

**INSECT PEST INCIDENCES AND YIELDS OF TOMATOES GROWN  
IN HIGH TUNNEL AND IN OPEN FIELD IN MWEA DIVISION,  
KIRINYAGA COUNTY, KENYA**

**By**

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**DECLARATIONS**

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

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**DEDICATION**

This thesis is dedicated to my husband Arphaxad Mativo, my sons Emmanuel and Evans, and to my parents Joseph Saii and Christine Musango.

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**ACRONYMS AND ABBREVIATIONS**

ANOVA	Analysis of Variance
AVDRC	Asian Vegetable Research and Development Corporation
CAN	Calcium Ammonium Nitrate
DAP	Di-Ammonium phosphate
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agricultural Organization
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KARI	Kenya Agricultural Research Institute
KHDP	Kenya Horticultural Development Program
OFRF	Organic Farming Research Foundation
SAS	Statistical Analysis Software
USAID-Kenya	United States Agency for International Development-Kenya
USDA	United States Department of Agriculture

## ABSTRACT

Tomato, *Lycopersicon esculentum*, is a major horticultural crop grown in many areas in Kenya. The main constraint to tomato production is insect pests with farmers relying heavily on chemical pesticides to control them. This has led to several problems such as contamination of farm produce and pollution of the environment among others. There is need therefore need for alternative methods to control insect pests. A study was carried out in Mwea region of Kirinyaga County to assess the insect pests incidences and the yields of tomatoes grown in open field and in high tunnel. Three tomato varieties, grafted Onyx, non-grafted Onyx and Anna F1 were planted in the two production systems in a Complete Randomized Block Design. Data collection commenced two weeks after transplanting. Assessing the abundance of insect pests on tomatoes was carried out by counting the numbers of insect pests and mines on tomato leaves. Ripe tomatoes were harvested per variety, sorted and classified into marketable and unmarketable fruits. The total fruit weights and marketable fruit weights were obtained. The data on the abundance of different insect pests and the yields of the three tomato varieties was subjected to Analysis of Variance (ANOVA), while abundance of insect pests and fruit yield for the two production systems was analyzed using a paired sample t-test. The significance level was set at  $P=0.05$ . The means were separated using the Student-Newman-Keuls (SNK). The insect pests species recorded attacking tomatoes were *Bemisia tabaci*, *Frankliniella occidentalis*, *Aphis gossypii* and *Liriomyza trifolii*. In cropping season one, the mean numbers of *F. occidentalis*, *B. tabaci*, *A. gossypii* and the mean numbers of *L. trifolii* mines were significantly higher on tomatoes in open field compared with those in high tunnel. In cropping season two, the mean numbers of *B. tabaci* were significantly higher on the tomatoes grown in open field compared with those in high tunnel ( $P=0.0001$ ). However, there were no significant differences between the mean numbers of *L. trifolii* mines recorded on the tomato plants grown in high tunnel and in open field ( $P=0.107$ ). The mean total and marketable fruit weights were significantly higher for tomatoes harvested in the high tunnel compared with those harvested in open field in cropping season one ( $P=0.0001$ ). The mean marketable fruit weights were significantly higher for tomatoes harvested in the high tunnel compared with those harvested in open field in cropping season two ( $P=0.0001$ ). There was lower incidence of insect pests on tomatoes in the high tunnel and this probably could have contributed to higher total and marketable fruit weights of tomatoes harvested in the high tunnel. There is therefore need to encourage tomato farmers in the country to embrace high tunnel technology in tomato production.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background information

Tomato, *Lycopersicon esculentum* is one of the most popular and widely grown vegetable in the world. Leading tomato producing countries include China, United States of America, Turkey, Russia, Italy, Egypt, India, Spain and Mexico (CABI, 2005). In Kenya, the major production areas of tomatoes include Kirinyaga County ( Mwea), Meru County (Mitunguu region), Nyeri County, Nakuru County (Bahati and Kabazi regions) and Taita Taveta County (Waiganjo *et al.*, 2010). The national average yield of tomatoes is estimated to be at 60 metric tons per hectare (Tschirley *et al.*, 2004).

The main constraints to tomato production in the country are diseases and insect pests. The main insect pests attacking tomatoes are bollworms *Helicoverpa armigera* Hb (Lepidoptera: Noctuidae), whitefly *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), thrips *Frankliniella occidentalis* Trybom (Thysanoptera: Thripidae), red spider mites *Tetranychus evansi* Baker (Acarina: Tetranychidae), russet mites *Aculops lycopersici* Masee (Acarina: Eriophyidae), leaf miners *Liriomyza trifoli* Burgess (Diptera: Agromyzidae), cutworms *Agrotis segetum* Denis and Schiffermuller (Lepidoptera: Noctuidae), leafhoppers *Empoasca fabae* Harris (Homoptera: Cicadellidae), and aphids *Aphis gossypii* Glover (Hemiptera: Aphididae) (Varela *et al.*, 2003). Major diseases of tomatoes include bacterial wilt caused by

*Pseudomonas solanacearum* (Hardcover), fungal diseases including damping-off disease, caused by *Pythium ultimum* and early and late blight caused by *Alternaria solam* and *Phytophthora infestans*, respectively. Important viral diseases of tomatoes include tomato yellow leaf curl disease, commonly referred to as “Kathuri” and tomato tospoviruses commonly referred to as “Kijeshi”. Tomatoes are also attacked by plant-parasitic nematodes such as root-knot nematodes (*Meloidogyne incognita*, *M. javanica* and *M. hapla*).

Smallholder vegetable farmers in Kenya rely on pesticides to control a wide range of serious pests and diseases (Waiganjo *et al.*, 2006). When used inappropriately, pesticides create a health hazard to the farm workers engaged in production and also lead to contamination of the produce and the environment (Varela *et al.*, 2003). Overuse, abuse and misuse of synthetic pesticides have led to pests developing resistance to the pesticides as well as elimination of natural enemies, ultimately causing more damage to the crop (Pimentel, 1971). Tomatoes can be grown in the open fields or in high tunnels. High tunnels have been used as part of an Integrated Pest Management (IPM) program in many developed countries in Europe, United States of America, Asia and Africa e.g. Egypt (Atherton and Rudich, 1986). They have shown reduced pest incidences if hygienic conditions are strictly observed (Lamont *et al.*, 2003). The use of high tunnels can enhance the success of organic vegetable farms, but information and outreach resources are limiting. This study was aimed comparing the insect pest abundance and the yields of tomatoes grown in the high tunnel and those grown in open field.

## **1.2 Statement of the problem**

Tomato is one of the most commonly eaten vegetables and yet its yields in smallholder cropping system in Kenya are generally far below the potential of the crop (Waiganjo *et al.*, 2006). Kenya produces an average of 12t/ha compared to Egypt and France which produces approximately 35t/ha and 120t/ha respectively (Atherton and Rudich,1986). Insect pests are the major constraint in tomato production in the country. The crop is attacked by several insect pests during its growth and development (Waiganjo *et al.*, 2010). Currently, the insect pest control practices in Kenya rely heavily on application of pesticides. This has led to several problems such as health hazards to farm workers, contamination of produce and the environment and elimination of natural enemies (Varela *et al.*, 2003). Overuse, abuse and misuse of synthetic pesticides have also led to insect pests developing resistance to the pesticides (Pimentel, 1971). There is therefore need to find alternative ways of controlling insect pests of tomatoes such as the use of high tunnels. These structures have been used as part of an Integrated Pest Management program and have shown reduced insect pest incidences (Lamont *et al.*, 2003).

## **1.3 Justification of the study**

Tomatoes are among the vegetables commonly eaten in the country (Oniang'o *et al.*, 2003). In Kenya food basket, the weight attributed to tomatoes is 2.95, 2.30 and 2.75 for the low income, medium income and other urban households (GOK, 2002). Smallholder farmers in the main tomato growing regions of the

country grow tomatoes in open fields with a few embracing high tunnel technology. They face challenges of insect pests, seasonality of the crop production as well as lower yields (Waiganjo *et al.*, 2006).

There is need to reduce pesticide use, increase yields as well as year round production of tomatoes in the country. High tunnel tomato production has been used in several countries as part of IPM program and has shown to reduce insect pest incidences (Lamont *et al.*, 2003). Countries such as Europe and United States of America where high tunnels have been used have shown lower pest incidences and this implies reduced pesticide applications. The protected environment within a high tunnel prevents many outbreaks of insect pests that would normally occur in field environment (Waterer, 2003; Jett *et al.*, 2004). They create a protective micro-climate to the plants grown in them and tomato produced are of higher quality and quantity. Open field cultivation can produce 100- 120 tons/ha of tomatoes while cultivation in high tunnels/green houses can yield upto 500 tons/ha (Naandanjain, 2012).

Other advantages of high tunnels are, all year production, protection of crops from harsh environmental factors such as frost and too much rainfall which may damage them. In Kenya, high tunnels are commonly used by the flower farmers, tomato farmers are yet to embrace this technology or are slowly embracing the technology even in the major tomato producing regions of the country such as Kirinyaga County. There is limited research in the country on the effects of high tunnels on the abundance of insect pests and on yields of

tomatoes. The purpose of conducting this study was to investigate the effects of high tunnel on the abundance of insect pests and the yields of tomatoes in comparison with tomatoes grown in open field.

#### **1.4 Research questions**

- a) What are the species of insect pests infesting tomatoes grown in high tunnel and in open field?
- b) What is the abundance of insect pests that infesting tomatoes grown in high tunnel and in open field?
- c) What are the yields of tomatoes grown in high tunnel and in open field?

#### **1.5 Research hypotheses**

- a) There is no difference in the species of insect pests infesting tomatoes grown in high tunnel and in open field
- b) There is no difference in the abundance of insect pests infesting tomatoes grown in high tunnel and in open field
- c) There is no difference in yields of tomatoes grown in high tunnel and open field

## **1.6 Objectives**

### **1.6.1 General objective**

To compare the abundance of insect pests and yields of tomatoes grown in high tunnel and open field in Mwea division, Kirinyaga County, Kenya

### **1.6.2 Specific objectives**

- a) To determine the species of insect pests infesting tomatoes grown in high tunnel and in open field
- b) To determine the abundance of insect pests species infesting tomatoes grown in high tunnel and in open field
- c) To compare the yields of tomatoes grown in high tunnel and in open field

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Tomato plant

The tomato, *Lycopersicon esculentum* Mill, belongs to the family *Solanaceae* (Taylor, 1986). The *Solanaceae* family includes chilli and bell pepper, eggplant, potatoes, aubergine, tomatillo and tobacco (CABI, 2005). The plant is native to Andean region of South America, which covers parts of what is now Bolivia, Chile, Ecuador, Colombia and Peru (Sims, 1980; CABI, 2005). Tomatoes were introduced in Kenya when Europeans arrived at the shores of Kenya in the 16th century (Atherton and Rudich, 1986).

The plant is dicotyledonous and grows as a series of branching stems, with terminal bud at the tip that does the actual growth. When that tip eventually stops growing whether because of pruning or flowering, lateral buds take over and grow into other fully functional vines. The plant typically grows to 1-3 metres in height and has weak stems that often sprawl over the ground and vines around other plants. Tomato plant vines are typically pubescent, meaning they are covered with fine short hairs. These hairs facilitate the vining process, turning into roots wherever the plant is in contact with the ground and moisture. Most tomato plants have compound leaves and are called regular leaf plants (Rick, 1995). The leaves are 10-25cm long, odd pinnate with 5-9 leaflets on petioles, each leaflet up to 8cm long with a serrated margin, both the stem and leaves have dense glandular hairs. Their flowers have the anthers fused along the edges, forming a column surrounding

the pistil's style. The flowers are 1-2 cm across and yellow in colour with fine pointed lobes on the corolla. They are borne in a cyme of 3-12 together (Acquaah, 2002). The tomato fruit is classified as a berry. As a true fruit, it develops from the ovary of the plant after fertilization, its flesh comprising the pericarp walls. The fruit contains hollow spaces full of seeds and moisture, called locular cavities (Rick, 1995).

Tomato plant is a warm season vegetable crop that thrives best in low to medium rainfall areas with supplemented irrigation during off-season. It is sensitive to frost and will be killed by freezing temperatures. Wet conditions increase disease attacks and affect fruit ripening. Tomato plant grows well in a wide range of soil types, but should be high in organic matter, well drained and with a pH range of 5-7.5. Tomatoes have either determinate or indeterminate growth habits. Determinate tomato vines produce side shoots that terminate in a flower cluster, and the plant reaches a height of 3-4 feet; yield is therefore concentrated over a 4-6 week period. Indeterminate tomatoes continue to produce additional vines and flower clusters throughout the growing season and may reach 5-7 feet in height (Rick, 1995). Tomato plants do not need a specific day length in order to flower. The flowers are self-pollinating, and this can be achieved by either physical vibration of the flower through shaking the plant. Wind or insects also facilitate pollination. The optimum temperatures for pollination are 20-24°C (night) and 15-35°C (day). Prolonged temperatures of less than 12.8°C or greater than 35°C leads to flower abscission from the plant. High humidity greater than 80% can also

adversely affect pollination as the pollen will not shed readily and the pollen grains may stick together, resulting in poor or no pollination at all. At very low humidity, the pollen grains become too dry and will not adhere to the stigma. Flowering until harvest is approximately 45 days for most tomato cultivars (Rick, 1995).

Tomato is one of the most widely eaten vegetables in the world. The tomato fruit can be eaten fresh or in multiple of processed forms. The three major processed products are, tomato preserves (whole peeled tomatoes, tomato juice, tomato pulp, tomato puree, tomato paste, pickled tomatoes); dried tomatoes (tomato powder, tomato flakers, dried tomato fruits) and tomato-based foods (tomato soup, tomato sauces, chilli sauce, ketchup) (CABI, 2005). Although botanically a fruit, tomatoes are served as vegetables and are rich in vitamin C, contains water ( more than 90%), and therefore seen as diuretics and help in elimination of toxins. They have an alkaline power to neutralize excess acids in the body. They also contain lycopene, one of the most powerful natural oxidants which is responsible for the red colour of tomatoes. It is a phytochemical which has been found to have powerful anti-cancer properties against prostate cancer, especially cooked tomatoes (USDA, 1999). Lycopene has also been shown to improve the skin's ability to protect against harmful UV rays. Tomato consumption has been associated with decreased risk of breast cancer, head and neck cancers, colon, lung and pancreas cancers (Evanelia *et al.*, 2005) and might be strongly protective against neurodegenerative diseases (Fall *et al.*, 1999; Rao and Balachandran, 2002;

Suganuma *et al.*, 2002). They have also been found to prevent heart and age related diseases (AVDRC, 2003). Tomatoes contain potassium that helps prevent high blood pressure and lessens chances of heart diseases. Potassium also aid in muscle contractions and may reduce the risk of kidney stones and bone loss. Tomatoes reduce blood clots and inflammation and also contain fibres that aid digestion, thereby preventing constipation. They are a good source of vitamins A and C. Vitamin A is very important for bone growth, cell division and differentiation, for helping in the regulation of immune system and maintaining surface linings of eyes, respiratory, urinary and intestinal tracts. Vitamin C is important in forming collagen, a protein that gives structure to bones, cartilage, muscles and blood vessels. It also aids in the absorption of iron, an important mineral in red blood cell formation (Purseglove, 1979).

## **2.2 Tomato production in Kenya**

In Kenya, tomato plant is one of the preferred grown horticultural crops, second only to Brassica. Smallholder farmers play an important role in tomato production in the country. Most of the fruit is sold fresh, but large tonnages are also processed into tomato paste, tomato sauce, and tomato juice and can also be dried. They are produced using both rain and irrigation water with the latter being used mainly by small scale farmers (Waiganjo *et al.*, 2006). An estimated 30% of households grow the crop for domestic consumption or for cash (Minot and Ngigi, 2003). Tomato production in Kenya has been a lucrative business for smallholder farmers who cannot afford huge capital to

invest in other cash crops. It is a major source of household income and has created employment that has resulted in improved livelihood (Minot and Ngigi, 2003). In 2004, an estimated 75,101 tons of tomatoes valued at over KSh 1 billion were produced in Central province, surpassing all other vegetables in value (KARI, 2005). Improved agricultural production methods such as use of high tunnels would enhance productivity, alleviate poverty and facilitate food security (Agong and Schittenhelm, 1993; Agong *et al.*, 1997). The major varieties grown in Kenya are Cal J, money maker, Beauty, Anna F1, Romana V F and Onyx among others (KARI, 2005) (Plates 2.1- 2.6).

### **2.2.1 Anna F1 tomato variety**

Anna F1 tomato variety is an indeterminate hybrid bred and developed by the Monsanto vegetable seed division for green house production (Monsanto Africa, 2011). The variety does very well in green houses and high tunnels, it can also do well in open field. It has a high resistance to Alternaria stem canker, verticillium, fusarium wilt as well as nemaodes. It performs best in well drained soil which should be loose and deep as Anna F1 has a root system of more than 60cm long. Seeds germinate within 8 days and takes about a month before the seedlings are ready for transplant. Maturity period is 75 days from transplanting (Monsanto Africa, 2011). It is a high yielder, ie approximately 74 tons/acre or 80- 90 Kgs/M<sup>2</sup> with an average of 35 Kgs per plant in its life span. It continues to produce fruits for upto 6- 8 months. Anna F1 tomato variety has excellent fruit quality for market. The fruits are oval shaped, deep red in colour, and firm (Monsanto Africa, 2011).



**Plate 2.1 Anna F1 tomatoes**



**Plate 2.2 Cal J tomato**



**Plate 2.3 Money maker tomatoes**



**Plate 2.4 Romanna V F tomatoes**



**Plate 2.5 Onyx tomatoes**



**Plate 2.6 Beauty tomatoes**

### **2.2.2 Tomato farming in Kirinyaga County**

Tomato production is a major business in Kirinyaga County and utilises more than one third of the total cultivated land. Tomato production is undertaken by small scale farmers throughout the year and utilises both the rain and irrigation water from the permanent rivers and water canals (Waiganjo *et al.*, 2006). According to the same authors, farmers practice furrow irrigation due to the short distances from their water source and they therefore do not need to use expensive irrigation equipments such as sprinklers. It is mainly male dominated due to its profitability with most of the growers being early to middle aged (25-45 years). It employs a large number of people during the various stages of development but majority are employed during harvesting of the crop. There is therefore the need to make the tomato production a more profitable business so as to sustain this population in Kirinyaga County.

The crop requires high number of inputs which include seeds, fertilizers and insecticides. Insect pests and diseases are the major challenges to tomato production in the county and the pest management strategy is fully depended upon pesticides, most of them being broad spectrum, thus worsening the pest problem due to extermination of natural enemies. The tomato varieties grown in the area include Onyx, Cal J, and Money maker. These varieties are adaptable to the warmer climate experienced in the region. The tomato variety Onyx is the most preferred because it is resistant to diseases and pests and it is also a high yielder with a long shelf life (14 days) of the harvested fruits (Waiganjo *et al.*, 2006).

### **2.3 Challenges to tomato production in Kenya**

The tomato yields in smallholder cropping systems in the African region continues to be generally far below the potential of the crop. There are many constraints to tomato production in Kenya which may be classified as high illiteracy rates among the farmers, financial constraints, post-harvest losses, abiotic stressors such high and low salinity among others. The major constraint in tomato production in Kenya is insect pests (Waiganjo *et al.*, 2006). The crop is attacked by several insect pests during its development.

#### **2.3.1 Biology and life cycle of soil insect pests**

These include the greasy cutworm *Agrotis segetum* Denis and Schiffermuller; (Lepidoptera: Noctuidae), the larvae of beetles such as dusty brown beetle *Gonocephalum simplex* (F) (Coleoptera: Tenebrionidae) and chafer grubs *Melolontha melolontha* Linnaeus (Coleoptera: Scarabaeidae) (Waiganjo *et al.*, 2010). The adult female beetle of *M. melolontha* lays approximately 60 to 80 eggs which are buried about 10 to 20 cm deep in the soil. The eggs hatch into larvae known as “white grubs” or “chafer grubs” after six weeks (Waiganjo *et al.*, 2010). The grubs develop in the earth for three to four years, in colder climates even five years, and grow continually to a size of about 4–5 cm, before they pupate in early autumn and develop into adult beetles in six weeks. These larvae hide in the soil, feeding on the underground parts of the plant during the day and come to the surface to feed on the aerial parts at night. They cut the seedling stems at the soil level and bore into roots (Waiganjo *et al.*, 2010).

### **2.3.2 Biology and life cycle of leaf miners (*Liriomyza trifolii* Burgess)**

The female deposits the eggs on the lower surface of the leaf, but they are inserted just below the epidermis. Eggs are oval in shape and small in size, measuring about 1.0 mm long and 0.2 mm wide. Initially they are clear but soon become creamy white in colour (Leibee, 1984). The eggs hatch into larvae which grow through four instars and transform into pupae. A fourth instar occurs between puparium formation and pupation, but this is a non-feeding stage. The puparium is initially golden brown in colour, but turns darker brown with time. Adults are small, measuring less than 2 mm in length, with a wing length of 1.25 to 1.9 mm (Parella *et al.*, 1985). The head is yellow with red eyes. The thorax and abdomen are mostly gray and black although the ventral surface and legs are yellow. The wings are transparent. The adults live about 13 to 18 days (Leibee, 1984).

The female make numerous punctures of the leaf mesophyll with her ovipositor, and uses these punctures for feeding and egg laying. The males live only two to three days, possibly because they cannot puncture foliage and therefore feed less than females, whereas females usually survive for about a week. Typically, they feed and oviposit during much of the daylight hours, but especially near mid-day. Punctures caused by females during the feeding and oviposition processes can result in a stippled appearance on foliage, especially at the leaf tip and along the leaf margins (Parella *et al.* 1985). However, the major form of damage is the mining of leaves by larvae, which results in destruction of leaf mesophyll. The mine becomes noticeable about

three to four days after oviposition and becomes larger in size as the larva matures. The pattern of mining is irregular. Both leaf mining and stippling can greatly depress the level of photosynthesis in the plant. Extensive mining also causes premature leaf drop, which can result in lack of shading and thus sun scalding of fruit. Wounding of the foliage also allows entry of bacterial and fungal diseases (Parella *et al.*, 1985).

### **2.3.3 Biology and life cycle of whiteflies (*Bemisia tabaci* Gennadius)**

Adult whiteflies are about 1mm long with two pairs of white wings and light yellow bodies. Their bodies are covered with a waxy powdery material. They deposit eggs on the underside of leaves. The eggs are tiny, oval-shaped, about 0.25mm in diameter and stand vertically on the leaf surface. Newly laid eggs are white then turn brownish. Upon hatching the first instar nymph (0.3mm in length), commonly called the “crawler”, moves about the leaf in search of a place to insert its needle-like mouthparts into the plant to suck up plant phloem (Nyoike, 2007). When the crawler finds this site, it moults to the second instar; its legs are pulled up under its body and the rest of the immature stage is sessile. There are three additional nymphal instars (0.4-0.8mm) with the successive stage moulting to a slightly larger form. The last nymphal instar develops red eye spots and is commonly called the “red-eyed nymph”.

As nymphs feed, they excrete large quantities of liquid waste in the form of honeydew. Honeydew is rich in plant carbohydrates and as whiteflies feed and excrete, this waste is distributed onto plant leaves, flowers and fruit and

supports the growth of sooty mould fungus, causing the plant to turn black (Nyoike, 2007). Whiteflies have an interesting reproductive strategy called arrhenotoky, in which females can lay eggs that have not been fertilized and these eggs will result in male offspring. Fertilized eggs will result in female offspring. Each female can produce as many as 200 eggs in her lifetime. It takes 30-40 days to develop from egg to adult, depending on the temperature. The EPPO (2004) states that, infested plants may exhibit a range of symptoms due to direct feeding damage, contamination with honeydew and associated sooty moulds, whitefly transmitted viruses and phytotoxic responses. There may be one, or a combination of the following symptoms: chlorotic spotting, vein yellowing, intervein yellowing, leaf yellowing, yellow blotching of leaves, yellow mosaic of leaves, leaf curling, leaf crumpling, leaf vein thickening, leaf enations, leaf cupping, stem twisting, plant stunting, wilting and leaf loss.

#### **2.3.4 Biology and life cycle of leafhoppers (*Empoasca fabae* Harris)**

The adult leafhopper is pale to bright green, wedge-shaped and about 1/8 inch long. The adults are very active, jumping, flying or running when disturbed. The immature forms, or nymphs are pale green and wingless. They run forward, backward or sideways rapidly when threatened. The eggs are deposited under the leaf epidermis and hatch in about two weeks (Varela *et al.*, 2003). The immature leafhoppers or nymphs are wingless and feed on the leaves where they hatch. Nymphs moult five times and then transform into adults. There are two or three generations of leafhoppers each season. Adults

and nymphs feed on leaves by puncturing the leaf cells and sucking out the contents. Each puncture causes a white blotch to appear on the leaf. In heavy infestations, the leaves turn yellow or brown, and many will fall off. Feeding by these leafhoppers may reduce the photosynthetic capacity of the plant, and the quality and quantity of the fruit may be affected (Varela *et al.*, 2003).

### **2.3.5 Biology and life cycle of aphids (*Aphis gossypii* Gloves)**

They are small, soft bodied, pear-shaped insects with winged forms having two pairs of membranous wings. Adult females lay eggs that hatch into female nymphs on the primary host and feed to maturity. Aphids alternate primary hosts with secondary hosts, sexual with non sexual (parthenogenetic) reproduction, migrant with non-migrant forms and wingless with winged forms. Winged (alatae) forms migrate and feed on summer crops. Females reproduce parthenogenetically, giving rise to nymphs (Zitter *et al.* 1996). Aphids suck sap from plant parts such as stems, leaves and fruits causing damages to the leaves and fruits. They excrete honeydew, a sugar-rich substrate that promotes the growth of sooty mould on harvestable plant parts and leaves, lowering their quality (Nyoike, 2007). They also cause stagnation of flower setting and fruit production. In addition, aphids transmit cucumber mosaic virus which attacks tomatoes.

### **2.3.6 Biology and life cycle of thrips (*Frankliniella occidentalis* Pergade)**

Adults are small, slender and winged. The females lay eggs in leaf tissue which hatch into wingless larvae that resemble the adults. These are followed

by pupae which are inactive and do not feed. They pupate in the soil or under debris near host plants. Thrips feed on the lower surfaces of the leaves and also attack buds, flowers and fruits. Plant damage occurs when the larvae and adults puncture the leaves and suck sap. Heavy infestation causes premature wilting, delay in leaf development and distortion of young shoots. When flowers are attacked, abortion usually occurs. They are vectors of tomato spotted wilt and tomato chlorotic spot viruses both in greenhouse and field grown tomatoes (Varela *et al.*, 2003).

### **2.3.7 Biology and life cycle of bollworms (*Helicoverpa armigera* Hb)**

The adult moth is fleshy, yellowish-brown with a dark speck, greyish irregular lines and a black kidney-shaped mark on the forewings. The hind wings are whitish with a black patch along the outer margin. The moth is about 14 to 18 mm long with a wingspan of 35 to 40 mm. They are relatively strong fliers, dispersing widely within areas where the host plants are found. They can also be carried by strong winds. Moths are strongly attracted to plants that provide honeydew or nectar (Komarova and Kuznetsova, 1969; Sukhareva, 1999). The eggs are tiny (about 0.5 mm in diameter), round and yellowish-white in colour which darken before hatching. They are deposited singly on tender parts of the plant. Egg-laying generally coincides with early flowering of host crops.

The young caterpillars (larvae) are generally yellowish-white to reddish brown. They have a dark brown to black head and several rows of black bumps with short hairs along their backs, which give them a spotted appearance. Fully-grown caterpillars are 35 – 40 mm long. Older caterpillars vary in colour from almost black, brown or green to pale yellow with dark grey yellow stripes along the sides of the body. The fully-grown caterpillars drop from the plant and burrow into the soil to pupate. The pupa is shiny brown, about 16 mm long, with smooth surface, with two short parallel spines at the posterior tip of the body. Pupation takes place in the soil (Komarova and Kuznetsova, 1969; Sukhareva, 1999).

Moths lay a large number of eggs, and the life cycle may be completed in a short time under warm conditions. Eggs hatch in 3 to 5 days, larval and pupal periods last 17 to 35 and 17 to 20 days, respectively. The life cycle is completed in 25 to 60 days, depending on temperature. The larvae cause damage to floral buds, flowers and fruits. They bore into the fruit and feed on the inner parts of the fruit, releasing plenty of excreta (frass) which is noticeable on damaged fruits. Feeding by the bollworm causes tomato fruit rot as a result of secondary infections by bacterial and fungal pathogens which penetrate fruit through the feeding holes.

#### **2.3.8 Biology and life cycle of red spider mites (*Tetranychus spp*)**

Spider mites are less than 1 millimetre (0.04 in) in size and vary in colour. They generally live on the undersides of leaves of plants, where they may spin protective silk webs to protect the colony from predators and get the "spider"

part of their common name from this webbing (Saito, 2009). They lay small, spherical, initially transparent eggs that hatch in 3 days into larvae which transforms into nymphs and become sexually mature in 5 days. One female can lay up to 20 eggs per day and can live for 2 to 4 weeks, laying hundreds of eggs. A single mature female can spawn a population of a million mites in a month or less (Fasulo and Denmark, 2009). Spider mites cause injuries to leaves through sucking on the underside of the leaves thus interfering with nutrient transportation and may be serious pest in hot weather and during drought (Knapp, 1999). Severe attack leads to stunted growth and reduced yields.

#### **2.3.9 Biology and life cycle of tomato russet mites (*Aculops lycopersici* Masee)**

The adults are about 0.15 to 0.2 mm long and 0.05 mm wide (Kay, 1986). Their bodies are torpedo-shaped and cream to light gray-brown in colour. Females live for about 22 days and males live for an average of 16 days. Females have a pre-ovipositional period of 2 days and an ovipositional period of 19 days. The female produces an average of 16 eggs during the ovipositional period. Offspring of both sexes are produced by fertilized females. Unfertilized females only produce males. Eggs are round and colourless to white (Kay, 1986). The eggs are laid on leaves and stems of plants and hatch in approximately 2 to 3 days into larvae. The first nymphal stage lasts about 11 hours for females and about 7 hours for males. The larval chrysalis (quiescent moulting period between stages) lasts about 13 hours for

both males and females. Larvae are white in colour and look similar to the adults, but they are smaller and less active. The second nymphal stage lasts a little over a day for females and about 19 hours for males. The nymphal chrysalis lasts 18 hours for females and 16 hours for males. The tomato russet mite can induce serious injury on tomato. Silvering of the undersurface of lower leaves is an early symptom (Kay, 1986). These leaves later become bronze coloured, wither and die. The lower part of the stem loses hairs, becomes rusty brown or smoky in colour, and may develop small cracks on the surface. Continuous feeding results in a wilted, russeted (reddish-brown) tomato plant, and eventually leaf desiccation and plant death occurs (Keifer *et al.*, 1982). Damage also occurs to the fruit and fruit setting is also curtailed in plants infested with tomato russet mite (Kay, 1986). Loss of foliage due to tomato russet mite feeding exposes the fruits to sunburn. In addition, green or ripening fruits from infested crops often have pale, yellow to white, halo shaped blotches. Severe infestations cause severe discoloration of the fruit surface and small cracks at the stem end (Kay, 1986).

#### **2.4 Integrated Pest management (IPM)**

Integrated Pest Management (IPM) is an ecosystem-based strategy that focuses on long term prevention of damage to crops by pests through a combination of many methods to suppress pest population levels below those causing economic injury (Strand, 2000). Applying multiple control tactics minimizes the chance that insects will adapt to any one tactic, hence reducing the occurrence of pest resistance to pesticides. Useful IPM approaches for

tomatoes include cultural, physical (mechanical), biological and chemical methods (Waiganjo *et al.*, 2010). Biological control involves the use of natural enemies which are living organisms that feed on crop pests and these include predators, parasitoids and pathogens. Mechanical methods involve various methods such as use of mass trapping, use of screening, hand picking and ploughing. Cultural methods include mixed cropping systems, pest and disease avoidance, providing conditions for growing healthy plants that can withstand pests better, sanitation, staking or trellising of indeterminate varieties, crop spacing, crop rotation and solarisation. Use of plant resistance has also been practiced as an IPM program. High tunnels have been used in developed countries such Europe as an IPM tool known to reduce insect pest incidences.

#### **2.4.1 Biological control**

Biological control is defined as the utilization of natural enemies (parasitoids, predators or pathogen) to reduce damage caused by noxious organisms to tolerable level (De Bach and Ronsen, 1991). Parasitoids are insects that live and feed on or in the tissue of a pest (host), parasitizing and eventually killing the host. Parasitoids are parasitic only in their immature stages with the adults being free-living, usually nectar or honeydew feeders. There are egg, larval, and cocoon parasitoids, categorized by the specific host stage that they attack. Parasitoids are either small wasps belonging to order Hymenoptera and in the families Trichogrammatidae, Eulophidae, Braconidae, Icnneumonidae,

Aphidiidae and Encyrtidae or flies (order Diptera: Family Tachinidae) (De Bach and Ronsen, 1991). Wasp parasitoids in the family Trichogrammatidae (e.g. *Trichogramma* sp) are egg parasitoids of many horticultural pests such as *Helicoverpa armigera*. Parasitoids in the family Eulophidae parasitize eggs and larvae of many insect pests including leaf miners and leaf-rollers (Sithanantham *et al.*, 2005).

Predators are mainly free-living species that directly consume a large number of preys during their whole lifetime. Ladybug larvae are voracious predators of aphids, and will also consume mites, scale insects and small caterpillars. The larvae of many hoverfly species principally feed upon greenfly, one larva devouring up to fifty a day, or 1000 in its lifetime. They also eat fruit tree spider mites and small caterpillars. Other useful garden predators include lacewings, pirate bugs, rove and ground beetles, aphid midge, centipedes, spiders, predatory mites (Varela *et al.*, 2003). The common green lacewing *Chrysoperla carnea* Stephens has the capacity to resist or tolerate insecticides like endosulfan, monocrotophos, fenvalerate, permethrin, pirimicarb cabaryl, carbosulfan, *Bacillus thuringiensis* Berliner, botanicals (nicotin, neem, rotenone, etc) and novel insecticides like nitenpyram, imidachloprid and acetamiprid (Gautam and Tesfaye, 2002). The predators of *H. armigera* in Kenya include anthocorids, *Orius* spp. and ants including *Pheidole* spp, *Myrmecaria* spp. and *Camponotus* spp. (Van den Berg and Cock, 1993). Predators observed on aphids of tomatoes include *Macrolophus pygmaeus* Rambur and *Orius niger* Wolf (Perdikis and Lykouressis, 1996). Predatory

mirids are well adapted to colonizing both protected and unprotected tomato crops. They contribute to reducing pest densities of greenhouse whitefly (Albajes and Alomar, 1999).

*Bacillus thuringiensis* Berliner, is one of the most commonly used biopesticide against larvae of Lepidoptera, Coleoptera (beetle) and Diptera (true flies) in peri-urban vegetable crops in Africa. This is in response to farmers concern over chemical insecticide efficacy (CABI, 2003). *Bacillus thuringiensis* is a bacterium which affects gut of larvae and must be eaten by the pest to be effective. Caterpillars cease feeding and die in two to three days (CABI, 2000). The bacteria is available in sachets of dried spores which are mixed with water and sprayed onto vulnerable plants such as brassica and fruit trees (Swan, 1964).

Fungi that cause disease in insects are known as entomopathogenic fungi, including at least fourteen species that attack aphids (Hall and Dunn, 1957). *Verticillium lecanii* Zimmenn is an entomopathogenic fungus of aphids and whitefly (CABI, 2000). It has been reported to infect various insects including larvae of beetles, mites, aphids, scales and other homopterans, particularly under greenhouse conditions (Hall, 1981). Meade and Byrne (1991) reported the successful use of *V. lecanii* worldwide to control greenhouse whitefly and various species of aphids. *Beauveria bassiana* is used to manage a wide variety of insect pests including whiteflies, thrips, aphids and weevils. Others include *Paecilomyces fumosoroseus* that attacks whiteflies, thrips and aphids, *Lecanicillium* spp which attacks white flies, thrips and aphids and

*Metarhizium* spp which attacks beetles, locusts and grasshoppers, Hemiptera, spider mites and other pests (Hall and Dunn, 1957).

Baculoviruses are pathogens that attack insects and other arthropods. Like some human viruses, they are usually extremely small (less than a thousandth of a millimetre across), and are composed primarily of double-stranded DNA that codes for genes needed for virus establishment and reproduction. Most insect baculoviruses must be eaten by the host to produce an infection, which is typically fatal to the insect (Mararmorosch and Sherman, 1985). The majority of baculoviruses used as biological control agents are in the genus *Nucleopolyhedrovirus*. These viruses are excellent candidates for species-specific, narrow spectrum insecticidal applications. They have been shown to have no negative impacts on plants, mammals, birds, fish, or even on non-target insects. This is especially desirable when beneficial insects are being conserved to aid in an overall IPM program, or when an ecologically sensitive area is being treated (Mararmorosch and Sherman, 1985).

On the other hand, the high specificity of baculoviruses is also cited as a weakness for agricultural uses, since growers may want one product to use against a variety of pests. Currently, researchers are attempting to use genetic engineering techniques to expand virus host ranges to the desired pest species (Mararmorosch and Sherman, 1985). Viruses such as Codling moth granulosis virus have been used in the control of codling moth, cabbage armyworm, nuclear polyhedrosis against cabbage moth and American bollworm, among others.

### **2.4.2 Cultural control**

Cultural control involves manipulation of the cropping environment to increase pest mortality or reduce rates of pest increase and damage. The primary strategy of cultural control is to maintain and increase biological diversity of the farm system (Atieri, 1993). Increased biodiversity results in stable agro-ecosystems which reduces recurrent pest outbreaks (Atieri, 1993; ATTRA, 2001). Estimated 75% of all insect pests as well as many of their natural enemies spend part of their life cycle in the soil. Therefore, a healthy soil with a diversity of beneficial organisms and high organic matter content helps maintain pest population below their economic thresholds (ATTRA, 2001). Cultural control methods include a broad range of normal management practices that can be modified or manipulated to manage one or more pest problems. Cultural control techniques may include crop rotation, tillage, timing of planting and harvesting, use of resistant cultivars, fertilizer or irrigation practices, sanitation, and soil solarisation among others. 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).

Intercropping is the practice of growing two or more crops in alternate rows in the same farm. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop. Careful planning is required, taking

into account the soil, climate, crops, and varieties. It is particularly important not to have crops competing with each other for physical space, nutrients, water, or sunlight. Intercropping of compatible plants encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single-crop environment. This in turn can help limit outbreaks of crop pests by increasing predator biodiversity. Additionally, reducing the homogeneity of the crop increases the barriers against biological dispersal of pest organisms through the crop (Atieri and Nicholls, 2004)

Mixed species cropping is the growing of two or more plant species in the same field in the same year at the same time. The increased crop diversity helps disguise crops from insect pests as well as allow for more efficient utilization of limited soil and water resources (Atieri, 1993; ATTRA, 2001; Varela *et al.*, 2003). Mixed species cropping permits an intensification of the farm system, which results in increased overall productivity and biodiversity in cropped fields (Vandermeer, 1989). Mixed species cropping has been seen as a promising technique to develop sustainable farming systems because it often has multifunctional roles and can potentially provide a number of eco-services within the farm system. Examples may include the addition and recycling of organic material, water management, protection of soil from erosion and pest or disease suppression. This functional diversity contributes to ecological processes to promote the sustainability of the whole farm system (Atieri, 1999).

Trap crops are plants of a preferred growth stage, cultivar or species that divert pest pressure from the main crop because they are more attractive (Cook *et al.*, 2007). Trap crops need to be more attractive by providing nectar, prey or favourable chemicals and physical properties to the pest. They also need to be more tolerant to pests than the main host, for example, flea beetles and aphids prefer mustard to collards. When planted together, the mustard attracts the pests and leaves the crop with less damage. Mustard when used as a trap crop has been reported to attract *Plutella* and other crucifer pests, thereby drawing them away from the main crop (Facknath, 1997). Egg plants have been reported to be effective trap crops for those aphids migrating early and transmitting virus disease (Stoll, 2003). However, trap crops have not proved to be a reliable approach to pest control because they eventually lose their attractiveness due to maturity, senescence, or high pest population (Stansly, 2001). The infested trap crop can be mowed or tilled to kill the pests before they reproduce.

Crop rotation is the practice of growing a series of dissimilar/different types of crops in the same area in sequential seasons. Crop rotation alters the environment both above and below the soil to the disadvantage of the pests of the previous crop. It is therefore used to control pests and diseases that can become established in the soil over time as it suppresses soil-borne insects, nematodes and pathogens through host deprivation. The same crop grown year after year on the same field will lead to build up of populations of organisms that feed on that plant (Atieri, 1993; ATTRA, 2001). The changing

of crops in a sequence tends to decrease the population level of pests. Plants within the same taxonomic family tend to have similar pests and pathogens. By regularly changing the planting location, the pest cycles can be broken or limited. For example, root-knot nematode is a serious problem for some plants in warm climates and sandy soils, where it slowly builds up to high levels in the soil, and can severely damage plant productivity by cutting off circulation from the plant roots (Sasser and Carter, 1985). Growing a crop that is not a host for root-knot nematode for one season greatly reduces the level of the nematode in the soil, thus making it possible to grow a susceptible crop the following season without needing soil fumigation (Sasser and Carter, 1985).

Deterrent plants such as marigolds (*Tagetes* spp.) have long been used as companion plants. They release compounds that can repel insects and nematodes, and inhibit bacterial, viral and fungal pathogens. Cabbage intercropped with marigolds was found to have fewer cabbage butterfly larvae and cabbage aphids than monocropped cabbage (Jankowska *et al.*, 2009). Likewise, carrots grown with marigolds had fewer forked or diseased roots than mono-cropped carrots, but the yields were sometimes lower, because the marigolds were too competitive (Wach, 2011).

Late-season or early season pest problems may be avoided by planting shorter season varieties or manipulating planting and rendering the crop less vulnerable to the pests. Early or delayed planting can be effective where the length of the growing season exceeds the time required to produce crop

(Stansly, 2001). Pruning (selective removal of side shoots to limit plant growth) may cause fruit to mature earlier and grow to greater size and uniformity. Pruning improves air circulation within the canopy, which reduces foliar diseases, and facilitates spraying and harvesting (AVRDC, 2001). Staking or trellising tomato plants provides support and keeps the fruit and foliage off the ground. It also increase fruit yield and size, reduce fruit rot and allow easy spraying and harvesting (Varela *et al.*, 2003).

Solarisation or mulching involves covering the soil with clear transparent polythene sheets for two to three months depending on the amount of sunshine (ATTRA, 2001; Varela *et al.*, 2003). Mulches, either living or non-living, are known to interfere with whitefly's host-seeking behaviour (Stansly, 2001). Some living mulches have been evaluated in Costa Rica, including perennial peanuts, a weed, cinquillo and coriander. Coriander gave the best economic results because it could be harvested and sold at about thirty days, removing potential competition and providing extra income to the farmers (Stansly, 2001). Research in Tennessee showed that there was 70% reduction in damage to vegetables by insects when hay or straw was used as mulch. Living mulches of various clovers were found to reduce insect pest damage to vegetables and orchard crops (Stansly, 2001). Winged aphids are repelled by silver or aluminium-coloured mulches (ATTRA, 2001).

Presence of a physical or temporal barrier separating new crops from the older infected crops has been used for the control of whitefly. This has been

accomplished through one or more crop free periods, and or exclusive methods such as an insect proof screening or sufficient distance from other susceptible crops (Stansly, 2001). Crop free periods have been used successfully against whitefly-borne geminiviruses since the 1920's and 1930's on tobacco in South Africa and cotton in Sudan (Stansly, 2001). They have also been used to protect vegetables crops in Florida, the Dominican Republic and Israel. In the Dominican Republic, a ninety day crop free period is mandated for summer months when only non-hosts such as sorghum are allowed. This system was mandated in response to devastating epidemics of TYLCV in the early 1990's (Stansly, 2001). Tilling and ploughing of old tomato fields expose pupae of the African bollworm and thrips in the soil to the sun and natural enemies. Hand picking and destruction of eggs is done in case of low infestations. Destruction of weeds which may harbour developing larvae is important in preventing pest infestations (Atherton and Rudich, 1986; Varela *et al.*, 2003).

### **2.4.3 Chemical control**

Chemical pesticides are substances that when applied to crops, reduce the vitality of pest populations while leaving crops unharmed. Chemical pesticides are manufactured in laboratories from synthetic materials, hence are referred to as synthetic pesticides, or from natural materials, hence botanical pesticides. Chemical control can kill pests that come in contact with the chemical (toxicants), eliminate the reproductive potential of pests (sterilants), disrupt their developmental potential (growth regulators) or influence their

behaviour (semiochemicals). Most of these chemical controls are fast acting and effective (Varela *et al.*, 2003).

#### **2.4.3.1 Synthetic pesticides**

There are many classes of synthetic pesticides. The main classes consist of organochlorines, organophosphates, carbamates, and pyrethroids, among others (Eldridge, 2008). Carbamates include Carbofuran, Aldicarb, Carbaryl and Methomyl, among others. Carbamates affect the central nervous system of the target insects. The organophosphates include Diazinon, Glyphosphate, malathion, Azinphos methyl and Guthion, among others. The organochlorines include DDT, Toxaphene, Dieldrin, Aldrin and Endosulfan, among others. Pyrethroids such as Fenvalerate and Deltamethrin among others (Eldridge, 2008). Exposure to pesticides can cause acute (short term) or chronic (long term) effects on animals and humans, especially in the reproductive, endocrine, and central nervous system. Intensive pesticide applications may be required to keep insect pests below the economic thresholds in tomato agroecosystems (Brun, 1981; Kennedy *et al.*, 1993). Various pesticides have been used in pest control. Imidacloprid, a neonicotinoid, is a broad spectrum systemic and contact insecticide exhibiting low mammalian toxicity with primary activity on sucking insects such as Homoptera and also has excellent potential in seed and soil applications (Schmeer *et al.*, 1990). It is primarily used to control sucking insects mainly aphids and whiteflies, and is effective against adult or immature stages of various species (Ebert *et al.*, 1990; Logadic *et al.*, 1993; Leicht, 1996). In greenhouse trials, imidacloprid has

been found to be effective against insects such as *B. tabaci*, *Amrasca biguttula* Ishida and *Aphis gossypii* Glover (Ebert *et al.*, 1990). Natwick *et al.* (1996) found all imidacloprid treatments to be effective for control of green peach aphids, cabbage aphid and whiteflies in cauliflower. Yardim and Edwards (1997), studying the influence of chemical management of pests, diseases and weeds on pests and secondary predatory arthropods associated with tomatoes using carbaryl, endosulfan and fenvalerate, observed that the insecticides controlled aphids, flea beetles and thrips in the first applications, but subsequent applications revealed an increase in the pest population. Various authors have reported that combination of insecticides such as carbaryl and Malathion (Roger *et al.*, 1991), Malathion and diazinon (Dinkins *et al.*, 1971), diazinon and deltamethrin (Whalon and Elsner, 1982; Thomas *et al.*, 1990), all affected predator population significantly.

Insecticides can have drastic effects on natural enemies of pests of tomatoes and this will result to an increase or resurgences in pest populations. Examples include increased populations of tomato fruit worms and cabbage looper after treatment with methomyl and carbaryl (Oatman *et al.*, 1983; Roltsh and Mayse, 1983; Hoffmann *et al.*, 1996). Many field studies have reported severe toxicity of different insecticides to beneficial predators such as coccinellids, for example, carbaryl (Lecrone and Smilowitz, 1980), Malathion (Roger *et al.*, 1991) guthion, Malathion, diedrin (Yun and Ruppel, 1964) and pyrethroid insecticides (Coats *et al.*, 1979). Other beneficial predators such as spiders also tend to be very sensitive to malathion (Whalon and Elsner, 1982),

azinphos methyl, dimethoate (Culin and Yeargan, 1983) and deltamethrin (Thomas *et al.*, 1990). The decision to use a pesticide is generally based on its effectiveness against particular pests, application costs, the economic value of the crop, and the relative risks to the crop of using the pesticides (phytotoxicity, resistance) versus not using it (pest outbreak, damage, yield reduction) (Van der Werf, 1996). The direct economic benefit associated with pesticide use is considered more often than the potential environmental and health hazards or risk reduction associated with pesticide use (Pimentel *et al.*, 1993). However, the intensive pesticide applications have their negative effects namely; environmental contamination, toxic residues, side effects on non target organisms, increase of pest resistance to pesticides, secondary pest outbreaks and pest resurgence (Seif *et al.*, 2003; Varela *et al.*, 2003). The principal aim of low-input of pesticides and organic agriculture is to avoid environmental degradation and health risks by reducing or eliminating the use of synthetic chemical pesticides, hence the concept of Integrated Pest Management.

#### **2.4.3.2 Botanical pesticides**

Botanical pesticides are obtained from plants. These pesticides can be as simple as extracts from plant parts or purified chemicals from plants (Pratap and Sharma, 2004). These pesticides can be as harmful as synthetic pesticides but their advantage over synthetic pesticides is that they decompose quickly as they are broken down by microbes and sunlight. This faster breakdown means fewer residues in the environment and less risk to the beneficial insects that

come in contact with them. These pesticides are less hazardous to transport and can be formulated in the field (Pratap and Sharma, 2004). The commonly used botanicals include pyrethrum, neem formulations, rotenone and nicotine. Azadirachtin found in neem tree interferes with the normal moulting process of insects. Several neem-based products are registered as pesticides in Kenya and have been proven to be efficient against several insect pests including *Brevicoryne brassicae* L. on kales, *Aphis fabae* Scop. on French beans, *Plutella xylostella* L and *Liriomyza* spp. on tomatoes and cut flowers (ICIPE, 1998). Neem products reduce egg-laying by *B. tabaci*, and they also inhibit growth and development of nymphs and significantly reduce the risk of tomato yellow leaf curl virus (TYLVC) (Varele *et al.*, 2003).

Kwanchi (1999), while testing the efficacy of neem seed extract in different forms (viz neem seed extract, neem fruit extract, mixture of neem seed extract and neem fruit extract with neem oil) observed that, all forms exhibited almost the same deterrence of oviposition in whiteflies. Extracts of neem fruit, seeds, seed kernels, twigs, stem bark and root bark were reported to show anti-feedant, insecticidal and insect growth disrupting activity (Kraus, 1995). Other effects of neem derivatives on insects include prevention of insect settling on the host plants, reducing fecundity and egg sterility, lessening insect fitness, and deterring egg laying (Schmutterer, 1990).

Neonicotinoids are a class of neuro-active insecticides chemically related to nicotine. The neonicotinoids show reduced toxicity compared to previously

used organophosphate and carbamate insecticides. Most neonicotinoids show much lower toxicity in mammals than insects, but some breakdown products are toxic (Chao and Casida, 1997). The neonicotinoid imidacloprid is currently the most widely used insecticide in the world (Yamamoto, 1999). Neonicotinoids, like nicotine, bind to nicotinic acetylcholine receptors of a cell and triggers a response by that cell. In insects, these receptors are limited to cells of the CNS. While low to moderate activation of these receptors causes nervous stimulation, high levels overstimulate and block the receptors (Yamamoto, 1999, Gervais *et al.*, 2010). This receptor blockage causes paralysis and death. Because most neonicotinoids bind much more strongly to insect neuron receptors than to mammal neuron receptors, these insecticides are selectively more toxic to insects than mammals (Tomizawa, 2004).

Pyrethroid is an organic compound similar to the natural pyrethrins produced by the flowers of pyrethrums (*Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids now constitute the majority of commercial household insecticides (Reigart *et al.*, 2009). They have insect repellent properties and are generally harmless to human beings in low doses but can harm sensitive individuals. They are usually broken down by sunlight and the atmosphere in one or two days, and do not significantly affect ground water quality. Pyrethroids kills insect pests by paralyzing their nervous system. Pyrethroids have also been used against lice and fleas in domestic as well as public buildings (Reigart *et al.*, 2009). It has also been successfully used against mosquitoes, house flies and other insects that spread diseases in animals and

human beings (Varma and Dubey, 1998). The commonly used synthetic pyrethroids in agriculture are cypermethrin, deltamethrin and fenvalerate.

## **2.5 High tunnels**

High tunnels, are also called high hoops or hoop houses or unheated greenhouses, include a range of designs from single-span to multi-span structures that are usually covered with a single layer of polyethylene greenhouse film (Plate 2.7). They may be constructed to be semi-permanent, movable, or temporary (Blomgren and Frisch, 2007). They have a peak height of at least 18 feet and the floor is soil (Jensen, 2000). High tunnels are cheaper than green houses, are unheated, are passively ventilated and have water for irrigation. They are used to produce a wide variety of crops directly in the soil (Lamont *et al.*, 2003). They are solar heated and venting is done by rolling up and down the side covers of high tunnels. Proof netting can also be used on the sides to increase ventilation (USAID-KHDP, 2008). Commonly used materials for the roof and sides are plastic sheets (polyethylene) and glass. Wood, steel or aluminium are used for structural support. Owing to the low construction and operating costs, it is common for producers to recover their investment within one or two years (Blomgren and Frisch, 2007).

High tunnels covered with ultraviolet (UV) plastic materials have been found useful not only for horticultural purposes, but also as a tool to combat fungal

diseases (Ben-Yakir, 2004). Additional observations and studies have demonstrated the dramatic inhibitory effect of UV blocking on the invasion of greenhouses and high tunnels by pests (Diaz and Fereres, 2007). Populations of *A. gossypii* and *T. vaporariorum* were lower on tomatoes grown in a high tunnel covered with UV blocking plastic film than on the same crop grown under standard plastic. Similarly, thrips (*F. occidentalis* and *Scirtothrips dorsalis*) were found at lower densities under the UV blocking plastics, and a similar trend was found for the leaf miner (*L. bryoniae*) (Ben-Yakir, 2004).

In a series of experiments carried out in Israel during recent years, it has been shown that UV blocking high tunnel covering materials can reduce the entry of insect pests and the spread of insect-transmitted viral diseases of plants (Diaz and Fereres, 2007). The protective effect of UV blocking films was confirmed by comparing the invasion rates of insect pests into experimental tunnels covered with UV blocking polyethylene films with those taking place under standard film. In small 'walk-in' tunnels (6m x 6m), the number of whiteflies (*B. tabaci*) trapped on yellow sticky traps under a UV blocking film was four to ten times lower than the number trapped under a standard film (Ben-Yakir, 2004). In a similar experiment, the number of aphids (*A. gossypii*) recorded under UV blocking film was approximately a hundred times lower than that recorded under standard film and the UV blocking films reduced the invasion of thrips (*F. occidentalis*) by a factor of ten (Diaz and Fereres, 2007). Ultraviolet blocking materials have properties to filter the UV

radiation (280-400nm) interfering with the vision of insect pests and in consequence, their behaviour related with movement, host location ability and their population parameters (Diaz and Fereres, 2007).

High tunnels can significantly increase the average daily temperature and protect the crop from wind, rain, snow, hail, insects and diseases. The crop is grown directly in the soil using raised beds or mulches depending on the type of vegetable. Irrigation is essential for providing water and nutrients to the crops during the growing season. Though high tunnel tomato production is widely practiced around the world, in Kenya it is common with flower farmers but is a relatively new concept for tomato farmers. High tunnel tomato production was introduced into Kenya by the Horticultural Crops Development Authority in 2007 (USAID-KHDP, 2008). For farmers constrained by small land sizes, the way to go is to adopt intensive farming of high value crops through technologies such as high tunnels.

The benefits of growing tomatoes in high tunnels are diverse first and foremost, they create a protective micro-climate to the plants grown in them and tomatoes produced are of higher quality and quantity. Tomatoes have the potential to perform better in high tunnels than in open fields ( Jett and Read, 2003) (Plate 2.7). Other benefits include year round production of tomatoes and reduced pest incidences if the hygienic conditions are strictly observed as

they present a barrier to some insect pests. There is therefore huge savings on crop protection chemicals, and exposure to chemical toxins associated with them is minimized or eliminated altogether thus the environment is saved from pollution (Lamont *et al.*, 2003; USAID-KHDP, 2008). Increased soil temperatures in the high tunnel hasten root growth which contributes to fast maturity and earlier harvests. With decreasing size of land under tomato cultivation, one can put up a high tunnel in a small plot and benefit from high yields (Loncaric *et al.*, 1999; Lamont *et al.*, 2001). High tunnel technology helps farmers to produce crops outside the normal season, thus meeting consumer demand on either end of the production curve when competition is low and prices are high (Wells and Loy, 1993; Wells, 1996; Hochmuth *et al.*, 1998). High tunnel tomato production being new in Kenya, not much work has been done to compare insect pest infestation levels and yields of tomatoes grown in high tunnels and open field hence their usefulness. This study was intended to do so with the aim of encouraging more tomato farmers to embrace the technology.

### **2.5.1 Pest management in high tunnels**

Crops grown in high tunnels are just as susceptible to pests and diseases as those grown in field conditions. Pesticides for high tunnel application are limited and sometimes non existence. There are however a wide range of Integrated Pest Management (IPM) strategies available to high tunnel producers. IPM an approach to managing pests that uses appropriate physical,

cultural, biological and chemical tactics that are safe, profitable and environmentally compatible (Thomas and Rajotte, 2004). IPM strategies for the control of *Frankliniella occidentalis* includes use of reflective mulches or screens to repel the insects (Antignus, 2000). Biological control for *F. occidentalis* include two predators namely, the predatory mites *Amblyseius cucumeris* (Bessin *et al.*, 1993) and the predatory bug *Orius* spp. (Weeden *et al.*, 2002)



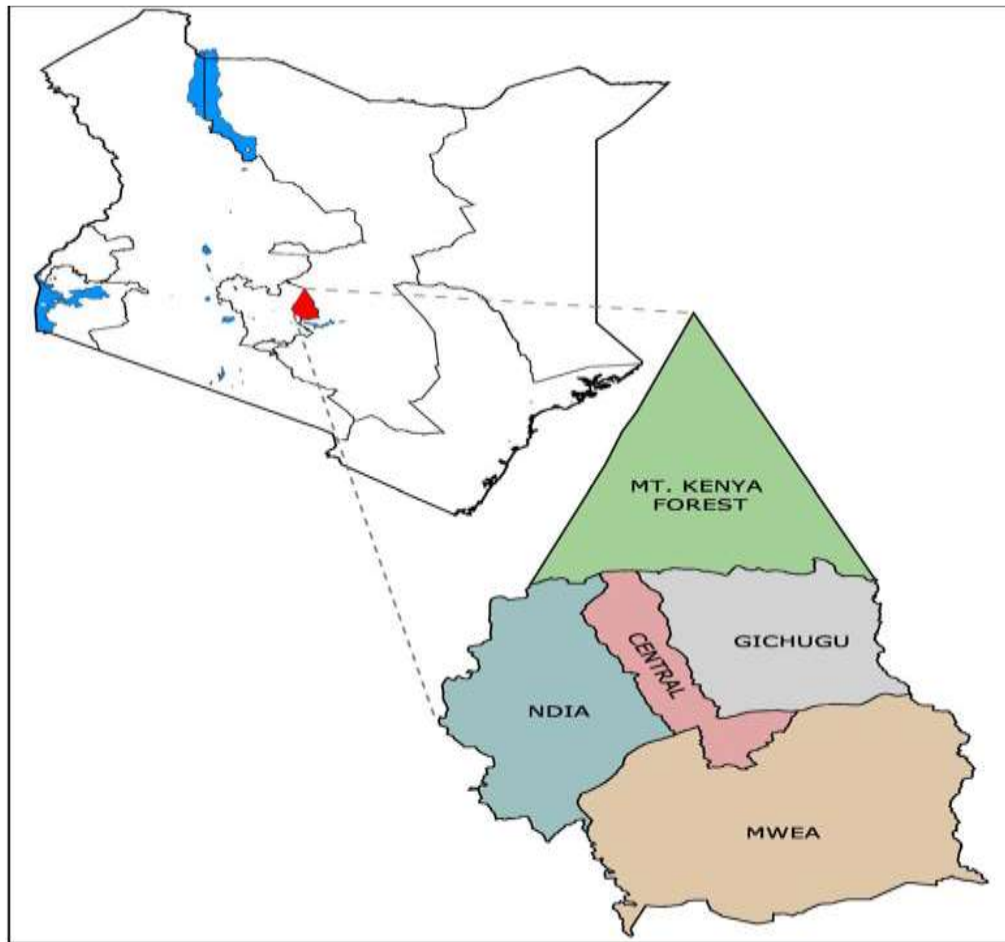
**Plate 2.7 A high tunnel with double door**

## CHAPTER THREE

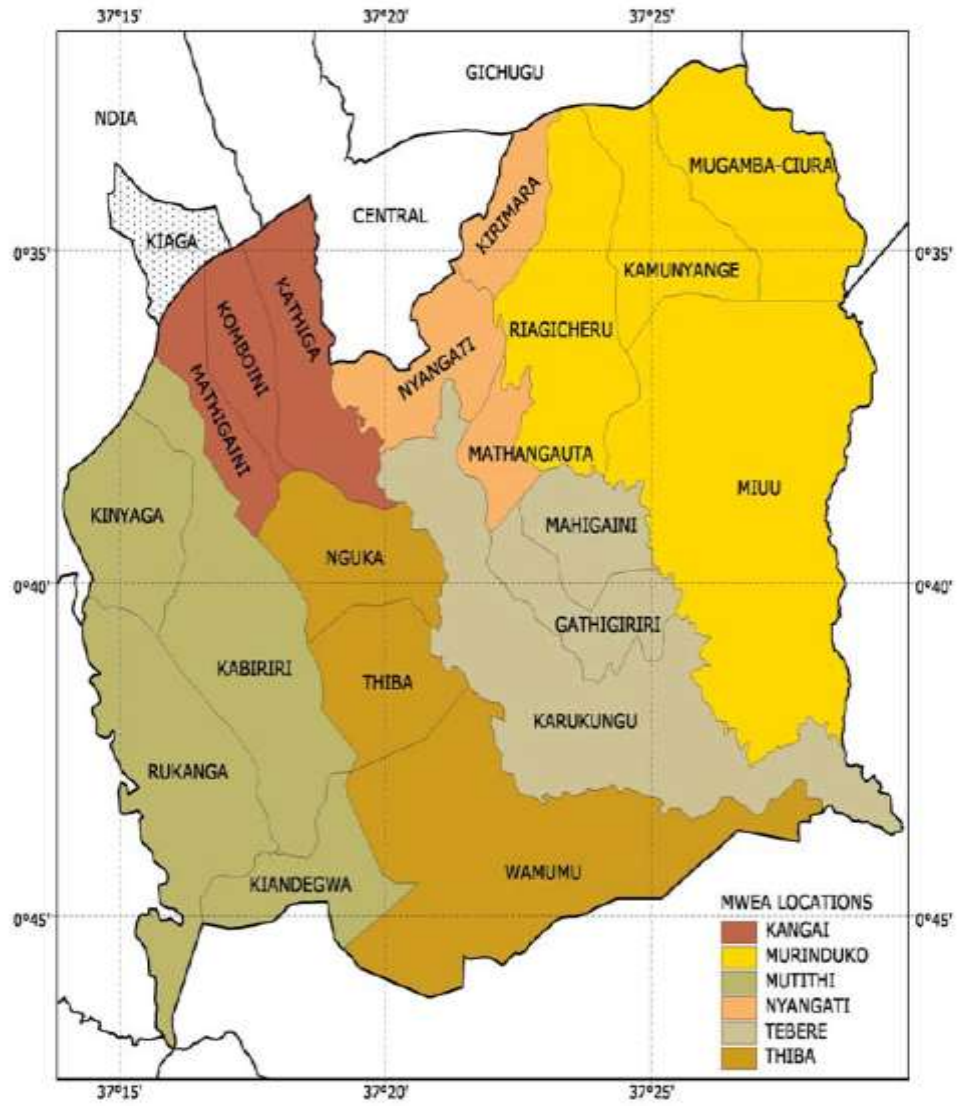
### MATERIALS AND METHODS

#### 3.1 The study area

The study was conducted in a smallholder farm in Kathiriku Sub location, Murinduko location, Mwea division of Kirinyaga County (Figure 1). It is a high agricultural potential area with a bimodal annual average rainfall ranging from 800-2200mm. In most of the areas, the soils are volcanic loam which are deep and moderately to highly fertile (Jaetzold and Schmidt, 1983). The average annual temperature is 9.7-21.6°C (Waiganjo *et al.*, 2006). The County covers an area of about 1437sq Km and has a total area of about 112,700 hectares of which 95,500 ha (85%) is under agriculture (Jaetzold and Schmidt, 1983). There are two permanent rivers passing through the county namely Thiba and Nyamindi, which facilitate the growing of rice and horticultural crops under irrigation. Among the most important horticultural crops are tomatoes, french beans, bananas, mangoes, pawpaw and avocado (Waiganjo *et al.*, 2006). Kirinyaga County is one of the most densely populated in Kenya with an estimated human population of 491,161 (KBS, 2007). The average arable land holding per individual is 0.19 hectares. Administratively, the county is made up of five divisions namely; Gichugu, Central, Ndia, Mount Kenya forest and Mwea (Figure 1 and 2).



**Figure 1 Kirinyaga County, Kenya and its administrative Divisions**



**Figure 2** Locations of Mwea Dision, Kirinyaga County, Kenya

### **3.2 Land preparation in high tunnel and open field**

The land was prepared by clearing vegetation using slashers and machetes. The land was then dug deep (at least 15cm) using forked hoes to break the soil. One week after, the soil was turned and large soil crumps were broken to small soil particles using a forked hoes. The soil in the high tunnel was fumigated with Metham sodium and covered with black polythene paper for 21 days for control of bacterial wilt causal pathogens *Pseudomonas solanacearum* Smith and soil borne pests such as greasy cutworm. Raised beds were then prepared at least 6 inches high and 1 meter wide. A walk way was left between the beds around 45cms wide. 100 Kgs of farmyard manure for every square meter of bed was applied and thoroughly mixed with the soil. The beds were then levelled to a fine tilt in readiness for transplanting with tomato seedlings. 10 grams of Di-Ammonium Phosphate (DAP) was added in every planting hole.

### **3.3 Preparation and planting of seeds in the nursery beds**

The nursery beds were prepared in a screen-house at KARI- Thika. Three nursery beds were prepared for planting three tomato varieties, Onyx, MT56 and Anna F1. A space was left between the nursery beds. The soil was dug deep and large soil particles broken down into small soil particles using a forked hoe. The nurseries were raised to enhance good drainage. The soil was fumigated with Metham sodium and covered with polythene paper for three weeks. Later on, 100grams of phosphate fertilizer (DAP) and 100Kgs of farmyard manure per square meter was applied and mixed well with the soil.

The soil was then levelled to give an even landscape. The seeds were singly sowed 3-4cm apart within rows and 0.5-1.0 cm deep with a distance between rows of 15cm. The seeds were then covered with a fine mixture of sand, soil and well decomposed and sieved farmyard manure at the ratio of 1:1:1. Irrigation of the nursery beds was carried out at regular intervals daily using a Rose can.

### **3.4 Grafting Onyx scion onto MT 56 rootstock**

One month after germination of the tomato seedlings some Onyx seedlings were grafted on MT 56 tomato variety to obtain grafted Onyx. MT 56 tomato variety was chosen as it is resistant to bacterial wilt, a serious disease of tomatoes in the region. The leafy part of the stem was cut out from the MT 56 seedlings and a V-shaped cut made on the stem. The basal end of the Onyx scion was also V-shaped to fit well in the V-cut of the rootstock. Plastic tubes were slit and placed onto the cut end of the rootstock and the cut end of the scion was inserted into the tube joining the cut surfaces together (Plate 3.1 and 3.2). The grafted seedlings were then kept at 28-30°C with more than 95% relative humidity for three days for healing and to promote successful grafting. The relative humidity and the irrigation rate was then gradually lowered, and the light intensity increased to harden or acclimatize the grafted seedlings before transplanting them. Seven to ten days after grafting, the plastic tubes were removed and the grafts were nursed in the nurseries for one month.



**Plate 3.1 Onyx tomato variety (scion) grafted on a MT56 rootstock**



**Plate 3.2 Plastic tube to hold the graft**

### **3.5 Transplanting of tomato seedlings in open field and high tunnel**

When the seedlings were 4 weeks old, the hardening process which involved reducing watering frequency and removal of shade began. Eight weeks old tomato seedlings were transplanted in the plots prepared in high tunnel and in open field (Plate 3.3 and Plate 3.4). One hour before transplanting, the nursery beds were watered, making it easier to remove the seedlings without damaging the roots. The beds where the seedlings were to be transplanted were also watered using irrigation system. Transplanting was carried out in

the late afternoon when the weather conditions are mild to reduce transplant shock. The seedlings of the three varieties of tomatoes ( Anna F1, non-grafted Onyx and grafted Onyx) were planted in the plots in a Complete Randomized Block Design. Onyx tomato variety was chosen as it is commonly grown in the area and is accepted in the market. Grafting of the Onyx tomato with a MT56 tomato variety increased its resistance to bacterial wilt, a very destructive disease in the region. Anna F1 is a determinate variety suitable for high tunnels and has high yields compared to the Onyx variety. For each variety, two rows of three tomato seedlings were planted hence six seedlings per plot (treatment) and then replicated randomly four times, thus a total of 24 seedlings per tomato variety. The spacing of the tomato seedlings both in high tunnel and open field was 60 cm× 60 cm between plants and between rows respectively. The study was carried out in two cropping seasons, season one was in the month of September 2010 to November 2010 while season two was in the month of January 2011 to March 2011.



**Plate 3.3 Tomato plants in high tunnel**



**Plate 3.4 Tomato plants in open field**

### **3.6 Crop management**

During the entire period of the plant growth various crop management activities were carried out for healthy growth of the crop. These included trellising, pruning, irrigation, fertilizer application and pest management practices.

#### **3.6.1 Trellis support system**

A support framework was put in place for providing support to the growing tomato vines. A T-type support system run down each bed (poles spaced 3 meters) where the tops of the poles were 7 feet above the ground (Plate 3.3 and 3.4). Two parallel lines of 12 gauge galvanized wire were attached to the horizontal top bars so that each row of plants had a wire running above it. Two weeks after transplanting, the plants were tied to the wires above using

sisal twine around the stems to support their upward growth. Once the stems reached the wires above, they were untied and lowered as far as they could go without the fruit touching the ground. All parts were moved forward in a clockwise direction and then tied to the wire above to give the plants more room for future vertical growth. This was done regularly every 2-3 weeks.

### **3.6.2 Pruning**

All lateral shoots were pruned to avoid overcrowding. The smaller fruits on a cluster were also removed to allow the remaining tomatoes to obtain the desired, marketable size. The lower leaves were harvested so as to improve ventilation in the canopy.

### **3.6.3 Irrigation**

Irrigation was carried out in the open field and the frequency was determined by the prevailing weather conditions. On hot sunny days the crops were irrigated at least twice a day (morning and late afternoon) while on cool days one irrigation in the late afternoon was sufficient. In the high tunnel, drip irrigation was used (Plate 3.5). On hot sunny days the plants were given at least 2 hours of drip irrigation per day but on normal days 1 hour of drip irrigation in late afternoon was normally sufficient.



**Plate 3.5 Drip irrigation system in high tunnel**

#### **3.6.4 Nutrition**

Two weeks after transplanting, top dressing of the beds with Calcium, Ammonium Nitrate fertilizer (CAN ) was carried out after every two weeks (two split application). The fertilizer was applied at a rate of 20 grams per plant and irrigation was then carried out. Monthly applications of Nitrogen: Phosphorous: Potassium compound fertilizer (NPK triple 17) was carried out when the plants were one and a half months old. Synergizer foliar feed was also applied biweekly during flowering period to help in flowering and fruiting.

#### **3.6.5 Pest and disease management**

Assessment of the abundance of insect pests was carried out fortnightly. Only when the insect population was found to be high after sampling, was chemical

control carried out. This was done approximately twice a month. The pesticides used for the control of *A. gossypii*, *B. tabaci* and *L. trifolii* was Agrinate® which is broad spectrum and was used, while Confidor® was most effective for the control of *F. occidentalis*.

### **3.7 Data collection method**

Identification of insect pests attacking tomatoes in the two production systems was carried out. Assessment of the abundance of the pests attacking tomatoes in the two production systems was carried out fortnightly.

#### **3.7.1 Identification of species of insect pests infesting tomatoes grown in high tunnel and open field**

Two weeks after transplanting, identification of the species of insect pests that infested tomato plants grown in high tunnel and open field was done. Specimens of insect pests attacking tomatoes in high tunnel and open field were collected in special specimen vials and taken to the Entomology laboratory at KARI Thika where identification using binocular microscopes and taxonomic keys was carried out.

#### **3.7.2 Determination of abundance of insect pests infesting tomatoes grown in high tunnel and in open field**

The determination of the number of the insect pests infesting tomato plants in the high tunnels and open fields was also carried out fortnightly (Plate 3.6).

For treatment and replicate, all the six plants were selected for assessing the abundance of insect pests. For *B. tabaci*, *F. occidentalis*, and *A. gossypii*, counting the number of insect pests species in 6 leaves (two from the bottom, two from the middle and two from upper region of the tomato plant) in all the plants was carried out. For the *L. trifolii*, the number of mines on the six leaves per plant was also obtained (Plate 3.6).



**Plate 3.6 Sampling insect pests on tomato plants in high tunnel**

### **3.7.3 Assessment of yields of tomatoes grown in high tunnel and open field**

When the tomato fruits became mature and started to ripen, harvesting in each plot per variety commenced (Plate 3.7). Fruits from each of the three tomato varieties were harvested separately and sorted out into marketable and non-marketable ones (Plate 3.8). The fruits were graded based on Canadian Food

Inspection Agency (2002) for acceptable size, shape and freedom from defects. All the tomatoes harvested per variety were weighed to get the total weight of harvested tomatoes which was expressed in kilograms per plot (Plate 3.8). After sorting out, all marketable and non-marketable tomatoes were weighed each separately to obtain the marketable fruit weight and non-marketable fruit weights, respectively (Plate 3.8).



**Plate 3.7 Harvesting ripe tomatoes in high tunnel**



**Plate 3.8 Sorting and weighing tomatoes harvested in high tunnel**

### **3.8 Data analysis**

The species of different insect pests identified in the two production systems were documented and presented in a tabular form. The data on the abundance of insect pests and yields of the three tomato varieties was subjected to Analysis of Variance (ANOVA) using general linear model (GLM) procedure of SAS (SAS, 2008). The significance level was set at  $p=0.05$ . The means were separated using the Student-Newman-Keuls (SNK). The data on the yields for the two production systems, and the yields in the two cropping seasons was subjected to a paired sample t-test.

## CHAPTER FOUR

### RESULTS

#### **4.1 Identification of species of insect pests infesting tomatoes grown in high tunnel and open field in cropping season one and two**

In cropping season one, four species of insect pests namely *A. gossypii*, *B. tabaci*, *F. occidentalis* and *L. trifolii* were recorded infesting the three tomato varieties grown in the open field (Table 4.1; Plates 4.1- 4.4). In contrast, three insect species namely *B. tabaci*, *F. occidentalis* and *L. trifolii* were recorded infesting the three tomato varieties grown in the high tunnel.

In the second cropping season, two insect pest species namely *B. tabaci* and *L. trifolii* were recorded infesting the three tomato varieties grown both in the high tunnel and in the open field (Table 1). *A. gossypii* and *F. occidentalis* were not recorded infesting the three tomato varieties grown both in the high tunnel and in the open field in this cropping season.

**Table 4.1 Insect pest species identified on three tomato varieties in high tunnel and open field in season 1 and 2**

INSECT PESTS		Season 1		Season 2	
Common name	Scientific name	High tunnel	Open field	High tunnel	Open field
Cotton aphids	<i>Aphis gossypii</i>	0	+	0	0
Tobacco whiteflies	<i>Bemisia tabaci</i>	+	+	+	+
Western flower thrips	<i>Frankliniella occidentalis</i>	+	+	0	0
Leaf miners	<i>Liriomyza trifolii</i>	+	+	+	+

Key

+ = Present

0 = Absent



**Plate 4.1 Adult *B. tabaci* collected in high tunnel**



**Plate 4.2 Adult *F. occidentalis* Collected from open field**



**Plate 4.3 Adult *L. trifolii* collected in open field**



**Plate 4.4 *A. gossypii* on a tomato leaf in open field**

#### **4.2 Abundance of insect pests on tomatoes grown in high tunnel and open field in season one and two**

The abundance of insect pests infesting tomatoes grown in high tunnel and open field in the two cropping seasons was determined.

##### **4.2.1 Abundance of insect pests infesting tomatoes grown in high tunnel and open field in season one**

There were no significant differences in the mean numbers of *F. occidentalis* and *B. tabaci* recorded infesting the three tomato varieties grown in the high tunnel in this cropping season ( $F=0.958$ ,  $p=0.0852$ ) (Table 4.2). There were no significant

differences in the mean numbers of *L. trifolii* mines recorded on the leaves of the three tomato varieties grown in the high tunnel in this cropping season ( $F = 0.958$ ,  $p = 0.0852$ ) (Table 4.2). *A. gossypii* was not recorded infesting tomatoes grown in high tunnel in this season. Similarly, there were no significant differences in the mean numbers of *F. occidentalis*, *B. tabaci* and *A. gossypii*, and the mean numbers of *L. trifolii* mines recorded on the three tomato varieties grown in the open field in this cropping season ( $F=0.958$ ,  $p=0.0852$ ) (Table 4.2).

The mean numbers of *B. tabaci*, *F. occidentalis*, and *A. gossypii* were significantly higher on tomatoes grown in open field than in high tunnel in this cropping season ( $t=8.23$ ,  $p=0.0001$ ;  $t=2.59$ ,  $p=0.011$ ;  $t=8.40$ ,  $p=0.0001$ , respectively). Likewise, the mean numbers of *L. trifolii* mines were significantly higher on the leaves of tomato plants grown in open field compared to those grown in high tunnel ( $t=8.42$ ,  $p=0.0001$ ) (Table 4.2).

**Table 4.2 Mean numbers ( $\pm$ SE) of insect pests/mines recorded on three tomato varieties in high tunnel and open field in cropping season one**

		Production system	
Insect pest	Tomato variety	High tunnel (no/leaf)	Open field (no/leaf)
<i>F. occidentalis</i>	Non-grafted Onyx	1.24 $\pm$ 0.07aB	2.09 $\pm$ 0.54aA
	Grafted onyx	1.38 $\pm$ 0.08aB	1.98 $\pm$ 0.54aA
	Anna F1	1.15 $\pm$ 0.07aB	2.10 $\pm$ 0.54aA
<i>B. tabaci</i>	Non-grafted Onyx	2.34 $\pm$ 0.53aB	6.36 $\pm$ 1.24aA
	Grafted onyx	1.97 $\pm$ 0.53aB	7.20 $\pm$ 1.24aA
	Anna F1	2.16 $\pm$ 0.53aB	7.43 $\pm$ 1.24aA
<i>A. gossypii</i>	Non-grafted Onyx	0aB	5.75 $\pm$ 1.18aA
	Grafted onyx	0aB	5.62 $\pm$ 1.18aA
	Anna F1	0aB	5.60 $\pm$ 1.18aA
<i>L. trifolii</i>	Non-grafted Onyx	0.18 $\pm$ 0.07aB	0.57 $\pm$ 0.09aA
	Grafted onyx	0.15 $\pm$ 0.08aB	0.59 $\pm$ 0.09aA
	Anna F1	0.25 $\pm$ 0.07aB	0.63 $\pm$ 0.09aA

Means denoted by same lower case letters within each blocked column are not significantly different at P= 0.05

Means denoted by the same upper case letters within each row are not significantly different at P=0.05

#### **4.2.2 Abundance of insect pests infesting tomatoes grown in high tunnel and open field in season two**

There were significant differences in the mean numbers of *B. tabaci* recorded infesting the three tomato varieties grown in the high tunnel in this cropping season (F=7.1, p=0.001) (Table 4.3). The mean numbers of *B. tabaci* recorded on grafted Onyx and Anna F1 showed no significant differences but were significantly higher than those recorded on the non-grafted Onyx tomato variety.

There were however, no significant differences in the mean numbers of *L. trifolii*

mines recorded on the leaves of the three tomato varieties grown in the high tunnel in this cropping season ( $F=2.3$ ,  $p=0.103$ ).

There were significant differences in the mean numbers of *B. tabaci* infesting the three tomato varieties grown in the open field in this cropping season ( $F=7.1$ ,  $P=0.001$ ) (Table 4.3). The highest mean number of *B. tabaci* was recorded on Anna F1 tomato variety and was significantly higher than the mean number recorded on grafted Onyx, but was not significantly different from the mean number recorded on non-grafted Onyx variety. There were however, no significant differences in the mean numbers of *L. trifolii* mines recorded on the leaves of the three tomato varieties grown in the open field in this cropping season ( $F=0.46$ ,  $p=0.103$ ) (Table 4.3).

There were significant differences in the mean numbers of *B. tabaci* recorded infesting the tomato varieties grown in the high tunnel and those grown in open field in this season. The mean number of *B. tabaci* was significantly higher in the tomato varieties grown in the open field compared to those grown in the high tunnel. ( $t=4.31$ ,  $p=0.0001$ ). There were however, no significant differences in the mean numbers of *L. trifolii* mines recorded on the leaves of the tomato varieties grown in the high tunnel and those grown in open field in this cropping season ( $t=1.63$ ,  $p=0.107$ ) (Table 4.3).

**Table 4.3 Mean numbers ( $\pm$ SE) of insect pests/mines recorded on three tomato varieties in high tunnel and open field in cropping season two**

Insect pest	Tomato variety	Production system	
		High tunnel (no/leaf)	Open field (no/leaf)
<i>B. tabaci</i>	Non-grafted Onyx	1.88 $\pm$ 0.39bB	5.00 $\pm$ 1.00abA
	Grafted onyx	3.78 $\pm$ 0.39aA	3.19 $\pm$ 1.00bA
	AnnaF1	3.59 $\pm$ 0.39aB	9.06 $\pm$ 1.00aA
<i>L. trifolii</i>	Non-grafted Onyx	0.06 $\pm$ 0.07bA	0.14 $\pm$ 0.07bA
	Grafted onyx	0.09 $\pm$ 0.07bA	0.19 $\pm$ 0.07bA
	AnnaF1	0.25 $\pm$ 0.07bA	0.21 $\pm$ 0.07bA

Means denoted by same lower case letters within each blocked column are not significantly different at P=0.05

Means denoted by same upper case letters within each row are not significantly different at P=0.05

#### **4.2.3 Variations in infestation rates on tomato plants in successive weeks in cropping season one**

There were significant differences in the abundance of insect pests recorded infesting tomatoes in high tunnel and open field in different sampling weeks in season one cropping season.

##### **4.2.3.1 Variations in infestation rates on tomato plants in high tunnel**

There were significant differences in the mean numbers of *F. occidentalis* recorded in different weeks, with week 3 (7.24 $\pm$ 0.64) recording the highest mean

number ( $F=15.2$ ,  $p=0.0001$ ) (Table 4.4). The mean numbers of *B. tabaci* were significantly higher in week 7 ( $7.24\pm 0.57$ ) compared to those recorded in the other weeks. ( $F = 18.4$ ,  $p = 0.0001$ ) (Table 4.4).

The mean numbers of *L. trifolii* mines were significantly higher in week 6 ( $0.89\pm 0.06$ ) compared to those recorded in the other weeks ( $F = 40.7$ ,  $p = 0.0001$ ; Table 4.4). There were no *A. gossypii* recorded infesting tomato plants grown in the high tunnel in this cropping season.

**Table 4.4: Mean numbers ( $\pm$ SE) of insect pests/mines recorded on tomato plants in successive weeks in high tunnel in cropping season one**

Sampling week	<i>F. occidentalis</i>	<i>B. tabaci</i>	<i>L. trifolii</i>
1	0b	$0.13 \pm 0.57c$	0c
2	$0.44 \pm 0.64b$	$0.25 \pm 0.57c$	0c
3	$7.24 \pm 0.64a$	$2.12 \pm 0.57c$	0c
4	0b	$0.27 \pm 0.57c$	0c
5	$0.48 \pm 0.64b$	$1.31 \pm 0.57c$	$0.58 \pm 0.06b$
6	$1.91 \pm 0.64b$	$2.00 \pm 0.57c$	$0.89 \pm 0.06a$
7	0b	$7.24 \pm 0.57a$	0c
8	0b	$3.99 \pm 0.57b$	0c
F-value	15.2	18.4	40.7
P-value	0.0001	0.0001	0.0001

NB: Mean values denoted by similar letters in the same column are not significantly different at  $P= 0.05$

#### 4.2.3.2 Variations in infestation rates on tomato plants in the open field

There were significant differences in the mean number of *F. occidentalis* recorded in different weeks, with the highest recorded on week 3 ( $8.17 \pm 0.27$ ) ( $F=133.7$ ,  $p=0.0001$ ) (Table 4.5). The highest mean number of *B. tabaci* was recorded in week 7 ( $20.08 \pm 0.98$ ) and was significantly higher compared to those recorded in the other weeks ( $F=44.6$ ,  $p=0.0001$ ) (Table 4.5). There were significant differences in the mean number of *L. trifolii* mines in different weeks ( $F = 303.3$ ,  $p= 0.0001$ ) (Table 4.5). The highest mean number of *A. gossypii* was recorded in week 3 ( $10.69 \pm 0.77$ ) and was significantly higher than the means recorded in other weeks ( $F=70.6$ ,  $p=0.0001$ ) (Table 4.5).

**Table 4.5: Mean numbers ( $\pm$ SE) of insect pests/mines recorded on tomato plants in successive weeks in open field in cropping season one**

Sampling week	<i>F. occidentalis</i>	<i>B. tabaci</i>	<i>A. gossypii</i>	<i>L. trifolii</i>
1	0c	0e	0d	0b
2	0c	$2.96 \pm 0.98d$	0d	$0.92 \pm 0.03a$
3	$8.17 \pm 0.27a$	$12.08 \pm 0.98b$	$19.42 \pm 0.77a$	$1.00 \pm 0.03a$
4	$3.79 \pm 0.27b$	$2.14 \pm 0.98d$	$10.69 \pm 0.77b$	$0.90 \pm 0.03a$
5	$4.52 \pm 0.27b$	$8.78 \pm 0.98c$	$3.60 \pm 0.77c$	$1.00 \pm 0.03a$
6	0c	$5.94 \pm 0.98c$	$3.88 \pm 0.77c$	$0.96 \pm 0.03a$
7	0c	$20.08 \pm 0.98a$	$3.90 \pm 0.77c$	0b
8	0c	$4.0 \pm 0.98cd$	$3.77 \pm 0.77c$	0b
F – value	133.7	44.6	70.6	303.3
P – value	0.0001	0.0001	0.0001	0.0001

Means denoted by similar letters in the same column are not significantly different at  $P=0.05$

#### 4.2.4 Variations in infestation rates on tomato plants in successive weeks in cropping season two

There were significant differences in the abundance of insect pests recorded infesting tomatoes grow in high tunnel and open field in different sampling weeks.

##### 4.2.4.1 Variations in infestation rates on tomato plants in the high tunnel

There were significant differences in the mean numbers of *B. tabaci* recorded on different weeks, with week 1 and 4 ( $4.65 \pm 0.52$  and  $5.31 \pm 0.52$ , respectively) recording the highest means than those recorded in the other weeks ( $F=8.5$ ,  $p=0.0001$ ) (Table 4.6). The highest mean number of *L. trifolii* mines was recorded in week 1 ( $0.88 \pm 0.08$ ) and was significantly higher than the mean numbers recorded in the other weeks ( $F=18.9$ ,  $P=0.0001$ ) (Table 4.6).

**Table 4.6: Mean numbers ( $\pm$ SE) of insect pests/mines recorded on tomato plants in successive weeks in high tunnel in cropping season two**

Sampling week	<i>B. tabaci</i>	<i>L. trifolii</i>
1	$4.65 \pm 0.52a$	$0.88 \pm 0.08a$
2	$2.60 \pm 0.52bc$	$0.04 \pm 0.08b$
3	$0.92 \pm 0.52c$	$0.02 \pm 0.08b$
4	$5.31 \pm 0.52a$	0.00c
5	$2.04 \pm 0.52bc$	0.00c
6	$3.42 \pm 0.52b$	0.00c
7	$2.65 \pm 0.52bc$	0.00c
F – value	8.5	18.9
P – value	0.0001	0.0001

Mean denoted by same letter in the same column are not significantly different at  $P=0.05$ .

#### 4.1.4.2 Variations in infestation rates on tomato plants in the open field.

There were significant differences of mean numbers of *B. tabaci* recorded in different weeks, with the highest recorded on week 2 and 4 ( $10.46 \pm 1.41$  and  $10.88 \pm 1.41$  respectively) ( $F=9.0$ ,  $p=0.0001$ ) (Table 4.7). The highest mean numbers of *L. trifolii* mines was recorded in week 1 ( $1.06 \pm 0.06$ ) and was significantly higher than the mean numbers recorded in the other weeks ( $F=41.3$ ,  $P=0.0001$ ) (Table 4.7).

**Table 4.7: Mean numbers ( $\pm$ SE) of insect pests/mines recorded on tomato plants in successive weeks in open field in cropping season two**

Sampling week	<i>B. tabaci</i>	<i>L. trifolii</i>
1	$5.98 \pm 1.41b$	$1.06 \pm 0.06a$
2	$10.46 \pm 1.41a$	$0.09 \pm 0.06b$
3	$5.36 \pm 1.41b$	$0.11 \pm 0.06b$
4	$10.88 \pm 1.41a$	0.00b
5	$3.02 \pm 1.41b$	0.00b
6	$2.45 \pm 1.41b$	0.00b
7	$2.10 \pm 1.41b$	0.00b
F – value	9.0	41.3
P – value	0.0001	0.0001

Mean denoted by same letter in the same column are not significantly different at  $P=0.05$ .

### **4.3 Comparison of yields of tomato plants grown in high tunnel and in open field**

There were significant differences in the mean total and mean marketable fruit weights of tomatoes harvested in high tunnel and those harvested in open field in cropping season one and two.

#### **4.3.1 Mean total and marketable fruit weight of tomatoes harvested in high tunnel and open field**

Results from cropping season one showed that the mean total fruit weight of tomatoes harvested from the open field ( $1.282 \pm 0.086 \text{Kg}$ ) was significantly lower than the mean total fruit weight of tomatoes harvested from the high tunnel ( $1.761 \pm 0.168 \text{Kg}$ ) ( $t=2.93$ ,  $P=0.0001$ ) (Table 4.8). There were also significant differences in the mean marketable fruit weight of tomatoes harvested from the two production systems ( $t=4.72$ ,  $p=0.0001$ ). The mean marketable fruit weight was lower for tomatoes harvested from the open field ( $0.887 \pm 0.066 \text{Kg}$ ) than for those harvested from the high tunnel ( $1.631 \pm 0.162 \text{Kg}$ ) (Table 4.8). Therefore the high tunnel recorded higher means for total fruit weight and marketable fruit weight than the open field.

Results for cropping season two showed that there were no significant differences in the mean total fruit weight of tomatoes harvested from the open field ( $0.208 \pm 0.023 \text{Kg}$ ) and those harvested from the high tunnel ( $0.266 \pm 0.020 \text{Kg}$ ,

$t=1.86$ ,  $P=0.066$ ) (Table 4.8). There were, however, significant differences in the mean marketable fruit weight of tomatoes harvested from the open field and those harvested from the high tunnel ( $t=2.64$ ,  $P=0.010$ ). The mean marketable fruit weight was significantly higher in tomatoes harvested from the high tunnel ( $0.227\pm 0.017\text{Kg}$ ) compared to those harvested from the open field ( $0.159\pm 0.020\text{Kg}$ ) (Table 4.8).

**Table 4.8 Mean weights ( $\pm$ SE) of total fruits and marketable fruits of tomatoes harvested in high tunnel and open field in cropping season one and two**

Season	Mean weights (Kg/plot)	High tunnel	Open field	T	P
1	Total fruits	1.761 $\pm$ 0.168a	1.282 $\pm$ 0.086b	2.93	0.0001
	Marketable fruits	1.631 $\pm$ 0.162a	0.887 $\pm$ 0.066b	4.72	0.0001
2	Total fruits	0.266 $\pm$ 0.020a	0.208 $\pm$ 0.023a	1.86	0.066
	Marketable fruits	0.227 $\pm$ 0.017a	0.159 $\pm$ 0.020b	2.64	0.010

Means denoted by same letter in the same row are not significantly different at  $P=0.05$

#### **4.3.2 Mean total and marketable weights of fruits harvested from the three tomato varieties grown in high tunnel and open field**

There were significant differences in the mean total fruit weight of tomatoes harvested from the three tomato varieties in high tunnel in season one ( $F=40.82$ ;  $P=0.0001$ ). The highest mean total fruit weight was recorded from Anna F1

(2.898±0.250), followed by non-grafted Onyx (2.088±0.206). The lowest was recorded from grafted Onyx (1.088±0.121).

There were significant differences in the mean total fruit weights of tomatoes harvested from the three tomato varieties in open field in season one (F=40.80; P=0.0001) (Table 4.9). The highest mean total fruit weight was recorded on Anna F1 and non-grafted Onyx while the lowest was recorded on grafted Onyx. There were significant differences in the mean total fruit weight of tomatoes harvested from the three tomato varieties in the high tunnel and open field. In the high tunnel, the three tomato varieties recorded a significantly higher mean total fruit weight than those obtained from the same varieties in open field (t=6.03, p=0.0001; t=6.76, p=0.0001 and t=3.13; p=0.005 respectively) (Table 4.9).

**Table 4.9 Mean ( $\pm$  SE) total fruit weight for the three tomato varieties harvested in high tunnel and open field**

Treatment	Production system	
	High tunnel	Open field
Non-grafted Onyx	2.088±0.206bA	1.435±0.185aB
Grafted Onyx	1.088±0.121cA	0.301±0.0541bB
Anna F1	2.898±0.250aA	1.323±0.130aB

Means denoted by the same lower case letters in the same column are not significantly different at p=0.05

Means denoted by the same upper case letters within the same row are no significantly different at p=0.05

There were significant differences in the mean marketable fruit weight of the tomato varieties grown in the high tunnel in season one. The highest mean marketable fruit weight was recorded from Anna F1 ( $2.696 \pm 0.262$ ) and was significantly higher than those recorded on non-grafted Onyx ( $1.928 \pm 0.194$ ) and grafted Onyx ( $0.807 \pm 0.105$ ). In the open field, the highest mean marketable fruit weight was recorded from Anna F1 ( $0.970 \pm 0.102$ ) and non-grafted Onyx ( $0.884 \pm 0.135$ ) and was significantly higher than mean recorded on grafted Onyx ( $0.271 \pm 0.048$ ) ( $F=42.51$ ;  $p=0.0001$ ).

There were significant differences in the mean marketable fruit weights of tomatoes harvested from the three tomato varieties harvested in high tunnel and open field. High tunnel recorded higher mean marketable fruit weight for the three tomato varieties than those recorded for the same varieties in open field ( $t=6.69$ ,  $p=0.0001$ ;  $t=5.52$ ,  $p=0.0001$  and  $t=5.54$ ;  $p=0.0001$  respectively) (Table 4.10).

**Table 4.10 Mean ( $\pm$  SE) marketable fruit weight for the three tomato varieties harvested in high tunnel and open field in season one**

Treatment	Production system	
	High tunnel	Open field
Non-grafted Onyx	1.928 $\pm$ 0.194bA	0.884 $\pm$ 0.135aB
Grafted Onyx	0.807 $\pm$ 0.105cA	0.271 $\pm$ 0.048bB
Anna F1	2.696 $\pm$ 0.262aA	0.970 $\pm$ 0.102aB

Means denoted by the same lower case letters within the column are not significantly different at  $p=0.05$

Means denoted by the same upper case letters within the same row are not significantly different at  $p=0.05$

There were no significant differences in the mean total weight of fruits harvested from the three tomato varieties grown in high tunnel in season two ( $F=0.98$ ;  $p=0.384$ ). The mean total fruit weights of tomatoes harvested from the three tomato varieties grown in open field in cropping season two were significantly different ( $F=39.40$ ;  $P=0.0001$ ). Anna F1 recorded the highest mean total fruit weight ( $0.346\pm 0.022$ ) followed by grafted Onyx ( $0.241\pm 0.032$ ) and non-grafted Onyx ( $0.038\pm 0.020$ ).

There were significant differences in the mean total weight of fruits from the three tomato varieties harvested from high tunnel and open field in season two ( $t=6.29$ ;  $p=0.0001$ ). Non-grafted Onyx from the high tunnel recorded higher mean total

fruit weight than that recorded by the same variety in open field. There were however, no significant differences in the mean total fruit weights of tomatoes harvested from Anna F1 and grafted Onyx tomato varieties harvested in open field and high tunnel in cropping season two ( $t=0.95$ ,  $p=0.352$ ;  $t=0.71$ ,  $p=0.482$  respectively) (Table 4.11).

**Table 4.11 Mean ( $\pm$  SE) total fruit weight for the three tomato varieties harvested in high tunnel and open field in season two**

	Production system	
Treatment	High tunnel	Open field
Non-grafted Onyx	0.228 $\pm$ 0.024aA	0.038 $\pm$ 0.020cB
Grafted Onyx	0.255 $\pm$ 0.028aA	0.241 $\pm$ 0.032bA
Anna F1	0.312 $\pm$ 0.046aA	0.346 $\pm$ 0.022aA

Means denoted by the same lower case letters within the column are not significantly different at  $p=0.05$

Means denoted by the same upper case letters within the same row are not significantly different at  $p=0.05$

There were no significant difference in the mean marketable fruit weight of tomatoes harvested from the three tomato varieties in high tunnel ( $F=0.50$ ;  $p=0.609$ ) (Table 4.12). However, there were significant differences in the mean marketable fruit weight of tomatoes harvested from the three tomato varieties in open field ( $F=15.79$ ;  $p=0.0001$ ). Anna F1 (0.258 $\pm$ 0.027) recorded the highest

mean followed by grafted Onyx ( $0.184 \pm 0.030$ ). Non-grafted Onyx ( $0.035 \pm 0.018$ ) recorded the lowest mean.

There were significant differences in the mean marketable fruit weight of tomatoes harvested from the three tomato varieties grown in high tunnel and open field in season two ( $t=5.54$ ;  $p=0.0001$ ). Non-grafted Onyx tomato variety in high tunnel recorded a significantly higher mean marketable fruit weight than those recorded on the same variety in open field (Table 4.12). There were however no significant differences in the mean marketable fruit weights of tomatoes harvested from Anna F1 and grafted Onyx in high tunnel and open field ( $t=0.42$ ,  $p=0.680$ ;  $t=1.24$ ,  $p=0.224$ , respectively) (Table 4.12).

**Table 4.12 Mean ( $\pm$  SE) marketable fruit weights for the three tomato varieties harvested in high tunnel and open field in season two**

Treatment	Production system	
	High tunnel	Open field
Non-grafted Onyx	$0.205 \pm 0.024$ aA	$0.035 \pm 0.018$ cB
Grafted Onyx	$0.217 \pm 0.024$ aA	$0.184 \pm 0.030$ bA
Anna F1	$0.258 \pm 0.036$ aA	$0.258 \pm 0.022$ aA

Means denoted by the same lower case letters within the same se column are not significantly different at  $p=0.05$

Means denoted by the same upper case letters within the same row are not significantly different at  $p=0.05$

### 4.3.3 Comparison of mean total and marketable fruit weight of tomatoes harvested in cropping season one and two

The total fruit weights and marketable fruit weights of tomatoes harvested in the two cropping seasons showed significant differences (Table. 4.13). The mean total fruit weight recorded in the high tunnel was significantly higher in cropping season one compared to cropping season two ( $t=8.84$ ,  $p=0.005$ ). Likewise, the mean total fruit weight recorded in open field was significantly higher in cropping season one compared to cropping season two ( $t=12.05$ ,  $P=0.005$ ). The mean marketable fruit weight recorded in high tunnel was significantly higher in cropping season one compared to marketable fruit cropping season two ( $t=8.64$ ,  $p=0.005$ ) (Table 4.13). Likewise, the mean marketable fruit weight recorded in open field was significantly higher in cropping season one compared to cropping season two ( $t=10.58$ ,  $P=0.005$ )

**Table 4.13 Mean ( $\pm$ SE) total and marketable fruit weights of tomatoes in cropping season one and two**

Production system	Mean weight	Season one	Season two	T	P
High tunnel	Total fruits	1.761 $\pm$ 0.168a	0.266 $\pm$ 0.020b	8.84	0.005
	Marketable fruits	1.631 $\pm$ 0.162a	0.227 $\pm$ 0.017b	8.64	0.005
Open field	Total fruits	1.282 $\pm$ 0.086a	0.208 $\pm$ 0.023b	12.05	0.005
	Marketable fruits	0.887 $\pm$ 0.066a	0.159 $\pm$ 0.020b	10.58	0.005

Means denoted by the same letter in the same row are not significantly different at  $p=0.05$

## CHAPTER FIVE

### DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Discussion

Insect pest species that infested tomato plants grown both in high tunnel and in open field in cropping season one in Mwea region of Kirinyaga County were identified. In cropping season one, three species namely *Bemisia tabaci*, *Frankliniella occidentalis* and *Liriomyza trifolii* infested tomatoes grown in the high tunnel while in the open field four species were found and these were, *Bemisia tabaci*, *Frankliniella occidentalis*, *Liriomyza trifolii* and *Aphis gossypii*. *A. gossypii* was not recorded on tomatoes grown in the high tunnel. According to a baseline survey on tomato production carried out in Kirinyaga County by Waiganjo *et al.* (2006), the above named four insect pest species were among the common insect pests of tomato plants in the region.

The absence of *A. gossypii* in the high tunnel could be attributed to their sedentary life. It has been reported that even the winged adults spend a considerable period of their life unable to fly (Helmut and Harrington, 1998), and even if they drifted with the wind (Loxdale *et al.*, 1993; Brown *et al.*, 1995), they could not get access to the enclosed environment of a high tunnel (Jett, 2006). *B. tabaci*, *F. occidentalis* and *L. trifolii* are active fliers and are therefore able to enter into the high tunnel from the outdoors if they get access.

In cropping season two, only two species of insect pests namely, *B. tabaci* and *L. trifolii*, infested tomato plants grown both in the high tunnel and in the open field. *F. occidentalis* and *A. gossypii* were not recorded infesting tomato plants grown both in the high tunnel and in the open field in this cropping season. The absence of *F. occidentalis* and *A. gossypii* in cropping season two could be attributed to the heavy rains experienced in the months of October and November, 2010, which could have killed these pests. These results agree with finding by Harding (1961), Etienne *et al.* (1990), Nakata (1995) and Kajita *et al.* (1996) who reported that high rainfall is considered an important cause of mortality for these two insect pests especially in the open field. The same authors reported that rain washes nymphs and adult of these pests from the plant leaves causing sudden sharp decline in their population densities (Harris *et al.*, 1936). The absence of *F. occidentalis* and *A. gossypii* in the open field may explain their absence in the high tunnels as the source of most high tunnel insect pests is usually from the outside environment (Lamont *et al.*, 2003).

*B. tabaci* and *L. trifolii* infested tomato plants in high tunnel and open field in the two cropping seasons. The presence of *B. tabaci* and *L. trifolii* in cropping season two could be due to the short period between the two cropping seasons. Harvesting for season one ended in September 2010 and planting for season two commenced in January 2011. This short period may not have been sufficient to

break the pest cycle of these insect pests. This is in agreement with the findings by Chapman and Carter (1976) and Otto (2001) who reported that continuous growing of the same crop in the same area, a practice called mono-cropping is usually associated with proliferation of insect pests.

The abundance of insect pests that infested tomato plants during the two cropping seasons revealed that more insect pests attacked tomato plants grown in the open field compared to those grown in the high tunnel. This concurs with the findings by Mohammed (2006) and USAID-KHDP (2007), who reported that high tunnel tomato production leads to reduced pest and disease incidences especially if the hygienic conditions in the high tunnels are strictly observed. Further, Lamont *et al.* (2003) and Jett (2003) reported that high tunnels act as barriers to insect pests thus protecting crops from pest infestation. It also has been reported that the purpose of growing crops under high tunnel conditions is to extend their cropping season and to protect them from adverse conditions such as extreme temperatures and precipitation, and from diseases and pests (Hanan *et al.*, 1978; Hodges and Brandle, 1996). Waterer (2003) and Jett *et al.* (2004) also reported that high tunnels are very effective in reducing pest outbreaks that routinely occur in the open field environment. This was further supported by Raviv and Antgnus, (2004); Espi *et al.* (2006) and Diaz and Fereres (2007) who reported that the Photo-selective polyethylene films covering high tunnels absorb or reflect specific

wavelength of light and that these films can suppress disease or insect pest growth or behavior. The same authors reported that UV absorbing films have the potential to suppress *A. gossypii*, *F. occidentalis* and *L. trifolii* populations by influencing their host locating behavior.

Insect pests were not only found attacking tomato plants grown in the open field but also tomato plants in high tunnel. This implies that high tunnels did not completely exclude insect pests from getting into them. The high tunnels were ventilated by opening the door especially in the hot afternoons, this could have let in flying insect pests from the outside environment. This is in agreement with findings by Lamont *et al.* (2002) and Lamont *et al.* (2003) who reported that the presence of insect pests in the high tunnel could be attributed to the fact that high tunnels are manually ventilated by rolling up the sidewalls and opening the door fully or partially to lower the inside temperatures. Insect screening has been developed for green house industry with specific mesh sizes which allow ventilation while excluding insects. However, these materials are expensive and may not be economical for low technology and low cost tunnels (OFRF, 2007).

The mean total fruit weights for cropping season one were significantly higher for tomatoes harvested from the high tunnel compared to those from the open field. These results were in agreement with the findings by Wells and Loy (1993),

Wells (1996) and Hochmuth *et al.* (1998) who reported a significant yield enhancement of tomatoes by growing them in high tunnels. This is also in agreement with the findings of Jett and Read (2003) who reported that many horticultural crops grown in the high tunnels show early maturity and quality yields which usually exceeds field grown crops of the same cultivar.

The mean marketable fruit weights in the two cropping seasons were significantly higher for tomatoes harvested from the high tunnels than those harvested from the open fields. Therefore, growing of tomatoes in high tunnels not only increased the mean fruit weights but also produced fruits of higher quality. These results concur with the findings by Jett (2009), who reported that tomatoes grown in high tunnels had higher marketable yields. The same author reported that high tunnels protected the growing crop from environmental extremes such as wind, rain, hail, insects and diseases which led to significantly higher marketable yields. Wells and Loy (1993) and Wells (2000), stated that high tunnels had considerable potential for year round production as well as significantly improving crop yields and quality relative to the open field during normal growing season, by providing favorable growing conditions. The high tunnel production system that registered lower pest numbers had higher means for fruit weight and marketable fruit weight. This concurred with findings by Jett *et al.* (2004) who reported that high

tunnels protected crops from insects and disease invasion that could lower their marketable yields.

The mean total and marketable fruit weights in high tunnel and open field in cropping season two were generally low compared to those of cropping season one. The timing of cropping season two coincided with very harsh climatic conditions in January to March, 2011. This period was generally very hot and dry leading to reduced tomato production. Waterer (2003), reported that high temperatures could lead to heat stress both in the field grown crops and those grown in the high tunnels thus affecting crop yield. The only ventilation on the high tunnel was by opening the door and this was probably not sufficient to reduce the heat build-up within the high tunnel.

The tomato plants also required more frequent irrigation both in the high tunnel and in open field. This was, however, not achieved as the farmers were facing water rationing and could not irrigate as often as was required. This irregular irrigation practices could have contributed to generally low yields both in the high tunnel and open field as the highest demand for water is during flowering period. Waterer (2003) reported that prolonged water deficiency limited growth of tomato plants and reduced yield. It has also been reported that water shortage during fruiting may cause abscission of flowers or young fruits, resulting in insufficient

fruit for maximum yield. Gent (1992) stated that lack of proper ventilation in high tunnels lead to heat build- up and this resulted in reduced total and marketable fruit yields.

## 5.2 Conclusions

- a) The tomato plants grown both in high tunnel and open field were attacked by the same species of insect pests, namely *A. gossypii*, *L. trifolii*, *B. tabaci* and *F. occidentalis*. There were however seasonal differences in the number of species infesting tomato plants in high tunnel and open field. Cropping season one recorded more insect pest species compared to season two.
- b) High tunnel recorded a significantly lower mean number of insect pests compared with those recorded in open field.
- c) The mean total fruit weights and marketable fruit weights were significantly higher for tomatoes grown in the high tunnel compared with those grown in open field.
- d) The mean total fruit weight and marketable fruit weight were significantly lower in cropping season two compared with season one. This implies that if the environment inside the high tunnel is not well controlled then it may not offer yield advantage over the open field environment.

### 5.3 Recommendations

- a) There is the need for research institutes such as KARI to educate tomato farmers on the advantages of embracing high tunnel tomato production for higher quality and quantity tomatoes.
- b) There is need for small scale tomato farmers to adopt Anna F1 tomato variety for high tunnel production for it is more suited for high tunnels and is also a high yielder with a long shelf life.
- c) More research need to be carried out in all the major tomato growing areas to compare the abiotic factors such as temperature and relative humidity among other factors in the two production systems. This would help ascertain if these factors have any significant effects on plant growth, pest incidences as well as crop yield.

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**APPENDIX I****RANDOMIZATION AND LAYOUT OF TOMATO TRIALS****Experimental lay out**

Rep 1	Rep 2	Rep 3	Rep 4
TR 1	TR2	TR3	TR1
TR 3	TR1	TR 2	TR 3
TR 2	TR3	TR 1	TR2

**Key**

TR 1=non-grafted Onyx

TR 2=grafted Onyx

TR 3=Anna F 1