EFFECTS OF INSECTICIDE TREATED NETS IN THE MANAGEMENT OF TOMATO PESTS AND THEIR IMPACT ON NATURAL ENEMIES AND YIELD IN NAIROBI AND MURANG’A COUNTIES

By

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science (Agricultural Entomology) in the School of Pure and Applied Sciences of Kenyatta University

September 2015
DECLARATION

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

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DEDICATION

This thesis is dedicated to my family and friends who have been a great source of motivation and inspiration. Particularly, my wife, Sarah, my son, Ethan, and my daughter, Shanelle, for being there for me throughout my study. Also, this thesis is dedicated to my parents for believing in the richness of learning and for continuously encouraging me during my studies. Finally, thanks to God Almighty, for giving me the strength to complete this journey in pursuit of academic excellence.
ACKNOWLEDGEMENTS

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I wish to thank the Centre Director, Kenya Agricultural and Livestock Research Organization Kabete Dr. Patrick Gicheru for granting permission to conduct this work, and in kind support by access to facilities and staff time. This research was made possible through the project, Low Cost Pest Exclusion and Microclimate Modification Technologies for small scale farmers in East and West Africa, financially supported by United States Agency for International Development (USAID) and Horticulture Collaborative Research Support Program (HORTCRSP). The Agronets were provided by A to Z Co. Ltd (Arusha, Tanzania) to which I am grateful. I thank Dr Lusike Wasilwa, Assistant Director, Horticulture and Industrial Crops at KALRO for allowing me to be part of this project.

I thank my fellow MSc students in the HORTCRSP project: Catherine Gacheri and Caroline Achieng’a both of Kenyatta University and Judy Jeptoo of Moi University for the fruitful discussions, encouragement and collaboration during the research work.
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# ABBREVIATIONS AND ACRONYMS

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<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABW</td>
<td>African Bollworm</td>
</tr>
<tr>
<td>AVRDC</td>
<td>Asian Vegetable Research and Development Corporation</td>
</tr>
<tr>
<td>CABI</td>
<td>Centre for Agriculture and Biosciences International</td>
</tr>
<tr>
<td>EPPO</td>
<td>European Plant Protection Organization</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>HCDA</td>
<td>Horticultural Crops Development Authority</td>
</tr>
<tr>
<td>HORTCRSP</td>
<td>Horticulture Collaborative Research Support Program</td>
</tr>
<tr>
<td>HPTC</td>
<td>Horticulture Practical Training Centre</td>
</tr>
<tr>
<td>ICIPE</td>
<td>International Centre of Insect Physiology and Ecology</td>
</tr>
<tr>
<td>IES</td>
<td>Insect Exclusion Screens</td>
</tr>
<tr>
<td>INSV</td>
<td>Impatiens Necrotic Spot Virus</td>
</tr>
<tr>
<td>IPM</td>
<td>Integrated Pest Management</td>
</tr>
<tr>
<td>KALRO</td>
<td>Kenya Agricultural and Livestock Research Organization</td>
</tr>
<tr>
<td>KEPHIS</td>
<td>Kenya Plant Health Inspectorate Services</td>
</tr>
<tr>
<td>KMD</td>
<td>Kenya Meteorological Department</td>
</tr>
<tr>
<td>MOARD</td>
<td>Ministry of Agriculture and Rural Development</td>
</tr>
<tr>
<td>NARL</td>
<td>National Agricultural Research Laboratories</td>
</tr>
<tr>
<td>RSM</td>
<td>Red Spider Mites</td>
</tr>
<tr>
<td>TSWV</td>
<td>Tomato Spotted Wilt Virus</td>
</tr>
<tr>
<td>TYLCV</td>
<td>Tomato yellow leaf-curl virus</td>
</tr>
<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural organization</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>USAID</td>
<td>United States Agency for International Development</td>
</tr>
<tr>
<td>USDA</td>
<td>United States Department of Agriculture</td>
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</table>
ABSTRACT

Tomato is a popular vegetable in Kenya and is extensively grown by small-scale farmers. In spite of the economic benefits to the farmers, insect pests remain one of the most significant constraints to tomato production. Current insect pests control measures rely on pesticides despite the known hazards to human health and the environment. Repeated use of pesticides has also led to the development of resistance by pests. Therefore, it is important to evaluate other pest control strategies that are safe, effective and economically viable with the aim of minimizing the hazardous effects of insecticide residues. This study investigated the effectiveness of alpha-cypermethrin treated nets against tomato insect pests and its impact on yield and natural enemies of tomato pests. The study was conducted on station at the Kenya Agricultural and Livestock Research Organization (KALRO) experimental plots at Kabete and at the Horticultural Practical Training Centre (HPTC) in Thika over a six month period. A local variety of tomato, Riogrande®, was sown in the nursery and was transplanted on the fourth week after sowing. The insecticide treated nets with a mesh size of 0.9 mm and two non-treated nets with a mesh size of 0.9 mm and 0.4 mm respectively were used. The efficacy of the insecticide treated nets and non-treated nets (mesh size of 0.9 mm and 0.4 mm respectively) were evaluated over a six month period. Each treatment was replicated five times in a completely randomized block design. Assessing the abundance and diversity of insect pests and their natural enemies on tomatoes was carried out by collecting and counting their numbers weekly for every replicate. Ripe tomatoes were harvested twelve weeks after transplanting, sorted and classified into marketable and unmarketable fruits. The total number of marketable fruits and fruit weights were obtained. The data on the abundance and diversity of insect pests and their natural enemies was analyzed using the Shannon-Weaver diversity index and Berger–Parker dominance index, while Analysis of Variance (ANOVA) was performed on the yield data to test the differences in the number and weight of marketable fruits from the different treatments. The significant means were separated using the Tukey test (P<0.05). A total of seven pest species were identified infesting tomato seedlings (Aphis gossypii, Thrips tabaci, Bemisia tabaci, Agrotis spp., Schizonycha spp., Tetranychus spp. and Liriomyza trifolii) while nine pest species were identified infesting tomato plants during field production (Aphis gossypii, Thrips tabaci, Bemisia tabaci, Haltica pyritosa, Helicoverpa armigera, Tetranychus spp., Liriomyza trifolii, Systates spp. and Planococcus spp.). The 0.9 mm alpha-cypermethrin treated nets were effective in protecting tomato plants against Aphis gossypii, Bemisia tabaci, Planococcus spp. Liriomyza trifolii and Helicoverpa armigera. The numbers of Aphidius spp. and Chilomenes lunata were not significantly affected by the use of nets to protect tomatoes against pest attack. The mean marketable fruit weights were significantly higher for tomatoes harvested under treated nets compared with those harvested from non-protected plots at Kabete (P=0.0000533). Similarly, the mean number of marketable fruit weight were significantly higher under treated plots at Thika (P=0.002). The results of this study demonstrate the potential of using alpha-cypermethrin treated nets as a viable strategy in improving tomato yields through the reduction of pest numbers on the crop. The netting covers can be used as a component of integrated pest management in tomato production.
CHAPTER ONE
INTRODUCTION

1.1 Background Information

Tomato (Solanum lycopersicum L.), is an economically important crop which belongs to the Family Solanaceae. The family includes potatoes (Solanum tuberosum L.), capsicums (Capsicum annuum L.), brinjals (Solanum melongena L.) and black nightshade (Solanum nigrum L.). Leading tomato producing countries include China, USA, India, Turkey, Egypt, Italy, Iran, Spain, Brazil, and Mexico (Desneux et al., 2011). The world’s average tomato yield in 2001 was 27 Mt/ha with only 8 Mt/ha from tropical Africa (Elphinstone et al., 2005). According to Ephinstone et al. (2005), Kenya produces an average of 12 Mt/ha compared to Nigeria (7 Mt/ha), Egypt (35 Mt/ha) and France (120 Mt/ha).

Tomatoes are popular vegetables grown in Kenya ranking second to Brassica (cabbage and kales) in the quantities produced and value and are grown in the open fields or in high tunnels for home consumption, fresh produce market, export and for processing (Mungai et al., 2000; MOARD, 2002). In spite of the economic benefits, Kenyan farmers face a number of constraints during production. Important among these constraints are arthropod pests and diseases (Waiganjo et al., 2006). The major arthropod pests include spider mites (Tetranychus spp., Acari: Tetranychidae), African bollworm (Helicoverpa armigera Hubner, Lepidoptera: Noctuidae), cutworms (Agrotis spp., Lepidoptera: Noctuidae), thrips (Thrips tabaci Lindeman and Frankliniella occidentalis Pergade, (Thysanoptera: Thripidae) and whiteflies (Bemisia tabaci Gennadius, Hemiptera: Aleyrodidae). Tomatoes are also attacked by
plant-parasitic nematodes such as root-knot nematodes (*Meloidogyne incognita, M. javanica* and *M. hapla*). Major diseases of tomatoes include bacterial wilt caused by *Pseudomonas solanacearum* Smith, late blight caused by *Phytophthora infestans* Mont.de Bary, leaf curl caused by the tomato leaf curl virus, leaf spot caused by *Alternaria solani* Ell. and Martin, blossom end rot caused by calcium deficiency in tomato fruit and powdery mildew caused by *Leveillula taurica* (Lev.) Arn.

The majority of smallholder vegetable farmers rely on spraying pesticides to reduce the damage from pests and diseases. The overuse of hazardous pesticides by smallholder farmers not only results in negative impacts on human health and the environment but also increases resistance of pests and destroys beneficial insects (Mathews, 2008). A potential means to break the reliance on pesticides is physical exclusion of pests using nets with a fine mesh screen as part of an integrated pest management (IPM) approach (Vidogbéna et al., 2015). The application of deltamethrin treated nets have been tested and proven to be effective against the diamondback moth (*Plutella xylostella* L., Lepidoptera: Plutellidae) and the aphid (*Lipaphis erysimi* Kaltenbach, Homoptera: Aphididae) on cabbage (*Brassica oleracea* var. *capitata*) in Benin, China and the Netherlands (Berlinger et al., 2002; Martin et al., 2006; Licciardi et al., 2008). The current study aimed at investigating the effects of alpha-cypermethrin treated nets in the management of key pests of tomato and its impact on natural enemies and yield.
1.2 Statement of the problem

Tomatoes are grown extensively by small holder farmers in Kenya as a high value horticultural crop for the domestic market, processing and export. The leading countries in fruit yield per hectare are the Netherlands (4,961,539 Mt/ha) and Belgium (4,166,667 Mt/ha) while Kenya produces an average of 12 Mt/ha (Elphinstone, et al., 2005). Despite the economic benefits, successful open-field production of tomato in the tropics is limited by pest infestations that contribute to reduced quantity and quality (Abate et al, 2000; Tumwine et al., 2002). Like other farmers in Africa, smallholder farmers in Kenya rely heavily on routine pesticide applications for the management of insect pests and diseases (Maerere et al., 2006). However, the overreliance on insecticides present several disadvantages due to the adverse effects on human health, soil, water resources and the development of resistance among most pests following repeated use (Martin et al., 2002; Otoidobiga et al., 2002; Gogo et al., 2014).

In Africa, insect-proof nets and particularly insecticide-treated nets have only been used as bed-nets in public health to prevent malaria morbidity and mortality (Hougard et al. 2002). Therefore, information on the effect of insecticide treated or untreated insect proof netting on tomato pests could lead to identifying environmentally safer management strategies that would be an alternative to frequent insecticide sprays. Thus, this study evaluated the effectiveness of alpha-cypermethrin treated polyethylene nets as a pest management option that could be useful in reducing the indiscriminate insecticide application among smallholder vegetable farmers in peri-urban areas.
1.3 Justification of the study

The repeated use of high dose and increased spray frequency of pesticides on vegetables by smallholder tomato farmers in Sub-Saharan Africa has led to severe ecological consequences like destruction of natural enemy fauna, adverse effects on non-target organisms, increased pesticide residues in the harvested produce as well as selecting for insecticide resistance in important pest species (Martin et al., 2002; Otoidogba et al., 2002). These unsustainable pesticide use practices provide an opportunity to identify eco-friendly, safer, and sustainable methods of pest control especially with the increasing demand for vegetables in expanding African cities and for export. One of the sustainable ecological friendly approaches is the use of insecticide treated nets. This approach has not been used in managing tomato pests in Kenya and there is therefore need to evaluate its efficacy. This study was thus initiated to evaluate the effectiveness of alpha-cypermethrin treated polyethylene nets as a pest management option that could be useful in reducing the indiscriminate insecticide application among smallholder vegetable farmers in peri-urban areas.

1.4 Research questions

i. How does the abundance and diversity of tomato pests and their associated natural enemies vary on tomatoes grown under alpha-cypermethrin treated nets, non-treated nets and in open field?

ii. What are the yields of tomatoes grown under alpha-cypermethrin treated nets, non-treated nets and in open field?
1.5 Hypotheses

i. There is no difference in the abundance and diversity of tomato pests and their associated natural enemies on tomatoes grown under alpha-cypermethrin treated nets, non-treated nets and non-protected control.

ii. There is no difference in yields of tomatoes grown under alpha-cypermethrin treated nets, non-treated nets and non-protected control.

1.6 Objectives of the study

1.6.1 General objective

To investigate the effectiveness of insecticide treated nets in managing major tomato pests during seedling and field production and their impact on natural enemies and yields.

1.6.2 Specific objectives

i. To determine the effect of alpha-cypermethrin treated and non-treated nets on the abundance and diversity of tomato pests and natural enemies in the nursery and field at Kabete and Thika.

ii. To assess the yield of tomatoes grown under alpha-cypermethrin treated and non-treated nets in the field at Kabete and Thika.
CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and cultivation of tomato

The wild relatives of cultivated tomato (Solanum lycopersicum L.) are native to western South America, including the Galapagos Islands (Peralta et al., 2008). After its introduction to Europe, tomato cultivation found success mainly in the Mediterranean countries, including Spain and Italy, which formed secondary centers for diversification (García-Martínez et al. 2006). Like the other horticultural crops, tomato was introduced in Kenya by the early European settlers in the 1900s (Atherton and Rudich, 1986).

Tomatoes grow well in well-drained, deep, uniform clay or silty loam soils, which are high in organic matter (Saeed et al., 2007). The crop is adapted to a wide range of climatic conditions and the optimum temperature required for growth and development for most varieties lies between 21 and 24 °C (Naika et al., 2005). According to the same author, tomato is moderately tolerant to a wide range of pH (level of acidity), but grows well in soils with a pH of 5.5 – 6.8 with adequate nutrient supply and availability.

Tomato forms part of the daily diet of most African families, particularly in Kenya (Onyambus et al., 2011). It is used in various forms, such as fresh salad, cooked foods, and in processed forms like ketchup and paste (Saeed et al., 2007). Tomatoes have numerous health benefits and contribute to a well-balanced diet (Rao and Agarwal, 1999). Tomato is an important source of antioxidant compounds such as
lycopene and nutrients such as vitamin A, vitamin C, potassium, phosphorous, magnesium and calcium as well as calories (Miller et al., 2002).

Tomato yields in the tropics vary widely, between one to 23 tons per hectare compared to the temperate regions, where yields of 10 to 20 tons per hectare have been realized (Lanny, 2001). Yields are lowest in tropical Africa as a result of both abiotic and biotic factors of which the latter include primarily insect pests, diseases, and weeds (Tumwine et al., 2002).

2.2 Tomato production in Kenya
Tomatoes are the second most important vegetable crop in Kenya, surpassed only by Brassicas (Onyambu et al., 2011). Tomato is an important horticultural crop in Kenya, with a potential for increasing incomes for small scale farmers in rural areas, improving their living standards and creating a source of employment (Ssejjemba, 2008). It is mainly grown in the open-field, but in the recent past adoption of greenhouse tomato growing technology is on the rise (Wachira et al., 2014). In 2012, the area under tomato production was 18,613 ha with a total production of 397,007 MT valued at 12.8 billion (HCDA, 2013). The major tomato producing Counties in Kenya are Kirinyaga (13.7%), Kajiado (9.1%) and Taita Taveta (6.9%) as shown in table 2.1.
Table 2.1: Production of tomato in selected counties in Kenya

<table>
<thead>
<tr>
<th>Counties</th>
<th>Areas (Ha)</th>
<th>Quantity (Tonnes)</th>
<th>Value in Millions (Kshs)</th>
<th>Share by quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirinyaga</td>
<td>1,978</td>
<td>54,524</td>
<td>1,070</td>
<td>13.7%</td>
</tr>
<tr>
<td>Kajiado</td>
<td>1,551</td>
<td>36,460</td>
<td>990</td>
<td>9.1%</td>
</tr>
<tr>
<td>Taita Taveta</td>
<td>548</td>
<td>27,400</td>
<td>959</td>
<td>6.9%</td>
</tr>
<tr>
<td>Meru</td>
<td>420</td>
<td>22,214</td>
<td>468</td>
<td>5.6%</td>
</tr>
<tr>
<td>Bungoma</td>
<td>1,022</td>
<td>21,720</td>
<td>887</td>
<td>5.5%</td>
</tr>
<tr>
<td>Kiambu</td>
<td>930</td>
<td>20,972</td>
<td>884</td>
<td>5.2%</td>
</tr>
<tr>
<td>Migori</td>
<td>1,068</td>
<td>18,429</td>
<td>910</td>
<td>4.6%</td>
</tr>
<tr>
<td>Makueni</td>
<td>408</td>
<td>17,552</td>
<td>682</td>
<td>4.4%</td>
</tr>
<tr>
<td>Homabay</td>
<td>803</td>
<td>13,120</td>
<td>638</td>
<td>3.3%</td>
</tr>
<tr>
<td>Nakuru</td>
<td>580</td>
<td>10,990</td>
<td>257</td>
<td>2.7%</td>
</tr>
<tr>
<td>Machakos</td>
<td>314</td>
<td>10,240</td>
<td>357</td>
<td>2.6%</td>
</tr>
<tr>
<td><strong>All counties</strong></td>
<td><strong>18,613</strong></td>
<td><strong>397,007</strong></td>
<td><strong>12,840</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

(Source: HCDA, 2013)

Two types of tomato varieties are grown in Kenya: determinate and indeterminate types. Open field production requires determinate varieties like Eden, Riogrande, Onyx, Tanzanite, Monyalla and Cal. J (Musyoki et al., 2005). Greenhouse production requires indeterminate tomato varieties like Kenom, Marglobe, Monset, Nemonneta and Anna F1 (Odame, 2009).
2.3 Challenges to tomato production in Kenya

Tomato production in Kenya is faced with many constraints along its value chain which include low quality seeds, a variety of pests and diseases, poor crop husbandry and post-harvest losses among other factors (Varela et al., 2003). According to Waiganjo et al. (2006) the major constraint in tomato production in Kenya is insect pests. The crop is attacked by several insect pests during its development. According to the Centre for Agriculture and Biosciences International (CABI, 2004), tomato yield losses in East Africa, including Kenya, can be as high as 88%, of which pests account for 56%.

2.4 Pests of tomatoes


Various insects and mites cause damage to tomato plants at all stages of growth as a result of direct feeding and through transmitting disease causing organisms (Lange and Bronson, 1981). According to the same author, damage on fruits was observed in the form of scarring, tissue reduction, and aberrations in shape or color making the
fruits unmarketable. Fruits also become contaminated by insect presence, insect excreta, insect parts, cast skins, and eggs which reduce market acceptability.

Insects attack tomatoes from the seedling stage until harvesting. The major soil insect pests attacking tomato seedlings are cut worms, *Agrotis* spp., (Lepidoptera: Noctuidae) which damage by cutting off the plant just below the surface of the soil making the plant fall over, and, chafer grubs, *Schizonycha* spp., (Coleoptera: Scarabaeidae) which feed on the roots of the plant (Waiganjo *et al.*, 2006). Foliage pests such as aphids, *Aphis gossypii*, thrips and whiteflies suck plant sap and cause leaf distortion and stunting of tomato plants (Waiganjo *et al.*, 2006). More importantly, *F. occidentalis* has been recorded on tomatoes, and is the key vector of the tomato spotted wilt virus (TSWV) disease (Kirk and Terry, 2003). Whiteflies are known vectors of the tomato yellow leaf curl viruses (TYLCV) which are the most widespread and currently rank third among the economically and scientifically most important tomato viruses worldwide (Scholthof *et al.*, 2011).

The African bollworm bores into the fruit and feeds on the inner part, releasing plenty of excreta (frass) which is noticeable on damaged fruits. Feeding by *H. armigera* causes tomato fruit to rot as a result of secondary infection by bacterial and fungal pathogens which penetrate the fruit through the feeding holes (Waiganjo *et al.*, 2006). *Helicoverpa armigera* is one of the most destructive insect pests of tomato, causing yield losses as high as 70% due to fruit boring (Varela *et al.*, 2003). The red spider mites, *Tetranychus urticae* Koch, infest tomato leaves and suck the sap thus interfering with nutrient uptake and may be serious pests in hot weather and
during drought (Knapp, 1999). Severe infestation by these insect pests usually causes significant yield loss and may result in total crop loss.

In a baseline survey conducted on tomato production in the major tomato growing areas of Kirinyaga District, farmers listed the main tomato pests according to their degree of importance as follows: spider mites (97.1%), African bollworms (76.9%), thrips (63.6%), whiteflies (58.7%), cutworms (45.5%), aphids (29.8%), crickets (16.5%) and leafminers (13.2%) (Waiganjo et al., 2006). Only 5% of the respondents mentioned other pests of economic importance in tomato production such as flea beetles (*Haltica pyritosa*, Coleoptera: Chrysomelidae) and mealybugs (*Planococcus* spp., Hemiptera: Pseudococcidae).

### 2.5 Integrated Pest management (IPM)

Integrated Pest Management (IPM) is an approach that can reduce the counterproductive pesticide applications (Wheeler, 2002). It is an ecosystem-based strategy that focuses on long term prevention of damage to crops by pests through a combination of cultural, chemical, biological and mechanical controls to suppress pest population levels below those causing economic injury (Flint, 2012). Applying multiple control tactics reduces the reliance on pesticides hence minimizing the occurrence of pest resistance to pesticides (Raini *et al*., 2005).

Integrated Pest Management (IPM) systems are available for a range of horticultural crops produced in Eastern Africa and farmers require appropriate training to utilize
such systems (Bekele et al., 2011). Integrated Pest Management (IPM) approaches for the control of tomato pests in Kenya include cultural, chemical, biological and physical (mechanical) methods (Waiganjo et al., 2010).

### 2.5.1 Cultural control

Cultural control methods are those management activities that the farmer can choose to carry out that make the environment unfavourable to one or more pests (Horn, 2008). The objective for this control strategy is to reduce pest numbers, either below economic injury levels, or sufficiently to allow natural or biological controls to take effect (Sithanantham et al., 2004). Cultural control techniques used to reduce insect pest populations include site selection, crop rotation, trap cropping, cultivar and seed selection, plant density and weed control (Jones, 2001). Cultural practices may have opposing effects on different pests (Glen, 2000), so selection of specific practices must be based on an overall pest risk assessment. Cultural controls are often most effective when used in conjunction with other pest management strategies (mechanical, biological, and chemical control methods) and should be part of every gardener’s integrated pest management (IPM) strategy (Varela et al., 2003).

In order to avoid losses caused by pest outbreaks, data on pest distribution is among the important factors to consider when selecting a suitable site for growing vegetable crops (Jackson, 1988). In some cases, a primary pest may be avoided by selecting a site that is ideal for the crop and natural enemies of the pest but unfavorable for the pest itself (Zehnder et al., 2007).
Crop rotation is the repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land (Palaniappan, 1996). Growing tomatoes on same field year after year will lead to build up of populations of organisms that feed on the crop (Atieri, 1993). Crop rotation practices reduce the availability of alternate hosts and prevent the buildup of pests, particularly aphids and thrips, over successive seasons by breaking their life cycle (Stoddard et al., 2010). Crop rotation with non solanaceous crops has been successfully implemented as part of an IPM strategy in the management of the tomato leafminer, *Tuta absoluta* (Meyrick), (Lepidoptera: Gelechiidae) in Ethiopia (Retta and Berhe, 2015).

Trap crops are plant stands grown to attract insects or other organisms like nematodes to protect target crops from pest attack, preventing the pests from reaching the crop or concentrating them in a certain part of the field where they can be economically destroyed (Hokkanen, 1991). According to the same author, the aim of trap cropping is to ‘lure’ and retain pest insects on attractive ‘trap crop’ plants in the vicinity of a main crop thereby reducing their numbers therein. Use of trap crops could reduce the pest damage and number of sprays needed to produce economic crop since they can push or pull away pests from the main crop (Francis, 2001). In India, the use of African tall variety of marigold cv. Golden Age (*Tagetes* spp.) as a trap crop afforded maximum reduction of both eggs and larvae of *H. armigera* in the intercropped tomato with a consequent reduction in the number of bored fruits (Dhandapani et al., 2003).
Higher plant densities, where the canopy closes early, incur lower aphid populations (Al-Jallad et al., 2007). Removal of weeds from cropping areas can help reduce the availability of alternate hosts for B. tabaci, which is a vector of tomato yellow leaf curl virus (TYLCV) (Hilje et al., 2001).

2.5.2 Chemical control

Chemical control is the use of pesticides to reduce pest populations. It involves the use of chemical compounds to kill pests or to inhibit their feeding, mating, or other essential behaviours. Most of these chemical controls are fast acting and effective (Varela et al., 2003). Chemical agents used to kill insects include synthetic pesticides, botanical pesticides, semiochemicals (natural chemicals produced by insects or plants as signals to affect insect behavior), and other agents whose effectiveness is based on particular chemical compounds (National Research Council, 1992).

2.5.2.1 Synthetic pesticides

The major classes of synthetic pesticides for agricultural use include organochlorines, organophosphates, carbamates, and pyrethroids, among others (Eldridge, 2008). Most synthetic pesticides act by interfering with biochemical and physiological processes that are common to a wide range of organisms (Pretty and Bharucha, 2015). Synthetic insecticides have a negative impact on farmers, consumers and the environment (Pimentel and Greiner, 1997). According to Gitonga et al. (2010), dimethoate, abamectin, imidacloprid, alpha-cypermethrin, and beta-
cyfluthrin are the most common insecticides used against insect pests in vegetable production systems in Kenya.

The demand for high tomato fruit quality is a factor that often increases the use of synthetic pesticides to keep pests and diseases below economic thresholds in tomato agro-ecosystems (Hamilton and Toffolon, 1987). According to Pimentel and Greiner (1997), majority of smallholder vegetable farmers rely on spraying synthetic pesticides to reduce the damage from pests and this has led to development of resistance by pests, resurgence of pests and the development of secondary pests and elimination of natural enemies. There have been reports of pest resurgence on tomatoes due to high use of pesticides in different parts of the world. Examples include increased populations of African bollworms, *H. armigera* and cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) after treatment with methomyl and carbaryl (Hoffmann et al., 1996). Similar increases were reported after applications of endosulfan (Campbell et al., 1991). Populations of leafminers, *Liriomyza salivae* also increased after methomyl treatments (Oatman et al., 1983) and chemical control of African bollworm resulted in tomato pest resurgences (Salas, 1992). Thomas et al. (1990) also reported the effect of deltamethrin in reducing predator populations significantly.

### 2.5.2.2 Botanical pesticides

Botanical pesticides are naturally occurring chemicals extracted from plants, and have long been touted as attractive alternatives to synthetic chemical insecticides for pest management because they pose little threat to the environment or to human
Botanical pesticides possess an array of properties including toxicity to the pest, repellency, antifeedance and insect growth regulatory activities against pests of agricultural importance (Prakash and Rao, 1996). According to Prakash and Rao (1996), there are four major types of botanical products used for insect control (neem, pyrethrum, rotenone, and essential oils).

Azadirachtin is a botanical insecticide obtained from seeds of the neem tree, *Azadirachta indica* Juss (Meliaceae) (Schmutterer, 2002). It is strong anti-feedent, repellent and growth regulator of a wide variety of phytophagous insects (Mitchell et al., 2004). The main advantages of neem are reduced human toxicity (Raizada et al., 2001), fast and complete degradation in the environment, low risk for resistance and selective properties reported for some non-target organisms (Walter, 1999). Currently, several neem-based products are registered as pesticides in Kenya (Knapp and Kashenge, 2003). These products have already proven to be effective against several insect pests like diamondback moth, *Plutella xylostella*, aphids, *Brevicoryne brassicae* L., *Myzus persicae* (Kalt) and *Lipaphis erysimi* (Sulz) in cabbage, *Brassica oleracea* var capitata, and *Lyriomyza* spp. on tomatoes and cut flowers (Knapp and Kashenge, 2003; Waiganjo et al., 2011). Neem can be used as a component in several IPM strategies. There is evidence on the synergistic effect of neem with microbial pesticides such as Nucleopolyhedrovirus (NPV) in the control of the African bollworm attacking tomato fruits (Senthilkumar et al., 2008).

Pyrethrum plant from the genus *Chrysanthemum* is grown in Kenya and the active ingredients consists of a mixture of pyrethrins and cinerin obtained from the dried
flowers of the pyrethrum daisy (*Tanacetum cinerariaefolium*; Asteraceae) (Rajapakse and Ratnasekera, 2008). The insecticidal action of the pyrethrins is characterized by a rapid knockdown effect, particularly in flying insects, and hyperactivity and convulsions in most insects (Isman, 2006). According to Isman (2006), natural pyrethrins are unstable in light compared with the synthetic derivatives (pyrethroids), a fact that has greatly limited their use outdoors. A recent study indicated that the half-lives of pyrethrins on field-grown tomato and bell pepper fruits were two hours or less (Antonious, 2004).

### 2.5.2.3 Use of semiochemicals

A semiochemical is a chemical signal produced by one organism that causes a behavioural change in an individual of the same or a different species. The most widely used semiochemicals for crop protection are insect sex pheromones which can be synthesized and used for monitoring pests or for controlling them by mass trapping (Reddy *et al.*, 2009). Pheromones and kairomones are insect hormones that can be used with great specificity in the monitoring of pest populations, to trap and kill pests, and to confuse mating behaviour (El-sayed *et al.*, 2009). The tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) is not effectively controlled by conventional chemicals and pheromone lures are used for both monitoring and mass trapping in an integrated pest management program in Argentina, South America (Pereyra and Sanchez, 2006). Pheromones are safe to use and there is no evidence of adverse effects on public health, non-target organisms, or the environment (Witzgall *et al.*, 2010). Pheromones are applied in slow release formulations, thus resulting in low exposure and residues of lepidopteran
pheromones in pheromone treated food crops have not been detected (Tinsworth, 1990).

2.5.3 Biological control

Biological control is defined as the use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be (Eilenberg et al., 2001). The use of natural enemies such as ‘macrobial’ agents (including arthropod parasitoids and predators, and entomopathogenic nematodes) and microbial agents (including viruses, bacteria, protozoa and fungi) for biological control is increasingly becoming an important part of integrated pest management strategies (Van Driesche and Bellows, 1996; Van Lenteren, 2008). In Kenya, the use of predators, parasitoids and pathogens has received considerable attention among horticultural farmers as part of an integrated strategy for insect pest management (Migiro et al., 2010). Biological control agents are selective and produce little or no toxic residues and therefore are good components of Integrated Pest management (IPM) (Hajek, 2004).

Several native trichogrammatid egg parasitoids (Hymenoptera: Trichogrammatidae) occur in Kenya. *Trichogramma* sp. nr. *Mwanzai* (Schulten and Feijen) and *Trichogrammatoidea* sp. nr. *lutea* (Girault) have been successfully utilized in Kenya for biological control against *H. armigera* infesting tomato crops (Kalyebi et al., 20015). Surveys carried out in Kenya by the International Centre of Insect Physiology and Ecology (ICIPE) between 2007 and 2008 indicated the presence of various indigenous leafminer parasitoid species. The most important were *Opius*
dissitus Muesebeck (Hymenoptera: Braconidae), *Diglyphus isaea* Walker, *Neochrysocharis formosa* (Westwood) (Hymenoptera: Eulophidae) and *Hemiptarsenus varicornis* (Girault) (Hymenoptera: Eulophidae) (Chabi-Olaye et al., 2008). However, according to Chabi-Olaye et al. (2008), the total parasitism rate of these species in the field was below 5%. It is within this context that the koinobiont larval endoparasitoid, *Phaedrotoma scabriventris* Nixon (Braconidae: Opiinae) was introduced into the International Centre of Insect Physiology and Ecology (ICIPE), quarantine facilities in Kenya during 2008 to improve the total parasitism rates achieved by the indigenous natural enemy complex in Kenya (Chabi-Olaye et al., 2013). The parasitoids against whiteflies that have been successfully used worldwide are dominated by two genera of aphelenid hymenopterans, Encarsia and Eretmocerus (Kumar et al., 2008). According to studies by Riis et al. (2005), *Encarsia sophia* (Girault and Dodd) (Hymenoptera: Aphelinidae) was the predominant whitefly parasitoid in Kenya although *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) and *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae) have also been recorded. The parasitic wasp *Aphidius ervi* (Haliday) (Hymenoptera: Braconidae) is widely found in Kenya and are very efficient for the biological control of the aphid *Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae) in tomato crops (Kennedy, 2003; Digilio et al., 2012).

Biological control of spider mites using predators is commonly practiced, most often using Phytoseiidae (Ferrero et al., 2011). The control of spider mites through the release of phytoseiids has been widely practiced, mainly in North America and Europe (Gerson et al., 2003). According to Gerson et al. (2003), *Phytoseiulus*
**Persimilis** Athias-Henriot (Acari: Phytoseiidae) is the most frequently used predator against the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) worldwide. Among the most important aphid predators observed during tomato production in Kirinyaga county, Kenya, by Awino (2013) included the generalist aphidophagous ladybird beetles, *Cheilomenes lunata* (Fabricius) (Coleoptera: Coccinellidae) and predatory spiders (Aranae). The dusty lacewing, *Conwentzia africana* Meinander (Neuroptera: Coniopterygidae) is considered to be one of the most important predators of *B. tabaci* in East and Southern Africa including Kenya (Legg et al., 2003).

*M. anisopliae* (Metsch) Sorok, a strain of the entomopathogenic fungus, was developed at the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya and has been used effectively in reducing populations of *Megalurothrips sjostedti* Trybom on cow pea (Ekesi et al., 1998). *Metarhizium anisopliae* has also been used effectively against *T. tabaci* on onions and *F. occidentalis* on French beans, with improved crop yields (Maniania et al., 1998). The relative safety and selectivity of this isolate (Ekesi et al., 1999) enables its use in integrated pest management programs for thrips with minimal impact on non-target organisms such as spiders, ants, ladybirds and earwings compared with chemical insecticides. Wekesa et al. (2005) also reported the effectiveness of *Beauveria bassiana* and *Metarhizium anisopliae* in the management of the tobacco spider mite *Tetranychus evansi* Baker and Pritchard (Acari: Tetranychidae). Sustainable management of *H. armigera* on tomato with less impact on the naturally occurring predatory arthropods has been achieved with microbials such as *Bacillus thuringiensis* var. *kurstaki*
Berlin (Btk) (Praveen, 2000). Most microbial biopesticides have a slower rate of kill compared to conventional chemical pesticides. Consequently, they cannot be applied as stand-alone treatments but as part of an integrated pest management (IPM) strategy (Chandler et al., 2011). Owing to their selectivity and safety they can contribute meaningfully to incremental improvements in pest management (Lacey and Shapiro-Ilan, 2008).

2.5.4 Physical and mechanical control

Physical and mechanical control methods can be defined as the alteration of the environment by physical or mechanical means to make it hostile, inaccessible or disrupt the normal behaviour of insect pests (Weintraub and Berlinger, 2004). According to Weintraub and Berlinger (2004), physical and mechanical control methods are unique in that they have no, or limited, negative environmental consequences and they leave no residue on agricultural commodities. In physical control methods, the idea is to protect plants from infestation by insects during the entire season from emergence to postharvest by constructing barriers using materials such as wood, metal, plastic, or other living materials (Vincent et al., 2003). One form of barrier, insect exclusion screens (IES), is probably the single most important physical control method developed in the last century (Weintraub and Berlinger, 2004). Other forms of barriers include: fences that prevent horizontal movement of flying insects; mulches that prevent or deflect insect penetration of soil and plants, conserve water, and inhibit weeds; trenches that prevent movement of crawling insects; and particle barriers applied directly to plants.
Mechanical methods involve the operation of machinery developed specifically for pest management purposes (Metcalf and Metcalf, 1993). According to Boiteau and Vernon (2001), the costs of developing physical or mechanical control techniques are considerably lower, and generally bypass the rigid registration procedures that pesticides require. They can also be integrated with other methods of pest control (cultural, chemical and biological) or can even replace the use of synthetic chemical insecticides in pest management.

Insect exclusion screens (IES) – fine mesh screening, act as a physical or mechanical barrier that prevents migratory insects such as whiteflies (*B. tabaci*) from reaching protected plants (Tietel, 2007). These insect nets also have indirect impacts on the behaviour of pests by modifying the visual and olfactory signals; masking the crop, thus deterring pests that detect their prey via visual signals (Weintraub and Berlinger, 2004). They are made from spun-bonded polyester or polyethylene (woven, knitted, and micro-perforated) and are cloth like in appearance (Alyokhin et al., 2012). Insect exclusion screens can be applied as a cover on erectable metal-framed tunnels after seeding or transplanting of tomatoes (Weintraub and Berlinger, 2004). According to Weintraub and Berlinger (2004) IES help in reducing the incidence of direct crop damage and also of insect-transmitted virus diseases such as the tomato yellow leaf curl virus. The advantages of IES include reductions in pest populations and as a consequence, the need for pesticide application is reduced; growers can comply with international mandatory regulations for maximum residue levels on produce (MRL’s); and lower incidences of insect-transmitted diseases (Teitel, 2007).
Other supplementary pest control measures such as biological control with beneficial organisms are still required when using IES since they do not eradicate pests but rather excludes most of them from infesting the crop (Berlinger et al., 1988). Therefore, they should be installed prior to pest appearance (Alyokhin et al. 2012). Insect exclusion screens are reliable and provide an environmentally safe means of pest control in tomato production and fits well into integrated pest management programmes greatly reducing the need for chemical control (Berlinger et al., 2002). The use of IES enables cost effective production of tomatoes and other vegetables even under significant pest pressure (Taylor et al., 2001).

In the late 1970s, the whitefly, *B. tabaci*, became a limiting factor for fresh-market tomato production in Israel and accordingly, whitefly-proof insect exclusion screens (50 mesh) were developed (Berlinger et al., 1996). While Bethke and Pain (1991), reported that the insects ability to pass through any barrier could not be predicted solely from thoracic width and mesh size, Berlinger *et al.* (2002) observed that the rate of whitefly exclusion is generally proportional to the screen’s mesh. Also, according to Berlinger et al. (2002), sliding of unevenly woven yarn revealed an unexpectedly high proportion of whitefly penetration with samples of the same screen showing great variability in laboratory tests.

The choice of netting generally depends on the climatic conditions and target pests (Bethke et al., 1994). In addition to regulating pest movement, mesh size affects air movement, light quality and quantity, air temperature and relative humidity (Simon et al., 2014). This modified microclimate may have profound impacts on crop growth
and development (Tanny et al., 2003) and pest population dynamics. In the subequatorial climatic conditions of Benin, Martin et al. (2006) showed that using loose-mesh polyester mosquito netting (25 holes/cm², or 1.6 mm mesh), which is draped over the crop at night and removed during the day, was efficient in controlling cabbage (*Brassica oleracea var. capitata*) pests such as the lepidopterans, *Plutella xylostella* and *Hellula undalis*, but was not effective against aphids. However, Martin et al. (2006) proved that deltamethrin treated nets with 24-mesh size were effective in protecting cabbage against the aphid *Lipaphis erysimi* (Kaltenbach) (Martin et al., 2006). An alpha-cypermethrin treated net with 40-mesh size was also shown to be effective for protecting a cabbage crop against aphids in France (Martin et al., 2013).

Although insect nets are “breathable” (air-permeable), ventilation is lower under tighter mesh netting than without netting (Harmanto et al., 2006). This confinement boosts the temperature and modifies the relative humidity, which may be detrimental to the crops (Molina-Aiz et al., 2012). Effective physical control with insect nets is thus the result of a trade-off between having the tightest mesh to keep the target pests away from the crop and sufficient ventilation to reduce the impact on the microclimate (Ajwang and Tantau, 2005).

### 2.6 Factors that affect the abundance and diversity of tomato pests and their natural enemies

Among the factors that affect the abundance and diversity of insect pests infesting vegetables and their natural enemies include pest management practices, cropping
seasons, agroecology, production systems and host plant species (Foba et al., 2015). Excessive and frequent applications of broad-spectrum insecticides to control arthropod pests can be directly toxic to natural enemies of tomato pests (Yardim and Edwards, 1998). The indirect effects of pesticides on predators and parasitoids are mainly because of the shortage of food caused by killing their insect hosts, but also because the predators and parasitoids may migrate away from pesticide-treated fields (Koss et al., 2005). As a result, this may lead to resurgences in pest populations.

Increased populations of tomato fruit worms (*Helicoverpa armigera*), cabbage looper (*Trichoplusia ni*) and leafminers (*Liriomyza salivae*) were reported in processing tomatoes grown in Carlifornia, in the United States, by Hoffmann et al., (1996) following repeated spray applications with methomyl, carbaryl and endosulfan. Pyrethroid resistance in the tomato red spider mite, *Tetranychus evansi* Baker and Pritchardonon on tomato crops in Kenya was reported by Toroitich et al. (2014). Sublethal effects can cause changes in the reproductive, feeding, dispersal, and locomotory behavior of predators and parasitoids (Haynes, 1988). Several field studies have also reported significant reductions in coccinellid beetle, *Coleomegilla maculata* (Coleoptera: Coccinellidae) and spider (Aranae) populations following treatments with broad-spectrum insecticides such as malathion, diazinon and deltamethrin (Thomas et al., 1990).

Environmental factors that include temperature and rainfall directly affect the survival, development, reproduction and dispersal of insect pests and their natural enemies (Cammell and Knight, 1992). According to Sorribas et al. (2012),
temperature fluctuations affect insect biology, activity and distribution of natural enemies in agro-ecosystems. Temperature extremes affect several life history parameters of insect pests and their natural enemies’ and this includes generation time, survival, fecundity, sex ratios and development (Hance et al., 2006). Low temperatures during development are known to cause deformations and low fecundity in parasitoids while rising temperatures result in reduced generation time and rapid population growth (Denlinger and Lee Jr, 2010).

In Kenya, most agricultural crop production systems have four cropping seasons, including the long rains, the short rains, the cold dry, and the hot dry seasons, which vary with respect to altitude (Jaetzold et al., 2006). Kibata and Ong’aro (2005) surveyed for whitefly incidence in major tomato growing areas in Kenya and reported that the overall whitefly (B. tabaci) infestation is usually very high during the hot and dry seasons compared to the long rainy seasons that are followed by cold seasons. A region wide survey on altitudinal differences in abundance and diversity of thrips on tomatoes in East Africa by Sevgan et al. (2010) indicated that the average thrips density per plant was more in mid altitude regions (600 – 1800m) in comparison to the high altitude regions (>1800m) because of the favourable temperatures (25 - 29°C ) for thrips development. Reports by Nyasani et al. (2013) in different French bean agroecosystems in Kenya indicated that during the long-rain seasons, high amount of rainfall suppresses thrips populations by washing off adult thrips from the plant and killing larvae. Studies by Ssemwogerere et al. (2013) on the occurrence of thrips on tomato in Uganda, reported high thrips populations during
the dry seasons characterized with low and infrequent rains (average of 74.8 mm/month).
CHAPTER THREE
MATERIALS AND METHODS

3.1 Study sites

This study was conducted on station at Kenya Agricultural and Livestock Research Organization (KALRO), Kabete and Horticulture Practical Training Centre (HPTC), Thika (Figure 3.1). Kenya Agricultural and Livestock Research Organization, Kabete, is near Nairobi, about 8 km Northwest of Nairobi at 36° 41’E and 01° 15’S and at an altitude of 1737 m above sea level in the upper semi-humid agro-ecological zone UM3 (Jaetzold and Schmidt, 1983). The mean annual precipitation at KALRO, Kabete, is 981 mm, which falls in two rainy seasons; March to May (the long rains) and mid-October to December (the short rains) (KMD, 1984) and the mean annual temperature ranges from 18 to 21 °C. Soils at KALRO, Kabete, are dominated by humic Nitisols (FAO/UNESCO, 1990) or Alfisols (USDA, 1975) with a clay texture and are known locally as Kikuyu Red Loam.

The study site at HPTC, Thika, is situated 5 km from Thika town, in Murang’a County, at 0° 59’S and 37° 04’ E at an altitude of 1548 m above sea level. Horticultural Practical Training Centre is 43 Km from Nairobi and experiences bimodal pattern of rainfall with an annual mean of 1000 mm. Long rains occur between March and May while short rains occur between October and December with a mean of 142 mm and 116 mm, respectively. The mean annual maximum and minimum temperatures are 25.1 and 13.7 °C, respectively (Ndegwa et al., 2009). The soils are classified as sandy loam to clay and depth ranges from deep to shallow with good to poor drainage.
Figure 3.1: Locations of KALRO and HPTC study sites in Nairobi and Murang’a, Counties, Kenya

3.2 Experimental materials

In this study, A to Z Textile Mills Ltd., Arusha, Tanzania, provided the knitted polyethylene alpha-cypermethrin treated insect proof nets with 0.9 mm pore diameter and two non-treated nets with 0.9 mm and 0.4 mm pore diameter respectively. The two non-treated insect proof nets (0.9 mm and 0.4 mm
respectively) were used for comparison with the 0.9 mm pore diameter alpha-cypermethrin treated nets. The nets were cut into 1 x 2 x 0.75 m covers to protect the plants in the nursery and 3 x 8 x 1.2 m covers to protect the plants in the field after transplanting. Treatments were laid in a completely randomized block design with five replications. Rio Grande® tomato cultivar with determinate growth habit was chosen based on the recommendation of KALRO.

3.3 Effects of alpha-cypermethrin treated and non-treated nets on tomato pest incidences and their natural enemies

Experiments were conducted at KALRO, Kabete, and Horticultural Practical Training Centre (HPTC), Thika, both in the tomato nursery and in the field after transplanting. Nursery experimental plots measuring 1 x 2 m were manually prepared using a hoe and the beds raised 15 cm above the ground to improve drainage. Thirteen rows, 1 m long and 15 cm apart were prepared per bed. On each bed, seeds of Rio Grande® tomato variety sourced from the local market were sown at a spacing of 1 cm within the drills. This resulted to 13 rows each with 100 seeds. Two iron arches (U shape) of 0.5 m high and 2 m width were used to keep the netting covers at 50 cm above the seedlings (Plate 3.1). Thereafter, watering was done using watering cans to field capacity whenever necessary ensuring that an equal amount was applied to each plot. Weeding and all other management practices were carried out uniformly in all the plots. This experiment consisted of four treatments: no net covering, 0.9 mm alpha-cypermethrin treated insect proof nets, 0.4 mm untreated nets and a farmers practice of using dry grass as mulch to shade the nursery (Figure 3.2). The tomato seedlings were covered throughout except during weeding and other
management practices. Pests and natural enemies sampling was carried out weekly on 20 randomly selected tomato plants from the central rows of each plot for a period of four weeks in the nursery before transplanting. Samples of slow moving and sedentary arthropods were collected from the plants by hand (Nderitu et al., 2008) and stored in labeled vials containing 70% alcohol before transportation to the National Agricultural Research Laboratories (NARL) at Kabete for species identification by taxonomic experts.

![Experimental layout of tomato nursery plots at KALRO-Kabete](image)

**Plate 3.1:** Experimental layout of tomato nursery plots at KALRO-Kabete

The field was ploughed to a depth of approximately 20 cm and later harrowed to a fine tilth using a disc plough and harrow, respectively. One week before transplanting, tomato seedlings were hardened off by reducing watering frequency to only once at the beginning of the week. Transplanting holes were manually dug
using a hoe and diammonium phosphate (18% N, 46% P₂O₅) applied at 10 g per hole and thoroughly mixed with the soil prior to transplanting. Four-week-old tomato seedlings from the established nurseries were transplanted in one row 8 m long and at 50 cm within the row based on the method by Naika et al. (2005) giving 16 tomato plants per experimental unit. Thereafter, standard good agricultural practices including top dressing with Calcium Ammonium Nitrate (CAN) fertilizer, watering and weeding were carried out uniformly on all the experimental units on a need basis. Transplants were established under three different treatments as follows: no net cover (untreated control), 0.9 mm alpha-cypermethrin treated nets and 0.9 mm untreated nets. Iron arches (1.2 m high) were used in the field to keep the netting covers above the crop (Figure 3.2). The tomato plants were covered throughout except during crop maintenance period. Sampling of pests was done weekly by inspecting 10 plants randomly selected from the middle of each of the 15 experimental plots starting from the first week after transplanting. Beating sheets were used to collect the camouflaged or hidden insect pests on plants that were missed during sampling by hand picking. A white sheet was placed beneath the plants and the insect pests were dislodged onto the sheet by shaking the plants. The insects were then picked up from the sheet with aid of a hand lens and forceps and placed into vials. This method was employed to collect sessile and wingless insect pests. Flying insects were collected using aerial nets and once the insects were caught, the end of the nets was flipped over to prevent them from escaping. Harmless insects were removed by hand, while harmful once were directed into a killing bottle.
Sampling of the numbers of pests and natural enemies was done early in the morning when most insects had low activity. During the insect assessments, the opening of the insect proof nets was minimal to avoid trapping insects inside the covers. Samples of unknown insect pests were collected and taken to the National Agricultural Research Laboratories (NARL) at Kabete for species identification by taxonomic experts.

**Figure 3.2:** Schematic drawing of tomato plot showing plants and iron arches used for keeping the netting covers above the crop

### 3.4 Assessment of the yield of tomatoes grown under alpha-cypermethrin treated nets, non-treated nets and open field production

Harvesting of fruits was done weekly at the pink stage, from the 12th week after transplanting. Fruits were harvested per plot in labelled polythene bags and weighed
using a spring scale (Salter industries, West Bromwich, United Kingdom) (Plate 3.2). The total weight and number of fruits was recorded per identical plots to get the total yields at each harvest.

Plate 3.2: Spring scale used for weighing tomatoes at KALRO laboratory, Kabete

The harvested fruits were transported to the KALRO laboratory to be graded as marketable or unmarketable quality based on surface defects, disease or insect damage displayed.
3.5 Data analysis

The data collected was entered into MS Excel spreadsheet for analysis. Diversity indices were computed for pest species and natural enemies for different treatments in Kabete and Thika using Past programme. The number and weight of tomatoes harvested were subjected to Analysis of Variance (ANOVA) to test the effect of different treatments on yield. Before analysis, the data was tested for normality test and subjected to appropriate transformation where the data failed normality test. Tukey test was used to separate the means where treatments were found to be significantly different (P<0.05).
CHAPTER FOUR

RESULTS

4.1 Diversity and abundance of tomato pests and associated natural enemies in the nursery and field conditions

A total of seven pest species, A. gossypii, T. tabaci, B. tabaci, Agrotis spp., Schizonycha spp., Tetranychus spp. and L. trifolii, were identified from the total 441 insects collected from the tomato nurseries (Table 4.1). Majority of these pests (n = 193) were collected from tomato seedlings shaded with dry grass mulch (farmer’s practice) (Kabete-99 and Thika-94) followed by control treatment (n = 186), in which 59 individuals were found in Kabete and 127 individuals in Thika.

There was generally low number of pests on tomato seedlings grown under netted nurseries (0.4 mm untreated nets – 44 and 0.9 mm treated nets – 18). The highest number of pest species in the nurseries was observed on the non-protected tomato seedlings in Kabete where six species were identified (A. gossypii, T. tabaci, B. tabaci, Agrotis spp., Schizonycha spp. and L. trifolii). The other treatments with higher number of species included the nursery shaded with dry grass mulch (farmer’s practice) and 0.9 mm treated nets, both in Thika, with four species recorded (A. gossypii, T. tabaci, B. tabaci and L. trifolii). Agrotis spp. (Plate 4.1) was the major soil pest evident on non-protected tomato seedlings especially at Kabete where six individuals were collected (Table 4.1).
Table 4.1: Abundance and diversity of tomato pests among different treatments in Kabete and Thika experimental nurseries.

<table>
<thead>
<tr>
<th>Pest species</th>
<th>Farmer’s practice</th>
<th>Control</th>
<th>0.9 mm Treated net</th>
<th>0.4 mm Untreated net</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kabete</td>
<td>Thika</td>
<td>Kabete</td>
<td>Thika</td>
</tr>
<tr>
<td>A. gossypii</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>T. tabaci</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>B. tabaci</td>
<td>2</td>
<td>53</td>
<td>1</td>
<td>46</td>
</tr>
<tr>
<td>Agrotis spp.</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Schizonycha spp.</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Tetranychus spp.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>L. trifolii</td>
<td>97</td>
<td>30</td>
<td>46</td>
<td>65</td>
</tr>
<tr>
<td>Taxa (S)</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Individuals (n)</td>
<td>99</td>
<td>94</td>
<td>59</td>
<td>127</td>
</tr>
<tr>
<td>Shannon (H)</td>
<td>0.10</td>
<td>0.99</td>
<td>0.82</td>
<td>0.97</td>
</tr>
<tr>
<td>Fisher (α)</td>
<td>0.36</td>
<td>0.85</td>
<td>1.67</td>
<td>0.55</td>
</tr>
<tr>
<td>Berger-Parker (d)</td>
<td>0.98</td>
<td>0.56</td>
<td>0.78</td>
<td>0.51</td>
</tr>
</tbody>
</table>
Among the pest species collected, *L. trifolii* was the most dominant in many treatments (Table 4.1) causing mining damages in the leaves (Plate 4.2). In Kabete, it constituted 98, 78, 50 and 67% of the total collection in nurseries under farmers practice of covering with dry grass mulch, control, 0.9 mm treated nets and 0.4 mm untreated nets respectively. In Thika, high *L. trifolii* numbers were observed in the control, farmer’s practice, and 0.4 mm untreated nets where it constituted 51, 56 and 51% of the total collection respectively. Though *L. trifolii* dominated the communities in different treatments, species such as *Schizonycha* spp. and *Tetranychus* spp. were only found in single treatment in Kabete, control (1) and treated nets (2) respectively.
Plate 4.2: Leaf mines on tomato leaves caused by *Liriomyza trifolii* at KALRO, Kabete

There was generally low number of natural enemies species recorded in the tomato nurseries. A total of 13 individual natural enemies were collected in the tomato nurseries which included the parasitoid, *Aphidius* spp. (Hymenoptera: Braconidae) which parasitized aphid eggs, ladybird beetles, *Chilomenes lunata* (Fabricius) (Coleoptera: Coccinellidae) and predatory spiders (Aranae) (Table 4.2). The highest numbers of natural enemies (*n* = 6) were collected from non-protected (no nets) tomato seedlings (Kabete-1 and Thika-5) followed by 0.4 mm untreated nets (4), where one individual was found in Kabete and three individuals in Thika and 0.9 mm treated nets, where three individuals were found in Thika and none in Kabete. There were no natural enemies sampled from tomato seedlings covered with dry grass mulch (farmer’s practice) from the nurseries in both Kabete and Thika.
Table 4.2: Abundance and diversity of natural enemies on tomatoes in the nursery

<table>
<thead>
<tr>
<th>Natural enemies</th>
<th>Farmers practice</th>
<th>No nets</th>
<th>0.9 mm Treated nets</th>
<th>0.4 mm Untreated nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kabete</td>
<td>Thika</td>
<td>Kabete</td>
<td>Thika</td>
</tr>
<tr>
<td>Aphidius spp.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>C. lunata</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Predatory spiders</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Individuals (n)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Kabete and Thika are two locations where the natural enemies were studied.
A total of nine pest species, *A. gossypii*, *T. tabaci*, *B. tabaci*, *Haltica pyritosa*, *H. armigera*, *Tetranychus* spp., *L. trifolii*, *Systates* spp. and *Planococcus* spp. were found in the tomato fields after transplanting from the total 17,782 insects collected (Table 4.3). Tomato plants grown with no net covering (untreated control) had the highest numbers of pests (*n* = 7,742) where 4,281 individuals were collected in Thika and 3,461 individuals in Kabete, followed by 0.9 mm untreated nets (*n* = 5,381) where 3,288 individuals were collected in Thika and 2,093 individuals in Kabete and 0.9 mm treated nets (*n* = 4,659), with 2,603 individuals collected in Thika and 2,056 individuals in Kabete respectively.

The highest number of pest species in the tomato field were observed in Kabete under all the three treatments (control, 0.9 mm treated nets and 0.9 mm untreated nest) where nine species were identified (*A. gossypii*, *T. tabaci*, *B. tabaci*, *H. pyritosa*, *H. armigera*, *Tetranychus* spp., *L. trifolii*, *Systates* spp. and *Planococcus* spp). This was followed by seven species (*A. gossypii*, *T. tabaci*, *B. tabaci*, *H. armigera*, *Tetranychus* spp., *L. trifolii*, and *Systates* spp.) observed on the non-protected tomato plants in Thika. Tomato plants covered with 0.9 mm treated nets and 0.9 mm untreated nets at the Thika study site had the least number of species observed with six pest species identified (*A. gossypii*, *T. tabaci*, *B. tabaci*, *H. armigera*, *Tetranychus* spp. and *L. trifolii*).
### Table 4.3: Abundance and diversity of tomato pests among different treatments at Kabete and Thika field experimental sites

<table>
<thead>
<tr>
<th>Pest species</th>
<th>Control</th>
<th>Treatment</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kabete</td>
<td>Thika</td>
<td>Kabete</td>
<td>Thika</td>
</tr>
<tr>
<td><strong>A. gossypii</strong></td>
<td>2178</td>
<td>1377</td>
<td>1634</td>
<td>46</td>
</tr>
<tr>
<td><strong>T. tabaci</strong></td>
<td>32</td>
<td>680</td>
<td>31</td>
<td>1637</td>
</tr>
<tr>
<td><strong>B. tabaci</strong></td>
<td>450</td>
<td>1104</td>
<td>161</td>
<td>128</td>
</tr>
<tr>
<td><strong>H. pyritosa</strong></td>
<td>118</td>
<td>0</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td><strong>H. armiger</strong></td>
<td>114</td>
<td>2</td>
<td>32</td>
<td>9</td>
</tr>
<tr>
<td><strong>Tetranychus spp.</strong></td>
<td>52</td>
<td>10</td>
<td>11</td>
<td>591</td>
</tr>
<tr>
<td><strong>L. trifolii</strong></td>
<td>242</td>
<td>1105</td>
<td>65</td>
<td>192</td>
</tr>
<tr>
<td><strong>Systates spp.</strong></td>
<td>37</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><strong>Planococcus spp.</strong></td>
<td>238</td>
<td>0</td>
<td>69</td>
<td>0</td>
</tr>
<tr>
<td><strong>Taxa (S)</strong></td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td><strong>Individuals (n)</strong></td>
<td>3461</td>
<td>4281</td>
<td>2056</td>
<td>2603</td>
</tr>
<tr>
<td><strong>Shannon (H)</strong></td>
<td>1.31</td>
<td>1.38</td>
<td>0.86</td>
<td>1.06</td>
</tr>
<tr>
<td><strong>Berger-Parker (d)</strong></td>
<td>0.63</td>
<td>0.32</td>
<td>0.79</td>
<td>0.63</td>
</tr>
</tbody>
</table>
Among the pest species collected during field production, *A. gossypii* (Plate 4.3) was the most dominant in many treatments (Table 4.3). In Kabete, it constituted 82, 79, and 63% of the total collection in tomato grown under 0.9 mm untreated nets, 0.9 mm treated nets and control respectively. In Thika, high *A. gossypii* numbers were observed in the control where it constituted 32% of the total collection. Though *A. gossypii* largely dominated the communities in different treatments at Kabete, *T. tabaci* was the most dominant pest at Thika. It constituted 66 and 63% of the total collection in tomatoes grown under 0.9 mm untreated nets and 0.9 mm treated nets respectively.

Plate 4.3: Adults of *Aphis gossypii* on tomato leaves
*Bemisia tabaci* numbers were higher in Thika under the non-protected tomato plants ($n = 1,104$) compared to Kabete ($n = 450$). Generally, lower numbers of *B. tabaci* were observed on tomatoes grown under netting covers, where 128 individuals were recorded under both 0.9 mm treated nets and 0.9 mm untreated nets in Thika, while 161 and 91 individuals were recorded under 0.9 mm treated nets and 0.9 mm untreated nets respectively at Kabete. Similarly, the numbers of *L. trifolii* were higher in Thika under the non-protected tomato plants ($n = 1,105$) compared to Kabete ($n = 242$). Also, lower numbers of *L. trifolii* were observed on tomatoes grown under netting covers, where 266 and 192 individuals were recorded under 0.9 mm untreated nets and 0.9 mm treated nets respectively in Thika, while 77 and 65 individuals were recorded under 0.9 mm untreated nets and 0.9 mm treated nets respectively at Kabete.

A total of 1,819 individual natural enemies were collected from tomato plants in the field (Table 4.4). These were composed of the parasitoid, *Aphidius* spp. (Hymenoptera: Braconidae) which parasitized aphid eggs and predatory spiders (Aranae). The highest numbers of natural enemies ($n = 946$) were collected from tomatoes grown under 0.9 mm treated nets (Kabete-935 and Thika-11) followed by 0.9 mm untreated nets (574), where 561 individuals were recorded in Kabete and 13 individuals in Thika.
**Table 4.4**: Abundance and diversity of natural enemies on tomato plants in the field

<table>
<thead>
<tr>
<th>Natural enemies</th>
<th>No nets</th>
<th>0.9 mm Treated nets</th>
<th>0.9 mm Untreated nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kabete</td>
<td>Thika</td>
<td>Kabete</td>
</tr>
<tr>
<td><em>Aphidius</em> spp.</td>
<td>251</td>
<td>12</td>
<td>934</td>
</tr>
<tr>
<td>Predatory spiders</td>
<td>9</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Individuals (n)</td>
<td>260</td>
<td>39</td>
<td>935</td>
</tr>
</tbody>
</table>

### 4.2 Effects of insecticide treated nets on tomato yield

At HPTC-Thika, there were no differences in the number of fruits harvested among the treatments ($F_{2,87} = 2.58; P=0.081$; Table 4.5). However, there was evidence of variation in the number of marketable fruits among the treatments ($F_{2,87} = 6.56; P=0.002$). The numbers of marketable fruits were considerably higher in both 0.9 mm untreated nets (16.4 ± 3.1) and 0.9 mm treated nets (14.9 ± 2.3) compared to plots where there were no nets (5.56 ± 1.1). Like the number of fruits in different treatments, the number of non-marketable fruits did not vary among the treatments ($F_{2,87} = 0.19; P=0.826$). The mean total number of fruits did not vary among the treatments in Kabete ($F_{2,102} =2.13; p = 0.124$; Table 4.5). However, there was evidence of significant variation in mean number of marketable fruits ($F_{2,102} =11.74; p =0.0000258$). The highest number of marketable fruits (19.9 ± 2.3) was recorded in 0.9 mm treated nets. This was significantly higher than 0.9 mm untreated nets (10.5 ± 1.5) and no nets (8.2 ± 1.1). In contrast, there was no variation in the mean number of non-marketable fruits among the treatments ($F_{2,102} =0434; p =0649$).
Table 4.5: The mean numbers (± S.E) of total fruits, marketable fruits and non-marketable fruits harvested at HPTC-Thika and KALRO-Kabete

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Mean ± SE</th>
<th>Total number of fruits (no./plant)</th>
<th>Number of marketable fruits (no./plant)</th>
<th>Number of non-marketable fruits (no./plant)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thika</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Nets</td>
<td>22.3 ± 3.1a</td>
<td>5.56 ± 1.1a</td>
<td>16.7 ± 2.2a</td>
<td></td>
</tr>
<tr>
<td>Treated nets</td>
<td>32.1 ± 3.6a</td>
<td>14.9 ± 2.3b</td>
<td>17.2 ± 1.8a</td>
<td></td>
</tr>
<tr>
<td>Untreated nets</td>
<td>36.2 ± 5.3a</td>
<td>16.4 ± 3.1b</td>
<td>19.8 ± 3.1a</td>
<td></td>
</tr>
<tr>
<td>(F_{2,87})</td>
<td>2.58</td>
<td>6.56</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>(p)-value</td>
<td>0.081</td>
<td>0.002</td>
<td>0.826</td>
<td></td>
</tr>
<tr>
<td>Kabete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Nets</td>
<td>48.4 ± 7.5a</td>
<td>8.2 ± 1.1a</td>
<td>40.2 ± 6.8a</td>
<td></td>
</tr>
<tr>
<td>Treated nets</td>
<td>64.9 ± 7.1a</td>
<td>19.9 ± 2.3b</td>
<td>45.0 ± 6.5a</td>
<td></td>
</tr>
<tr>
<td>Untreated nets</td>
<td>49.5 ± 8.0a</td>
<td>10.5 ± 1.5a</td>
<td>38.9 ± 6.8a</td>
<td></td>
</tr>
<tr>
<td>(F_{2,102})</td>
<td>2.13</td>
<td>11.74</td>
<td>0.434</td>
<td></td>
</tr>
<tr>
<td>(p)-value</td>
<td>0.124</td>
<td>2.58E-05</td>
<td>0.649</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letters within the same column are not significantly different (Tukey test, \( P = 0.05 \))

At HPTC-Thika, there were variations in the mean total fresh weight of tomatoes harvested among the treatments (\( F_{2,87} = 3.46; P = 0.035 \); Table 4.6). There were also differences in the mean marketable fruit weight among the treatments (\( F_{2,87} = 7.02; P=0.002 \)). However, there were no differences in the mean weight of non-marketable fruits among the treatments (\( F_{2,87} = 0.52; P = 0.599 \)). The highest mean weight of marketable fruits was observed in 0.9 mm treated nets (921.9 ± 142.6) followed by 0.9 mm untreated nets (911.8 ± 149.3), while the least weight of marketable fruits was harvested in control(no nets) (356.1 ± 75.8). The mean total weight of fruits did not vary among the treatments in KALRO-Kabete (\( F_{2,102} =2.96; P = 0.056 \); Table
4.6). However, there was evidence of variation in the mean weight of marketable fruits ($F_{2,102} = 10.85; P = 0.0000533$). The highest weight of marketable fruits (1182.9 ± 144.5) was recorded in 0.9 mm treated nets. However, there were no differences in the mean weight of tomatoes harvested under untreated nets (658.25 ± 92.36) and no nets (485.12 ± 70.97).

<table>
<thead>
<tr>
<th>Table 4.6: The mean weight (± SE) of total fruits, marketable fruits and non-marketable fruits harvested at HPTC-Thika and KALRO-Kabete</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>No Nets</td>
</tr>
<tr>
<td>Treated nets</td>
</tr>
<tr>
<td>Untreated nets</td>
</tr>
<tr>
<td>$F_{2,87}$</td>
</tr>
<tr>
<td>$P$-value</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kabete</th>
<th><strong>Mean ± SE (g/plant)</strong></th>
<th><strong>F</strong></th>
<th><strong>P-value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>No Nets</td>
<td>2583.9 ± 429.0a</td>
<td>485.12 ± 70.97a</td>
<td>2098.7 ± 390.3a</td>
</tr>
<tr>
<td>Treated nets</td>
<td>3890.9 ± 412.0a</td>
<td>1182.9 ± 144.5b</td>
<td>2707.9 ± 379.1a</td>
</tr>
<tr>
<td>Untreated nets</td>
<td>2990.2 ± 465.3a</td>
<td>658.25 ± 92.36a</td>
<td>2331.9 ± 395.7a</td>
</tr>
<tr>
<td>$F_{2,102}$</td>
<td>2.96</td>
<td>10.85</td>
<td>0.77</td>
</tr>
<tr>
<td>$P$-value</td>
<td>0.056</td>
<td>5.33E-05</td>
<td>0.466</td>
</tr>
</tbody>
</table>

Means followed by the same letters within the same column are not significantly different at (Tukey test, $P = 0.05$)
The marketable fruit numbers and fresh weights were reduced when the tomatoes were grown with no net covering largely due to fruit boring damages caused by the African bollworm larvae (*H. armigera*) (Plate 4.4).

**Plate 4.4:** Tomato fruit damaged by larvae of *Helicoverpa armigera*
CHAPTER FIVE
DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion
This study revealed variation in the abundance and diversity of arthropod pests that infested tomato seedlings in the nurseries at both Kabete and Thika. Despite variations in arthropod pests’ abundance and diversity, *L. trifolii* was the most dominant pest species in the tomato nurseries, confirming their key pest status on tomatoes as previously reported by Waiganjo *et al.* (2006). Among the treatments at the tomato nurseries in both Kabete and Thika, *A. gossypii*, *B. tabaci* and *L. trifolii* were the most abundant insect species on tomato seedlings that were not covered with nets. Considerably reduced populations of *A. gossypii*, *B. tabaci* and *L. trifolii* were observed under both 0.9 mm alpha-cypermethrin treated nets and 0.4 mm untreated nets. These results support earlier findings by Gogo *et al.* (2012) who reported reduced populations of *L. trifolii*, *B. tabaci* and *A. gossypii* in tomato seedlings covered with polyethylene nets through physical exclusion. According to Majumdar (2010) cover mesh diameter affects entry of insect pests into the crops. This could probably explain the lower population of pests observed under covers with finer mesh diameter (0.4 mm untreated nets). According to Gogo *et al.* (2012), higher relative humidity recorded under the netting covers can also affect the feeding habits of sucking pests, such as *A. gossypii* and *B. tabaci* consequently lowering their population under netting.

The most abundant natural enemies species observed amongst the treatments at the tomato nurseries in Thika were the predatory spiders (Aranae). These results were in
contrast with the observations of Berlinger et al. (2002) about the reduction of crossing rate of beneficial insects through physical barriers. This could be an indication that when the netting covers were temporarily opened to perform agronomic practices such as weeding or watering, the predatory spiders gained entry and remained trapped inside the nets as nets were a physical barrier.

The results from this study also revealed that more insect pests infested tomato plants during field production compared to seedling production. This suggests that tomatoes are prone to infestations by several pests of economic importance during field production as previously reported by Waiganjo et al. (2006). The abundance of insect pests that infested tomato plants during field production at Kabete and Thika also revealed that more pests attacked tomato plants grown in the open field compared to those grown under 0.9 mm untreated and 0.9 mm alpha-cypermethrin treated nets respectively. The treated nets considerably reduced infestations by A.gossypii, B. tabaci, H. armigera, H. pyritosa, L. trifolii, Systates spp. and Planococcus spp compared to open field production. This concurs with the findings by Martin et al. (2012) who reported that alpha-cypermethrin treated nets added two effects, a physical barrier and a chemical barrier, in reducing pest infestations on cabbage crop in France. Previous studies by Berlinger et al. (2002) in Israel have also demonstrated that insect exclusion screens can be used effectively as physical barriers against pests of tomatoes. Covering the crop at night when the moth activity is high also prevents the female moth from entry inside the covered crop to lay eggs. Martin et al. (2006) demonstrated that treating the nets with deltamethrin offered complete protection of cabbage plants against aphids. In addition, the white nets used
could also have offered a visual barrier for flying pests such as *L. trifolii*, *H. armigera*, *B. tabaci*, and *H. pyritosa* distracting their feeding and mating habits, hence lowering their population under the covered treatments.

The use of netting covers during field production of tomatoes did not considerably reduce the numbers of *T. tabaci* at both Kabete and Thika. This indicates that both the 0.9 mm alpha-cypermethrin treated nets and 0.9 mm untreated nets were not effective barriers to *T. tabaci*. These findings are in contrast with earlier reports in which Allen and Broadbent (1986) reported that the use of nets on horticultural and floricultural crops protected the crops against thrips and prevented the transmission of impatiens necrotic spot virus (INSV) and tomato spotted wilt virus (TSWV). Though the rate of penetration by insects is directly proportional to a screen’s mesh (Berrlinger *et al.*, 1996), the use of treated or untreated nets to protect tomato plants in the field could have allowed the penetration of thrips inside the nets.

At Thika, both the 0.9 mm alpha-cypermethrin treated nets treated and 0.9 mm untreated nets were not effective in reducing infestations by *Tetranychus* spp. These results were consistent with previous findings by Martin *et al.* (2010) in Benin, which showed that nets treated with a pyrethroid insecticide, deltamethrin, had no effect on mite control. Instead, nets treated with an acaricide, dicofol, was found to be effective in controlling the broad mite (*Polyphagotarsonemus latus* Banks) and *Tetranychus* spp. on the African eggplant (*Solanum macrocarpon*). Additionally, according to Denlinger and Lee Jr (2010) hot and dry conditions results in reduced
generation time and rapid population growth of pests and this could explain higher population of *Tetranychus* spp. observed in Thika compared to Kabete.

During field production of tomatoes, the natural enemies, *Aphidius* spp. and predatory spiders, were not only found on tomato plants grown in the open field but also on tomato plants grown under both 0.9 mm alpha-cypermethrin treated nets and 0.9 mm untreated nets. More parasitized aphids were observed on tomato plants covered with both 0.9 mm alpha-cypermethrin treated nets and 0.9 mm untreated nets at Kabete. This implies that the netting covers did not completely exclude *Aphidius* spp. from getting into the crop. This could be an indication that when the treated nets were temporarily opened to perform agronomic practices such as weeding or watering, the *Aphidius* spp. gained entry and remained trapped inside the nets as nets were a physical barrier. These findings are in contrast with reports by Martin *et al.* (2012) on the irritant and repellent effects of the alpha-cypermethrin treated nets on the aphid parasitoid *Aphidius colemani* (Haliday) (Hymenoptera: Braconidae) on cabbage protected with the treated nets. More predatory spiders were observed on non-protected tomatoes (control) with the least number under treated nets, suggesting that the treated nets physically excluded the predatory spiders and also had an irritant and repellent effect.

The use of 0.9 mm alpha-cypermethrin treated nets helped improve tomato yield. At harvest, the mean number of marketable fruits (not damaged by pests or diseases) was significantly higher for tomatoes harvested from the 0.9 mm alpha-cypermethrin treated nets compared with the non-protected tomatoes. Tomato grown under 0.9 mm alpha-cypermethrin treated nets had lower pest damage compared to the non-
protected tomatoes. Therefore, growing tomatoes under 0.9 mm alpha-cypermethrin treated nets not only increased the mean fruit numbers but also produced fruits of higher quality. El-Aidy and Sidaros (1996) reported higher marketable yields under protected compared to non-protected tomato. Similarly, Nair and Ngouajio (2010) reported more total marketable yield of cucumber (Cucumis sativus L.) under nets compared with the control. These results are similar to those found by Martin et al. (2006) where at harvest the percentage of cabbages damaged by insect pests was significantly lower under deltamethrin impregnated nets compared with the untreated nets resulting into more marketable yield. Besides, the modified microclimate (increased air temperature and soil moisture) under covered treatments may also have contributed to the improved crop performance and reduced physiological disorders favouring the production of more fruit that met the market standards. Similarly, tomato grown under 0.9 mm alpha-cypermethrin treated nets had significantly higher marketable fruit weight compared to non-protected tomato. This concurred with findings by Martin et al. (2006) who reported higher marketable weight for cabbages protected with netting covers in Benin.

This study shows that the protection of tomatoes against insects with netting covers may need to be complemented by foliar sprays of fungicides due to infection from airborne microorganisms like blight (Phytophthora infestans) which was responsible for partly reducing tomato yield under the netting covers. Without active ventilation, when the nets are permanently covered, they substantially increase temperatures and humidity which encourage disease development. In contrast, these findings differ with that of Gogo et al. (2012) who found that the nets effectively managed late
blight incidences in tomato seedlings in the nursery. These results also differ with that of Kashyap and Dhiman (2010) who used nylon nets in the management of alternaria blight and black rot in cauliflower seedlings.

5.2 Conclusions

i. Alpha-cypermethrin treated nets with a cover mesh diameter of 0.9 mm was effective in protecting tomato plants and tomato seedlings against major pests especially *A. gossypii*, *B. tabaci*, *L. trifolii*, *Planococcus* spp. and *H. armigera*.

ii. The use of 0.9 mm alpha-cypermethrin treated nets was not effective in protecting tomato plants against *T. tabaci* and *Tetranychus* spp.

iii. The netting covers, either treated with alpha-cypermethrin or untreated, allowed an opportunity for entry of natural enemies inside the netting covers when performing agronomic practices such as weeding, watering and fertilizer application hence can be used effectively in an integrated pest management strategy.

iv. Alpha-cypermethrin treated nets can be considered as a viable strategy for enhanced tomato production through reduction of pest population.

5.3 Recommendations

i. Smallholder tomato farmers should consider using treated nets as part of integrated pest management strategy in an effort to reduce tomato pests and enhance production of marketable tomatoes.
ii. There is the need for research institutes such as KALRO to educate tomato farmers on the advantages of using netting covers, either treated or untreated to improve tomato yields and quality.

iii. Further research needs to be carried out in different tomato growing agro ecological zones on the effects of netting covers on tomato pests and beneficial insects (pollinators and natural enemies) using a wider range of mesh sizes in different tomato varieties.

iv. Further studies need to be undertaken on the effect of netting covers on the management of tomato diseases.
REFERENCES


APPENDIX I

Research Authorization

KENYATTA UNIVERSITY
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Our Ref: 156/CE/12139/07

DATE: 10th November, 2012

The Permanent Secretary,
Ministry of Higher Education, Science & Technology,
P.O. Box 30040,
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION FOR JUMA VICTOR H. OMONDI – REG. NO. 156/CE/12139/07

I write to introduce Mr. Juma Victor H. Omondi who is a Postgraduate Student of this University. He is registered for M.Sc degree programme in the Department Zoological Sciences.

Mr. Omondi intends to conduct research for a proposal entitled, “Management of Tomato Pests using Insecticides Treated Nets and its Impact on Natural Enemies and Yield”.

Any assistance given will be highly appreciated.

Yours faithfully,

MRS. LUCY N. MBAABU
FOR: DEAN, GRADUATE SCHOOL