IDENTITY, ABUNDANCE AND MANAGEMENT OF BANANA THRIPS IN EMBU COUNTY, KENYA

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DECLARATION

I declare that this is my original work and has not been presented for any award of a degree in any other university

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To God whose favour and faithfulness has been with me this far. My lovely wife Rachel Ireri, whose love, unwavering support, patience and understanding has been felt throughout this time of study. My two beautiful daughters; Patience and Love for giving me every reason to work hard.

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LIST OF ABBREVIATIONS

CABI	-	Centre for Agricultural Bioscience International
EU	-	European Union
FAO	-	Food and Agricultural Organization
GDP	-	Gross Domestic Product
HCDA	-	Horticultural Crops Development Authority
ICIPE	-	International Centre of Insect Physiology and Ecology
IITA	-	International Institute of Tropical Agriculture
INIBAP	-	International Network for the Improvement of Banana and Plantain
KARI	-	Kenya Agricultural Research Institute
MOA	-	Ministry of Agriculture
NRCB	-	National Research Centre for Bananas
UK	-	United Kingdom
WFT	-	Western Flower Thrips

GENERAL ABSTRACT

Thrips continue to be one of the most important pests affecting agricultural production systems. They have become important pests of banana and the objective of this study was to determine the species composition and abundance, the qualitative losses attributed and evaluate the effect of different coloured polythene bags and plant extracts on management of banana thrips in Embu County. Three studies were conducted in three agro-ecological zones namely; Upper highland UM1, Mid highland UM2 and Lower highland UM3. Two thrips sampling surveys were done in two seasons in March 2013 and June 2014 to identify the species composition and abundance. In each zone, 10 farms were randomly selected and 10 male buds randomly picked and opened to collect the thrips. Collected thrips were then transferred into vials with 70 % ethanol then safely transported to the National Museums of Kenya entomology laboratory where they were identified to species level. Thirteen species were identified across the zones with the upper zone having the highest thrips populations. The most common species identified were *Frankliniella schultzei* (51.3 %), *Megalurothrips sjostedti* (27.9 %), *Haplothrips gowdeyi (*5.6 %), *Thrips spp* (5.2%) and *Frankliniella occidentalis* (3.5 %). To assess the qualitative losses a structured questionnaire was administered to 60 farmers, where 20 farmers were randomly selected in each zone. Thrips were the most important pests with 96.7 % of the farmers reporting damage by thrips on banana fingers. Forty percent of farmers perceived hot and dry season to be most severe infestation season. To evaluate the effectiveness of differently coloured polythene sleeves and plant extracts on management of banana thrips two field experiments were conducted. The first experiment was conducted to evaluate the effect of polythene bunch covers on thrips in banana. Four differently coloured bags which consisted of black, blue, yellow and clear against one control which was untreated. The second experiment was carried out to assess efficacy of different plant extracts against thrips in banana. The rates were Imidacloprid (Confidor®) at 5g/20l, neem leaves extract at 1000g/20l, Garlic bulb extract at 1000g / 20l and pepper at 500g/ 20l. In both experiments, treatment applications began at the flowering stage when thrips were expected to infest the male flower buds. All polythene bunch covers across the three zones had similar level of control. Black polythene resulted to scorching of bunches in lower and mid zones. Imidacloprid (Confidor®) had significantly ($P \leq 0.05$) higher efficacy on thrips compared to neem, pepper and garlic. Bunches sprayed with neem had significantly less scarification compared to garlic and pepper. Bunches sprayed with pepper had significantly ($P \leq 0.05$) higher damage compared to those treated with Imidacloprid (Confidor®), neem, and garlic. This shows that plant extracts have some effect on thrips albeit with varying levels thus they can be deployed as alternatives to thrips management for scarring control on banana and as a tool for insecticide resistance management. Banana farmers should be advised to apply the polythene sleeves and neem based products as alternatives to pesticides.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Banana is an important food crop and plays a major role in the diets of both rural and urban households and the economy of Kenya (Nguthi, 2007). It is rich in potassium, carbohydrates and Vitamin A providing more than 25% of the carbohydrate requirements for over 70 million people (IITA, 1998). The crop is a source of income for the majority of smallholder growers in Kenya (MOA, 2006). The year-round fruiting habit of the crop ensures food security at household level with a potential of sustaining food supply to urban markets especially in periods between cereal crop harvests. This potential coupled with the environmental conservation attributes of the plant makes banana an ideal crop for economic growth and sustainability of the agricultural resource base. The crop is the 5th most important tropical fruit after mango, pineapple, avocado and papaya and they are the fourth most important food crops in developing countries after rice, wheat and maize (Karamura, 2004). Banana has emerged as a major income earner and food item in most parts of the country. The crop is used for cooking and as dessert. It is the most affordable fruit both in rural and urban households and has gained popularity in Kenya with about 60% stalls in fresh markets stocking bananas (Technoserve, 2009). It plays a dual role as a staple food in the tropics and also as a table fruit sold both local and international markets (Karamura, 2004).

The area under banana and plantain cultivation in Kenya has continued to increase over the years (Technoserve, 2009) with key production areas being Central, Nyanza, Western and Eastern Provinces. Banana yield is still very low at 4.5-10 tons/ha compared to the potential of 30-40 tons/ha (Qaim, 1999). Pests and diseases are the main production constraints and can reduce yield of bananas by upto 100% depending on pathogen, while quality is also compromised (Jones, 2000). Thrips are among the main pests affecting banana production in Kenya. According to Mould (2009) over 6,000 thrips species are currently recognized worldwide. These insects cause substantial crop losses by feeding on the petals, anthers, pollen, and floral nectaries and ovipositing in the panicles, which leads to discoloration and reduced vigor of the panicles (Pena *et al*., 2002). They also feed and oviposit on the pericarp of the young fruits, which causes bronzing of the fruit surface, and severe infestations often result in the cracking of the fruit skin. These cosmetic injuries reduce the economic value of fruits and their marketability (Grove *et al*., 2000; Nault *et al*., 2003).

Thrips lay their eggs in soft tissue of green fruits, panicles, and tender leaves. When the last instar (larva II) completes its development, it seeks protected places to develop into the pre-pupal and pupal stage, which do not feed and remain immobile (Lewis, 1973). Many species of the subclass Terebrantia undergo pupation in the soil beneath the trees because soil offers better conditions and more protection (Grove *et al*., 2000). However, thrips adults also emerge from various places such as bark, flowers, leaves, and plant cavities, which are safe from unfavorable conditions and insect predators (Pearsall and Myers, 2000).

The damaged areas develop a silvery blemish, spotted with the thrips' dark excreta. In severe infestations the blemishes may become reddish brown, and deep longitudinal cracks may develop in the blemished skin. The characteristic symptom of attack is a silvery sheen of the attacked plant tissue, and white or silvery patches and streaks on fruits. Affected tissue will dry up when the damage is severe. A further indication of attack by thrips is small black spots of faecal material on the infested parts of the plant. Feeding on fruits leaves a roughened silvery texture on the skin.

Banana farmers are currently incurring qualitative losses as a result of thrips infestations. This has been exacerbated by increased consumer demand for consistent supply of uniformly coloured banana fruits with blemish free peels in Kenya like in the supermarkets and other fresh produce markets. Consumers use visual quality to purchase fresh produce (Shewfelt, 2009).

In the management of the thrips, chemical control measures have been used and are the most widely known form of control of this pest in most horticultural crops. However, the rapid development of insecticide resistance in thrips populations has rendered the chemical treatments ineffective (Morse and Hoddle, 2006). In addition, the cost of insecticides and proper application equipment is beyond the economic means of the majority of resource-poor farmers who grow the crop. Again, economic realities and public sensitivity to environmental degradation have currently rendered extensive insecticide use unacceptable.

To successfully manage thrips, correct identification of the damaging species is critical due to their resistance to a range of insecticides from different chemical groups including synthetic pyrethroids, organophosphates, and carbamates (Herron and Gullick, 2001), and newer chemistries such as fipronil and spinosad (Herron and James, 2005).

The use of bags as bunch covers has been shown to offer physical barrier to pests (Amarante *et al.*, 2002). Thrips can also be controlled by use of botanical extracts like neem, garlic, pepper and pyrethrum. Use of chemical pesticides increases the production costs, results in pest resistance and causes adverse effects to human health and the environment (Burkett-Cadena *et al*., 2008).

The purpose of this study was therefore, to develop sustainable thrips management strategy that would effectively control thrips without posing any adverse health effects to human and environment.

1.2 Problem statement and justification

Bananas are among the most important fruit crops in Kenya with about 60% of all the fresh stalls stocking them. However, current production of this crop is below the yield potential that can be achieved under good agricultural management practices. The current situation of low quality is due to both biotic and abiotic constraints with thrips infestation being a major biotic production constraint. They cause silvery patches on fingers and this condition makes the fruit to be of low quality hence rejected or fetch low prices at the market level.

There is need to improve banana quality per unit area in order to feed the ever-increasing population and generate income to the farmers. Currently, no control recommendations are in place for banana thrips. Most of the recommended chemicals for the management of thrips in other crops are expensive or unavailable to an average farmer. They also pose adverse effects to human health and the environment.

Most banana growers are resource poor farmers and do not use insecticide for pest control. Such farmers are more likely to adopt new pest management technologies especially those production systems that are readily available and affordable within the farming environment. Examples of such pest management technologies are use of plastic bunch covers and spraying using botanical extracts. These production systems may be manipulated to come up with an integrated approach of reducing the damage caused by banana thrips.

1.3 Objectives

1.3.1 Overall objective

The main objective of the study was to promote banana productivity and profitability through thrips management in Embu County.

1.3.2 Specific objectives

1. To determine the abundance and diversity of banana thrips in Embu County.
2. To estimate the loss attributed to banana thrips damage at farm level based on responses from farmers in Embu County
3. To develop a cost effective management strategy for thrips in Embu County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and cultivation of bananas

Bananas originated from South East Asia, a region considered as the primary centre of diversification of the crop and where the earliest domestication occurred (Simmonds, 1962,). This area borders on the west India and on the east Samoa, Fiji and other South Pacific islands (Simmonds, 1966). According to Daniells *et al.*, (2001) the dispersal of banana out of East Asia was as a result of human movement across the world. The low land areas of West Africa contain the world's largest range of genetic diversity in plantains (*Musa* AAB) (Ortiz and Vuylsteke, 1994). Conversely in East Africa, bananas have highly evolved into an important zone of secondary genetic diversity for the East African highland bananas (*Musa* AAA) (Smale, 2006).

2.2 Morphology and reproduction of banana

Bananas are large perennial herbs with an underground stem called a corm, which is the true stem of the banana plant. The corm produces aerial shoots which arise from the lateral buds which develop into eyes and later suckers. The continuous vegetative growth of suckers perpetuates the corm's life and hence the perennial status of bananas.

The aerial shoot is called a pseudostem and grows to height of 2 to 8 m depending on the variety and the conditions. The pseudostem consists of large overlapping leaf bases which are tightly rolled round each other forming a cylindrical structure almost 48 cm in diameter. The roots are initiated from the corm and they range from 50 to 100 cm in length; occasionally sub-horizontal roots reach 3 m (Blomme and Ortiz, 2000). The corm also consists of the apical meristem from which the leaves and ultimately the flowers are initiated. On average, each plant produces 35 to 50 leaves in its growth cycle. When the banana plant has formed an average of 40 leaves (within 8 to 18 months), the terminal bud of the corm develops directly into the inflorescence which is carried up on a long smooth unbranched stem through the centre of the pseudostem emerging at the top in the centre of the leaf cluster. The inflorescence is a compound spike of female and male flowers arranged in groups. Each group consists of 2 rows of flowers, one above the other, closely appressed to each other, and the whole collection is covered by a large subtending bract. The bracts and their axillary groups of flowers are arranged spirally round the axis and the bracts become closely overlapping each other forming a tight conical inflorescence at the tip. The lower bracts of the axis enclose female flowers; the middle few bracts enclose neuter flowers (absent in some cultivars) whilst at the tip of the inflorescence male flowers occur. In a few cases, (*M. schizocarpa, M. acuminata* ssp. *banksii* and *M. acuminata* ssp. *errans*) hermaphrodite flowers are produced (Sharrock *et.al*., 2001).

The female inflorescences develop into fingers that constitute the bunch. Banana bunches possess 4 to 12 hands (clusters), each with at least 10 fingers. In wild bananas both male and female flowers produce abundant nectar and pollen whereas in cultivated bananas, many clones lack pollen. Banana pollen is tiny and sticky, being coated with waxes and proteins held in place by sculpture elements. The quantity of pollen is an important factor to enhance the germination potential of pollen grains (Dumpe and Ortiz, 1996). The female flowers have ovaries that develop first by parthenocarpy (without fertilization) to form pulp which is the edible part of the crop. However, wild bananas exhibit cross pollination and ultimately fertilization to form seeds instead of pulp (non-parthenocarpic).

2.3 Uses

The fruit is the main product of the banana plant and bananas are the developing world's fourth most important food crop after rice, wheat and maize (INIBAP, 2000). Millions of small-scale farmers in Africa, South Asia and Northern Latin America grow the fruit for household consumption and/or local markets. The highest consumption of bananas per person is in Uganda, estimated at close to 1 kg per person per day (Edmeades *et al*., 2006).Total world production of bananas (sweet bananas + plantains) in 2005 was over 100 million tonnes (FAO, 2007).

The banana fruit can be eaten raw or cooked (e.g. deep fried, dehydrated, baked in the skin, steamed), can be processed into flour and can be fermented for the production of beverages such as banana juice, beer (e.g. Mbege brewed by the Chagga people in the Kilimanjaro region of Tanzania), vinegar and wine (Morton, 1987; Pillay *et al.*, 2002; Nelson *et al*., 2006; Edmeades *et al*., 2006 and Pillay and Tripathi, 2007).

Other parts of the banana plant are also eaten (Espino *et al.*, 1992) e.g. the flower is eaten raw or cooked in Southeast Asia; the core of the pseudostem (trunk) is used for cooking in Burma and Bengal; leaf buds are eaten as a vegetable (Nelson *et al*., 2006); the corm is a source of starch and has been eaten in times of famine in Africa and Asia (De Langhe, 1995).

All parts of sweet banana/plantain plants, and particularly the fruits have also been used to feed livestock in those parts of the world where there is excess production (Babatunde, 1992). Ashes obtained from burning banana leaves are used as flavouring for curries and a salt substitute in India (Nelson *et al*., 2006).

Banana leaves have a variety of practical uses including wrapping for food, plates for serving food, polishing floors, thatching (Espino *et al*., 1992; Nelson *et al*., 2006). Fibres obtained from the pseudostem are used for making cloth (Espino *et al.*, 1992; Nelson *et al*., 2006) and leaf fibres are utilized in string, cordage and rope (Nelson *et al*., 2006).

The sap of banana plants, particularly the Fe'i cultivars that have a distinctive reddish-violet sap (Sharrock, 2000), has been used as a dye and ink (Nelson *et al.*, 2006; Pillay & Tripathi, 2007). Root sap can be used to treat mouth thrush in children and skin warts. Banana peel has been found to have antibiotic properties (Nelson *et al*., 2006).

2.4 Production constraints

2.4.1 Banana production constraints in Kenya

The area under banana and plantain cultivation in Kenya has continued to increase over the years (Technoserve, 2009). The key production areas include Central, Nyanza, and Eastern Provinces. Pests and diseases are the main production constraints and can reduce yield of bananas by upto 100% depending on pathogen, while quality is also compromised (Jones, 2000). Other constraints are declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, genetic erosion and high cost of inputs (Seshu

Reddy *et al*., 1999). Thrips are emerging as major pests of banana as their infestation causes silvery scarification on the fingers making them less appealing to buyers and consumers. Severe damage may cause cracking of fingers.

2.4.2 Banana thrips

2.4.2.1 Biology and distribution of thrips

Thrips are small, opportunistic and ubiquitous insects often only a few millimeters length and generally yellow, brown or black in color (Morse and Hoddle, 2006). They are mainly phytophagous, mycophagous, or predatory insects that inhabit a wide range of habitats, generally in the tropical, subtropical and temperate regions. Their adaptive diversity has enabled successful exploitation of diverse niches, so that they have not only established themselves in a variety of plant formations, but in fungus-infested habitats such as plant litter and in barks of living and dead trees (Lewis, 1973; Mound, 1976; Bournier, 1983; Ananthakrishnan, 1984).

Thrips frequently inhabit flowers or inflorescence of various kinds, shoots, tender leaves, and fungus-infested dead or decaying wood. These insects feed on pollen as well as on spores. They are susceptible to environmental changes and because of the polyphagous nature of many species, one can determine their abundance by the types of plant formations. They are also essential elements of the soil, occurring at depths of 10-30 cm in the soil, where some species complete their metamorphosis or hibernate (Lewis, 1973; Ananthakrishnan, 1984). Pollen provides nutrients for greater egg production (Tsai *et al*. 1996) and the adults of most species feed on the flowers of a wide range of the available plant species, including those that are not suitable reproductive hosts (Chellemi *et al*. 1994). Young leaves are exploited by adults when flowers are scarce (Toapanta *et al*. 1996). Leaves are preferred as a more stable source of food for developing larvae in some species (Funderburk *et al*. 2002)

Most thrips complete their life cycle from egg to adult stage in two to three weeks. The duration varies with the host and with abiotic factors such as temperature and humidity (Andrewartha, 1971). The life cycle consists of egg, two nymph stages, two pupae stages, and an adult (Morse and Hoddle, 2006). A female can lay 20 - 40 eggs with unmated females producing only males. Hatching of the egg takes an average of 3 days (Reitz, 2009). Nymphs (larvae) are yellowish-white (Morse and Hoddle, 2006). The second stadium is longer than the first one and pupation takes place in the soil (Reitz, 2009). The larval stage is followed by short transitional pro pupa followed by pupae stages which do not feed. According to Salifu (1992) flower bud thrips development from egg to adult takes about 19 days at 29°C and 58% relative humidity and adults live for about 23 days. Rapid breeding, laying eggs on leaf petioles, peduncles, inflorescences and pods have also been reported in flower bud thrips by Tamo *et al*. (1993).

Weather variables including rainfall, temperature, relative humidity and wind have been reported as important factors that significantly affect thrips numbers (Kirk, 1997; Legutowska, 1997). Relatively high temperatures and lack of rainfall have been associated with the increase in thrips population, while high relative humidity and rainfall reduce their population (Hamdy and Salem, 1994). In addition to their effect on thrips activity, temperature and relative humidity further influence the intrinsic rate of natural increase of the thrips (Murai, 2000).

2.4.2.2 Economic importance of thrips

Thrips can contaminate a wide variety of commodities and human devices because of their small size, ability to build to high numbers, cryptic behavior, egg deposition inside plant tissue and a propensity to secrete themselves in tight spaces (Morse and Hoddle, 2006).They feed on plant tissues by piercing and sucking sap, resulting in tissue scarification and depletion of the plant's resources (Welter *et al*., 1990; Shipp *et al*., 1998). The scarification reduces the photosynthetic capacity of leaves and causes blemishes on fruits.

Thrips are ranked as a major pest of snap beans in Kenya (Nderitu *et al*., 2009; Nyasani *et al*. 2012, 2013). It attacks the crop before budding, and causes the flower buds to dry and brown, progressively aborting to leave dark red scars on the plant (Childers and Achor, 1995). They cause 63 - 68% of pod losses in Kenya (Nyasani *et al*., 2010). They are also major pests of vegetables and fruits in Kenya causing significant qualitative and quantitative yield losses. Annual losses of up to $75,000 per hectare have been reported due to direct damage to cucumbers in UK glasshouses due to thrips (Zhang *et al*., 2007).

Fourteen thrips species in the family Thripidae have been identified as vectors of major tospoviruses globally (Ullman *et al*., 1997; Jones, 2005; Pappu *et al*., 2009; Ciuffo *et al*., 2010; Hassani-Mehraban *et al*., 2010). *Frankliniella occidentalis* is the most studied vector of tospovirus. Apart from the direct damage, WFT transmits tospovirus diseases (Funderburk *et al*., 2009). The most important of which are Impatiens Necrotic Spot Virus (INSV) and Tomato Spotted Wilt Virus (TSWV) (German *et al*., 1992; Ullman *et al*., 1997; Cloyd, 2009). Tospovirus infections can lead to total crop losses (Kyamaywa and Kuo, 1996). Over 80% potential yield losses of TSWV were reported by tomato farmers in Nakuru County (Wangai *et al*., 2001).

2.4.3 Management of banana thrips

2.4.3.1 Cultural control

Cultural control methods include sanitation practices like rouging old infected plants and alternate hosts such as weeds (Cloyd, 2009). Weeds from the Compositae family; dandelion and sowthistle and Solanaceae family; silverstar, with yellow flowers not only attract adults thrips, but also serve as reservoirs for the tospoviruses vectored by thrips.

Mulching with black polythene paper (Hajek *et al.*, 2003) hinders the life stages of thrips especially pre-pupae and pupae from attacking plants during susceptible stages, thus evading thrips. Over-head irrigation also creates less favorable conditions for thrips development and decreases thrips population (Lindquist *et al*., 1987). Use of lure or trap crops such as, yellow flowering chrysanthemums and eggplants may also help in managing WFT by attracting WFT away from the main crop (Hoyle and Saynor, 1993; Pow *et al*., 1998; Bennison *et al*., 2001). The trap crops may be removed from the field, sprayed with an insecticide, or inoculated with biological control agents such as predatory bugs or predatory mites that will feed on the nymph and adult stages residing in the flowers (Bennison *et al*., 2001). Intercropping on crops as snap beans has been shown to improve marketable yield due to reduced damage by thrips (Nyasani *et al*., 2012).

2.4.3.2 Use of bagging

The use of polyethylene bunch covers typically made of thin plastic (low density polyethylene; 5 to 40microns) and which are 81.3 to 91.4 cm (32 to 36 inches) is widespread throughout the commercial banana growing regions of the world. Bagging of bananas with bags impregnated with insecticides has been shown to protect fruits from insect attack (Amarante *et al*., 2002).They are also commonly used to protect plantain fruit intended for export market during development. The practice is regarded as essential to improve the market quality of bananas (Gowen, 1995; Robinson, 1996; Harhash and Al-Obeed, 2010).

Bagging has been shown to exert multiple effects on the growth and quality of fruits (Hoffman *et al*., 1997, Wang *et al*., 2007, Son and Lee, 2008 and Li *et al*., 2008). Fruit bagging promotes fruit coloration (Hu *et al*., 2001 and Jia *et al*., 2005).

2.4.3.3 Use of plant extracts

The use of broad spectrum synthetic pesticides' has led to increasing problems of pests resistance, pesticides residues on foods and contamination of the environment. This has resulted to a worldwide interest to develop alternative strategies (Dayan *et al*., 2009) which will have to meet entirely different standards. They must be pest specific, non-phytotoxic, nontoxic to mammals, ecofriendly, less prone to pesticide resistance, relatively less expensive, and locally available (Hermawan, 1997). This has led to more focus on plant extracts to control pests on crops, which have been known to resist insect attack (Talukder, 2006, Sahayaraj, 2008) and the practice of using plant derivatives or botanical insecticides in agriculture dates back at least two millennia in ancient China, Egypt, Greece and India (Isman, 2006).

Plant derived materials are more readily biodegradable, less likely to contaminate the environment and may be less toxic to mammals (Isman, 2006). A great number of plant species from a wide range of families have been assessed for their toxic, antifeedant and repellant properties (Isman, 2006; Talukder, 2006; Dubey *et al*., 2008; Ogunleye et *al*., 2010).

Some plant extracts possess significant oviposition, antifeedant or toxic effects on selected pests (Hazarika *et al.,* 2008). Plant extracts possess one or more useful properties such as repellency, antifeedant, fast knock down, flushing action, biodegradability, broad-spectrum of activity and ability to reduce insect resistance (Stoll, 1988). Some of them have weak insecticidal effects or may require other plant species with different mode of action to increase their potency (Oparaeke, 2004).

Botanical pesticides are extracted from various plant parts as leaves, stems, seeds, roots, bulbs, rhizomes, unripe fruits and flower heads of different plant species. Botanical pesticides are hailed for having a broad spectrum of activity, being easy to process and use, having a short residual activity and for not accumulating in the environment or in fatty tissues of warm blooded animals, (Philip and Robert, 1998). Their modes of action against pests are diverse. Natural compounds are well suited to organic food production in industrialized countries and can play greater roles in the protection of food crops in developing countries. Some plant based insecticides such as neem products, pyrethroids and essential oils are already used to manage pest populations on a large scale. They are environmentally safe, less hazardous, economic and easily available (Mamun, 2011).

2.4.3.4 Neem

Neem has emerged as the single most important source of botanical insecticides having a wide control of numerous insects and mites. Azadirachtin is derived from the neem tree *Azadirachta indica*, grown in India and Africa (Isman, 2006). Azadirachtin has an extremely low mammalian toxicity and is least toxic of the commercial botanical insecticides, with an LD50 of 13,000 mg/kg. Neem is a natural source of eco-friendly insecticides, pesticides and agrochemicals (Brahmachari, 2004). Neem products have no ill effects, on human and animals and have no residual effect on agricultural produce. Azadirachtin is considered a contact poison; however, it has "some" systemic activity in plants when applied to the foliage. The material is generally nontoxic to beneficial insects and mites. Azadirachtin has broad mode of activity, working as a feeding deterrent, insect-growth regulator, repellent, and sterilant; and it may also inhibit oviposition (Isman, 2006,) The material is active on a broad range of insects, including stored grain pests, aphids, caterpillars and mealybugs (Talukder, 2006).

2.4.3.5 Garlic

The insecticidal and repellent activity of garlic has been widely reported (Rahman and Motoyama, 2000; Amiri, 2009). The bulb of garlic has been reported to possess insect controlling properties with repellant, antifeedant, bactericidal, nematicidal and fumigant mode of action that kill aphids and other soft bodied pest (Grainge *et al*.,1985). Jacquelin du Val indicated that two essential oils, garlic and onion had potent fumigant activities (Isikber, 2010). Osipitan and Mohammed (2008) reported the ability of garlic to repel borers, fleas, ticks and thrips.

2.4.3.6 Pepper

Capsicum frutescens and *Capsicum annum* have been shown to have insecticidal properties (Oni, 2009). Pepper derivatives have been regarded as safe, affordable and effective natural plant products with some degree of medicinal and insecticidal properties (Ashamo, 2007; Oni, 2009; Adedire and Lajide, 2001).

CHAPTER THREE

IDENTITY AND ABUNDANCE OF BANANA THRIPS IN DIFFERENT AGRO-ECOLOGICAL ZONES IN EMBU COUNTY

Abstract

Thrips continue to be one of the most important pests facing banana production systems in Kenya. Their adaptive diversity has enabled successful exploitation of diverse niches coupled with reproductive potential, cryptic behaviour; vectors of tospovirus and being highly polyphagous make them significant pests. The main objective of this study was to identify the species composition and abundance in Embu County. The study was conducted in three agro-ecological zones namely; Upper highland UM1, Mid highland UM2 and Lower highland UM3 in two seasons in March 2013 and June 2014. In each zone, 10 farms were randomly selected and 10 male buds randomly picked and opened to collect the thrips. The collected thrips were then transferred into vials with 70 % ethanol then safely transported to the laboratory where they were identified to species level.Thirteen species were identified across the zones with the upper zone having the largest thrips populations. The major species identified were *Frankliniella schultzei* (51.3 %), *Megalurothrips sjostedti* (27.9 %), *Haplothrips gowdeyi (*5.6 %), *Thrips spp* (5.2%) and *Frankliniella occidentalis* (3.5 %).

From the study, it was concluded that bananas are infested by a complex of thrips species which pose a major production constraint that could be contributing to the decline in banana productivity. This information is important in studying pest crop phenology for the development of proper management strategies for banana thrips.

3.1 Introduction

Thrips (Order Thysanoptera) of the world comprise 5500 species in 750 genera (Moritz *et al*., 2004). They are more common in warmer tropical parts of the world than in the temperate regions. About 50% of them are fungal feeders, while 40% feed on living tissues of dicotyledonous plants and grasses and 10% exploit primitive plants or are predatory (Morse and Hoddle, 2006). Those infesting living plant tissues are sap feeders while flower dwelling species feed on pollen (Mound, 2004). Thrips have emerged as a significant biotic constraint affecting banana production in Kenya as they cause silvery scarifications on fingers thus lowering their quality. Morse and Hoddle (2006) described thrips as small, opportunistic and ubiquitous insects of often only a few millimeters length and generally yellow, brown or black in color. Their adaptive diversity has enabled successful exploitation of diverse niches, so that they have not only established themselves in a variety of plant formations, but on fungus-infested habitats such as plant litter and in bark of living and dead trees (Lewis, 1973; Mound, 1976; Bournier, 1983; Ananthakrishnan, 1984). They are a significant pest of virtually all crops, including fruiting vegetables, leafy vegetables, ornamentals, tree fruits, small fruits and cotton (Lewis 1997).

Thrips frequently inhabit flowers or inflorescence of various types, shoots, tender leaves and fungus-infested dead or decaying wood. These insects feed on pollen as well as on spores. Most thrips complete their life cycle from egg to adult stage in two to three weeks. The duration varies with the host and with abiotic factors such as temperature and humidity (Andrewartha, 1971). Salifu (1992) reported that flower bud thrips development from egg to adult takes about 19 days at 29°C and 58% relative humidity and adults live for about 23 days. Rapid breeding, laying eggs on leaf petioles, peduncles, inflorescences and pods was also reported in flower bud thrips by Tamo *et al*., (1993).

Thrips can damage a wide variety of crops because of their small size, ability to build to high numbers, cryptic behavior, egg deposition inside plant tissue and a propensity to secrete themselves in tight spaces (Morse and Hoddle, 2006). Direct crop damage results from both feeding and oviposition (Childers, 1997). Because of their thigmotactic behavior, feeding damage is often inflicted on developing tissue, consequently it goes undetected until flowers or fruits mature (Welter *et al*., 1990; Pearsall, 2000; Steiner and Goodwin, 2005; Guide *et al*., 2006). The feeding damage can be mistaken with damage caused by other pests or diseases (Steiner and Goodwin, 2005). Such incorrect diagnoses may result from the small size and cryptic habits of thrips and the fact that damage is not immediately apparent and associated with the causal organism.

By feeding on pericarp, these thrips extract chlorophyll and cause a bronzing of the surface of the fruit, while the skin of severely damaged fruit may crack (Annecke and Moran, 1982; de Villiers and van den Berg, 1987; de Villiers, 1990). Black dots caused by the deposition of their excreta are also visible on the discoloured parts of the pericarp (de Villiers and van den Berg, 1987; de Villiers, 1990).

Thrips feed by piercing and sucking resulting to scarification thus reduce the photosynthetic capacity of leaves and cause blemishes on fruits. To feed, most thrips press their mouth cone against the plant surface; this is held in place by the labral pad. The mandible is used to pierce through the substrate; it is quickly withdrawn and replaced by the maxillae which locate an individual plant tissue cell and suck out the contents (Chisholm and Lewis, 1984, Childers and Achor, 1995, Kirk, 1995, Moritz, 1997). When feeding on pollen grains, thrips use their forelegs and/or palps to hold the grain while they pierce it (Childers and Achor, 1995).The direct injury results in the discoloration of fruits, thus lowering their quality. Female oviposition causes another type of damage to developing fruits. Females insert eggs under plant epidermis with their saw-like ovipositor. This wounding elicits a physiological wound response in some plants that produce spottings on fruits. Extensive spotting can lead to downgrading of quality.

This study was conducted to determine the species composition, abundance and the diversity of thrips on banana in Embu County. This information would support thrips management on banana by identifying the damage causing species and improve the knowledge of their bionomics.

3.2 Materials and methods

3.2.1 Study area

The study was undertaken in Runyenjes sub-county which lies between 1,200 – 2070 m above sea level. The area receives bimodal rainfall pattern from March to May and October to December that range between 1000 – 2000 mm. To study the area, stratification was done into three agro-ecological zones (AEZ) namely; Upper highland (UM1), mid highland (UM2) and lower highland (UM3), (Jaetzold *et al*., 2006).

3.2.2 Study sites

Thrips were collected in 30 sites located in three administrative districts covering three agro-ecological regions of the sub-county in two seasons March 2013 and June 2014. In March 2013, the season was hot and dry just before onset of the long rains while in June 2014 it was cool and wet. 10 farms were randomly selected in each zone totaling to 30 banana farmers. In each farm, 10 male buds were randomly picked and opened to collect the thrips. The insects were swept with a bristle brush into a sample bottle and then quickly transferred into a universal bottle containing 70% alcohol. In each farm, all thrips collected from the 10 male buds were pooled together to make one sample, then labeled per farm and zone. Samples were then safely transported to the National Museums of Kenya, where they were counted and identified to species level.

3.2.3 Sample preparation

Specimens were carefully macerated to remove the body contents. They were then put in Alcohol-Glycerin-Acetic Acid solution (AGA) with fresh 60% alcohol and stored for 24hrs. 60%

alcohol was then replaced with 5% NaOH and left for 30 minutes. The abdomens were then punctured between the hind legs coxae with fine needle and gently squeezed to expel most of the body contents, legs and antennae were then spread. NaOH was then replaced with distilled H_2O and 50% alcohol gradually added for 20 minutes. The mixture was then replaced with fresh 60 % alcohol and stored for 24hrs. 60 % alcohol was replaced with 70% alcohol and stored for 1 hour. After an hour, 70% alcohol was replaced with 80 % alcohol for 30 minutes. 80 % alcohol was replaced with 95 % alcohol for 10 minutes. 95 % alcohol was replaced with absolute alcohol for 5 minutes. Absolute alcohol was then replaced with fresh absolute alcohol for 5 minutes and then replaced with clove oil and stored for 30 minutes.

Specimens were then placed on slides, and covered with cover slips 13mm and mounted with Canada balsam. They were then labeled as per farmer, zone, date and collector then dried in an oven at 37 °C. Specimens were then identified and grouped according to their species and counted. Total counts per farm were also recorded.

3.2.4 Data analysis

Data was subjected to analysis of variance (ANOVA) using Microsoft Excel version 2010 and SAS 9.2 statistical packages for analysis of variance (ANOVA). Significantly different means at $P \leq 0.05$ were separated using the Turkey-Kramer's HSD comparison test.

3.3 Results

3.3.1 Species composition of thrips on banana in farmers' fields

All sampled adult thrips were identified to species level as shown in table 1. In total, thirteen thrips species were recorded and the most commonly encountered species were *Frankliniella schultzei* (51.3 %), *Megalurothrips sjostedti* (27.9 %), *Haplothrips gowdeyi (*5.6 %), *Thrips tabaci* (5.2%) and *Frankliniella occidentalis* (3.5 %).

Table 1: Thrips species collected from banana male flower buds in all zones in March 2013 and June 2014 in Embu County

Species	Mean±SEM		
	March 2013	June 2014	Percent
Megalurothrips sjostedti	15.3±2.37	4.63±0.85	27.9
Frankliniella schultzei	20.53±3.26	8.53±1.65	51.3
Frankliniella occidentalis	4.07±1.1	0.58±0.28	3.5
Haplothrips gowdeyi	0.8±0.39	0.93±0.27	5.6
Thrips florum	0.37±0.28	0.22±0.15	1.3
Microcephalothrips abdominalis	0.23±0.13	0.2±0.09	1.2
Ceratothripoides brunneus	0.23±0.23	0.33±0.204	2
Sericothrips adolfifriderici	0.23±0.16	0.05±0.04	0.3
Dendrothrips spp.	0.03±0.33	0.02±0.02	0.1
Thrips australis	0.0	0.12±0.08	0.7
Thrips tabaci.	0.0	0.87±0.51	5.2
Chirothrips frontalis	0.0	0.08±0.05	0.5
Stenchaetothrips spp	0.0	0.07±0.05	0.4

Thrips populations were higher in March 2013 a hot and dry season before the onset of the long rains compared to June 2014 which was cool and dry after the rains. In both collection seasons, upper zone had higher thrips populations compared to both mid and lower zones though not significantly different (Table 2).

Table 2: Thrips abundance in each agro-ecological zone in Embu County

Means of total thrips counts		
Zone	**March 2013**	**June 2014**
UM1	25.4[a]	16.1[a]
UM2	23.8[a]	13.9[a]
UM3	11.4[a]	10.2[a]

Means followed by the same letters along each column are not significantly different at P ≤0.05

Five species were noted to occur in all the zones and their populations were higher compared to other species that either occurred in one zone and in low numbers as shown in table 3. *Frankliniella schultzei* was the major thrips species across the zones and the numbers did not differ significantly. The population of this species increased as the altitude increased.

There were no significant differences in the number of *Megalurothrips sjostedti* which were observed between the zones in both seasons. However, there was a general increase in the number *M. sjostedti* as one moved from lower to higher altitude zones. There were no significant differences in the number of *Frankliniella occidentalis* across the zones in both seasons.

M.sjostedti was present in all the zones and more populations were found in the mid zone, compared to the upper and the lower zones. *F. schultzei* were also present across the zones and higher populations were found in the upper zone, followed by mid and lower zones respectively. *F. occcidentalis* populations were almost uniform in all the zones, with slightly higher populations on the upper zone. All the other species were found in the lower and mid zones albeit in small numbers..

Table 3: Abundance of the most widely spread thrips species across the agro-ecological zones in Embu County

AEZ	*Frankliniella schultzei*	*Megalurothrip ssjostedti*	*Frankliniella occidentalis*	*Haplothrips gowdeyi*	*Thrips florum*
March 2013					
UM1	14.7a	6.4a	0.7a	0.9a	2.3a
UM2	10.8a	4.3a	0.5a	0.1a	0.8a
UM3	4.5a	3.4a	0.3a	0.1a	0.6a
June 2014					
UM1	7.9a	6.7a	0.7a	0.2a	0.0a
UM2	7.9a	3.3a	1.3a	1.3a	0.1a
UM3	5.4a	3.7a	0.0a	0.4a	0.1a

Means followed by same letters along each column are not significantly different at P ≤0.05

Generally for all thrips species listed, particularly in the March 2013 season the populations were higher in UM1 compared to UM2 and UM3 as shown in table 3.

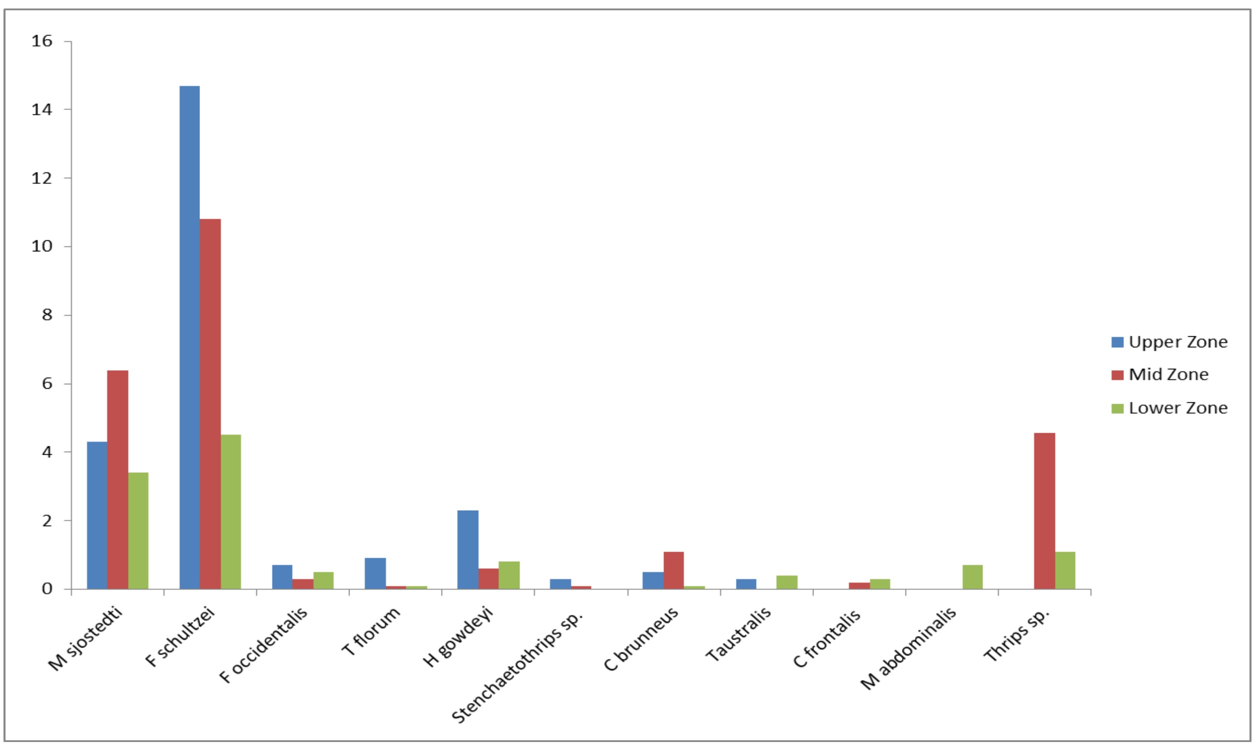

Figure 1: Thrips species distribution across the agro-ecological zones in Embu County

3.4 Discussion

The survey results showed that all the banana male buds in the area of study were infested with thirteen thrips species. Studies which have been conducted on various crops have established a combination of thrips species on different crops. Okwakpam (1967) reported that any plant in Nigeria is attacked by one or more thrips. This is in conformity with Higgin's (1992) observation, where it was noted that different crops normally have a different number of species of thrips on them. Two thrips species were observed in tomatoes and 29 species were associated with barley. In Kenya, four species namely *M. sjostedti, F. schultzei, H. aldolfifriderici,* and *F. occidentalis* have been established to infest snap bean (Nyasani *et al*., 2012; Moritz *et al*., 2013). This is an indication that several species infest the crops. There is a possibility that banana fingers may be damaged by a complex of thrips species they are polyphagous. The major species which were identified in this study were *Frankliniella schultzei* (51.3 %), *Megalurothrips sjostedti* (27.9 %), *Haplothrips gowdeyi (*5.6 %), *Thrips spp* (5.2%) and *Frankliniella occidentalis* (3.5 %). These thrips were distributed in all the zones where bananas are grown in Embu County.

The presence of the five major thrips species which were recorded on the banana male bud could be attributed to their polyphagous nature and being widespread. *Megalurothrips sjostedti* is a common, polyphagous and widespread pest in Africa (Karungi *et al*., 2000; Alabi *et al*., 2004; Ngakou *et al*., 2008). *Frankliniella occidentalis* is invasive and was reported for the first time in Kenya in 1989 (Kedera and Kuria, 2003).This species is also polyphagous, feeding and breeding on more than 240 host species belonging to 62 plant families. Ecologically, western flower thrips is highly polyphagous and capable of reproducing on numerous host plants (Northfield *et al*., 2008; Paini *et al.,* 2007). As large thrips populations can develop on non-crop hosts, mass dispersal into crops occurs, whether open field crops (Pearsall and Myers, 2001; Puche *et al*., 1995) or crops in protected environments (Antignus *et al*., 1996).

Thrips preferentially reside within flowers or other concealed, protected places on plants (Hansen *et al*., 2003; Kirk, 1997). This thigmotactic behavior of thrips limits their exposure to many foliar applied insecticides. Also, the anthophilous nature of western flower thrips limits their exposure to systemic insecticides, which are not readily transported into floral tissues (Cloyd and Sadof, 1998; Daughtrey *et al.,* 1997). Therefore, some of the most effective insecticides are those with translaminar properties, which increase the probability of thrips concealed in flowers actually ingesting toxins (Kay and Herron, 2010).

There were fewer thrips in June 2014 compared to March, 2013 and this could be attributed to weather conditions. In March 2013, the weather was dry and hot whereas June 2014, the weather was cool and dry preceding the long rains. Temperature and relative humidity are known to have an effect on thrips activity and they also influence the intrinsic rate of natural increase of the thrips (Murai, 2000). Studies by Dobson *et al.* (2002) and Akemo *et al*. (1999), indicated that the drier the weather, the quicker the onset of thrips damage and the more severe the symptoms. This was in agreement with the results obtained from this study, as a high thrips populations were observed in March 2013 a season that was hot and dry. This was also in agreement with earlier findings by Lewis (1997) that the distribution of a thrips population is strongly influenced by climatic conditions. Stacey and Fellowes (2002) and Pearsall and Myers (2001) also showed that temperature affects the development rate of thrips and consequently their population dynamics.

Earlier research has shown that rainfall affects thrips populations both negatively and positively (Morsello *et al.,* 2010). It can suppress populations by killing larvae, and thrips populations so affected often recover slowly (Morsello and Kennedy, 2009). Rainfall also suppresses thrips dispersal by suppressing flight (Lewis, 1997). However, by maintaining adequate soil moisture, rainfall can positively influence thrips populations by fostering plant growth and enhancing pupal survival (Morsello and Kennedy, 2009). These authors also found out that the degree to which population growth is affected by precipitation depends on the timing, amount, and duration of the precipitation.

The most outstanding observation was that in UM1 (upper), where the total number of thrips were higher than those in the UM2 (Mid) and UM3 (lower) which contradicts the previous belief that thrips prefer low altitudes which are characterized by hot and dry weather for most parts of the year. Nevertheless, it is in agreement with the surveys conducted by ICIPE which clearly indicated that *F. occidentalis* is widely distributed in the high altitude and mid-altitude zones of Kenya, while *F. schultzei* is prevalent throughout Kenya (Subramanian, 2011). This could be attributed to changes in climatic factors like temperature and precipitation have a strong influence on the development, reproduction and survival of insect pests. Such climatic conditions could profoundly affect the population dynamics and the status of insects of crops (Woiwod, 1997).

3.5 Conclusion

The current study has shown that there were various thrips species infesting banana in all agro-ecological zones in Embu County. The most abundant and widely distributed species was *Frankliniella schultzei* with high altitude zone, UM1 having the highest thrips populations.

3.6 Recommendations

1) There is need to raise awareness amongst farmers on thrips infestations on banana.
2) There is need to develop farmer friendly thrips management strategy to help minimize losses incurred by the farmers.
3) There is need to assess the losses that can be attributed to thrips infestations on banana.

CHAPTER FOUR

ASSESSMENT OF LOSSES ATTRIBUTED TO BANANA THRIPS IN EMBU COUNTY

Abstract

Banana production in Kenya continues to face various biotic constraints and thrips are among the major pests. The main objective of this study was to identify the qualitative losses which are attributed to banana thrips in Embu County. The study area was stratified into three agro-ecological zones namely; Upper highland UM1, Mid highland UM2 and Lower highland UM3. A structured questionnaire was administered to 60 farmers, where 20 farmers were randomly selected in each zone. From the study, 38.3 % of the farmers had primary level of education, 33.3% secondary, 25% tertiary level and 3.3 % university level. Majority of the farmers were aged between 51-60 years with 20-30 years being the least. There was a significant difference ($P \leq 0.05$) between land ownership in all zones. Sale of the farm produce was the major source of income accounting for 34%. Thrips were the most important pests with 96.7 % of the farmers noticing damage by thrips on fingers. Hot and dry season was termed by 40% of farmers as the most severe infestation season.

The average price per kilo was Ksh.13 and bunches which were damaged by thrips were bought at an agreed price between the farmer and the buyer at prices almost half of the buying price and some rejected depending on percentage of the damage. The study has found out that banana thrips pose a major production constraint that could be contributing to the decline in productivity. Efforts should be made to enlighten farmers and also to identify strategies that can be adopted by the resource poor growers in order to restore the status of bananas as major income earner to farmers as well as an alternative source of food to the country.

4.1 Introduction

Bananas have played and continue to play a major role in the diets of both rural and urban people and the economy of Kenya (Nguthi, 2007). The crop is also a major source of income for the majority of smallholder growers in Kenya (MOA, 2006). It is rated as the most important table fruit sold both at local and international markets and the most important starchy staple food after cassava and sweet potato (FAO, 2009).Banana fruits throughout the year thus ensuring food security at household level with a potential of sustaining food supply to urban markets especially in periods between cereal crop harvests. This potential coupled with the environmental conservation attributes of the plant makes banana an ideal crop for economic growth and sustainability of the agricultural resource base. The crop is the 5th most important tropical fruit after mango, pineapple, avocado and papaya (Karamura, 2004).

The area under banana and plantain cultivation in Kenya has continued to increase over the years with plantations replacing coffee in Eastern and Central regions (Technoserve, 2009). The key production areas include Central, Nyanza, Western and Eastern Provinces. They are the most affordable fruit both in rural and urban households. They have gained popularity in Kenya with about 60% stalls in fresh markets stocking bananas (Technoserve, 2009). The demand for ripened fruit often outstrips supply, which has created opportunities for imports from neighbouring countries (Biruma *et al*., 2007). Banana plays a dual role as a staple food in the tropics and also as a table fruit sold both local and international markets (Karamura, 2004).

Banana yield is still very low, 4.5-10 tons/ha compared to the potential of 30-40 tons/ha (Qaim, 1999). Pests and diseases are the main production constraints and can reduce yield of bananas by upto 100% depending on pathogen, while quality is also compromised (Jones, 2000). Other constraints are declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, genetic erosion and high cost of inputs (Seshu Reddy *et al*., 1999). Thrips are emerging as major pests of banana as their infestation causes silvery scarification on the fingers making them less appealing to buyers and consumers. They feed by piercing and sucking resulting to scarification thereby reduce the photosynthetic capacity of leaves and causes blemishes on fruits. Because of their thigmotactic behavior, feeding damage is often inflicted on developing tissue, which may go undetected until flowers or fruits mature (Welter *et al*., 1990; Pearsall, 2000; Steiner and Goodwin, 2005; Guide *et al*., 2006). The feeding damage can be mistaken with the damage caused by other pests or diseases (Steiner and Goodwin, 2005). By feeding on pericarp, these thrips extract chlorophyll and cause a bronzing of the surface of the fruit, while the skin of severely damaged fruit may crack (De Villiers and Van den Berg, 1987; de Villiers, 1990). Black dots, caused by the deposition of their excreta are also visible on the discoloured parts of the pericarp (de Villiers and van den Berg, 1987; de Villiers, 1990). In severe infestations the blemish may be reddish brown and deep longitudinal cracks may develop in the blemished skin.

There has been increased demand for consistent supply of uniformly coloured fruits with blemish free peels in Kenya like in the supermarkets. Consumers use visual quality to purchase fresh produce (Shewfelt, 2009). This study was conducted to obtain basic information on how thrips damage on banana fingers affects the fruit marketability in Embu, as a justification for development of thrips management technologies that are sustainable and compatible with banana farmers' conditions. The specific objective was to estimate the loss attributed to banana thrips damage at field level based on responses from the farmers in Embu County.

4.2 Materials and methods

4.2.1 Study area

The study was undertaken in Runyenjes sub-county which lies between 1,200 – 2070 m above sea level. The area receives bimodal rainfall pattern from March to May and October to December that range between 1000 – 2000 mm. Runyenjes has a population of 142,360 (KNBS, 2009) occupying an area of 261.50 Sq. kms and is located about 145 kms from Nairobi. To study the area, stratification was done into three agro-ecological zones (AEZ) namely; Upper highland (UM1), mid highland (UM2) and lower highland (UM3), (Jaetzold *et al*., 2006).

4.2.2 Data collection

A semi-structured questionnaire was administered to 60 households in the three agro-ecological zones, whereby 20 banana farmers were randomly selected in each agro-ecological zone and a questionnaire administered.

Sample size (n) determination formula:

$$n = N \div \{1+N (e)^2\} \text{ where,}$$

e= 0.05 at a confidence of 95% (Yamane, 1967)

4.2.3 Data gathered

The questionnaire was subdivided into sections that dealt with the information required for household and land characteristics, banana pests and marketability loss and sources of market and agricultural information. Farm and household data included information on gender, education, land size owned and main crops grown. The general information on farmers ranking of banana pests, thrips damage, seasons when damage was most severe and marketability loss due to thrips was also collected. Market and agricultural information sources data was gathered from the farmers through ranking of the available sources of information. Farmers were also asked about social/ community group membership and subsequent benefits.

4.2.4 Data analysis

Data was subjected to analysis of variance using Microsoft Excel version 2010, IBM SPSS statistics version 21 and SAS 9.2 statistical packages for analysis of variance (ANOVA). Significantly different means at $P \leq 0.05$ were separated using the Tukey-Kramer's HSD comparison test.

4.3 Results

4.3.1 Household and farm characteristics

4.3.1.1 Gender

The study did not show any significant differences ($P \leq 0.05$) in terms of gender of the household heads across the agro-ecological zones but the proportion of the male household heads was higher compared to that of the female heads as indicated in fig. 2. In UM1 (Upper zone) the proportions were 70 % male and 30 % female, UM2 (Mid zone) 75 % were male whereas 25 % were female and in UM3 (Lower zone) 65 % were male while 35 % were female.

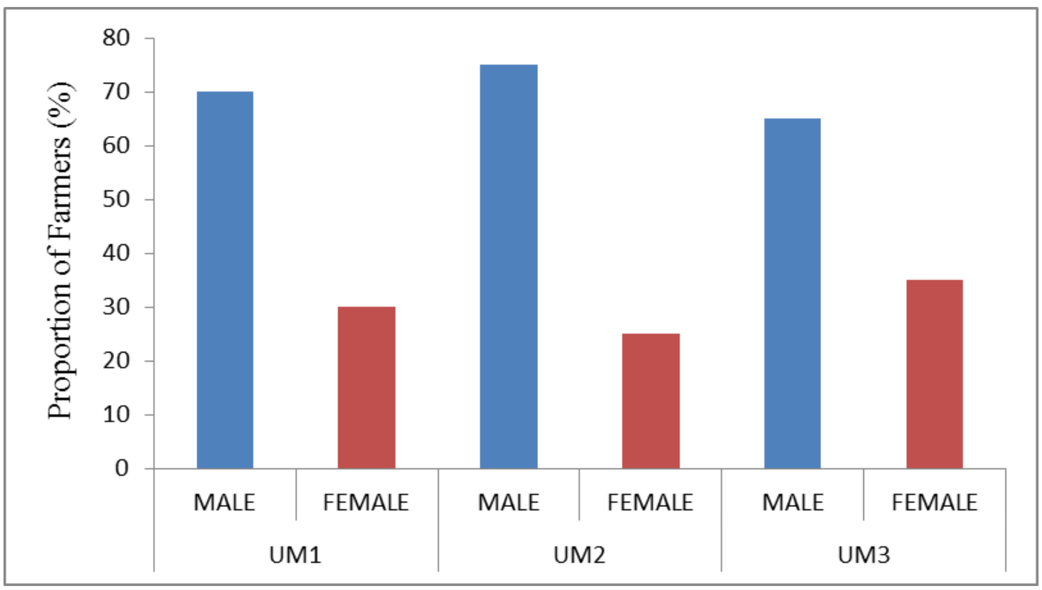

Figure 2: Gender of household heads in different banana production zones in Embu County

4.3.1.2 Age of farmers

Five age groups were identified during the study as indicated in fig. 3 below and their ages did not significantly *(*$P \leq 0.05$*)* vary. There was a high proportion of the farmers were aged 41 to 60 and above years. The proportion of the farmers who aged between 51 to 60 years was 35 % in UM1, 25 % in UM2 and 40 % in UM3 (Fig. 3)

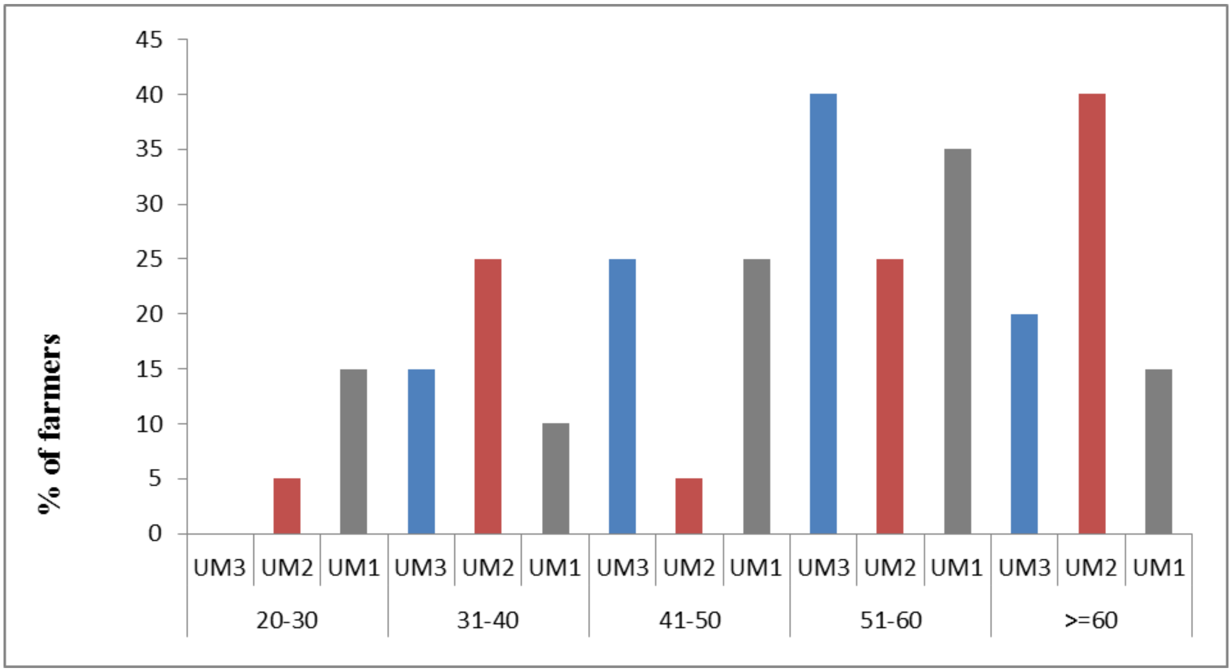

Figure 3: Age of household heads in different banana production zones in Embu County

4.3.1.3 Education levels

Banana growers in Embu County were clustered into four education levels. There were no significant differences ($P \leq 0.05$) between the education levels across the agro-ecological zones (Table 4). The highest proportion of farmers in all zones had acquired primary education with those in UM1 at 45%, in UM2 at 35% and those in UM3 at 35%. The proportion of farmers who had acquired secondary education was 30% in UM1, 40% in UM2 and 30 % in UM3. The proportion of farmers who had acquired university education was a low in the in all zones at 0 % in UM1, 0.05 % in UM2 and 0.05 % in UM3.

Table 4: Levels of education attained by farmers in Embu County

Education Level	AEZ	Frequency	Percent
Primary	UM1	9	45a
	UM2	7	35a
	UM3	7	35a
Secondary	UM1	6	30a
	UM2	8	40a
	UM3	6	30a
Tertiary	UM1	5	25a
	UM2	4	20a
	UM3	6	30a
University	UM1	0	0a
	UM2	1	0.05a
	UM3	1	0.05a

Percentages of farmers followed by similar letters along the column are not significantly different at $P \leq 0.05$.

4.3.1.4 Sources of income

The main source of income for the farmers who engaged in different income generating activities in the respective agro-ecological zones is indicated in Table 5. Though not significantly different ($P \leq 0.05$), most of the farmers termed sale of farm produce as their main source of income. There were significant differences ($P \leq 0.05$) between the proportions of farmers who got their main income from sale of livestock products, UM1 had the highest proportion of farmers with 75% compared to UM2 with 40% and UM3 with 35 %. There were significant differences ($P \leq 0.05$) between proportions of farmers who reported small business as their main source of income with 50 % of farmers in UM3 compared to 20 % in UM2 and 5 % in UM1.

Table 5: Main Sources of income for farmers in Embu County

AEZ	Sale of farm produce	Sale of livestock	Small Business	Dividends	Pension	Formal employment	Lease	Rent	Casual Labour	Support from family members	Interest
UM1	100^a	75^a	5^b	10^a	0^a	35^a	10^a	20^a	0^a	5^a	10^a
UM2	95^a	40^b	20^b	5^a	15^a	45^a	0^a	10^a	10^a	0^a	20^a
UM3	95^a	35^b	50^a	5^a	0^a	25^a	10^a	20^a	0^a	5^a	30^a

Proportions of farmers followed by different letters along the same column is significantly different at $P \leq 0.05$

4.3.1.5 Land sizes and use

There were significant differences (P≤0.05) between the average sizes of land owned in acres across the zones as indicated in table 6. Farms in UM3 were significantly bigger in size at an average of 2.8325, compared to the farms in UM2 and UM1 where land sizes averaged 1.7425 and 1.40125 acres, respectively. Significantly higher land proportions of 0.686 acres were allocated for tea production in UM1, compared to UM2 and UM1 at 0.288 and 0.0, respectively. A significantly higher proportion of land size was allocated for coffee production in UM3 and UM2 compared to UM1. The average land sizes allocated to the banana production did not vary significantly (P≤0.05) across the zones. However, it ranked among the top three crops which are grown by farmers in Embu County. In UM1, it ranked second after tea and in UM2 it ranked second after coffee while in UM3 it was third after coffee and maize respectively.

Table 6: Farm sizes in acres and main crops produced in Embu County

Mean farm sizes		
Size	**AEZ**	**Mean acreage (Acres)**
Total farm size	UM1	1.40^{b}
	UM2	1.74^{b}
	UM3	2.83^{a}

Main crops grown by farmers in Embu County based on mean acreage allocated								
AEZ	**Tea**	**Coffee**	**Banana**	**Maize**	**Bean**	**Macadamia**	**Mango**	**Vegetable**
UM1	0.69^{a}	0.0^{b}	0.35^{a}	0.11^{a}	0.18^{a}	0.02^{a}	0.0^{a}	0.01^{a}
UM2	0.29^{b}	0.32^{a}	0.31^{a}	0.22^{a}	0.08^{a}	0.03^{a}	0.0^{a}	0.02^{a}
UM3	0.0^{c}	0.43^{a}	0.29^{a}	0.31^{a}	0.18^{a}	0.03^{a}	0.04^{a}	0.03^{a}

Mean land sizes followed by different letters along each column are significantly different at P≤0.05.

4.3.2 Banana pests and market loss

4.3.2.1 Banana pests

Farmers in all the agro-ecological zones reported to have noticed changes in trends of banana pests as shown in table 7. The higher proportion of farmers reported to have noticed an increase in pest trend, with 70 % in UM1 and UM3, compared to 45 % in UM2. However, significantly high ($P \leq 0.05$) proportion of farmers in UM2, 40 % reported the trend to have decreased as compared to 30 % in UM1 and 5 % in UM3.

Table 7: Pest trends noticed by farmers in Embu County

% of farmers who noticed changes in trend			
AEZ	**YES**	**NO**	
UM1	100[a]	0.0[a]	
UM2	90[a]	10[a]	
UM3	85[a]	15[a]	
	Type of change noticed		
	Increased	**Decreased**	**Remained the same**
UM1	70[a]	30[ab]	0[a]
UM2	45[a]	40[a]	10[a]
UM3	70[a]	5[b]	10[a]

Proportions of farmers followed by different letters along each column are significantly different at $P \leq 0.05$.

4.3.2.2 Factors attributed to change

High proportion of farmers attributed the changes in pest trend to the increase in temperature in all the agro-ecological zones with 65 % in UM1, 35 % in UM2 and 45 % in UM3. Other factors that could be contributing to the change included decrease in temperature, emergence of new crop diseases and change in weather patterns (Fig. 4)

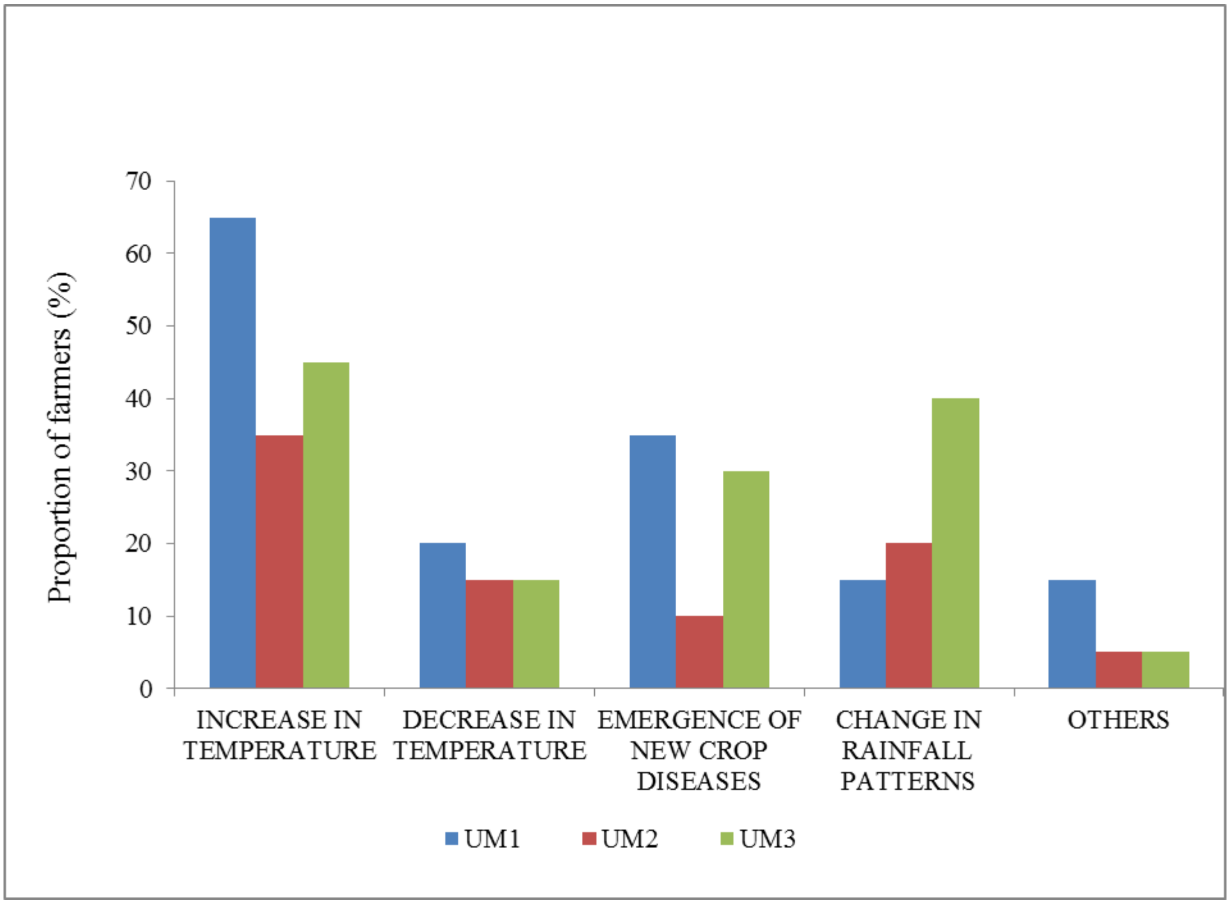

Figure 4: Factors attributed to change in pest trends as perceived by farmers in Embu County

4.3.2.3 Importance of pests

Thrips were ranked as the most important pest by the farmers. A significantly higher ($P \leq 0.05$) percentage of the farmers (85 %) in UM1 perceived thrips as very important pests whereas in UM2 and UM3 there were only 25 % and 5 % respectively. Significantly high ($P \leq 0.05$) percent of farmers, 60 % in UM3 recognized thrips as slightly important compared to 25 % in UM2 and 0.0 % in UM1. Significantly high ($P \leq 0.05$) proportion of farmers 35 % in UM2 recognized nematodes as very important compared to 10 % in UM3 and 5 % in UM1.

A significantly high proportion of farmers reported banana weevil to be moderately important (45 % in UM3, 20 % in UM1 and 5 % in UM2). A small proportion of farmers (20 % in UM3 and none in UM1 and UM 2) reported banana weevil as very important. There were significantly high (P≤0.05) differences between the proportions of farmers who reported banana weevil as a slightly important pest with 35 % of farmers in UM1, 10 % in UM3 and 5 % in UM2 (Table 8).

Table 8: Ranking of pests as perceived by banana farmers in Embu County

	Pest Importance								
	Thrips			**Nematodes**			**Banana Weevil**		
AEZ	**Very**	**Moderately**	**Slightly**	**Very**	**Moderately**	**Slightly**	**Very**	**Moderately**	**Slightly**
UM1	85a	15a	0.0c	5b	20a	35a	0.0b	20ab	35a
UM2	25b	45a	25b	35a	20a	10a	0.0b	5b	5b
UM3	5b	35a	60a	10b	35a	10a	20a	45a	10b
Rank		1			2			3	

Percentages of farmers followed by different letters along each column are significantly different at P≤0.05.

4.3.2.4 Banana thrips

Farmers in all the three agro-ecological zones reported to have noticed thrips damage on their banana of 100 % in UM1, 100 % in UM2 and 95 % in UM3 as shown in table 9. A significantly high (P≤0.05) proportion of farmers (47 %) in UM1 reported upto 75 % of the crop to have been damaged compared to 5 % in UM2 and none in UM3. Seventy percent (70 %) of the farmers in UM3 which was significantly high (P≤0.05) reported that less than 10 % proportion of their crop was damaged compared to 30 % in UM2 and 10 % in UM1 (Table 9).

Table 9: Proportion of farmers who noticed part of the crop was damaged by thrips in Embu County

AEZs	% of farmers				
	Proportion of the crop damaged				
	Less than 10 %	Upto 25 %	Upto 50 %	Upto 50 %	Over 75%
UM1	10^{b}	10^{a}	35^{a}	47^{a}	0.0^{a}
UM2	30^{b}	40^{a}	25^{a}	5^{b}	0.0^{a}
UM3	70^{a}	10^{a}	10^{a}	0.0^{b}	0.0^{a}

Percentages of farmers followed by different letters along each column are significantly different at $P \leq 0.05$.

4.3.2.5 Seasonal thrips damage on banana

The majority of farmers in all zones reported that thrips damage varied across the year. High proportions of farmers indicated that hot and dry season had the most severe damage (Table 10).

Table 10: Farmers perception of thrips damage across the year and season most severe in Embu County

AEZs	% of farmers			
	Season when thrips damage is most severe			
	Dry and Hot	Cool and Dry	Cool and Wet	Warm and Wet
UM1	70^{a}	10^{a}	20^{a}	0^{a}
UM2	65^{a}	15^{a}	5^{a}	15^{a}
UM3	60^{a}	20^{a}	10^{a}	10^{a}

Percentages of farmers followed by similar letters along each column are not significantly different at $P \leq 0.05$

4.3.2.6 Loss of marketability

A significantly high (P ≤0.05) percent (65 %) of farmers in UM1 indicated that a proportion of upto 25 % of fingers was damaged by thrips compared to 20 % in UM2 and 5 % in UM3 areas whereas a significantly high proportion of farmers (60 % in UM3 and 45 % in UM2) reported 0% damage on the fingers (Table 11).

Table 11: Marketability loss assessment due to thrips damage on banana fingers in Embu County

	% of farmers				
AEZs	**Proportion of fingers damaged**				
	0 %	**10 %**	**Upto 25%**	**Upto 50 %**	**More than 50%**
UM1	10b	10	65a	10a	5a
UM2	45a	30	20b	0.0a	0.0a
UM3	60a	30	5b	0.0a	0.0a

Percentages of farmers followed by different letters along each column are significantly different at P≤0.05.

4.3.2.7 Control of thrips

High proportion of farmers in all zones reported not to have taken any measure to control thrips. (100 % in UM3, 85 % in UM2 and 80 % in UM1). Use of chemicals was reported by 15 % and 10 % of the farmers in UM1 and UM2 respectively. A small proportion of 5 % in UM2, applied botanical extracts (Table 12).

Table 12: Thrips control measures taken by banana farmers in Embu County

	% of Farmers		
AEZ	**No Measures taken**	**Application of botanical extracts**	**Application of chemicals**
UM1	80a	0a	15a
UM2	85a	5a	10a
UM3	100a	0a	0a

Percentages of farmers followed by different letters along each column are significantly different at P≤0.05.

4.3.3 Market and agricultural information

4.3.3.1 Market information

A higher proportion of farmers relied on their neighbours as the main source of banana market information as shown in fig 5. Only 20 % of the farmers got information from radio whereas a much smaller proportion obtained market information from other sources such as the internet and print media. Extension officers were the second preferred source of market information.

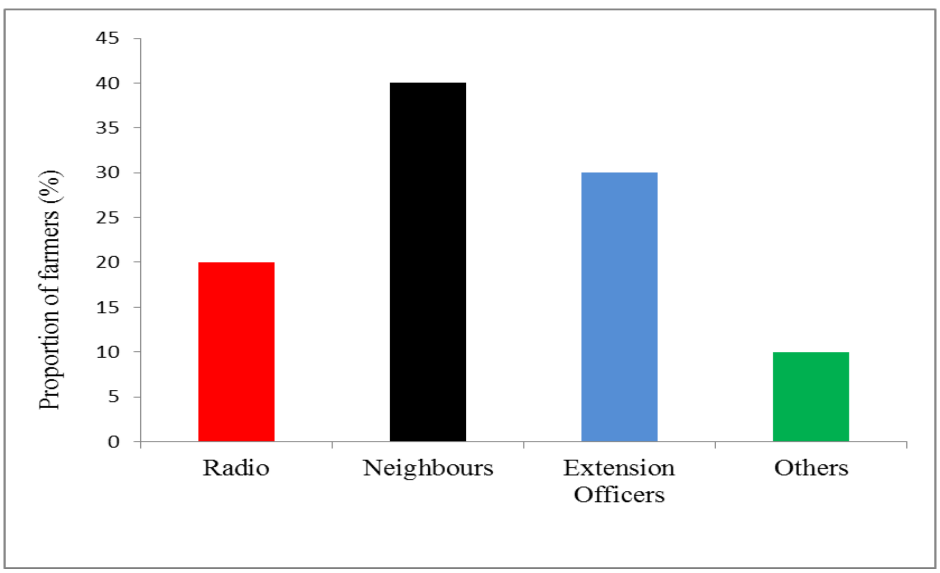

Figure 5: Farmers sources of market information in Embu County

4.3.3.2 Membership to social groups

Majority of the farmers or their family members belonged to one or more social or community based organization. A higher proportion (45%) had membership to women groups, while 42.5 % were members of co-operative societies. Membership to microfinance was 8.8 % whereas farmers associations, community/ village group and community marketing groups had a membership of 1.3% which was much lower compared to other organisations (Fig. 6).

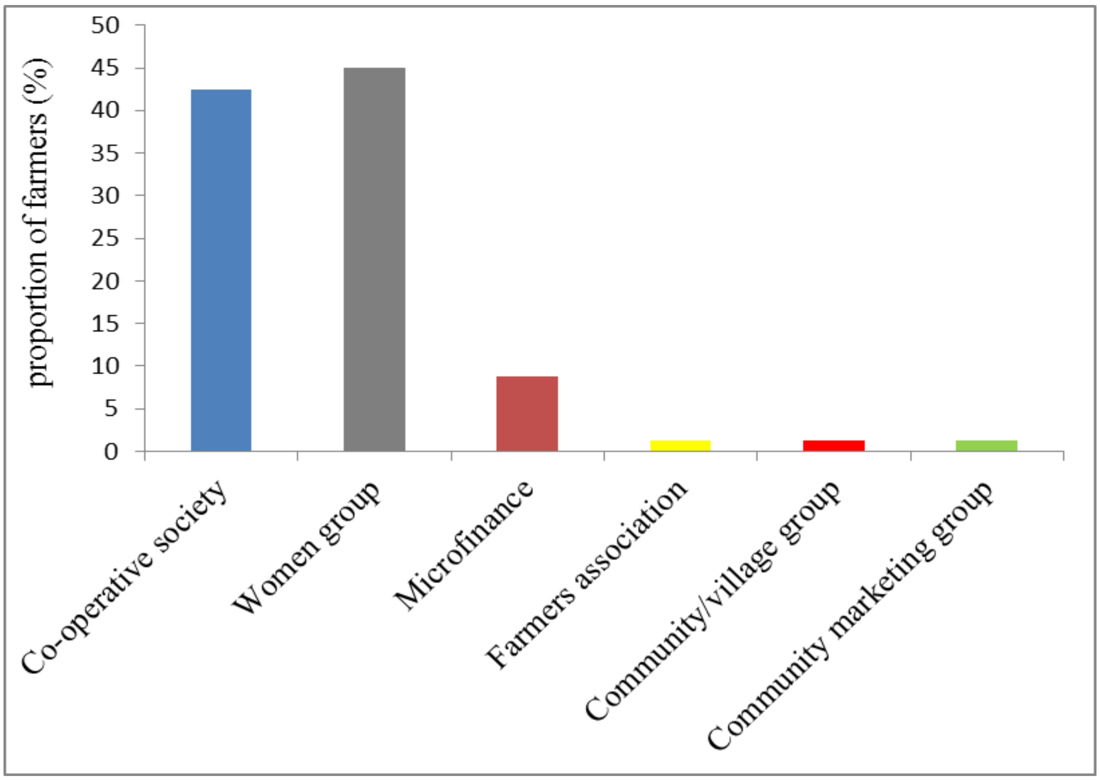

Figure 6: Membership of banana growers to social and community groups in Embu County.

4.3.3.3 Services rendered by social/community groups

Farmers who were accrued some benefits from membership to various social organizations with a proportion of 44.2 % receiving loans from their organizations. Other benefits were savings, training and input access (Fig. 7).

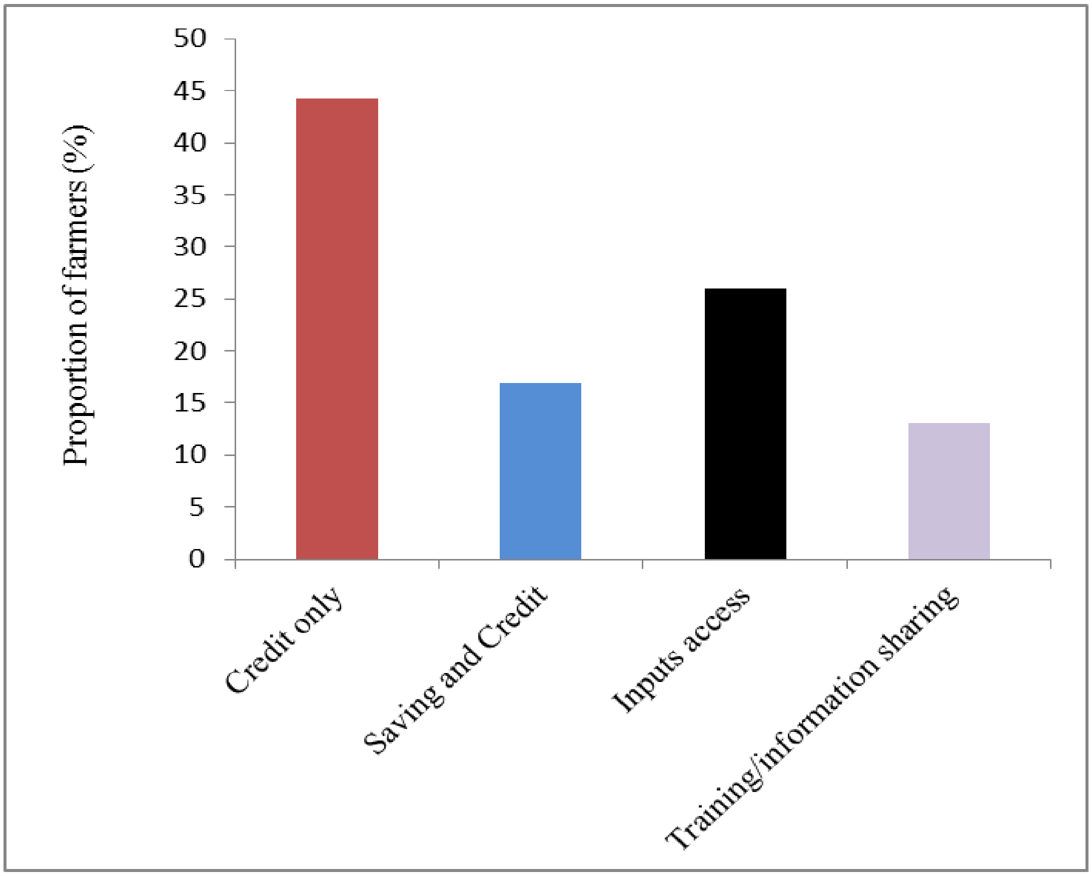

Figure 7: Services rendered to farmers by social and community groups in Embu County

4.3.3.4 Sources of agricultural information

All farmers interviewed ranked government extension officers as their most preferred source of agricultural information. Other sources cited were private extension, neighbours, field days, other farmers, field days and NGO's in order of decreasing importance (Fig. 8).

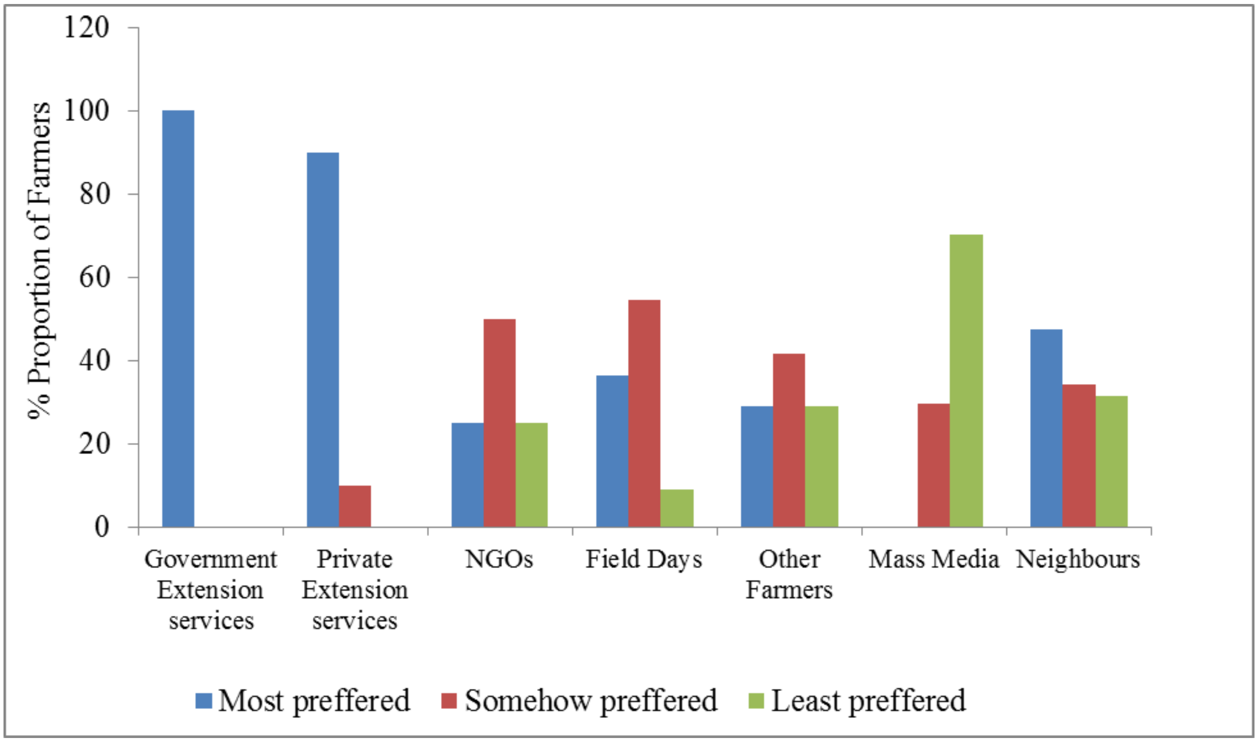

Figure 8: Sources of agricultural information for farmers in Embu County

4.4 Discussion

Gender of the farmers who were interviewed showed that the majority of household heads were male hence the responsibility to make decisions on which crops to grow and technologies they should adopt on their farms. This agrees with a study conducted by Raphael (2013) in Maragua, Kenya which showed that majority of the households heads in banana farms were males. The findings also concur with studies done by Ogunsumi, (2007) on the socio-economic conditions of peasant farmers in Southwest Nigeria, which showed that the majority of the respondents who were interviewed were male household heads and decisions on agriculture activities were influenced by the heads. The findings also relate to Iwueke (2006) on farmer related factors influencing the adoption of agricultural innovations in Imo.

The age of the respondents was varied with the majority of the household heads aged above 50 years. Old farmers are less amenable to change from their way of doing things as their age represents experience in farming. These results suggest that older farmers are less likely to adopt new thrips management technologies than younger farmers. As with experience and age, many famers stick to the old ways of farming rather than trying new techniques, probably due to their risk averse tendencies (Deressa *et al*. 2010). However, older farmers have attained hands-on experience with time and have more exposure to credit and extension services unlike younger farmers.

The education levels of the household heads were varied from primary to university with primary level being the majority. A study done by Njoku (1991) found that farmers age and education level influence the level of technology adoption on smallholder farms. Thi and Yamada (2002) in their studies indicated that technology adoption was found to be positively related to the education level of the farmer. Education is key to improving agricultural production especially on decision making regarding new technologies. Education is widely considered to be the most important form of human capital (Schultz, 2005). Low level of formal education is a barrier in disseminating useful information and the rate of adoption varies from farmer to farmer depending upon the situation and availability of information sources (Taley and Khadase, 2006). In particular, highly educated farmers tend to adopt productive innovations faster than those who are relatively poorly educated (Basu *et al.*, 2002). Knight *et al.* (2003) have found that the schooling of the head of the household reduces risk aversion and encourages the adoption of agricultural innovations in rural Ethiopia. According to Akinbile (2003), the more literate farmers are, the more they are likely to comprehend technologies. Primary education level being the majority coupled with old age may affect negatively adoption of new thrips management technologies.

The majority of farmers had more than one main source of income. This meant that they had some income at their disposal to access inputs, quality planting materials and information. Farmers endowed with resources such as livestock are more likely to access information on new agricultural technologies and consequently adopt them unlike the resource-poor ones (Bationo *et al*., 2004, Dutta, 2009).

The average size of the land owned was 1.96 acres which corroborates a study by Enoch *et al.*, 2013 who reported that the average size of land in major banana growing areas of Kenya is less than 5 acres. This is contrary to studies by Qaim, 1999 who reported that the average size is less than 0.5 acres. All banana farmers grew other crops in their farms with the selection of crops mostly being dictated by the agro-ecological zone. The types of crops grown may have a negative impact on farm thrips populations, since they are polyphagous and the crops grown could serve as alternate hosts.

Thrips were ranked as the most important pest in all zones. This could have been because their attack causes silvery blemishes on fingers that are easily visible and this has a bearing on the average price of a damaged bunch. Bunches are visually inspected for the presence of thrips damage, hence the price negotiated with the buyer according to the percentage of the damage with prices dropping to even less than half of the undamaged bunch. Thrips attack was perceived to be most severe during dry and hot seasons. This is in agreement with studies done by Nyasani *et al.* (2012), Stacey and Fellowes (2002) and Pearsall and Myers (2001) who showed that temperature affects the development rate of thrips and consequently their population dynamics positively.

Farmers in UM1 and UM2 reported high losses due to thrips compared to those in UM3. This could be attributed to cropping systems practiced and varietal influence on thrips infestations. Most of the farmers who were interviewed did not undertake any control measures in all the zones despite having noticed the damage. This could have been due to the limited pest management knowledge that left farmers with no options.

All farmers who were interviewed belonged to social/ community based groups. These groups help members to gain access to credit, extension services and collective purchase of inputs (Owuor *et al.,* 2004). Farmer groups have also become entry-points for the Non-Government Organisation (NGOs) and other organisations promoting agricultural development to reach many targeted farmers and reduce cost of operations. According to Owuor *et al*. (2004), farmer groups were effective, especially in pooling external inputs, lobbying for favorable policies and disseminating market information in Kenya. This is critical for banana farmers especially in marketing of the crop. Thus, farmers that are members to a group are likely to produce more and consequently sell more due to skills and joint learning among them as opposed to those who do not belong to any group.

The majority of farmers obtained market information from their neighbours. The information mostly involved the price per kilo or per bunch offered by the buyers. According to Uematsu and Mishra, (2010) farmers with higher education have better access to information and knowledge. This form of information exchange coupled with unorganized marketing platform and lower education levels may negatively affect the returns that farmers accrued from banana farming as they may not be able to get up to date market information. Farmers with wider market information may avoid losses especially in terms of surplus. Kamara, *et al*. (2002) observed that large quantities of agricultural commodities which are produced by farmers tend to rot away un-marketed, while the smallholder farmers do not have the technology for timely consumption.

Agricultural productivity is improved by relevant, reliable and useful information and knowledge (Demiryurek *et al.,* 2008), thus agricultural information is essential for improving agricultural production. Farmers had many sources of agricultural information such as government extension, private extension, NGOS, mass media, neighbours and other farmers. Government extension services were the most preferred source of agricultural information and this could be attributed to the built-in feedback potential and the fact that the source is highly credible (Rogers, 1995).

4.5 Conclusion

1) Thrips cause significant losses in banana.
2) Farmers do not seem to apply any thrips control measures.
3) The farmers perceive that damage is more severe during hot and dry season.

4.6 Recommendations

1) Although banana farmers in Embu could identify thrips damage and seasons when damage is severe, there were no clear thrips management strategies deployed by the farmers. There is need for entomologists to develop integrated and cost effective strategies that can be adopted by farmers.
2) More research also needs to be directed on varietal influence and soil fertility to increase banana production.

CHAPTER FIVE

EFFICACY OF POLYTHENE SLEEVES AND PLANT EXTRACTS IN THE CONTROL OF BANANA THRIPS

Abstract

Thrips have become a major problem in agriculture particularly in horticulture, with their pest status seemingly increasing on a wide range of crops worldwide. Two field experiments were conducted to determine the efficacy of different coloured polythene sleeves and plant extracts in the control of banana thrips. The first experiment was conducted to determine the effect of polythene bunch covers on thrips in banana. Four differently coloured sleeves which consisted of black, blue, yellow and clear were evaluated against untreated control.

The second experiment was carried out to assess the efficacy of different plant extracts against thrips in banana. The rates were Imidacloprid (Confidor®) (5g/20l), neem leaves extract (1000g/20l), Garlic bulb extract (1000g/20l) and pepper (500g/ 20l). In both experiments, treatment applications started at the flowering stage when thrips were expected to infest the male flower buds.

This study showed that all polythene bunch covers across the three zones had similar level of control. Black polythene resulted to the scorching of bunches in lower and mid zones. Imidacloprid (Confidor®) had significantly ($P \leq 0.05$) higher efficacy on thrips compared to neem, pepper and garlic treatments. Bunches sprayed with the neem extract had significantly less damage compared to garlic and pepper whereas those sprayed with pepper had the highest damage symptoms. The results obtained from this study show that plant extracts have some effect on thrips albeit with varying levels thus they can be deployed as alternatives for thrips management on banana and as a tool for insecticide resistance management.

5.1 Introduction

Thrips (Thysanoptera: Thripidae) are one of the most significant agricultural pests globally because of the damage they inflict on a wide range of crops. They have been ranked as primary pests of many horticultural crops in Kenya. According to Nderitu *et al*. (2008) and Nyasani *et al*. (2013) thrips are the most important pests of French beans causing up to 60 % losses. Adults and larvae feed by piercing plant tissues with their needle-shaped mandible and sucking the contents of punctured cells (Kirk, 1997b). Feeding by adults and larvae produces scarring on foliage, flowers and fruits, which results in aesthetic crop damage and disrupts plant growth and physiology. Also, oviposition produces wound responses in fruiting structures, which reduces the marketability of certain horticultural produce (Childers, 1997).

Thrips cause silverly scarring on banana thus reducing their marketability since consumers use visual quality to purchase fresh produce (Shewfelt, 1999; Shewfelt, 2009). Banana bunches with thrips scarring have less demand at the market level as consumers prefer large fruits that are blemish-free (Johns, 1996). The supply of blemish-free fruit is difficult due to various types of mechanical injury and insect damage imparted on the delicate peel surface during growth and development, with wind and insects being the principal agents of this damage (Anon, 2003). Pre-harvest insect feeding has been shown to be a main cause of peel damage to the banana fruits (Shanmugasundaram and Manavalan, 2002).

Methods for banana thrips management are still limited but use of polythene bags as bunch covers has been shown to protect fruits from insect attack (Amarante *et al*., 2002). Wind blows dust and debris which hit the delicate outer skin causing cellular damage and subsequent fruit scarring. Considerable physical injury and damage to the fruit peels can also be caused by the blowing of adjacent leaves and rubbing of leaf petioles onto the developing bunch (Anon, 2003). This chaffing from leaves during growth is eliminated by bunch covers (Weerasinghe and Ruwapathirana, 2002). Bunch covers of various colours and conditions (perforated and non-perforated) have been extensively used in both tropical and subtropical banana growing countries with the aim of improving yield and quality (Stover and Simmonds, 1987; Robinson, 1996). Improved quality includes appealing skin colour, reduced sunburn, reduced fruit splitting, increased finger length and bunch weight among others (Robinson, 1996; Amarante *et al*., 2002). Bunch covers have also been used to protect bunches from low temperatures, especially in temperate countries (Gowen, 1995; Robinson, 1996; Harhash and Al-Obeed, 2010). Indeed bagging has been shown to reduce winter stress under supra-optimal condition which resulted in early fruit maturation (Jia *et al*., 2005). This is due to enhanced physiological and metabolic activities provided by the microclimate which is created by bagging (Johns and Scott, 1989a).

Plant extracts have been shown to repell insect attack on crops (Talukder, 2006, Sahayaraj, 2008). The practice of using plant derivatives or botanical insecticides in agriculture dates back at least two millennia in ancient China, Egypt, Greece and India (Isman, 2006). Plant derived materials are more readily biodegradable, less likely to contaminate the environment and may be less toxic to mammals (Isman, 2006). A great number of plant species from a wide range of families have been assessed for their toxic, antifeedant and repellant properties on pests (Isman, 2006; Talukder, 2006; Dubey *et al*., 2008; Ogunleye et *al*., 2010).

Plant extracts possess one or more useful properties such as repellency, antifeedant, fast knock down, flushing action, biodegradability, broad-spectrum of activity and ability to reduce insect resistance (Hazarika *et al.,* 2008). Some of them have weak insecticidal effects or may require other plant species with different modes of action to increase their potency (Oparaeke, 2004).

Botanical pesticides are extracted from various plant parts as leaves, stems, seeds, roots, bulbs, rhizomes, unripe fruits and flower heads of different plant species. Botanical pesticides are hailed for having a broad spectrum of activity, being easy to process and use, having a short residual activity and for not accumulating in the environment or in fatty tissues of warm blooded animals, (Philip and Robert, 1998). Their modes of action against pests are diverse. Natural compounds are well suited to organic food production in industrialized countries and can play greater roles in the protection of food crops in developing countries. Some plant based insecticides such as neem products, pyrethroids and essential oils are already used to manage pest populations on a large scale. They are environmentally safe, less hazardous, economic and easily available (Mamun, 2011). However, there are no reports of studies done in Kenya on management of thrips in banana.

This study was therefore undertaken to assess the effect of polythene bunch bagging and use of plant extracts on the percentage and intensity of damage on banana fruits in Embu County.

5.2 Materials and methods

5.2.1 Study area

Two studies were carried out in the six already established banana orchards in Runyenjes sub-county which lies between 1,200 – 2070 m above sea level. The annual average rainfall is between 1000 – 2000 mm and distribution is bimodal. The area was stratified into three agro-ecological zones (AEZ) namely; Upper highland (UM1), mid highland (UM2) and lower highland (UM3), (Jaetzold *et al*., 2006).

5.2.2 Effect of botanical extracts in the management of banana thrips

Three farms were selected one in each of the three agro-ecological zones (UM1, UM2 and UM3) with good banana stands. Randomized complete block design (RCBD) was used to lay the experiment. Each farm was subdivided into three equal blocks. Each block was then divided into five equal plots of banana stools and the treatments were randomly assigned into each plot. The treatments were; Neem, Garlic, Pepper, Imidacloprid (Confidor®), and the control (untreated) which were replicated three times. Crude plant extracts were prepared as follows;

One kilogram of fresh leaves of *Azadirachta indica* (neem) were obtained from a private farm in Runyenjes, Embu County. They were picked from the plant and placed in polythene bag. They were then crushed and covered with a clean cloth then soaked in 20l water for 24 hours.

one kilogram of *Allium sativum* (garlic) bulbs was sourced in Embu town vegetables market and placed on clean polythene bag. The bulbs were then crushed and covered with a clean cloth then soaked in 20l water for 24 hours.

500g of *Capsicum frutescens* (pepper) was sourced in Embu town vegetables market and placed on clean polythene bag. The pepper were then cut into small pieces then boiled in 5l of water to make a strong tea and mixed with 20l of water.

Imidacloprid (Confidor®) dosage rate was used according to the label recommendation for thrips on snap beans which was 5 g per 20l of water. The application was done in the morning hours using 20l knapsack sprayer and the applications were repeated once weekly for four weeks.

Damage assessment for thrips was then carried out when the fingers were ¾ mature using silvery patches on banana fingers. Percentage surface area damaged was rated based on the Merz 0 to 6 scale (Merz, 2000), adopted for surface area covered by damage instead of lesions where, 1 = 0 to 2%, 2 = 2 to 5%, 3 = 5 to 10%, 4 = 10 to 25%, 5 = 25 to 50% and 6 = > 50% of the surface area covered by thrips damages. Incidence of thrips damage was determined by counting the number of damaged fingers over the total number of fingers per bunch.

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5.2.3 Effect of polythene bunch covers in management of banana thrips

One farm was selected in each of the three agro-ecological zones (UM1, UM2, and UM3) with good banana stands. Randomized complete block design (RCBD) was used to lay the experiment. Each farm was subdivided into three equal blocks. Each block was then divided into five equal plots and the treatments randomly assigned into each plot. The treatments were four different coloured (Blue, Black, Clear, Yellow) polythene sleeves measuring 30 x 36″and control (uncovered) which were randomly assigned into each plot then replicated three times.

The bags were perforated using a needle to avoid the build-up of excessive humidity and heat. They were put when the inflorescence were emerging and firmly tied at the basal end using a rubber band. The bags were removed after 20 days and firmly tied on the stem as a mark. The male bud (distal end) was removed immediately (as per farmer cultural practices).

Damage assessment for thrips was as described in 5.2.2.

5.2.4 Data analysis

Data was subjected to analysis of variance (ANOVA) using Microsoft Excel version 2010 and SAS 9.2 statistical packages for analysis of variance (ANOVA). Significantly different means at $P \leq 0.05$ were separated using the Tukey-Kramer's HSD comparison test.

5.3 Results

5.3.1 Effects of differently coloured polythene bunch covers on thrips damage severity

All polythene bunch covers applied successfully reduced the percentage of scarring and was significantly different from the control in all the zones (Table 13), and there was no significant difference between the different coloured bunch covers among themselves and across the zones.

The total damage on bunches was rated between 1-5 % in all the zones thus marketability was not affected.

Table 13: Effects of polythene bunch covers on severity of damage by thrips on banana fingers across the zones based on the Merz 0 to 6 scale in Embu County

Treatment	scarring / silvery blemishes (Rating)		
	UM1	UM2	UM3
Blue	1b	1b	1b
Black	1b	1b	1b
Yellow	1b	1b	1b
Clear	1b	1b	1b
Uncovered	6a	6a	5a

Percentage damage followed by different letters in each column are significantly different at $P \leq 0.05$

5.3.2 Effects of black polythene on fingers

Bunches covered with black polythene exhibited some scorching effect on fingers across the zones. UM2 and UM3 expressed higher percent of fingers scorched on the first two hands on the side with direct sunlight.

5.3.3 Effects of plant extracts on thrips damage incidence on banana fingers across the zones

Thrips damage was evident in all the experimental plots as silvery patches appeared on fingers. Thrips damage incidence was significantly (P≤0.05) high on the unsprayed and the plots sprayed with pepper which was visible as the fingers attained their physiological maturity. Significantly (P≤0.05) fewer fingers were damaged from bunches on the plots sprayed with Imidacloprid (Confidor®). Bunches sprayed with neem and garlic extracts did not differ significantly (P≤0.05) with regard to thrips damage incidence (Table 14).

Table 14: Effects of plant extracts on incidence of damage by thrips

Treatment	AEZs		
	UM1	**UM2**	**UM3**
Confidor®	12.2^{d}	11.2^{d}	11.5^{d}
Neem	21.9^{c}	21.5^{c}	22.9^{c}
Garlic	24.9^{c}	25.5^{c}	25.0^{c}
Pepper	40.9^{b}	40.6^{b}	41.0^{b}
Unsprayed	65.6^{a}	65.8^{a}	66.1^{a}

Means followed by different letters in each column are significantly different at P≤0.05

The damage severity by thrips varied significantly among different treatments. Bunches from the plots sprayed with Imidacloprid (confidor®) had fingers with significantly lower percent of scarring compared to all the other treatments in all the agro-ecological zones. In UM1 the scarring was about 1-5 % of the total surface area of fingers damaged, In UM2, percentage of scars/ blemishes on the bunches from the plots sprayed with Imidacloprid (confidor®) did not differ significantly with those from plots sprayed with neem. Plots that were sprayed with neem and garlic did not differ significantly however the level of damage was significantly lower than those that were sprayed with pepper and the unsprayed ones. The plots sprayed with pepper had the highest level of damage compared to other extracts. There was no significant difference between bunches sprayed with pepper and those from the unsprayed plots (Table 15).

Table 15: Thrips damage severity per finger across the zones based on the Merz 0 to 6 scale

Treatment	% scarring		
	UM1	UM2	UM3
Confidor®	1c	1c	1c
Neem	3b	2bc	3b
Garlic	3b	3b	3b
Pepper	5a	5a	5a
Unsprayed	6a	5a	6a

Percentage damage followed by different letters in each column are significantly different at $P \leq 0.05$

5.4 Discussion

In the present study, differently coloured polythene bags attained high control of thrips and this could be attributed to the physical barrier they offered to thrips thus limiting access to the forming fingers. Since bunch covers were placed only for the limited period of flowering and finger formation, thrips severity reduction therefore indicated that thrips infest and inflict scarring damage on banana at the flowering stage and during the fruit formation. Timely placement of the polythene bags at the emergence of inflorescence therefore provided a physical barrier for thrips to access the forming fingers. This could be possibly because the fruits were protected from the thrips during the pollen collecting time, which is a prominent source of protein for thrips to produce an egg (Tsai *et al*., 1996). Studies on citrus have demonstrated that late placement of 3–5 weeks after flowering increased the severity of fruit damage (Hasyim *et al*., 2003). Scarring on young fingers leaves a characteristic silvery appearance (De Jager, 1995). Damage to plants may also occur when females use their sharp ovipositors to insert eggs into the plant tissues (Jensen, 2000). High reduction on the percentage of scarring by the polythene bag was possibly due to the effective barrier of that treatment to cut off the lifecycle of the thrips.

Bunches from the plots covered with black polythene bags in UM3 and UM2 zones demonstrated scorching effect on the fingers and this could be attributed to the heat absorbing effect of the black coloured materials due to high daily temperatures in lower altitudes. Black-plastic when struck by sunlight, absorbs most of the energy at all the wavelengths of significance as ultra-violet, visible, and infrared then re-emits that energy as long wavelength thermal radiation. This contradicts earlier studies that showed bagging of bananas resulted in sun scorching of the fruits irrespective of the colour of the bunch covers (Weerasinghe and Ruwapathirana, 2002).

Observation on bunches from the plots sprayed with Imidacloprid (confidor) showed a high reduction in damage level. Dzemo *et al.*, (2010) observed that chemicals provide a rapid, effective and dependable means of controlling complexes of insects. The nymphal thrips were found to be more sensitive to the test insecticide than the adult thrips as a result of their larger numbers, low mobility, confined habit and gregarious feeding on the plants. Imidacloprid has a systemic mode of action thus its ability to be translocated to all parts of the crop even with poor coverage thus enhancing its efficacy.

Bunches from the plots sprayed with neem had a significant reduction in damage severity. Neem contains azadirachtin which has a broad mode of activity, working as a anti-feedant, insect-growth regulator, repellent, and sterilant; and it may also inhibit oviposition or hatching (Isman, 2006). The garlic sprayed plots also resulted in reducted severity of the damage. These findings agrees with a study by Ekesi (2000) who reported that crude extract of garlic bulbs and neem extracts significantly reduced egg viability thus minimizing the gregarious larvae stage which is more destructive.. The insecticidal and repellent activity of garlic has been widely reported (Rahman and Motoyama, 2000; Amiri, 2009). The bulb of garlic has been reported to possess insect controlling properties with repellant, antifeedant, bactericidal, nematicidal and fumigant mode of action that kill aphids and other soft bodied pests (Grainge *et al*.,1985). Jacquelin du Val indicated that two essential oils in garlic and onion had potent fumigant activities (Isikber, 2010).

Osipitan and Mohammed (2008) reported the ability of garlic to repel borers, fleas, ticks and thrips.

Capsicum frutescens and *Capsicum annum* have insecticidal properties (Oni, 2009). Pepper derivatives have been regarded as safe, affordable and effective natural plant products with some degree of medicinal and insecticidal properties (Ashamo, 2007; Oni, 2009; Adedire and Lajide, 2001). However, in this study pepper was found to be ineffective for thrips management as its treatment had the highest damage levels.

5.5 Conclusion

The study has shown that the various thrips management approaches which were applied have considerable potential for managing thrips in Embu County. The percentage damage on the bunches was found to reduce with the placement of polythene bunch covers. Imidacloprid (Confidor®) and sleeves offered the best protection resulting in higher quality of fingers. There was a remarkable reduction in damage by neem and garlic extracts. Farmers can use the combination of these strategies for effective thrips management hence high banana quality. The use of any of the management strategy would therefore depend on the availability, cost, environmental sustainability and compatibility with the farming systems and production practice in the zone. The placement of sleeves and plant extracts must coincide with the most vulnerable growth stages of the crop and high risk period of insect pest infestations.

5.6 Recommendations

1) All polythene bags can be adopted for thrips management except the black coloured one due to scorching effect.
2) The Imidacloprid (Confidor®), neem and garlic maybe used interchangeably to manage thrips to avoid dependence on a single tactic that would lead to the build up of resistance.
3) Further work needs to be done to verify the economic efficacy of these management strategies under multiple seasons and locations.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

Thrips can contaminate a wide variety of commodities because of their small size, ability to build to high numbers, cryptic behavior, egg deposition inside plant tissue and a propensity to secrete themselves in tight spaces (Morse and Hoddle, 2006). They preferentially reside within flowers or other concealed, protected places on plants (Hansen et al., 2003; Kirk, 1997a). This thigmotactic behavior of thrips limits their exposure to many foliar applied insecticides. Also, the anthophilous nature of western flower thrips limits their exposure to systemic insecticides, which are not readily transported into floral tissues (Cloyd and Sadof, 1998; Daughtrey *et al*., 1997). They feed on plant tissue by piercing and sucking sap, resulting in tissue scarification and depletion of the plant's resources (Welter *et al*., 1990; Shipp *et al*., 1998). The scarification reduces the photosynthetic capacity of leaves and causes blemishes on fruits.

Several species infest the male flower buds resulting into scarification of young fingers as they emerge. Okwakpam (1967) found that any plant in Nigeria is attacked by one or more thrips species. This is in conformity with Higgins (1992) observation, in which he noted that different crops normally have a different number of species of thrips on them whereas he found two species on tomatoes, there were 29 species infesting barley.

Majority of banana farmers are old and with low levels of education and this may affect the adoption of new technologies in thrips management. Njoku (1991) found that farmers age and education level influence the level of technology adoption on smallholder farms. Thi and Yamada

(2002) in their study indicated that technology adoption is positively related to the education level of the farmer. Education is key to improving agricultural production especially on decision making regarding new technologies. It is also widely considered to be the most important form of human capital (Schultz, 2005). Low level of formal education is a barrier in disseminating useful information and the rate of adoption varies from farmer to farmer depending upon the situation and availability of information sources (Taley and Khadase, 2006).

In particular, highly educated farmers tend to adopt productive innovations earlier than those who are relatively poorly educated (Basu *et al.*, 2002). Knight *et al.* (2003) found that schooling of the head of the household reduces risk aversion and encourages the adoption of agricultural innovations in rural Ethiopia. According to Akinbile (2003), the more literate farmers are, the more they are likely to comprehend technologies. Primary education level being the highest level of education attained by most household heads coupled with old age may affect negatively adoption of new thrips management technologies.

Thrips cause silverly scarring on banana fingers thus reducing their marketability as consumers use visual quality to purchase fresh produce (Shewfelt, 1999; Shewfelt, 2009). The management of thrips using polythene bunch covers demonstrated their ability to offer physical barriers for thrips to access the male flower buds (Amarante *et al*., 2002). The colour of polythene bunch covers had no effect on scarring; however black coloured ones had fingers with sun burns.

The plant extacts which were applied exhibited a good level of control of thrips with neem and garlic reducing the level of damage. Neem contains azadirachtin which has a broad mode of activity, working as a feeding deterrent, insect-growth regulator, repellent and sterilant; and it may also inhibit oviposition (Isman, 2006). Ekesi (2000) reported that crude extracts of garlic bulbs and neem extracts significantly reduced egg viability thus minimizing the gregarious larvae stage which is more destructive.The insecticidal and repellent activity of garlic has been widely reported (Rahman and Motoyama, 2000; Amiri, 2009).

6.2 Conclusions

Banana is a major crop in Embu County and hosts several thrips species throughout the cropping seasons. These thrips cause significant qualitative yield losses as the bunches with damaged fingers are either bought at lower prices per kilogram or rejected altogether. Most farmers notice the thrips damage but no management measures have been instituted so far. Use of polythene bunch covers and plant extracts as neem and garlic would help to manage thrips thus reduce losses which farmers incur.

6.3 Recommendations

1). Having established that thrips species infesting banana vary, there is need to undertake further studies to identify the actual species that cause damage and which banana cultivars are more susceptible.

2). There is no thrips management strategy on banana in place, therefore further research needs to be carried out to offer a holistic management tactic that is not stand alone.

3). The cost of management practices is dependent on the value of the crop, therefore further research on cost benefits ratio of any management strategy proposed needs to be done.

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APPENDIX 1: BASELINE SURVEY QUESTIONNAIRE

CONSTRAINTS TO THE BANANA VALUE CHAIN IN EMBU COUNTY

Questionnaire number……………

1.0 HOUSEHOLD CHARACTERISTICS

1.1 Name of the farmer …………………………Location/Zone……………… GIS……

1.2 Gender of the head of household [1] = Male [2] = Female

1.3 Marital Status [1] = Married [2] = Single [3] = Widowed

1.4 Age of farmer in years: [1] = 20-30 [2] = 31-40 [3] = 41-50

[4] = 51- 60 [5] = ≥ 61

1.5 Age of the head household head (Years) _______________

1.6 Highest level of education for the head of the household

[1] = None [2] = Primary [3] = Secondary [4] = Tertiary [5] = University

1.7 No. of household members? ____________

1.8 No of dependants: children under 18 years______Old people (over 60)_______

1.9 What are the three (3) main sources of the household income?

[1]= Sale farm produce [2]= Formal employment [3]= Sale of livestock

[4]= Small Business [5]= Casual labour [6]=Pensions [8] = Dividends [9] = House rentals [10] = Interest savings [11] = Land lease [12] =support from family members

[13]= Others (specify)…………………………………

2.0 LAND USE PRACTICES

2.1 What is the size of your farm………………………Acres

2.2 What is the type of land ownership?

[1]= Own [2]= Family owned

[3]= Communal [4]= Rented/Hired [5]= Others specify……………

2.3 What are the main farm enterprises? Tick the appropriately:

[1]= Crops [2]= Livestock – (cattle, poultry etc)

[3]= Woodlot//agro-forestry [4]= Other (specify)………………..

2.4 What factors influence the size of land allocated to different enterprises?

[1]=Food security [2]= Income generation [3]= Size of family

[4]= Social status [5]= Availability of labour [6]=Others (specify)…………………………………

2.5 If growing crops, what cropping patterns do you practice?

[1]= Monocropping [2]= Inter-cropping [3]= Relay cropping

[4]= Others (specify)…………………………………………………………….

2.6 What are the major crops grown on your farm?

Crop	Acreage	Usage :[1]= HH use [2]=Sale	Rank
1			
2			
3			
4			
5			

2.7 Are there **any** diseases that attack banana in the field? [1]= Yes [2]= No

If **YES**, name the diseases and rank them based on the losses that they cause

Disease	Ranking	Control measures
	1. 2. 3.	1. 2. 3
	1. 2. 3.	1. 2. 3
	1. 2. 3.	1. 2. 3
	1. 2. 3.	1. 2. 3

Disease ranking-[1]-Heavy loss [2]-Moderate loss [3]-Slight loss

2.8 Are there any pests that attack bananas?

2.9 If **YES**, name the pest and rank them in order of importance and state the methods applied to control them

Pest	**Ranking CODE A**	**Control measures**	**Relative effectiveness CODE B**

CODE A Pest Importance ranking	**CODE B**: Control measure effectiveness ranking
1 = Very important 2 = Important 3 = Slightly important	1 = Highly effective 2 = Moderately effective 3 = Sligtly effective

2.10 Have you observed a change in damage by pest and diseases over last 5 years?

[1]= Yes [2]= No

2.11 If **YES**, state the changes fill the table below

Pest/Disease	Trend 1= Decrease 2= Increase 3= remained the same	Remarks

2.12 What do you attribute the changes to:

[1]= Increase in temperature [2]= Decrease in temperature

[3]= Emergence of new crop diseases [4]= Change in rainfall patterns

[5]= others specify …………………………………………………

2.13 What strategies/measures have you taken in response to these changes?

1. Planting of different varieties
2. Planting of tissue culture
3. Planting treated/disinfected planting materials
4. Application of conservation agriculture like use of organic manure, mulching, pruning and removal of old stems from the farm
5. Use of irrigation
6. Migrate to other areas
7. Use of pesticides
8. Others specify…………………………………………….

2.14 What are the main sources of planting materials and the proportion of materials obtained from each source? (based on your demand)

Source	**Proportion (half, quarter etc)**	**Remarks**
Own Farm		
Neighbours		
Local market (Specify)		
Institution/organizations (KARI, GTL lab, University- specify		
Other sources(e.g shows) specify		

2.15 Have you noticed attack by thrips in your farm (interviewer to take a photo or sample with him)

[1] = Yes [2]= No

2.16 If yes, what proportion of bananas are affected

[1]= less than 10% [2]= up to 25% [3]= up to 50% [4]= up to 75% [5]= Over 75%

2.17 Does damage by thrips vary across the year? [1] = Yes [2] = No

2.18 If **YES**, in which seasons is the damage most severe?

[1] = Dry and hot [2] = Cool and dry [3]= Cool and wet [4] =Warm and wet

2.19 Does banana variety influence attack by thrips? [1] = Yes [2] = No

2.20 If **YES,** name the varieties that are most susceptible

2.21 How would you rate the severity of thrips attack in your farm?

Ranking of thrips damage among other pests

<table>
<tr><th>Pest</th><th>Ranking</th><td rowspan="5"><u>Coding for Ranking</u>
1 = 0% infection
2 = 10% plants infected
3 = 25% of the plants infected
4 = 50% of the plants infected
5 = more than 50% of the plants infected</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

3.0 CROP LOSS AND MARKETABILITY

3.1 How would you rate the severity of the losses due to pests?

Rank based on the number of fingers/bunches attacked

<table>
<tr><th>Pest</th><th>Ranking</th><td rowspan="5"><u>Coding for Ranking</u>
1 = 0% infection
2 = 10% plants infected
3 = 25% of the plants infected
4 = 50% of the plants infected
5 = more than 50% of the plants infected</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

3.2 How would you relate the loss by pest to marketability of the banana fingers? Rank based on the marketability of fingers/bunches attacked

<table>
<tr><td>Pest</td><td>Ranking</td><td rowspan="5"><u>Loss Ranking</u>

1 = 0 % Loss of highly marketable
2 = 10% of fingers lost lowly marketable
3 = 25 % of fingers lost not marketable</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

4.0 FARMERS PERCEPTION ON SOIL FERTILITY

4.1 List the 3 major indicators of soil quality on your farm e.g. amaranth?

Good quality soils	Low quality soils
1.	
2.	
3.	

4.2 Which of these indicators have you seen on your farm?

Good quality soils	Low quality soils
1.	
2.	
3.	

4.3 How would you classify the soils in your farm in terms of quality currently?

[1] =Very good soils

[2]= Good quality soils

[3]=Satisfactory

[4] = Poor quality soils

[5] = I don’t know

4.4 Do you apply any soil fertility inputs to your banana crop?

Input	Type of the input	Amount applied per stool	Remarks/comment
Manure	1. Composite 2. Farm yard 3. Cattle Manure	1. 2. 3	
Fertilizer	1.N.P.K. 2.D.A.P. 3 T.S.P. 4. Any other specify----	1. 2. 3.	

4.5 What are the main constraints to adoption of the recommended practices on soil fertility?

[1] =They are expensive to undertake [3] =High labour demanding

[2] =Lack of information [4] =They are not clear

[5] =Other specify ……………………………………

5.0 SOCIAL CAPITAL

5.1 Do you or any member of your household belong to any social or community?

Organization /Association

[1] = Co-operative society [2] = Microfinance

[3] = Women Group [4] = Producer Group

[5] = Farmers Association [6] = Community/Village Group

[7] = Community Marketing Group [8] = Others (specify)……………

5.2 What services do you get from the organization/association?

[1] = Credit only [3] = Training/ Information sharing

[2] = Savings and Credit [4] = Others

6.0 MARKET AND MARKETING INFORMATION

6.1 What is your main source of market information?

1 = Radio 2= Neighbours 3 = Extension officer 4= Others (specify)…………

6.2 Which is your main market for bananas?..

6.3 Distance to nearest market (km) _____Time taken to nearest market ______ (hours)

6.4 How do you market your produce?

[1]= individually [2]= through brokers/middlemen

[3]= Contract with buyers [4]= Group marketing

[4]= Others (specify)………………

6.4 What is the average price per bunch? (Ksh)………………….

6.5 What is the price per kilogram? Ksh………………….

6.6 Does thrips damage to the fingers affect the marketability of banana

[1]= Yes [2]= No

6.7 If yes, how does it affect? [1]= fetch low prices [2]= no preference

7.0 AGRICULTURAL INFORMATION

7.1 In the past one year has the household had access to agricultural information?

1 = Yes,   2 = No

7.2 What are main sources of agricultural information and order of preference?

Source of Information	***Rank the 3 most important sources using the scores*** 1= Most preferred, 2 = somehow preferred, 3 = Least preferred)
1. Government extension staff	
2. Private extension staff	
3. NGOs	
4. Field day	
5. Other farmers	
6. Mass media (Radio/TV)	
7. Print media	
8. Family and friends	
9. Agrovet shops	
10. Neighbours	
11. Internet	
12. Cellphones	

APPENDIX 2: WEATHER DATA FOR EMBU COUNTY

2013									
	January			February			March		
Date	Rainfall (mm)	Temperature (°C) Highest	Humidity %	Rainfall (mm)	Temperature (°C) Highest	Humidity %	Rainfall (mm)	Temperature (°C) Highest	Humidity %
1	0.3	24.6	64	0	24.4	62	0	29.6	32
2	0	24.4	66	0	26.2	56	0	29	37
3	0	23.8	51	0	25.2	51	0	29	37
4	0	23.4	60	0	26.7	41	0	29.6	37
5	0	23.7	64	0.1	27.4	43	0	30.3	29
6	0	26.3	57	0	26.2	52	0	29.1	38
7	0	26.1	56	0	25.7	49	0.3	29.6	39
8	0	25.9	57	0	25.3	48	0	29.3	39
9	0	24.7	60	0	28.1	37	0	28	39
10	0	26.6	44	0	27.2	42	0	28.2	48
11	0	26.7	48	0	27.7	42	0	28.7	40
12	0	26.2	48	0	29.2	41	0	28.7	36
13	0	25.5	52	0	27.6	52	8.1	28.4	44
14	0.2	25.3	47	0	28.5	40	2.8	25.4	47
15	7.4	24.2	58	0	28.6	36	0	28	43
16	0.8	24.1	60	0	28.3	37	0	27.5	49
17	0	24.8	60	0	28.4	33	0	27.5	41
18	0	24.8	55	0	27.8	40	15.8	27	45
19	0	25.2	52	0	29.5	35	17.4	24.5	68
20	0	25.9	47	0	30	36	3.2	23.7	68
21	0	25.8	49	0	29.7	36	14.7	22.1	80
22	0	27	41	0	29	39	1.1	24.5	63
23	0	27.6	40	0	28	36	0	25	49
24	0	26.7	48	0	27.7	27	0	26.3	54
25	0	25.8	52	0	27.5	41	0	26.6	48
26	0	26.2	50	0	27.1	37	1.3	27	65
27	0	26.2	53	0	27	37	5.6	24.4	54
28	0	26.2	55	0	28.3	36	7.3	25.5	76
29	0	27.7	47				1.2	24.5	69
30	8.4	27.1	50				7.1	23.7	64
31	4.6	26.2	65				0.2	25.6	70

2014									
	April			**May**			**June**		
Date	Rainfall (mm)	Temperature (°C) Highest	Humidity %	Rainfall (mm)	Temperature (°C) Highest	Humidity %	Rainfall (mm)	Temperature (°C) Highest	Humidity %
1	0	23.4	83	0	23.4	79	0	19.5	62
2	0	22.1	83	11.8	22.5	87	1.2	19.4	74
3	0	23.5	73	0	21.7	72	0	18.5	76
4	27.6	21.5	81	1.1	21.9	71	0	20.5	75
5	29	22.5	88	0	24.5	80	55.7	20.6	84
6	0	23.7	85	0	23.7	86	0	19.5	93
7	84	22.5	80	1.2	22.5	85	20	20.5	85
8	0	24.5	72	0	21.5	84	0	21.4	79
9	0	25.3	56	1.8	24.5	75	0	19.5	80
10	7	22.7	78	16.2	22.5	81	5	17.5	81
11	9	23.2	83	0.7	22.3	76	2.9	18.5	91
12	20.9	21.8	87	0.5	22.5	78	1	18.5	91
13	15.1	22.5	83	0.5	22.7	84	0	19	88
14	30	23.5	82	0	20.5	88	0	19.3	86
15	12.3	24.4	82	0	19	81	0	20.1	80
16	20	23.3	80	0	18.5	82	0	20.1	82
17	7.1	23.5	83	0	20	81	0	19.5	87
18	20.1	24	84	2.3	21.5	81	0	19	85
19	6	23	91	1.6	19.5	65	0.7	17.5	90
20	0	24.5	83	0	18	83	0	18	81
21	0	25	83	0.2	20.5	69	2.7	18	92
22	0	25	77	7.1	20	83	0	23	82
23	46	24.7	76	0	21.5	84	0	18	74
24	0	25.5	78	0	19	66	0	20.5	77
25	0	26	83	0	19.8	65	0	20.3	76
26	0	24.6	78	0	21.5	80	4	19	75
27	0	25	83	2.8	18	81	0	19.5	64
28	0	25.5	83	1	20.5	92	0	19.5	88
29	0	23.4	76	1.1	18	93	0.2	22	77
30	0	25	66	0	19	90	0	21.5	77
31				0	20.5	72			

Source: Kenya Meteorological Department, Embu Station.