against several crop pests (Oparaeke *et al*., 2000 and Ahmed *et al*., 2009).

The results also showed that treatment of both tomato varieties with Pyegar® recorded lower *T. absoluta* larvae compared with Nimbecidine® treatment. This result concur with findings of Blue *et al*. (2012) who reported that treatment with azadirachtin on open field grown tomatoes was not effective to reduce leaf damage. This could be due to the fact that Pyegar® has a combination of two natural products; pyrethrin and garlic with different modes of action. Garlic, (*Allium sativum L*) extracts have been shown by several researchers to have insecticidal effects to a number of pest species, in all life stages with most susceptible orders including Lepidoptera and Diptera (Prowse et al., 2006) . Meles *et al*. (2012) reported that garlic works efficiently as the way DDT insecticides worked with broad spectrum action on insects. The salphone hydroxyl ion found in garlic penetrates the blood brain barrier and produce a specific poison even for higher life forms. On the other hand, Pyrethrins insecticides have been reported to cause rapid knockdown or paralysis in insects as they act very fast (Nabil, 2013, Nabil and Sherif, 2014).

In general, the tested botanical pesticides reduced the leaf damage and the *T. absoluta* larvae in the tomatoes compared with the control. This study agrees with findings of Shiberu and Getu (2018) who reported that plant extracts sprayed on infested tomato three times at vegetative, flowering and fruiting stage reduced population density of tomato leaf miner significantly. Tylka F1 tomato variety was slightly tolerant to infestation and damage by *T. absoluta.* These findings agree with results of Gharehkhani and Salek-Ebrahimi (2014) who demonstrated that different tomato varieties exhibit different resistance levels to *T. absoluta* infestation. Resistance to infestation of Tylka F1 compared to tomato Rio Grande by *T. absoluta* could possibly be associated with trichome density. Mulusew *et al.* (2013) demonstrated that resistance of infestation by *T. absoluta* of different tomato varieties was due to leaf trichome density. Azadi *et al*., (2018) observed positive correlation between trichome density and tolerance level to *T. absoluta* larvae.

CHAPTER FIVE

General Discussion, Conclusions and recommendations

5.1 General Discussion

The farmer's survey findings revealed that majority of the respondents involved in tomato production were men. Most of them engage were aged between 30 and 50 years. This result agree with Wachira *et al.* (2014) in their study in Nakuru who found majority of farmer involved in tomato production were within 40-50 years age bracket. The finding also agrees with survey done by Nguyen *et al* (2018) on pesticide use in vegetable production in Vietnam, who found out that majority of the respondents were men and were within the same age bracket of 41-50 years. Nguetti *et al* (2018) while assessing knowledge and use of pesticides by the tomato farmers in Mwea reported similar findings. The authors found out that majority of the respondents were male and most aged between 36-49 years. The result also confirms studies done in India by Himani *et al*. (2015) and by Tarla *et al*. (2015) in Cameroon. However, this finding contradicts studies of Ayandiji and Omidiji (2011) in Nigeria who found no greater difference among the gender in their survey findings. The study also established that majority of farmers in tomato production were those who had attained middle level of education; primary and secondary education. Nguetti *et al* (2018) also reported that most of the farmers had primary and secondary levels of education.

Different tomato varieties were grown in the study area. Rio Grande, Cal J and Oxyl tomato varieties were the popular varieties. They are the determinate varieties and most grown in open fields. Cal J though susceptible to disease is popular due to its high market value and long shelf life (Musyoki *et al*., 2005). Indeterminate varieties including Tylka F1, Monica F1, Kilele F1, and Anna F1 were grown by few farmers. They are usually expensive and mainly grown in greenhouses (Odema, 2009).

The major challenges faced by farmers in tomato production in the study area included pests and diseases, inadequate capital and inadequate water for irrigation. The tomato leaf miner

(*Tuta absoluta*) white fly and red spider mite were singled out as major pest and difficult to control in that order. These findings agree with study conducted by Momanyi *et al* (2019) in Mwea irrigation scheme in Kirinyaga County, who established the three insect pests as the major insect pest problem in open field tomato farms. Bacterial wilt, late blight and tomato leaf curl virus were the top three serious tomato diseases. Masinde *et al.* (2011) and Maerere *et al.* (2006) established bacteria, fungal and viral diseases among the biotic constraints of economic importance in tomato production. Late blight disease has been identified as one of the main constraints (Tumwine *et al*., 2002) and difficult to manage tomato disease (Jett, 2002).

Synthetic pesticides are the main pest management strategy adopted by majority of farmers with Alpha-cypermethrin and Lambda-cyhalothrin as the most applied pesticide active ingredients for insect pest management. They belong to Pyrethroid Pesticide Classification. According to Mutuku *et al.* (2014), Pyrethroid insecticides were the most widely applied in tomato insect pest management in Kaliluni in Kathiani Sub County. Insecticides in this group are preferred because they are cheaper and have quick knockdown. They are considered safe pesticides but quite toxic to bees and parasitic wasps and their persistent use in bees pollinated plants can cause significant yield reduction (WHO, 1986). In the management of tomato leaf miner (T*uta absoluta*), majority of the farmers in the study area were using Belt® (Flubendiamide). This finding disagrees with study by Nderitu *et al.*, (2018) where farmers in Kirinyaga preferred Coragen (Chlorantraniliprole) for *T. absoluta* management.

Majority of farmers rely on fellow farmers, agro input dealer and media for source of agricultural information. This result agrees with finding by Nguetti *et al* (2018) who found that agricultural extension officers are ignored by some farmers at the expense of agro input suppliers. Farmers relying on fellow farmers because of unavailability of extension workers or due to their limited coverage as recorded in Vietnam by Huynh (2014).Good performance from neighbouring farms also influences their behaviour for continuous reliance on fellow farmers (Nguetti *et al*,. 2018).

The study on efficacy of combining synthetic pesticides and botanicals in the management of Tomato Leaf Miner (*Tuta absoluta*) revealed the potential of the tested botanicals in reducing tomato leaf damage and larval infestation. Treatment with Pyegar® product combining garlic and pyrethrin showed superiority to neem extract botanical with azadirachtin as an active ingredient. The differences can be attributed to different modes of action of the products. Meles *et al.* (2012) and Prowse *et al*. (2006) reported garlic (*Allium sativum L*) extracts as being toxic in controlling a wide range of insect pest effectively, targeting all the stages of the life cycle including the eggs, larvae and adult. On the other hand, Pyrethrin insecticides have been reported by Nabil and Sherif (2014) to act very fast and cause rapid knockdown effect or paralysis in insects. The good performance of combined two plant extracts can be attributed to synergistic interaction due to different modes of action. Nimbecidine® treatment with only neem extract showed less activity compared with Pyegar®. Neem products and extracts don't kill insects, but instead they repel insects from attacking and inhibiting their feeding (Lokanadhan, 2012). Achio *et al*. (2012) recommended that the synergistic effect of the neem products can be enhanced by addition of natural additives such as garlic (*Allium sativum*) and hot pepper (*Capsicum frutescens*). Garlic extracts have insecticidal activity and is toxic to a number of pest species (Prowse *et al*., 2006).The mechanism of Garlic on insects is associated with an olerisine substance, a volatile oil in it. The antifeedant characteristic is due to the presence of an essential oil; allyl propyl disulphide (Ben *et al.*, 2010). Pyegar, a mix of pyrethrum and garlic is reported to be as efficient as DDT insecticide which has broad spectrum action on insects (Meles *et al.,* 2012). The salphone hydroxyl ion found in garlic penetrates the blood brain barrier and produces a specific poison even for higher life forms while the three compounds in pyrethrum, pyrethrin, cinerin and jasmolin, together knock down the insects (Nabil and Sherif, 2014).

5.2 Conclusions

The study determined pest management practices of tomato pests by small scale farmers and evaluated the efficacy of selected botanicals in the management of *Tuta absoluta* infesting tomato. The management practices adopted by the farmers are not effective and there is limited knowledge on identification and use of appropriate and effective management of *Tuta absoluta*. The small scale tomato producers relied on application of pesticides as the main pest management strategy which were mainly synthetic pyrethroids, alpha-cypermethrin and Lambda-cyhalothrin. These pesticides develop resistance quickly. Non-chemical management methods such as cultural methods intercropping, field hygiene and use of physical barrier were not commonly used by the farmers. The farmers also relied on each other and agro input dealers for agricultural information. *Tuta absoluta* was considered the most important pest of tomatoes associated with high yield losses. Inadequate of knowledge and identification of *Tuta absoluta* hindered application of appropriate methods of control.

The tested botanicals (Neem, Pyrethrum and Garlic) were effective in reducing *Tuta absoluta* larvae population and tomato leaf damage compared to control leading to increased productivity. Application of Pyegar®, a product combining garlic and pyrethrin was more superior in reducing larval infestation and leaf damage in comparison to neem extract containing azadirachtin active ingredient. Although the botanical extracts were rarely used, the study has demonstrated that they have the potential and are effective for the management of *Tuta absoluta* and can be considered for its management.

5.3 Recommendations

- Capacity build tomato producers with diverse pest management strategies based on and not limited to eco-friendly natural botanical pesticides, field sanitation, tolerant varieties and clean planting material that are sustainable pest management approaches and avoid overreliance on synthetic pesticide as the only option for *T. absoluta* management.

- Extension workers should campaign for adoption of alternative pest management strategies that include botanical bio pesticides such as Pyegar® (Pyrethrin + Garlic extract) and Nimbecidine (Azadirachtin) biopesticides for *Tuta absoluta* management.
- Future research should focus on developing and evaluating for effectiveness, new active ingredients and new molecules from natural and plant origin for sustainable tomato production and protection of the quality of the environment.

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Appendices

Appendix 1: Survey questionnaire

A Survey Questionnaire to determine the pest management strategies for tomato production by small scale farmers in lower Eastern region of Kenya

Name of the Enumerator……………………………………Date of survey……………

A. Demographic data

1. Respondent/ Farmers name: …………………………………………………
2. Phone no……………………….…… Date……………………………………
3. Gender: Male ☐ Female ☐
4. County: …………………………… Sub county………………………………
5. Location: …………………Sub location ……………………Ward………………….
6. Altitude…………………………… Farm size (Acres): …………………..
7. Agro-Ecological Zone………………………………..
8. What is your age group (years)? (Tick appropriately)

i.	Below 20 years	☐	i.	41-50 years	☐
ii.	21-30 years	☐	ii.	51 -60 years	☐
iii.	31-40 years	☐	iii.	61 and above	☐

9. What is your household size………………….

10. Education level (Tick appropriately)

i.	No formal education	☐	ii.	Secondary school education	☐
iii.	Primary education	☐	iv.	Tertiary education	☐
v.	Informal Education	☐			

11. Numbers of years spend in acquiring the above level of education………………

B. Production detail

12. For how long have you been involved in production and selling of tomatoes? (Tick appropriately)

i.	Less than 1 year	☐	ii.	10-20years	☐
iii.	1-2 years	☐	iv.	20-30 years	☐
v.	2-5 years	☐	vi.	More than 30 years	☐
vii.	5-10 years	☐			

13. Where do you grow your tomatoes? (Tick)

i. Open field ☐	ii. Greenhouse ☐
iii. Both ☐	
Other (specify)……..	

14. What is the average acreage you have been growing tomatoes ………………………………………

15. What other crops do you grow in your farm apart from Tomatoes?(List them)

16. Which tomato varieties have you been growing and what is the reason for preference of that variety?

	Tomato Variety	**Reason for preference of the variety**
i.		
ii.		
iii.		
iv.		

17. Which system of Tomato production do you use? (Tick appropriately)

Rain fed ☐	Irrigation ☐
Both ☐	

18. If you use irrigation, which irrigation method (s) do you use? (Tick appropriately)

Drip irrigation ☐	Furrow irrigation ☐
Overhead irrigation ☐	Sprinkler ☐
Basin irrigation ☐	Any other (specify) ☐

19. What are the Source of irrigation water; (Tick appropriately)

River/stream ☐	Borehole ☐
Rain ☐	Sewage water ☐
Other (specify ☐	

20. What is the average yield of tomatoes per acre in crates (1 crate 65kg) …………

21. What packaging material do you use for tomatoes?(List)

22. How do you transport tomato produce to the market? (lists in order of importance)

Boda boda/ bicycles	☐	Ox cart	☐
Trucks	☐	Wheelbarrow	☐
Pick ups	☐	Other (specify)	☐

23. What is the source of extension messages/ advice on tomato production? (Rank them in order of importance)

Input suppliers/ Agro vet	☐	Radio/ TV	☐
Fellow farmers	☐	NGO	☐
GOK extension	☐		
Others (specify)……			

24. What are the main challenges of growing tomato production? (lists in order of importance)

Pest and Diseases	☐	Lack of Capital	☐
Lack of market	☐	Inadequate technical knowledge	☐
Drought	☐	Inadequate water for irrigation	☐
Other (specify)………			

C. Pest and Diseases

25. What are the major pests you have observed in your tomato field? (lists in order of importance)

Whiteflies	☐	Cut worm	☐
African boll worm	☐	Thrips	☐
Aphids	☐	Red spider Mite	☐
Leaf miner	☐	*Tuta absoluta*	☐
Others (specify)…….			

26. What are the major diseases you have observed in your tomatoes? (lists in order of importance)

Bacterial wilt	☐	Late blight	☐
Septoria leaf spot	☐	Anthracnose	☐
Powdery mildew	☐	Fusarium wilt	☐
Bacteria canker	☐	Tomato Mosaic virus	☐
Leaf curl virus	☐	Early blight	☐
Other specify……………			

27. Which of the pests below, cause major yield loss? (lists in order of importance)

Whiteflies	☐	Cut worm	☐
African boll worm		Thrips	☐
Aphids	☐	Red spider Mite	☐
Leaf miner	☐	*Tuta absoluta*	☐
Others (specify)…….			

28. Which crop(s) do you use in rotation with tomatoes ………………………………………

29. Which of the pest(s) below is difficult to manage? (lists in order of importance)

Whiteflies	☐	Cut worm	☐
American boll worm	☐	Thrips	☐
Aphids	☐	Red spider Mite	☐
Leaf miner	☐	*Tuta absoluta*	☐
Others (specify)…….			

30. Do you know of *Tuta absoluta* and have you observed it in your tomato crop?
Yes ☐ No ☐

31. If yes, when did you observe in your tomato field (month and year)……………………………………

32. Which month(s) of the year is the pest more devastating? ………………………………………

33. What is the average loss in % of tomato as a result of this pest ……………………………..…………

34. What stage of tomato was the *Tuta absoluta* most damaging? (lists in order of importance)

At nursery	☐	Seedling	☐
Vegetative	☐	Flowering	☐
Fruiting	☐		

35. What part of tomato is severely affected by *Tuta absoluta*? (lists in order of importance)

Stem	☐	Inflorescence	☐
Fruits	☐	Foliage /leaves	☐

36. How have you been managing the pest in tomatoes? (Rank them in order of importance)

Use of synthetic pesticide	☐	Use of eco friendly /natural pesticides	☐
Use of tolerant variety(s)	☐	Uprooting affected plants	☐
Crop rotation	☐	Intercropping	☐
Use of pheromone traps	☐	Field hygiene	☐
Cultural practices	☐	Adjustment of planting dates	☐
No action(Doing nothing)	☐	Use of physical barriers	☐
Any other (specify) …			

37. Name the pesticides you have been using to control insect pests

Trade Name	**Active ingredient**

38. Name the pesticide(s) you have been using to control *Tuta absoluta?*

Trade Name	**Active ingredient**

39. Have you ever received any training on identification and management of *Tuta absoluta?*

Yes ☐ No ☐

40. What has been the major challenge in control of pests in tomatoes?

Inadequate knowledge in pest identification ☐	Lack of knowledge on pesticides ☐
Lack of capital ☐	New emerging pest ☐
Any other (specify) …	

41. What are the major challenge in control of *Tuta absoluta* in tomatoes

Inadequate knowledge in pest identification ☐	Lack of knowledge on pesticides ☐
Lack of capital ☐	New emerging pest ☐
Any other (specify) …	

42. Which of the methods do you use to manage tomato diseases? (Rank them in order of importance)

Use of synthetic pesticide ☐	Use of eco-friendly /natural pesticides ☐
Use of tolerant variety(s) ☐	Uprooting affected plants ☐
Crop rotation ☐	Intercropping ☐
Quarantine ☐	Field hygiene ☐
Cultural practices ☐	Adjustment of planting dates ☐
Use of physical barriers ☐	No action(Doing nothing) ☐
Use of clean planting material ☐	Destruction of crop residue ☐
Other (specify)……	

43. Where do you seek advice of pest related problems? (Rank them in order of importance)

GOK extension service ☐	Input suppliers ☐
Radio/ TV ☐	Fellow farmers ☐
NGO ☐	
Others (specify)…………………	