`

SEASONAL DIVERSITY AND ABUNDANCE OF INSECT POLLINATORS AS INFLUENCED BY FARMING PRACTICES IN COWPEA AND CUCUMBER CROPPING SYTSEMS IN KIKOME, MAKUENI COUNTY, KENYA

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Seasonal Diversity and Abundance of Insect Pollinators as Influenced by Farming Practices in Cowpea and Cucumber Cropping Systems in Kikome, Makueni County, Kenya

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A Thesis submitted in partial fulfilment for the degree of Master of Science in Plant Health Science and Management in the Jomo Kenyatta University of Agriculture and Technology

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DECLARATION

Candidate:

This is my original thesis and has not been submitted to any other institution for the award of a degree.

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DEDICATION

I dedicate this work to my parents, my fiancé and siblings for their prayers, support and guidance during the pursuit of my degree.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
ASALS	Arid and semi-arid lands
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
DAP	Di-ammonium Phosphate
EASAC	Europeans Academies Science Advisory Council
EFSA	European Food Safety Authority
FAO	Food and agriculture organization
FAOSTAT	Food and Agriculture Organization Statistics Databases
GDP	Gross Domestic Product
GENSTAT	General Statistics
IPM	Integrated Pests Management
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KNBS	Kenya National Bureau of Standards
LD	Lethal dose
MEMR	Ministry of Energy and Mineral Resources

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Meq	Mill equivalent
MoALF	Ministry of Agriculture Livestock and Fisheries
NMK	National Museums of Kenya
NRC	National Research Council
OECD	Organization for Economic Co-operation and Development
PCPB	Pest Control Product Board
S.E	Standard Error
SPSS	Statistical Package for Social Sciences
TOC	Total Organic Carbon
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
USA	United States of America
USD	United States Dollar
USDA	United States Department of Agriculture
WHO	World Health Organization
WHO	World Health Organization.

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ABSTRACT

Cowpea (*Vigna unguiculata (*L.): Fabaceae) and cucumber (*Cucumis sativus (*L.); Cucurbitaceae) are crops of economic importance in Kenya. They are mainly grown by small scale farmers in the arable areas of Makueni County. Despite the economic importance of these crops, insufficient pollination is one of the major constraints in their production. This has contributed to low crop yield, hunger, malnutrition and elevated levels of poverty in the region. Makueni County is characterized by high temperatures that favor growth and multiplication of pests causing yield losses through their damage on the crops. This has compelled farmers to indiscriminately use chemical pesticides to control pests which are problematic during the cropping cycle. Chemical pesticides present toxic effects on insect pollinators reducing their foraging activities and leads to reduced crop yield and quality. There is scanty information on the common pesticides that farmers use and the various application practices that they apply during various cropping stages in Kikome village, Makueni County. In addition, no information has been documented on the insect pollinators and their impact on the yield and quality of cowpea and cu cumber in the region. Therefore, the main aim of the present work was to assess the extent of pesticide use and application practices and seasonal variation of insect pollinators in Kikome village, Makueni Kenya. Field surveys were conducted in 2017 among small holder horticulture farmers in Kikome village, located in Makueni County using an open and close ended questionnaire administered by face to face interviews with farmers. A survey involving 53 respondents, selected by purposive sampling, was carried out to assess pesticide use and application practices. Open ended questionnaires were administered through face to face interviews with the respondents. All the respondents interviewed during the study were using chemical pesticides as the sole method of pest management. Among various chemical compounds of pesticides used by farmers, pyrethroids (87 %), neonicotinoids (69.6 %), and carbamates (63 %) were the most frequently used. Farmers used pesticides more frequently at flowering stage (44 %) relative to other phenological stages. Most of the respondents (69.2 %) had no access to extension services. This study reported poor farmers' practices on pesticide use which threatens the diversity and abundance of insect pollinators. An experiment was carried out in Kikome village, Makueni County during the short (2017) and long (2018) rain seasons to determine the diversity and abundance of insect pollinators and their contribution to yield and quality improvement of cowpea and cucumber. It was laid out as a split-plot within a randomized complete block design and involved bagged and unbagged treatments replicated three times. The study reported eight and twelve insect pollinator species on cowpea and cucumber flowers respectively. *Apis mellifera* was the most abundant of all insect pollinators observed in both test crops during the two growing seasons. The species represented 74.1 % and 80.5 % of all insect pollinators observed as average of the two growing seasons in cowpea and cucumber respectively. In cowpea, the peak foraging activity of the species was recorded at 9:00 am - 10:00 am (Mean=12.92, p=0.52) and 7:00 am - 8:00 am (Mean=7.5, p=0.021) during the short and long rain seasons respectively. In cucumber, *A. mellifera* foraged mainly between 9:00 am - 10:00 am (Mean=7.36, p<.001) and 8:00 am - 9:00 am (Mean=4.89, p<.001) during the short and long rain seasons respectively. The study recorded a higher diversity of pollinating species during the long rain season (cowpea: H=1.53; cucumber: H=1.21), compared with the short rain season (cowpea H=0.18; cucumber: H=0.16). A higher yield and quality of the test crops was recorded in unbagged treatments relative to bagged treatments ($p<0.05$). This study shows that insect pollinators are important for improvement of the yield and quality of cowpea and cucumber in Kikome, Makueni County.

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CHAPTER ONE INTRODUCTION

1.1 Background information

Insect pollination is an important ecosystem function and essential input in crop production worldwide. Many plants grown for fruits, vegetables, oilseeds, legumes, and fodder depend on insect pollinators (Richards, 2001). Insect pollination contributes to fruits and seed production in 70 % of tropical crops (Roubik, 1995). Out of 124 leading food crops, 84 crops depend on insect pollination (Klein *et al*., 2007). Insufficient pollination can therefore be a limiting factor causing reductions in crop yield translating to food insecurity, hunger, malnutrition and elevated levels of poverty. Efforts to increase crop yield calls for the employment of approaches that are insect pollinators friendly to manage them on farm. It has been shown that managed pollination contributes to fruit and seed formation in vegetable crops (Hogendoom *et al*., 2006). Due to a decline in pollinators' population, studies in pollinator diversity in natural and crop ecosystems are important (Kevan *et al*., 1999). Modern agriculture is increasingly dependent on managed pollinators and less on wild insects living on the periphery of crop fields (Richards, 2001).

Cowpea (*V. unguiculata*) and Cucumber (*C. sativus*) are important vegetable crops in Kenya, commonly grown at Makueni County. Cowpea is an important crop in this region since it is drought tolerant. It grows well at an optimum temperature of 30 °C and 300 mm of rain per year, characteristic of conditions in the Arid and Semi-Arid Lands. The crop is rich in proteins (23-25 %), starch (50-67 %) and vitamin B (Ntoukam *et al*., 1993). It is both self and cross-pollinating producing nectar that attracts a variety of insects that forage on its flowers (Ige et *al*., 2011). Despite cowpea being an important food source in Makueni County, there is little information that is known about the contribution of insect pollinators to its yield and quality improvement.

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Cucumber is an economically important commercial crop whose economic success is dependent on high yield and good quality fruits which mainly depend on insect pollination (Mcgreger, 1976). The male and female flowers of cucumber are separate and hence require biological agents of pollen transfer between them. There is limited transfer of pollen grains from anthers to stigma in absence of pollinating species since the pollen grains are heavy and sticky (Gingras *et al.*, 1999). Vegetables of both domestic and commercial value such as tomato (*Solanum esculentum* Duna (l.), squash (*Cucurbita pepo* (L.) and cucumber have been shown to benefit from animal pollination in yield and quality improvement (Hogendoom, 2006). There are no studies that have reported on the diversity and abundance of insect pollinators and their role in yield and quality improvement of cowpea and cucumber in Kikome, Makueni County.

Insect pollinators are threatened on a global scale and are declining leading to food insecurity which is likely to disrupt the ecosystem functions of insect pollinators (Potts *et al*. 2010). Global declines are attributed to weather alteration (Le-Conte & Navajas, 2008)), air contamination (Girling *et al*., 2013), electro-magnetic radiation from the sun (Ferrari, 2014), exposure to life pressure (Wray *et al*., 2011), nanomaterials (Millivojevic *et al*., 2015) and improper use of chemical pesticides with lethal and sub-lethal effects on insect pollinators (Ngowi *et al*., 2007). When other factors influencing crop yield such as nutrients, water, micro-climate, diseases or pest status are sub-optimal, the positive effects of pollination can be hidden or reduced (Klein *et al*., 2007).

1.2.Statement of the Problem

The ecosystem services of insect pollinators are hindered by reductions in diversity and abundance of insect pollinators. Key drivers identified in global pollinators decline includes land use change, reduced resource diversity, alien species, pests and diseases, environmental pollution and indiscriminate use of chemical pesticides (Kevan *et al*.,

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1997). Prolonged exposure of bees to chemical pesticides causes lethal and sublethal effects on them. Insects belonging to the orders Diptera, Coleoptera, Lepidoptera and Heteroptera are problematic at the flowering stage compelling farmers to make frequent pesticide applications at this stage (Rogers, 1992). Chemical pesticide applications made at the flowering stage poses adverse effects on the foraging honeybees relative to applications made at the pre-flowering stage. Evening applications are safer to honeybees than morning applications (Nderitu *et al*., 2007). Besides, spraying chemical pesticides whether at flowering or pre-flowering stage reduces the foraging activity of *Apis mellifera* (Linnaeus) (Hymenoptera: Apidae) and leads to reduced number of developed seeds (Nderitu *et al*., 2007) due to insufficient pollination.

Limited awareness on pollinator-plant interplay in the ASALS has exposed insect pollinators to threats that causes their decline. Farmers do not understand the need for managing insect pollinators. As a result, they use chemical insecticides indiscriminately as the sole method for control of insect pests (Nderitu *et al.*, 2007). It is important to create awareness on the need to conserve the biodiversity by adopting Integrated Pest Management practices (IPM).

Inadequate pollination results in improperly formed small and misshaped fruits causing low yield of marketable fruits (Abrol *et al*., 2019). Besides, different insect pollinators have different pollination efficiencies implying the need for biodiversity conservation.

Insect pollination contributes to yield and quality improvement of crops. Cowpea and cucumber are crops of economic importance in Makueni County for subsistence and commercial purposes respectively. There are high levels of poverty, hunger, and malnutrition in Makueni County due to the prevailing harsh climatic conditions. Therefore, the present study is important for evaluation of the potential of insect pollination as an additional input in the yield and quality improvement of cowpea and cucumber in the region.

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1.3 Justification

Kenya is predominantly an agricultural country with more than 75 % of the population engaged in farming for domestic and export markets (KNBS, 2015). Makueni County Development Plan calls for intensifying social-economic activities through mainstreaming agriculture to increase employment and curb poverty. It implies choosing the right crops and development of secure crop husbandry. Indigenous and commercially produced crops such as cowpea and cucumber have the potential to contribute to the national economy and have been shown to address food shortage and malnutrition for the poor. The slow progress in addressing hunger and malnutrition may be hastened if pollination, an important aspect in fruit and seed production in vegetables, is understood (Smith *et al*., 2013). The crops used in this study will provide candidate crops for supporting people's livelihoods in the study area. Kikome village located in Makueni County is characterized by a poverty index of 64.3 % hence high levels of malnutrition (Makueni County Development Plan, 2017). One of the key efforts in reducing the levels of poverty in the ASALs is increasing the agricultural productivity (World Bank, 2014).

Kenya Vision 2030 of Agriculture identifies agriculture as one of the major sectors that will contribute to an annual economic growth rate that is projected as 10 % (Ministry of Agriculture, Livestock and Fisheries, 2017). This income is achievable through the employment of commercially oriented, modern farming. It implies the increase in the yield of principal crops and increased smallholder specialization. Insect pollination is one of the contemporary approaches to crop improvement involving the use of pollination ecosystem services provided by insect pollinators. It is an important aspect of fruit and seed production in vegetables (Smith *et al*., 2013). This approach is environmentally friendly making use of resources provided by nature. It is contraryto the current agricultural practices utilizing high inputs of inorganic fertilizers and indiscriminate use of chemical pesticides which kills both pests and beneficial organisms as decomposers, nutrient recyclers, parasitoids, and insect

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pollinators. The approach is also cheap involving managing insect pollinators within the farmland and the surrounding habitats.

Crop yield is low in poorly pollinated crops. While bees are the main agents of pollination, it is important to explore the potential of other insect pollinators in addressing crop yield losses. Most farmers rely on feral pollination rather than managed pollination. In recent years, reductions in insect pollinators' abundance and diversity hamper crop pollination services (Partap , 2001). Biodiversity enhancement is a reliable and sustainable approach towards crop improvement and increased food supply. This is important for the over two billion people who depends on small-scale farming and can benefit from this approach. Identification of key pollinators of cowpea and cucumber and understanding their role in crop improvement is important in creating awareness on the urgency to conserve insect pollinators. This will eventually lead to increased food production due to sufficient pollination.

Although farmers have relied on the use of fertilizers and pesticides to improve yield, crop improvement using these approaches is minimal. Farmers would need to understand the role of insect pollination in crop improvement to address these challenges (Kasina *et al*., 2009). Previous studies have documented increase in yield associated with insect pollination in crops such as radish (*Raphanus sativus* L.,) (22-100 %), cabbage (*Brassica oleraceae* L.) (100 - 300 %), turnip (*Brassica rapa* L.) (100 – 125 %), carrots (*Daucus carota* L.) (91-135 %) and onions (*Allium cepa* L.) (350-900 %) (Partap *et al.*, 2012). Therefore, insect pollinators have a great role in supporting farming practices and ultimately food security for subsistence farmers. Understanding the diversity of insect pollinators in ASALS and formulating policies for their conservation and management is a key step in addressing yield reductions in these regions.

The studies are important in providing policy makers with information needed for managing insect pollinators and prevent their declines in the future. Establishment of the contribution of pollinators to yield and quality of key vegetables in ASALS will

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help to create awareness on the need to employ good agricultural practices to reduce pressure on them.

1.4 Objectives

1.4.1. General objective

To establish the seasonal diversity and abundance of pollinators as influenced by farming systems in cowpea and cucumber cropping systems in Kikome village, Makueni County

1.4.2. Specific objectives

1. To assess the extent of pesticide, use and application practices in Kikome village, Makueni County.

2. To determine the seasonal diversity and abundance of insect pollinators associated with cowpea and cucumber cropping systems in Kikome, Makueni County.

3. To assess the effects of insect pollinators on seed quality and fruit yield in cowpea and cucumber cropping systems respectively in Kikome, Makueni County

1.5. Hypotheses

2. Pesticide use and application practices by farmers do not influence the diversity and abundance of insect pollinators in Kikome, Makueni County

3. Seasonality does not influence the abundance and diversity of insect pollinators in Kikome, Makueni County

4. Insect pollinators do not influence seed quality and fruit yield in cowpea and cucumber respectively.

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CHAPTER TWO REVIEW OF LITERATURE

2.1. Cowpea and cucumber production

2.1.1 Origin of cowpea

Unlike other economically important crops, there is little information that is known about cowpea's domestication, dispersal and cultivation (Xiong *et al*., 2016). It is universally agreed that West Africa is cowpea's centre of origin and domestication (Ogunkanm, 2005) although there is no archaeological evidence exists for its early cultivation. Research with molecular markers have shown that cowpea's domestication could have taken place in East Africa instead, and both theories are currently of same weight (Xiong, *et al.*, 2016).

2.1.2 Economic importance of cowpea

Cowpea is an economically important crop which can be utilized as both a vegetable and grain. The semi spreading varieties of cowpea are best utilized as vegetables (Noubissié *et al*., 2011). In addition, the cowpea seeds utilized as seed vegetables is a relatively cheap and reliable source of protein. In Kenya, Western Kenya leads in cowpea leaves production, while the Eastern, Coast and Nyanza regions produces cowpea mainly for grains (Rusike *et al*., 2013).

The seeds of cowpea are a rich source of dietary calories, proteins, vitamins and minerals (Gonçalves *et al.*, 2016), which complements cereals in countries where cowpea is the main food crop (Phillips *et al.*, 2003). Research has shown that cowpea grains are a rich source of folic acid, and vitamins which helps protect unborn babies from Neural tube defects (Witthöft & Hefni, 2016). Cowpea also plays a key role in

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improvement of soil fertility by deriving atmospheric nitrogen and fixing 75-150 kg in the soil for the next crop (Otal *et al*., 2015).

The high protein content of cowpea, its adaptation in drought prone areas, and its role in soil fertility improvement and soil erosion makes it an economically important crop in the developing countries (Hall, 2004).

2.1.3. Cowpea production

Cowpea is an annual or biannual grain legume and among the top important legumes in the world, second in Africa and third in Kenya (Awurum &Enyiukwi, 2013). The area under production worldwide is approximately 12.3 million ha of which 85 % is produced in Africa (FAO, 2015). About 85 % of the total area under production in Kenya is in the ASALs, while 15 % is in Coastal and Central regions of Kenya (Kimiti *et al*., 2009). Cowpea is drought tolerant (Ngugi *et al*., 2007) and able to adapt in areas of low soil fertility (Ayieko & Tschirley, 2006). Besides, cowpea has a short growth cycle making it a crop of importance for farmers in the marginal and drought-prone areas (Hallensleben *et al*., 2009). Cowpea performs well in a dry and hot environment, while the optimal annual rainfall for growth ranges between 400 mm and 700 mm. The crop can also be grown under irrigation during the dry spell (Miriti, *et al*., 2012).

According to report issued by the Ministry of Agriculture, Livestock and Fisheries (2015), there is a decline in cowpea production despite an increase in area under production. Production is constrained by low soil fertility, noxious weeds, lack of adequate inputs and inadequate pollination amongst other factors. This has contributed to a decline in the yield of cowpea from 531 kg/ha in 2013 to 495 kg/ha in 2014 (MoALF, 2015).

2.1.4. Origin of cucumber

Cucumber is indigenous to India, which is the primary center of diversity, and was domesticated approximately 3000 years (Staub, 2008). From India, cucumber is said

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to have spread westwards to Asia Minor, North Africa and Southern Europe and subsequently to entire Europe and Eastwards to China.

2.1.5. Economic importance of cucumber

Bioactive peptides, fatty acids, vitamins, saponins, collagens, amino acids, carotenoids, and fatty acid derived from cucumber are of high health value. These compounds can be added at various stages of biomedicine and food production process (Kim *et al*., 2012) to improve human health.

According to Muruganantham *et al*., (2015), cucumber has an anti-cancer activity against liver cancer HePG2 cell line. In addition, the curcubitacins A, B, C, D and E in fresh cucumber have anti-cancer properties (FAO, 2004). Studies have also shown that consumption of cucumber reduces risks of breast, uterus, ovary and prostate cancer (Thoennissen *et al*., 2009).

2.1.6. Cucumber production

Cucurbits are important vegetable crops in developing countries where they account for more than 50 % of the total fresh vegetable production (Lecoq, 2003). In Kenya, cucumber is mainlygrown in the Eastern, Central, Coast and Rift Valley provinces by smallholder farmers (HCDA, 1995). Irrigation-dependent large commercial farms grow the crop for the urban and export market (HCDA, 1996). It is ranked 5th amongst major export vegetable crops (HCDA, 1995). Apart from the export market, large amounts of cucumber are also produced for local consumption. The crop has a short growth cycle usually around four months in relatively warm environments. The optimal temperature for growth ranges from 21 ºC to 30 ºC and requires adequate soil moisture for growth to supplement inadequate rainfall (Veeraragavathatham *et al.*, 1998). It does well in a variety of soils ranging from clay to sandy loamy, at a pH range of between 6.0 -7.5.

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2.2. Taxonomy, and phenology of cowpea and cucumber.

2.2.1. Taxonomy and phenology of cowpea

Cowpea (*V. unguiculata)* belongs to the Fabaceae familyand the sub family Faboidae (Marechal & Stainier, 1978). It is an annual herb with a strong taproot and several fibrous roots. The leaves are trifoliate and alternate with the first pair usually simple and opposite. They have long peduncles holding flowers and the seed pod. They are usually green colored. The petiole is 5 cm - 25 cm long while stems have variations from striate, slightly hairy or smooth (FAO, 2004). The plant height varies from 20 cm (bushy varieties) to 2 m tall (trailing varieties) (Sheahan, 2012) while the colors are variable amongst cultivars from purple, blue, yellow and pink. Floral arrangement is an intermediate inflorescence usually at distal ends of the peduncles and borne on alternate pairs with one or two flowers on every inflorescence.

2.2.2. Taxonomy and phenology of cucumber

Cucumber (*C. sativus*) belongs to the Cucurbitaceae family. It is an herbaceous annual climber with a taproot system which consists of the main root branching out into elongated secondary roots (Renner *et al*., 2007). It can also create adventitious roots below the stem. The stem is usually angular and thorny reaching an average height of 3.5 m in length. It has nodes, where the leaves and tendrils sprouts. Lateral buds and one or several flowers develop from the leaf axils. The leaf is simple with a long petiole. The leaf lamina is large-heart shaped with more or less pronounced three lobes. The leaves are dark green colored, alternately and oppositely arranged on the tendrils (Renner *et al*., 2007). The flowers are usually yellow in color sprouting in each leaf axil. The flowers can be unisexual or hermaphrodite. The monoecious varieties of cucumber produce male and female flowers on separate parts of the plant. While male flowers have short stems borne on clusters, the female ones are borne singly usually with an ovary at the base of the flower which later develops into a fruit (Schultheis *et al*., 2016).

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2.3. Pollination in legumes and curcubits

Pollination is a crucial process in sexual reproduction. Insect pollination involves the distribution of pollen grains usually of but not always of flowering plants, by insects. Such plants are usually brightly colored and at times with conspicuous honey guides leading to pollen or nectar rewards. Adaptation of insects to aid in pollination includes sucking or lapping mouthparts for feeding on nectar.

Agriculture production globally is increasingly becoming pollination dependent (Aizen *et al*., 2008) notably in the developing countries compared to the undeveloped countries. This increase has partly been due to an increase in the cultivation of crops dependent on pollination than the cultivation of pollinator-independent crops (Aizen *et al*., 2008). Amongst the 115 global crops widely consumed by humans, the production of 87 species relies on animal pollination at varying degrees, while 28 species do not need animal pollination (Klein *et al.*, 2006). On average, the same authors reported that about 75 % of the global food crops are beneficiaries of animal pollination with the global value being estimated at USD 163 Billion.

Cowpea is self and cross-pollinating. The flowers open early in the morning (0600-0630 hours) and closes at around midday (1130-1200 hours). The stigma remains receptive in a short time. Unfertilized flowers fall after 24 hours of initiation, while fertilized ovary remains attached to cowpea plant 48 hours upon anthesis (Ige *et al*., 2011).

Both male and female flowers of cucumber produce nectar which attracts insect pollinators that collects nectar from the flowers. The male flowers are more in number than the female ones and appear 10 days before the appearance of the female flowers (Allman, 2018). There are also gynoescious varieties bearing female flowers predominantly and results in a more uniform crop. Pollen is provided by monoecious varieties planted along with them.

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2.4. Diversity and abundance of insect pollinators of legumes and curcubits.

Bees of various species are the most recognized insect pollinators and have variety of adaptations for pollination (Klein *et al*., 2007). They are fuzzy with an electrostatic charge that helps in adherence of pollen on their bodies. Most bees also have scopa on their hind legs and in some species on the lower abdomen e.g. the megachilid bees. The honeybees and bumble bees lack a scopa and instead have a corbicula (pollen basket) (Koning, 1994). Most bees inadvertently transfer pollen between flowers as they collect pollen and nectar to feed their young ones. The honey bees collect pollen grains on the hind legs as they rub against the anthers. The pollen grains are transferred onto the stigma of other flowers as the honey bees move between flowers (Dafni *et al*., 2005).

Other insects accomplish pollination as they visit flowers to collect nectar and pollen. Diversity in the assemblage of insect pollinators ensures the inclusion of species of different pollination efficiencies. Most ecologists have documented the role of large mammals in pollination (Kohi, 2013). Bees have for a long time been used mainly to offer pollination for improved crop production (Kevan & Phillips, 2001) due to the presence of numerous hairs on their body and their foraging behavior which increases their efficiency in pollination (Free, 1993). Over 2600 bee species from Africa are effective pollinators except for the parasitic bee taxa (Roubik, 1995).

2.4.1. Diversity of insect pollinators of legumes

Flower visitation by pollinating species is dependent on floral resources such as pollen (Stone *et al*., 1998) or nectar (Pouvreau, 2004). Previous studies have recorded *A. mellifera* as the most abundant insect pollinator of cowpea (Fohouo *et al*., 1991: Ige *et al.*, 2011). Other studies have recorded insect pollinators of cowpea *viz Megachille* spl.atreille., (Hymenoptera: Megachilidae), *Xylocopa* sp Latreille., (Hymenoptera : Apidae), *Polistes* sp l.atreille., (Hymenoiptera : Vespidae) *Orius* sp Wolff.,(Hemiptera : Anthocoridae), *Bombus* sp l.atreille., (Hymenoptera : Apidae) , *Ceratina* sp l.atreille., (Hymenoptera : Apidae), *Lipotriches* sp Gerstaecker.,

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(Hymenoptera : Halictidae), *Xylocopa calens* Lepeletier.,*(*Hymenoptera : Apidae *),* *Xylocopa. Imitator* Smith.*,* (Hymenoptera: Apidae) *Melecta* sp l.atreille., (Hymenoptera : Apidae) *Apis cerana* Fabricius.,, (Hymenoptera : Apidae)*, Apis florea* Fabricius (Hymenoptera
:Apidae)*, A. dorsata* Fabricius., (Hymenoptera : Apidae)*, Amegilla* sp Friese., (Hymenoptera : Apidae) and *Lasioglossum* sp Curtis., (Hymenoptera : Halictidae) (Abrol *et al*., 2017: Hordzi, 2011).

Insect pollinators have also been reported in other members of the Fabaceae family. In pigeon pea (*Cajanus cajan* L.,.)*, A mellifera, Apis cerana, Syrphus* sp Fabricius., (Hymenoptera: Syrphidae)*, Bombus* sp*, Vespa magnifica* Smith.*,* (Hymenoptera: Vespidae)*, Athalia lugens* Klug.*,* (Hymenoptera : Tenthredinidae)*, Pelopidas mathias* Fabricius.*, (*Lepidoptera *:* Hesperidae)*, Musca domestica* Linnaeus., (Diptera: Muscidae)*, Pierris brassicae* Linnaeus., (Lepidoptera ; Pieridae)*, Tabanus* sp Linnaeus., (Diptera : Tabanidae)*,* and *Ergolis merione Cram.*, (Lepidoptera : nympharidae) have been reported (Thapa, 2006). Bee species belonging to three families: Apidae, Halictidae, and Anthophoridae were reported as insect pollinators of lima beans. Amongst these pollinators, *Eucera purveracea* (49.9 %) and *A. mellifera* (42 %) were the most abundant of all pollinator species reported (Aouar Sadli *et al*., 2008).

Previous studies reported 20 bee species of five genera with different visitation frequencies as insect pollinators of the dry common bean in Kakamega farmland (Kasina *et al*., 2007). The authors indicated that *A. mellifera*, *X. calens* and *X. inconstans* Smith., (Hymenoptera: Apidae) were the most frequent visitors. Besides,
A. mellifera was the most active relative to other bees while *X. calens* was the most active among the solitary bees. Due to the low activity density of the pollinators observed, the authors reported that pollination was not sufficient.

Fidelity of insect pollinators to specific flowers is linked to recognition and memorization of flower colors during previous foraging trips (Wright *et al*., 2002).

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The high concentration of sugars present in cowpea nectar could account for the high foraging rate of pollinating species (Fohouo *et al*., 2009).

2.4.2. Diversity of insect pollinators of curcubits

The honey bee has been studied as the primary and the single dependable insect pollinator in cucumber (Free, 1993: Rust *et al.*, 2003: Sajjanar *et al.*, 2004; Njoroge *et al*., 2004: Oronje *et al.,* 2012) and other members of Cucurbitaceae family such as squash (Kasina *et al*., 2007). Other studies have reported *X. chlorine* Cockerell., (Hymenoptera: Apidae) *X. philippinensis* Smith., (Hymenoptera: Apidae), A. *cerana*, *A. dorsata*, small ants, bumblebees, Nomia, and syrphids as the main flower visitors of cucumber (Rana *et al*., 2005).

Insect pollinators of 12 species under 10 genera and 7 families were recorded as insect pollinators of cucumber. These included *A. cerana, A.dorsata, A.mellifera, Aulacophora foveicolis* Lucas., (Coleoptera : Chrysomelidae), *Diabrotica undecimpunctata* Fabricius., *(*Coleoptera : Chrysomelidae), *Coccinella septumpunctata* Linnaeus., (Coleoptera : Coccinellidae), and *Mylabris pustulata* Thunberg., *(*Coleoptera *:* Meloidae) *(*Thakur (2007). The author reported Hymenoptera as the most dominant order (6 species), followed by Coleoptera (4 species) and Diptera (2 species). *A. mellifera, Formica* sp Linnaeus., (Hymenoptera: Formicidae) *and Apis cerana* were the most dominant insect pollinators.

Insect pollinator species belonging to the orders Hymenoptera (81.25 %), Diptera (12.5%), and Lepidoptera (6.5 %) have also been reported in musk melon (Cucurbitaceae) (Revanasidda & Akshatha, 2015). The major insect pollinators recorded were *A.florea* and *A.cerana* with the latter as the most abundant and efficient insect pollinator.

In bitter gourd, Tharini (2016) reported 26 insect pollinators belonging to the families Apidae, Halictidae, Scolidae, Formicidae, Syrphidae, Sarcophagidae, Calliphoridae,

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Lycaenidae, Pieridae, Lycaenidae, Nymphalidae, and Hesperidae. Insect pollinators of the family Apidae were the most abundant: *A. cerana, A.florea, A.dorsata, Tetragonula iridipennis* Smith (Hymenoptera: Apidae), *Ceratina hieroglyphica* Smith., (Hymenoptera : Apidae), *Braunsapis* sp Michener., (Hymenoptera : Apidae), and *Xylocopa aestuans* Linnaeus*., (*Hymenoptera : Apidae).

2.5. Foraging behavior of insect pollinators of legumes and curcubits

The Optimal foraging theory assumes that every unit time an insect spends while foraging translates to maximum caloric gain and that fitness correlates with foraging efficiency (MacArthur & Pianka 1966). During foraging, an insect pollinator follows basic movement rules as it flies from flower to flower, and plant to plant. Following the reception of visual or olfactory information for detecting flowers, the convoluted looping path starts a local search. At times, variations may occur in visitation frequencies of honey bee some feet apart due to microclimate surrounding the plant while all flowers could be expected to receive equal visits (Whitaker & Bohn, 1952).

Previous studies reported that the number of *A. mellifera* visits corresponds with the number of cowpea flowers opened (Fohouo *et al*., 2009). The authors observed that the foraging activity of *A. mellifera* was highest between 7:00 am and 8:00 am (highest sugar concentration) while the lowest visitation frequency was observed between 11:00 am -1200 noon (lowest sugar concentration). According to Saboor *et al*., (2015), the maximum foraging activity of insect pollinators of *Pea sativum* L., (Fabaceae) is between 9:00 am and 1200 pm and lowest between 3:00 pm and 5:30 pm.

There are variety of studies that have reported on the maximum foraging activity of insect pollinators of cucurbits. The maximum foraging activity of insect pollinators of cucumber has been recorded between 09:00 am to 10:00 am (3.88 insects / m^2/10 min), followed by 12:00 pm - 1:00 pm (3.37 insects / m^2 /10 min), and 3:00 pm-4:00 pm (2.45 insects/m^2/10 min) (Thakur, 2007). In Brazil, an experiment involving two stingless bees in cucumber (*Scaptotrigona aff* and *Nannotrigona Testaceicornis*)

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recorded the peak activity of S.aff at 12:00 pm, and two peaks of *Testaceicornis* at 10:00 am and 1:00 pm (dos Santos et *al*., 2008).

The maximum foraging activity of insect pollinators have also been recorded in other members of Cucurbitaceae family. Sugar concentration in nectars of squash (*Cucurbita maxima* Duchesne.,) was reported to increase with time (Manjula, 2007). The authors indicated maximum sugar concentration at 9:00 am, and recorded a decrease thereafter. The maximum foraging activity of *A.cerana, A.florea*, and *Tetragonula irripennis* in ridge gourd (*Luffa acutangula* l.,: Cucurbitaceae) was reported between 09:00 am and 11:00 am (Lakshmi, 2013). The author recorded maximum foraging activity of other insect pollinators between 12 noon and 4:00 pm. In eggplant (*Solanum melongena* L.*:* Solanaceae,) and ridge gourd (*Luffa acutangula*), Bodlah & Waqar (2013) recorded the peak foraging activity of the insect pollinators in the morning hours, between 06:00 hours and 07:00 hours.

2.6. Effects of insect pollinators on yield and quality of legumes and cucurbits

Previous studies have reported that insect pollination improves the yield and quality of legumes. For instance, the number of cowpea pods per plant, number of seeds per pod, and number of well-developed seeds was higher in open pollinated crops than in self-pollinated ones (Fohouo *et al*., 1991). Other studies have also indicated that insect pollination results into more number and weight of seeds per pod and the protein content in cowpea, beans, green grams (*Vigna radiata* L., : Fabaceae), Bambara nuts (*Vigna subterranea* L., : *Fabaceae*) (Kasina *et al*., 2007). Similar observations were made in broad beans (*Vicia faba* L.*:* Fabaceae) (Free 1966: Auor-Sadli *et al*., 2008), pigeon peas (*Cajanus cajan*) (Prashanth, 2011), and lima beans (*Phaseolus lunatus* L.: Fabaceae (Blackwall, 1971).

Studies have also reported that insect pollination contributes to yield and quality improvement in cucumber. For instance, Khaja-Rubina (2010) observed that fruit set, fruit volume, weight, length, seed weight and the number of sound seeds per fruit was

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more in open pollinated crops followed by *A. florea*, *A. cerana* and *T. Iridipennis* pollinated crops.

In other members of the Cucurbitaceae family, insect pollination is also important in crop improvement. This has been reported in *Cittrulus lanatus* Thunb., (Cucurbitaceae) (William, 2001), *Momordica charantia* L., (Cucurbitaceae) (Nidagundi, 2004: Dorjay *et al*., 2017), *Cucurbita pepo* L., (Cucurbitaceae) (Hemantha Kumar, 2006), *Cucumis Melo* L., (Cucurbitaceae) (Yang *et al*., 2007: Revanasidda & Akshatha, 2015) and *Momordica charantia* L., (Cucurbitaceae) (Deyto & Cervancia, 2009).

2.7. Threats to insect pollinators

Insect pollinators are threatened at a global scale and are declining owing to various drivers. These includes climate change, pests and diseases, changes in land use and indiscriminate use of chemical pesticides with lethal and sub-lethal effects on insect pollinators.

2.7.1. Climate change

Flower development, nectar and pollen production are affected by climate and are directly related with the foraging behavior and development of bees (Reddy *et al*., 2013). Detrimental effects of climate change on the honeybees arises from changes in distribution of flowering plants (Thuiller *et al*., 2005), which provides bees with food. Besides, climate affects honeydew production by the stinging insects from varying plant species. In Alsace plant, whose honeydew is attractive to honey bees, the development and growth of balsam fir for increased rate of aphid population requires special conditions (Le Conte, 2008 & Navajas, 2008). Moreover, there is a likelihood that extremely dry conditions limits production and quality of pollen (Stokstad, 2007).

It has also been reported that honey bees born during the autumn season spend the winter season in the hives and needs a pollen diet to rear the future worker bees (Mattila & Otis, 2006). A drought during the autumn contributes to food shortages in

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the winter, predisposing honey bees to a weak immune system and increased susceptibility to pathogens which decreases their lifespan.

Due to global warming, variety of species have migrated to higher latitudes (McCain &King, 2014). This has caused mismatches between interacting species (Tylianakis *et al*., 2008) especially if the species are from different trophic levels, for instance, plants and their pollinators (Visser & Both, 2005). This mismatch may result in reduced reproductive performance and decline in the population of insect pollinators. In addition, there could be few pollinating species to pollinate abundant flowering plants or too many pollinating species to pollinate available resources (Rafferty & Ives, 2011).

There exists a relationship between reductions in British bumble bee populations and climate change (Winfree *et al*., 2007). Climate change has led to changes in bees' temporal activities (Stone & Wilmer, 1989), population genetics as evolution changes in butterflies, shifts at species levels as phenological changes (Hegland *et al*., 2009), reductions in bumble bees' population due to narrow climate niches, as well as changes in community composition and function of pollinators communities (Memmott *et al*., 2007).

2.7.2. Pests and diseases

Records of declining honey bee colony health have been made since 1990 (Potts *et al*., 2010; Burkle *et al*., 2013). Pests such as the small hive beetles are a threat to both feral and managed honey bees (Neumann & Elzen, 2004). The honey bee viruses have been shown invading multiple host species (Eyer *et al*., 2009) therefore infecting non-*Apis* wild species while the wild bee viruses can infect the honey bees.

The ectoparasitic mite, (*Varroa destructor* Anderson & Trueman., (Parasitiformes : Varroidae) has been reported as one of the most serious threats of the honey bees (Dietemann *et al*., 2012). Besides attacking the honey bees' brood and adult workers, the pest feed on the bees' haemolymph causing reduced vigor, immunity, weight,

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lifespan, and death of entire colony with time (Le Conte *et al*., 2010). In addition, feeding on bees predisposes them to diseases by providing entry points for the diseases.

Varroa destructor is a vector and transmits viral diseases besides suppressing the bees' immune system to enhance intensive viral replication (Kuster *et al*., 2014a). The Deformed wing virus (DWV), Israeli acute paralysis virus (IAPV) and Kasmir bee virus (KBV) have been reported as being transmitted by the *V. destructor* (Gisder *et al*., 2009; Di Prisco *et al*., 2011). Recent studies have also reported elevated levels of DWV in honey bees exposed to *V. destructor* (Abbo *et al.*, 2017). Besides, the authors reported a positive correlation between the DWV titer and *V. destructor* infestation levels.

Exposure of pollen foragers to high *V. destructor* levels affects their flight distance and time (Duay, 2002). In addition, the homing success of foraging bees is reduced when honey bees are infested with *V. destructor* (Kralj & Fuchs, 2006). The mite infests the larvae of honey bees during the pupation stage reducing the body size of the emerged bees (Van Dooremalen *et al.*, 2013) whose flight muscles are formed at the pupation stage before emergence (Tautz *et al.*, 2003).

2.7.3. Land use changes

Habitat loss has been reported as one of the key drivers in insect pollinators decline (Brown & Paxton, 2009). Land fragmentation has largely contributed to declines in abundance of wild bees as well as species richness (Rickets *et al*., 2008). Reductions in species richness and diversity have been attributed to declines in the fragment areas for bees (Steffan-Dewenter, 2003). Losses in floral and nesting resources due to habitat degradation may as well affect the diversity and abundance of bees' species.

2.7.4. Use of inorganic fertilizers

The use of inorganic fertilizers is increasing steadily as opposed to the use of organic manure (Richards, 2001). Excessive use of fertilizers in the field can cause reductions

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in diversity as well as a cover of less competitive species of wild plants (Klein, 2009). Furthermore, inorganic fertilizers have been shown to decrease floral resource availability. Previous studies have reported higher abundance of the honey bees in organic wheat fields relative to conventional wheat fields (Holzschuh *et al*., 2008) implying that inorganic fertilizers are one of the key drivers of insect pollinators decline.

2.7.5. Chemical pesticides

Agricultural pesticides are key drivers of insect pollinators' population decline. Most synthetic pesticides are highly persistent in water and soil and are taken up into plants. As a result, they are transferred to pollen and nectar leading to chronic sub-lethal risks to pollinators health (Van der Sluijs *et al*., 2013).

Chemical pesticides as Lambda-cyhalothrin have lethal and sub-lethal effects on bees as well as parasitic organisms (Mutuku *et al*., 2014). A recent study on pesticide use in winter cereals recorded that insecticide use poses negative effects on the bees' species richness and abundance (Kovacs-Hostyanszki *et al*., 2012).

Neonicotinoid based pesticides are toxic to insects (Tomizawa & Casida, 2005) and wildlife (Hallmann *et al*., 2014). Previous studies have indicated that they impair the homing ability of honey bees, increase incidences of mortality (Krupke *et al.,* 2012: Hallmann *et al*., 2014), affects interannual viability of the honey bee colonies (Woodcock *et al*., 2017), contributes to queenlessness with time, reduces social immunity (Tsvetkov *et al*., 2017) and reduces the reproductive performance of solitary bees (Sandrock *et al*., 2014) and bumble bees (Whitehorn *et al*., 2012; Goulson, 2015).

Following the colony collapse disorder reported in 6 commercial bee keeping farms in the United States (Johnson, 2010), experiments were done to identify potential causes of the disorder. One of these experiments was a report issued by van Engelsdorp *et al*., (2009) who tested the colony for known honey bee parasites, pesticide residues, genetic lineage, and protein content and morphological measurements. In all samples

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tested, 50 different chemical pesticides residues with varying metabolites were detected.

Studies have indicated that spraying insecticides mostly at the flowering stage results in few number of foraging *A. mellifera* (Nderitu *et al.*, 2007). Pesticides effect may be through direct contact or by imbibing water (dew) (McGregor, 1976). Improper use of pesticides also results in decreased number and weight of developed seeds of sunflower (*Helianthus annuus* L.) due to few number of foraging *A. mellifera* important in pollination (Nderitu *et al.*, 2007).

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CHAPTER THREE

EXTENT OF PESTICIDE USE AND APPLICATION PRACTICES IN SMALL-SCALE FARMS IN KIKOME, MAKUENI COUNTY

Abstract

Pesticides play a key role in agriculture by decreasing crop losses caused by insect pests. They increase crop production translating to national food security and contributes to improvement in human health by controlling disease vectors. Despite their role in controlling disease vectors, pesticides are toxic and have detrimental effects on human health, environment and biodiversity if used improperly. The present work reports findings of an assessment of pesticide use and application practices in Kikome village, Makueni County, Kenya. The major economic activity in this region is farming. Pests are problematic in this region due to high temperature that favor their growth and multiplication compelling farmers to use pesticides in their management. A survey involving 53 respondents, selected by convenience sampling, was carried out to assess pesticide use and application practices. Open ended questionnaires were administered through face to face interviews with the respondents. All the respondents interviewed during the study were using chemical pesticides as the sole method of pest management. Among various chemical compounds in the pesticides used by farmers, pyrethroid (87 %), neonicotinoid (69.6 %), and carbamate (63 %) based pesticides were the most frequently used. Farmers used pesticides more frequently at flowering stage (44 %) relative to other phenological stages. Most of the respondents (69.2 %) had no access to extension services. This study reported poor farmers' practices on pesticide use which threatens the diversity and abundance of insect pollinators.

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3.1. Introduction

Biodiversity and associated ecosystem services are key to human health (Millenium ecosystem Assessment, 2005). Pollination is essential in provision of food and fibre, overall ecosystem resilience, aesthetics, and genetic diversity. Approximately, two thirds of crops feeding the world is insect pollinator dependent (FAO, 2008). Reduced crop yield and misshapen fruits are caused by inadequate pollination and not necessarily inadequate agricultural inputs (African pollinator Initiative, 2008). Pests are major causes of crop yield and quality reductions in that they contribute to endemic poverty mostly in the developing countries (Nderitu *et al.,* 2007). They are key inputs in agricultural production in reducing crop losses due to infestation by pests and diseases. Pesticides are toxic and cause environmental pollution and death of beneficial organisms such as insect pollinators (Nderitu *et al.*, 2007). Unexpected environmental contamination has resulted from use of very toxic pesticides, inadequate management and poor handling practices (Ntow, 2006). Carbamate based pesticides are toxic to parasitic wasps and bees (Liu *et al.*, 2012). Although organosulphates are easily hydrolysed, they are highly toxic to invertebrates and insects (Anderson & Lydy, 2002). Majority of farmers in Eastern Kenya using pesticides do not manage pollination in any way and use pesticides as sole method of pest control (Nderitu *et al.*, 2007). The present study seeks to assess the extent of pesticides use and application practices in Kikome village in Makueni County and their potential detrimental effects on seasonal diversity and abundance of insect pollinators in Kikome, Makueni County.

3.2 Materials and methods

3.2.1. Description of the study area

The study was conducted in Kikome village, Makueni-Eastern Kenya between the month of September and October, 2017 (Figure 3.1). Makueni County is divided into six sub counties, namely, Makueni, Kilungu, Mukaa, Kibwezi, Kathonzweni, Makindu, Mbooni East, Mbooni West and Nzaui. Kikome village is located in

Makueni sub-county and Kitise ward. The village is in the arid and semi-arid zones of

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Eastern Kenya.

3.2.1.1.Soils and vegetation

Soils are usually sandy characterized by a pH range of 5.1 to 7.2 and low to moderate organic matter content (0.43 % -1.87 % TOC). The arable land measures approximately 74 % of the total area. The area under food and cash crop production is 8.1 % and 2.9 % respectively. The area is characterized by dense bushes, shrubs and wild trees

3.2.1.2.Rainfall and temperature

The area experiences a bimodal type of rainfall with short rains in November/December and long rains in March/April. The area experiences high temperatures of 35.8 ºC and high rate of evaporation. Generally, high temperatures are experienced during the day and low temperatures at night.

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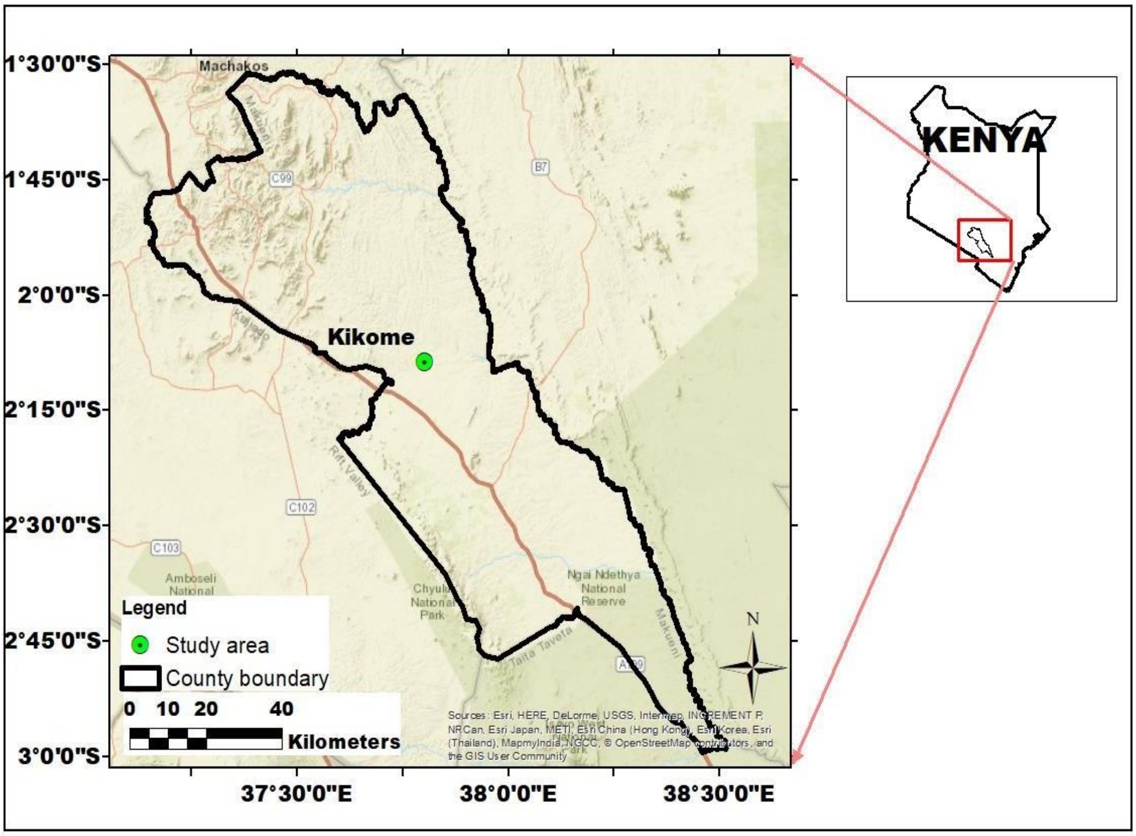

Figure 3.1: The study site within Kikome village, Makueni County

3.2.2.Study design

The instrument for the survey was a questionnaire which was designed using information sourced from literature review. A pilot test was done before the actual survey to ensure that the questionnaire was adequate in obtaining the required information. The questionnaire had both open and close-ended questions (Appendix 1). Pre-visits were done to familiarize with the study area, discuss with the relevant authority (chief, area- in charge and village elders) and inform the respondents of the intended exercise and its purpose. The study population was comprised of horticulture farmers in Kikome village and was determined using procedures established by Whitley & Ball (2002) (equation 3.1). A total of 53 respondents were involved in the survey using the formulae:

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$$nf = \frac{N}{1+\frac{N}{POPULATION}} \qquad \text{Equation 3.1}$$

Where N is the known population, n is the sample size.

Out of the 53 respondents, 7 did not answer the questions correctly and were therefore excluded from data analysis. Therefore, only data from 46 respondents was considered for analysis.

3.2.3. Data collection

The questionnaire was administered to individuals within households who used pesticides and not necessarily the farm owners. The respondents were selected by purposive sampling method. A standardized questionnaire was used as a measurement tool and consisted of (1) socio-demographic characteristics as age, gender, and level of education, (2) information regarding pesticides use in controlling common pests, the common crops, major problematic pests and the types of pesticides that they used in pest management, (3) practices on using pesticides, including time of the day and cropping stage that respondents applied pesticides more frequently. Information on whether farmers received any training on pesticides use and application practices were also gathered.

3.2.4. Data analysis techniques

Quantitative data collected was analyzed using descriptive statistical techniques that were frequencies, percentages, and standard errors. This was done using the statistical package for Social sciences (SPSS) version 22 (IBM Corp. 2013. In regards to qualitative data, farmers were allowed to list their responses in an open-ended format and later analyzed using statistical techniques which includes frequencies, percentages and standard errors using SPSS version 22. The multinomial logit model was used to estimate the factors that determined farmers' choices in using and applying chemical pesticides. Estimated coefficients were compared with the base category. The likelihood ratio statistics were indicated by the Chi-square test and checked if it was significant statistically. The Hausman's specifications test procedure was used to

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check the validity of the model of the independence of the irrelevant alternatives.

3.3. Results

3.3.1. Characteristics of the study population

The characteristics of respondents within the study area are given in table 3.1. About 69.6 % of the respondents were male while 30.4 % were female. The majority of respondents were young people aged between 34 – 41 years (26.1 %). Most respondents had acquired primary level of education (52.2%), while the least had attained college/university level of education (15.2 %) (Table 3.1). There was a wide diversity of crops grown within the County (22). The most commonly crops grown include cowpea, maize, green grams and sorghum in increasing order of importance. Cowpea was the most commonly grown (91 % of all crops grown in the study area) (Figure 3.2). The least commonly grown crops were corriander, *Amaranthus* sp, pumpkin and cucumber.

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Table 3.1. Characteristics of the study population

Demographic aspect	Frequency (n)	Proportion (%)
Gender		
Male	32	69.6
Female	14	30.4
Total	46	100
Age brackets		
18-25	4	8.7
26-33	11	23.9
34-41	12	26.1
42-49	6	13.0
50-57	9	19.6
>58	4	8.7
Total	46	100
Level of education		
Primary	24	52.2
Secondary.	15	32.6
University/college	7	15.2
Total	46	100.0

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3.3.2. Common crops grown within the study area

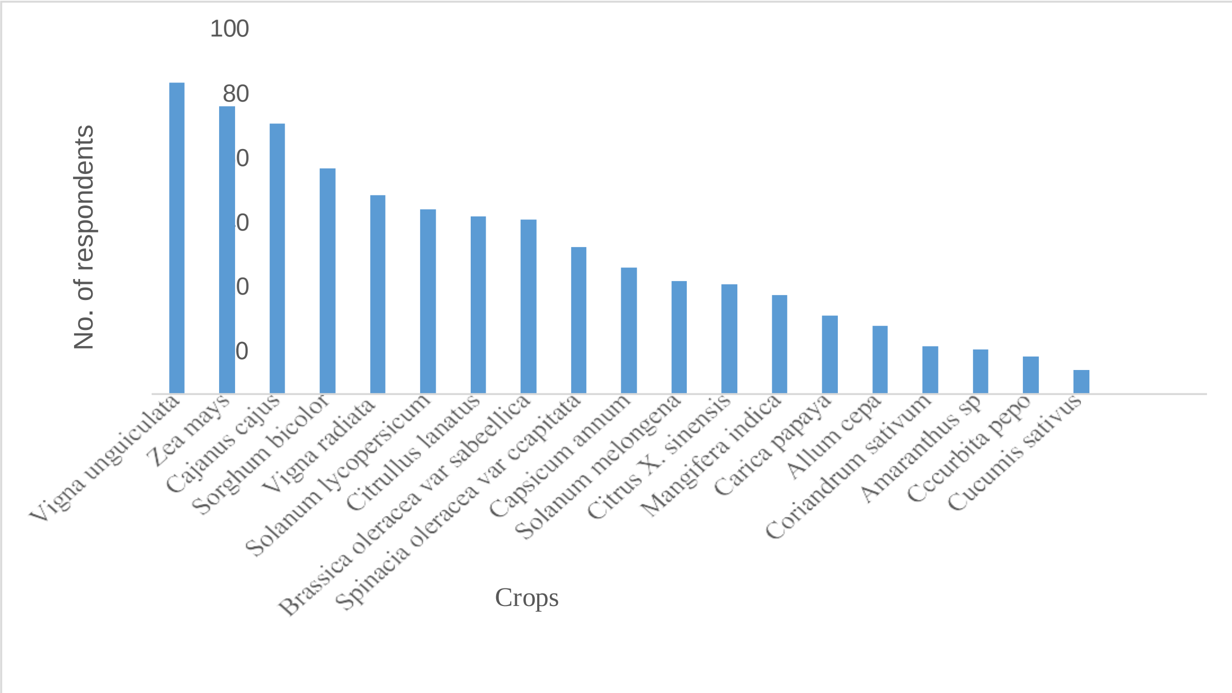

Figure 3.2: Common crops grown within Kikome village, Makueni County.

3.3.3. Arthropod pests encountered by farmers in Kikome, Makueni County.

The study recorded a diverse population of arthropod pests within the study area (Figure 3.3). The most problematic pest reported affecting crop production was whiteflies (84.6 %) while the diamondback moth was the least problematic (2.2 %) (Figure 3.3

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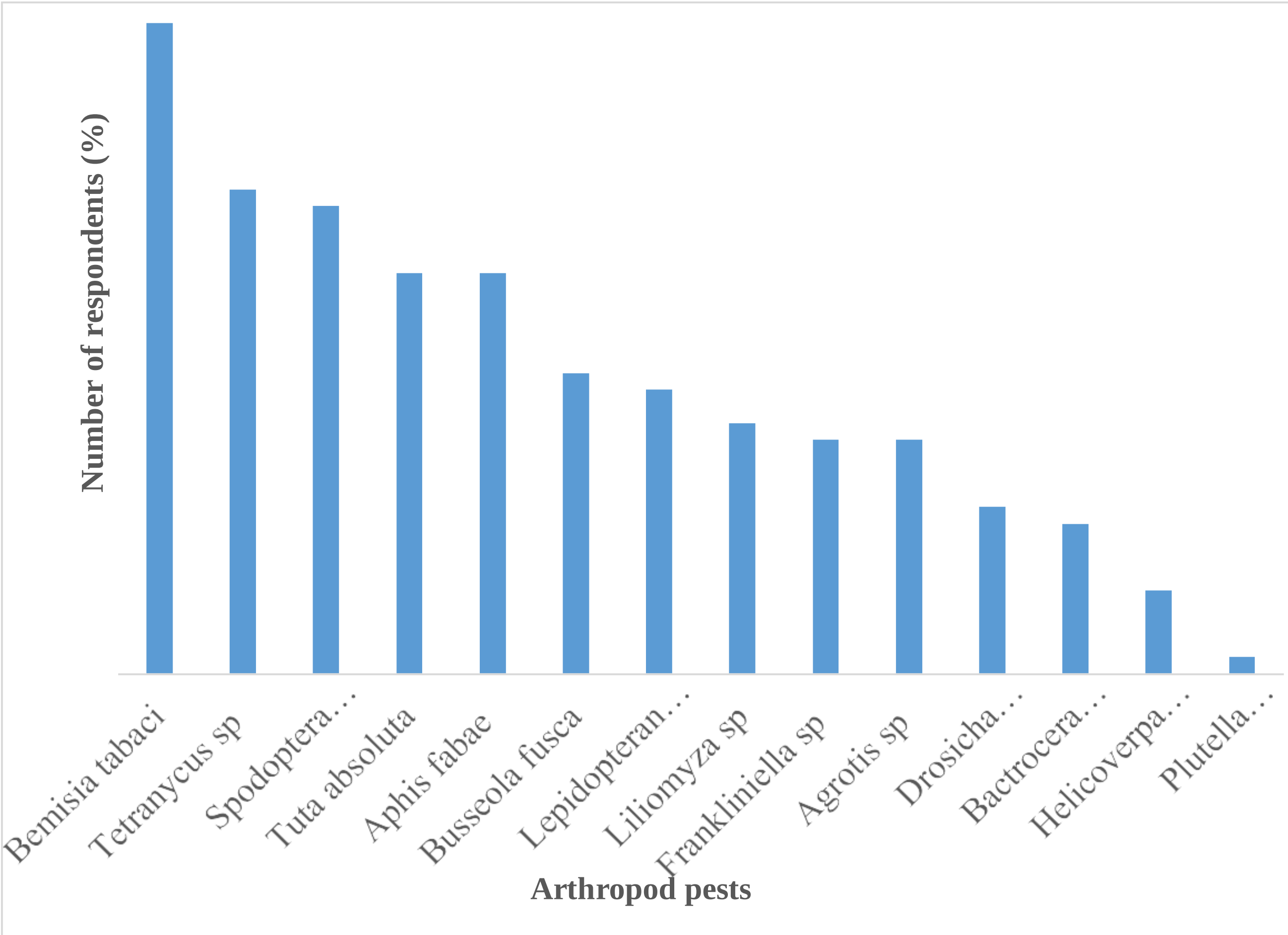

Figure 3.3: Arthropod pests encountered by farmers in Kikome, Makueni County.

3.3.4. Pesticides used within the study area

All the respondents interviewed during the survey were using chemical pesticides in pest management. A total of 41 pesticides that belonging to 14 chemical groups were recorded. Pyrethroid (87 %), carbamate (69.6 %) and neonicotinoid (63 %) based pesticides were the most frequently used (Table 3.2). In addition, 58.7 % of the pesticides used belonged to WHO class II while Class IV pesticides were the least used (15.2 %) (Figure 3.4)

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Table 3.2: **Pesticides used within Kikome, Makueni-Eastern Kenya**

S/N	Chemical class	% use	Pesticide	Active Ingredient	WHO Class
1	Pyrethroid	87	Karate[I]	Lambda Cyhalothrin	II
			Pentagon[I]	Lambda Cylohathrin	II
			Duduthrin[I]	Lambda Cylohathrin	II
			Engeo[I]	Lambda Cylohathrin	II
			Tornado[I]	Lambda Cyhalothrin	II
			Tata alpha[I]	Alphacypermethrin	II
			Profile[I]	Alphacypermethrin	II
			Bestox[I]	Alphacypermethrin	II
			Atom[I]	Deltamethrin	II
			Cyclone[I]	Cypermethrin	II
			Betafos[I]	Beta cyfluthrin	II
2	Carbamate	69.6	Antracol[F]	Propineb	1V
			Antracol[F]	Propineb	IV
			Merit[I]	Indioxacarb	III

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S/N	Chemical class	% use	Pesticide	Active Ingredient	WHO Class
			Ridomi[l] Gold[F]	Metalaxyl	III
			Milthane super[F]	Mancozeb	IV
			Dithane[F]	Mancozeb	III
			EMthane M45[F]	Mancozeb	IV
			Dithane M45[F]	Mancozeb	IV
3	Neonicotinoid	63	Actara[I]	Thiamethoxam	III
			Engeo[I]	Thiamethoxam	II
			Prosper[F]	Clothianidin	II
			Presento[I]	Acetamiprid	II
			Thunder[I]	Imidacloprid	II
			Confidor[I]	Imidacloprid	II
4	Strobilurins	26.1	Ortiva[F]	Azoxystrobin	II
			Prosper[F]	Triflocystrobin	II
			Nativo[F]	Tryfloxystrobin	III
			Nativo[F]	Tebuconazole	III

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S/N	Chemical class	% use	Pesticide	Active Ingredient	WHO Class
			Ortiva[F]	Difenoconazole	II
5.	Avermectin	60.2	Alonze[I]	Abamectin	II
			Dynamic[I]	Abamectin	II
			Romectin[I]	Abamectin	II
			Prove[I]	Emamectine Benzoate	II
6	Inorganics	21.7	Thiovit[F]	Sulfur	II
			Amicop[F]	Copper oxychloride	II
			Funguran[F]	Copper hydroxide	II
7	Organophosphate	19.6	Dithane M45[F]	Chlorpyrifos	IV
			Betafos[I]	Chlorpyrifos	II
			Oshothion[I]	Malathion	II
8	Triazole	19.6	Score[F]	Difenoconazole	III
9	Phthalic acid diamides	34.8	Belt[I]	Flubendiamide	III
10	Sulfonylaminocarbonyl-triazoniline	8.7	Attribute[H]	Propoxycarbazone-Sodium	II
11	Benzimidazole	17.4	Chariot[F]	Carbendazim	II

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S/N	Chemical class	% use	Pesticide	Active Ingredient	WHO Class
12	Sulfooarbaide	10.9	Pegasus[I]	Diafenthiuron	III
13	Acylamines	30.4	Ridomil Gold[F]	Mancozeb	II
14	Anthranilic diamide	34.8	Coragen[I]	Chlorantraniliprole	IV

I=Insecticide, F=Fungicide, H=Herbicide

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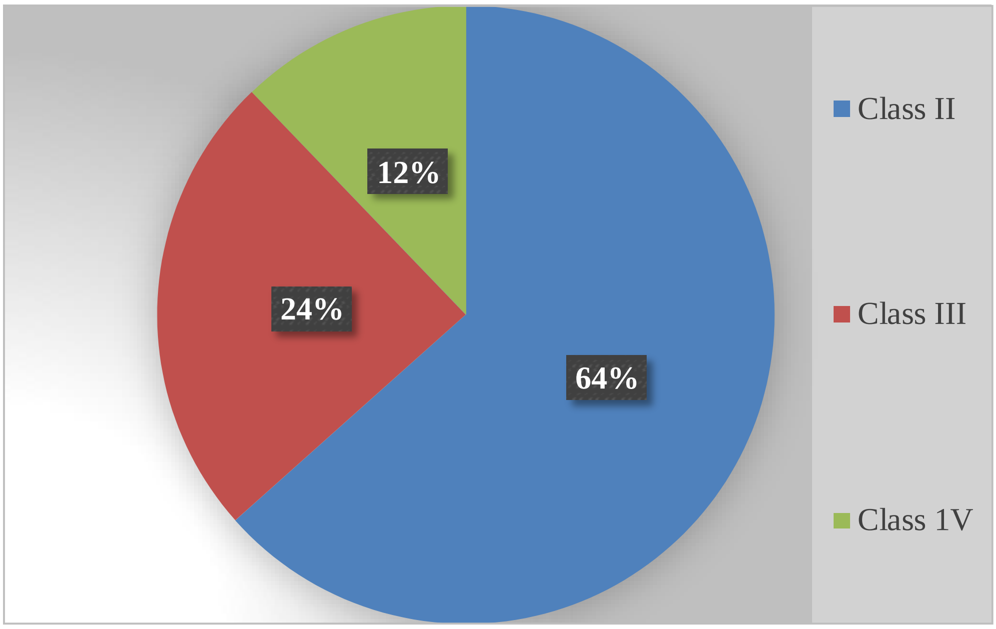

Figure 3.4: WHO classification of the commonly used pesticides within Kikome, Makueni County.

3.3.5. Pesticide application practices

The number of respondents who applied pesticides in the morning was twice (13%) higher than those who applied in the evening (6%). About 17 % of the respondents chose either a morning or evening spraying regime. In addition, 10 % of respondents applied pesticides at any time of the day (Figure 3.5).

About 44 % of the respondents applied pesticides more frequently at the flowering stage while a few number (3 %) applied pesticides frequently in all stages of production (Figure 3.6). Other respondents applied pesticides frequently during the germination, vegetative, budding, and fruit set stages.

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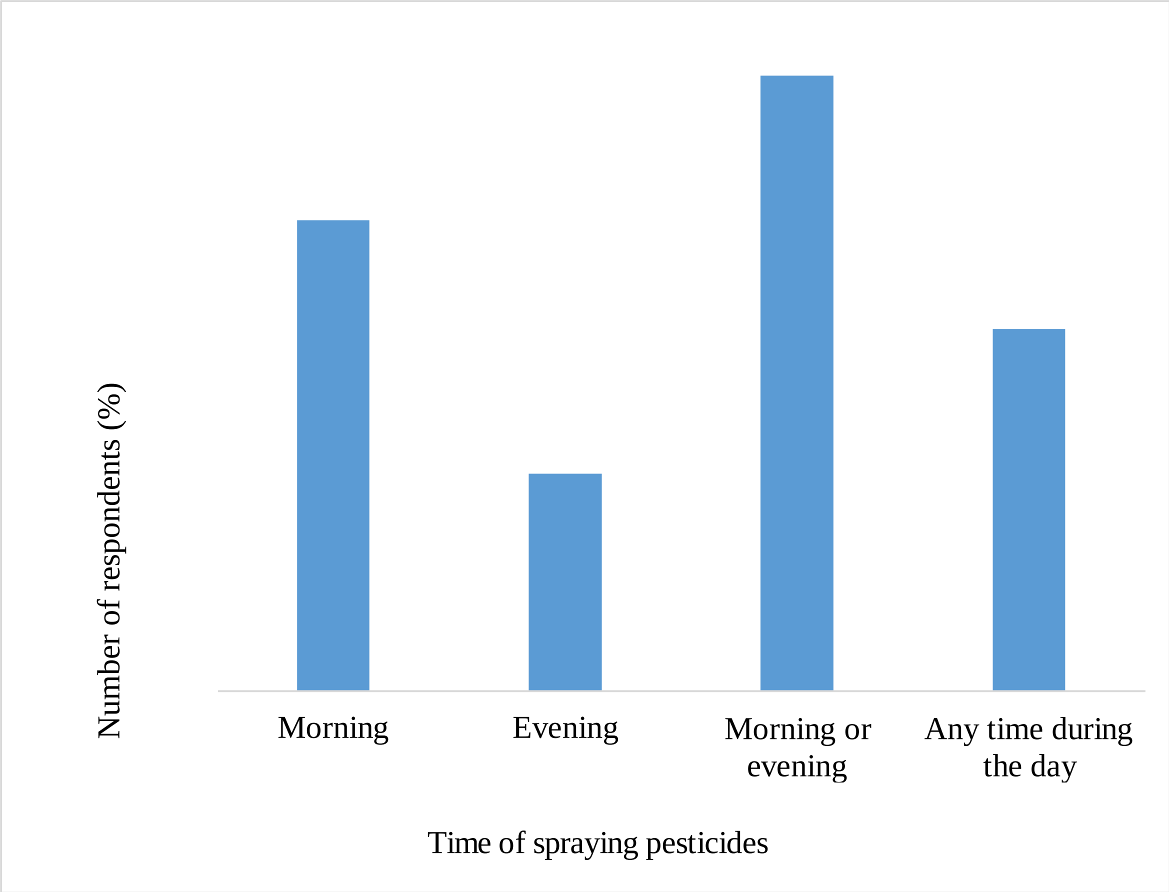

Figure 3.5: Time of the day of spraying pesticides

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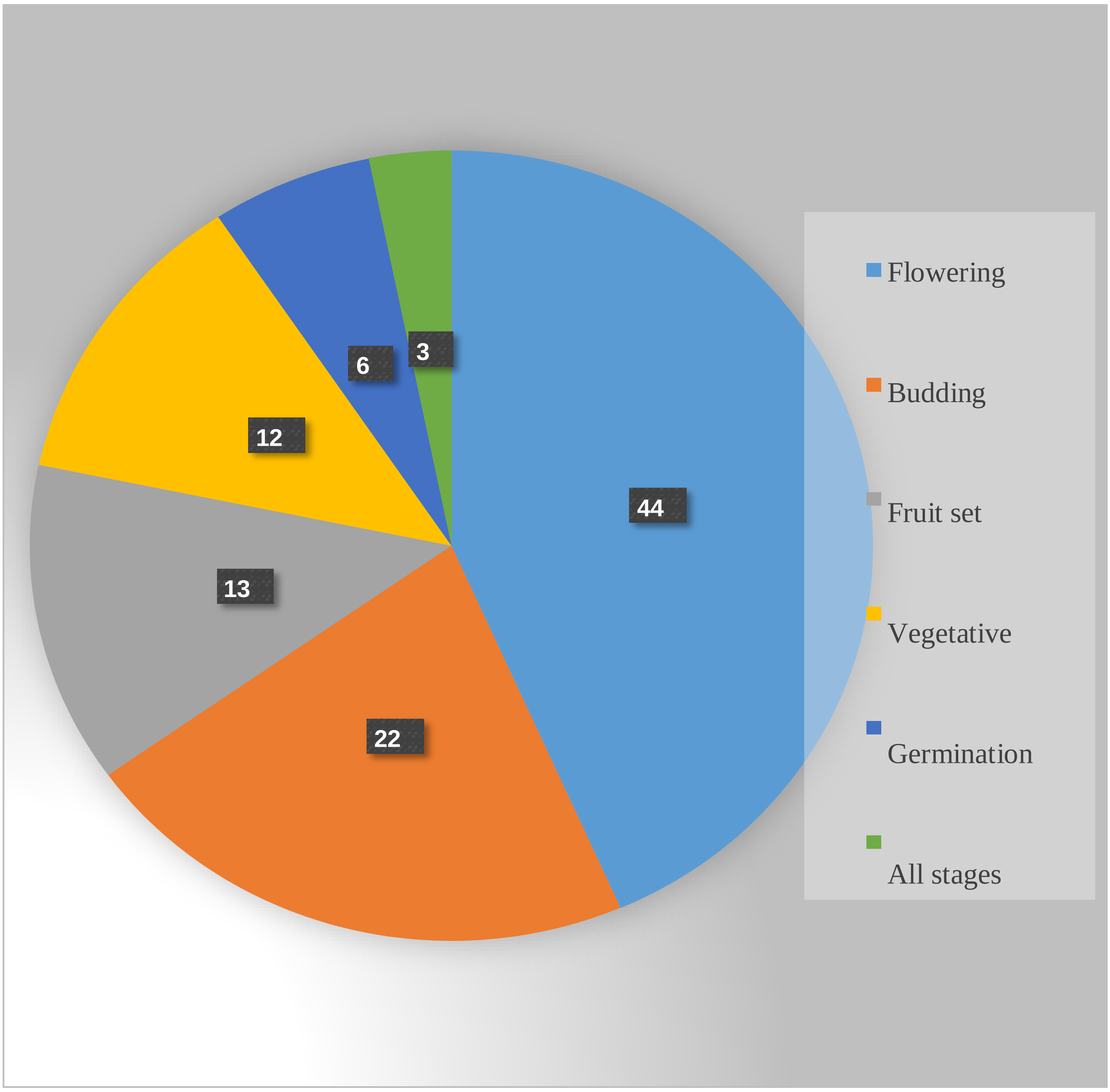

Figure 3.6: Cropping stage when farmers applied pesticides more frequently.

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3.3.6. Farmers training on pesticide use and application practices

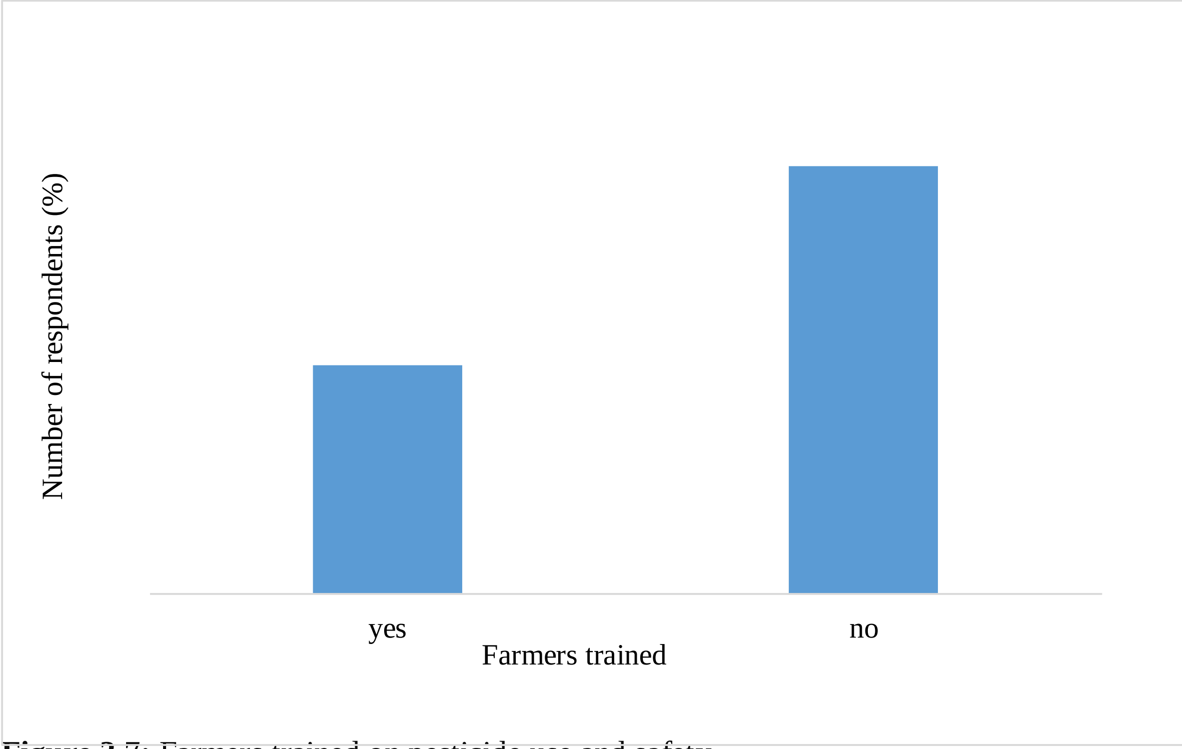

Figure 3.7: Farmers trained on pesticide use and safety

3.3.7. Determinants of farmers' choices in pesticide use and application practices.

Different social economic characteristics are important for their consideration in their potential to influence the proper use or misuse of pesticides.

3.3.7.1. Time of spraying pesticides

The multinomial regression model was found to be significant (X2=46), d.f=27, p= .013), and explained 68.1% of variation of spraying time as explained by gender, age, education level (table 3.3). Education and age were found to significantly influence time of spraying but gender of farmers did not have any impact (table 3.4).

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Table 3.3: Model Fitting Information

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	Df	Sig.
IUN	97.051			
Final	51.041	46.009	27	.013

Table 3.4: Likelihood Ratio Tests

Effect	Model Fitting Criteria -2 Log Likelihood of Reduced Model	Likelihood Ratio Tests Chi-Square	df	Sig.
Intercept	51.041[a]	.000	0	.
age bracket	78.023	26.982	15	.029
level of education	72.735	21.694	9	.010
Gender	52.053	1.012	3	.798

3.3.7.2.Cropping stage when farmers frequently used pesticides

The multinomial regression model was found to be significant (X2 =79), d.f=45, p= .001), and explained 86 % of variation of the cropping stage when farmers frequently applied pesticides as explained by gender, age, education level (table 3.5). The age, level of education and gender were found to significantly influence time of spraying (table 3.6)

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Table 3.5: Model Fitting Information.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept only	119.327			
Final	39.716	79.611	45	.001

Table 3.6: Likelihood Ratio Tests

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	39.716[a]	.000	0	.
Age bracket	87.070	47.354	25	.004
Level of education	76.976	37.259	15	.001
Gender	56.960	17.243	5	.004

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3.4. Discussion.

Gender is an important aspect influencing social practices as each gender has hyper sensitivities that are hormonally controlled (Duah, 2002). Previous studies have indicated that spraying of pesticides is mainly done by men who also decide on what pesticides to spray (Mengistie *et al.,* 2017).

Majority of the respondents in this study were young people aged between 34-41 years. Age is an important factor influencing decision making, (de Acode Lizarraga *et al*., (2007), as young people in farming tends to be flexible in decision making and the ability to adopt new technologies. This is in agreement with studies done by de Acode Lizarraga *et al*., (2007). who reported that old people did not trust any new technology, as well as adopting safe handling methods in pesticide use. The same authors also observed that old farmers were conservative and held onto their past convectional practices as the use of DDT (Dichlorodiphenyltrichloroethane) due to the earlier gains in inputs associated with its use.

Majority of respondents in this study had acquired primary level of education, while the least had attained university/college level. According to Rios-Gozalez *et al*., (2013), education has positive impact on farmers' lifestyles. Educated farmers have an ability to understand effects of pesticides effects on human health and environment (Karlsson, 2004). It is encouraging that 15.2 % of respondents had received college/university education. Such a category of farmers would need little exposure in pollinator conservation issues to enable them to embrace good agricultural practices that are biodiversity friendly. According to Hordzi (2015), having the majority of farmers with low levels of education is a major concern. This is because such farmers may not understand the scientific principles of insect pollination and implications of indiscriminate use of chemical pesticides on insect pollinators. As a result, they may engage in pest control practices that have detrimental effects on insect pollinators interfering with benefits associated with them.

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All the respondents interviewed during the survey used chemical pesticides in pest management. In assessment of pesticide use among smallholder vegetable farmers in Ethiopian Central Rift Valley, Mengistie *et al.*, (2017) reported that all respondents were using chemical pesticides as the sole method of pest management. The authors observed that no IPM strategy or biological control was being used by farmers neither were the principles fully understood.

In another study, Mutuku *et al.*, (2014) recorded that 98.6 % of respondents used pesticides solely in the management of tomato pests in Kathiani District, Kenya. The authors reported 19 chemical pesticides containing 21 chemical compounds with carbamates, pyrethroids and organophosphates being the most frequently used. Besides, Class II pesticides were the most frequently used (68.4 %) followed by class IV (21.1 %) and class III (10.5 %).

In the assessment of farmers' knowledge on pesticide use within smallholder potato farms in Uganda, Okonya & Kroschel (2015) recorded that all respondents in South-Eastern highlands were using chemical pesticides in pest management majorly fungicides and insecticides. Similar observations were made by Macharia *et al*., 2013).

Majority of the respondents in the present study were using pesticides more frequently during the flowering period. A study was conducted at both pre-flowering and flowering stage to compare the impacts of Dimethoate (organophosphate) and lambda-cyhalothrin (pyrethroid) on sunflower pollination and associated yield in Eastern Kenya (Nderitu *et al*., 2007). The authors observed that plots treated with insecticides recorded a lower number of developed seeds, of smaller size and lower weight than the control (untreated plots). In addition, the plots that were treated with dimethoate (organophosphate) recorded a lower number of foraging bees relative to plots sprayed with lambda-cyhalothrin (pyrethroid). They recommended that farmers should adopt pest management practices that are bee-friendly.

The majority of respondents applied pesticides either in the morning or evening. This

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shows that they were informed on the best time of the day when pesticides should be applied. Applications made either early in the morning or late evening minimizes exposure of insect pollinators to pesticides since the floral resources are depleted and the foraging activity of diurnal insect pollinators is low (Jonathan *et al*., 2017). Evening applications are safer because of the longer exposure period before diurnal insect pollinators visit the crop (Abrol, 2012). Previous studies indicated that evening insecticide applications, even at the flowering stage, reduced negative impacts of pesticides on the foraging activities of the honeybees (Nderitu *et al.*, 2007). In addition, the authors recorded more yield in plots treated with insecticides in the evening than in the morning.

In Ethiopia, Jansen and harmsen (2011) observed and reported that the respondents did not fully understand the environmental effects of pesticides. Majority of farmers were unable to read pesticide labels which could provide instructions for use since the label was written in foreign language or the letter font was too small.

The majority of respondents in the present study had no access to extension services on pesticides use and safety. This agrees with studies done elsewhere. In a survey to assess the impacts of training farmers on pesticide use and application practices in Greece, Damalas & Koutroubas (2017) observed that farmers' knowledge and beliefs in pesticide hazard control correlated with safety compliance. Similar findings were also indicated by other authors (Van den Berg & Jiggins, 2007; Gautum et *al*., 2017; Mengistie *et al*., 2017).

Poor practices in using chemical pesticides as well as application practices in the present study can be attributed to farmers' lack of adequate technical knowledge and training on pesticide use and application practices. All stakeholders including

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environmental Non-Governmental Organization, agrochemical industry, extension workers and health practitioners should provide technical support to farmers to address the existing knowledge gaps.

Training farmers has proved useful in changing farmers' mindset in using and applying chemical pesticides (Van den Berg& Jiggins, 2007; Gautum et *al*., 2017). This is because pesticides are complex, hazardous and toxic. Also, small scale farmers may find the information provided on the label to be verytechnical to understand. Farmers would therefore need technical support from both state and non-state actors for correct pesticide use and application practices.

Lack of training on pesticide safety is the possible reason why the principles of biodiversity conservation are not put into consideration during pest management. As such, farmers have a mindset that chemical pesticides have a quick knockdown effect hence their preference. Moreover, methods of pest management such as biological control and IPM (Integrated Pest Management) and are not fully understood by farmers.

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CHAPTER FOUR.

DIVERSITY AND ABUNDANCE OF INSECT POLLINATORS AND THEIR EFFECT ON YIELD ND QUALITY OF COWPEA AND CUCUMBER IN MAKUENI, KENYA

Abstract

Inadequate pollination is one of the key limitations in crop yield and quality of key vegetable crops. Cowpea and cucumber are crops of economic importance in Makueni County-Kenya. An experiment was carried out in Makueni County Kenya during the short (2017) and long (2018) rain seasons to determine the seasonal diversity and abundance of insect pollinators and their contribution to yield and quality improvement of cowpea and cucumber. It was laid out as a split-plot within a randomized complete block design and involved bagged and unbagged treatments replicated three times. The study reported eight and twelve insect pollinator species on cowpea and cucumber flowers respectively. *Apis mellifera* was the most abundant of all insect pollinators observed in both test crops during the two growing seasons. The species represented 74.1 % and 80.5 % of all insect pollinators observed as average of the two growing seasons in cowpea and cucumber respectively. In cowpea, the peak foraging activity of the species was recorded at 9:00 am -10:00 am (Mean=13.05, $p=0.52$) and 7:00 am - 8:00 am (Mean=7.5, $p=0.021$) during the short and long rain seasons respectively. In cucumber, *A. mellifera* foraged mainly between 8:00 am - 9:00 am during both short (Mean=7.36, $p<.001$) and long rain seasons (Mean=4.882, $p<.001$). The study recorded a higher diversity of pollinating species during the long rain season (cowpea: H=1.53; cucumber: H=1.21), compared with the short rain season (cowpea H=0.18; cucumber: H=0.16). A higher yield and quality of the test crops was recorded in unbagged treatments relative to bagged treatments ($p<0.05$).

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This study shows that insect pollinators are important for improvement of yield and quality of cowpea and cucumber in Makueni County.

4.1.Introduction

Cowpea is drought tolerant and grows well at an optimum temperature of 30 °C and 300 mm of rainfall per year hence an important crop in the arid and semi-arid regions of Eastern Kenya. It is a highly nutritious crop which is rich in proteins (23 - 25 %), starch (50 - 67 %) and vitamin B (Ntoukam *et al*., 1993). Cucumber is a warm-season crop that does well in temperature ranging from 18 ºC - 30 ºC, elevation of 1700 m above sea level and optimum of 800 mm of rainfall hence supplemental irrigation necessary for consistent moisture availability (Pedrini, 2018). The male and female flowers occurs on the same plant, hence the crop termed as monoecious. Male flowers are found in clusters on a slender stem and housing three stamens. In contrast, female flowers occur singly with a large ovary at the base. Cucumber flowers are usually yellow, with wrinkled petals. Both male and female flowers produce large volumes of nectar attracting a variety of insect pollinators. Stigma is receptive during the day, but more receptive early in the morning (Collins, 2007). Fresh cucumbers are reliable sources of dietary fiber, vitamin C, thiamine, niacin, iron, calcium, and phosphorous (Gopalan *et al*., 1982).

Cowpea is both self and cross-pollinating producing nectar that attracts variety of insects such as *A. mellifera*, *Megachile sp, Melecta sp, Brussel sp, Brausepis sp, Melecta sp, Amegilla sp, Lasioglossum sp, Ceratina sp, Xylocopa calens, Lipotriches sp, X. imitator*, moths, butterflies *(*Lepidoptera*)*, wasps *(*Hymenoptera), and thrips (Hordzi, 2011). Its flowers open between 6:00 am - 6:30 am and closes between 11:30 am -12:00 pm (Ige *et al*., 2011).

Insect pollination contributes to higher fruit set, heavy pods, larger pod length, healthy seeds, and higher number and weight of seeds per pod (Fohouo *et al*., 2009). Cucumber, like other cucurbits, is cross-pollinated resulting in maximum fruit set with

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well-shaped fruits, while poor pollination results in deformed fruits. Additionally, insect pollination results in fruits of higher weight, large size, more number of seeds per fruit, higher seed weight and uniform maturity (Thakur, 2007).

Information about cowpea and cucumber pollination and their pollinators is scanty in Makueni-Eastern Kenya. Limited knowledge of pollinator-plant interaction in the ASALS has exposed insect pollinators to diseases, pests, parasites, predators, and pesticides use. Despite the economic importance of cowpea, seed production is still limited due to poor crop husbandry and insufficient pollination. Insect pollinators plays a key role in the transfer of pollen grains from anthers to stigma since the pollen grains are heavy and sticky (Sarwar *et al*., 2008).

Research has however shown that cucumber and other curcubits are able to set fruits to a smaller extent without insect pollination attributed to chances of wind pollination leading to considerably lower yield than cross-pollinated crops (Inam *et al*., 2015). In addition, pollination of crops can take place by chance if assisted by man or nectar thieves (Kasina *et al*., 2007).

Keeping in view the pollination requirements of the two crops, the present investigations were done to study various insect pollinators, their abundance in selected time of the day, and their impact on the yield and quality of the respective test crops.

4.2.Materials and methods

4.2.1. Description of the study area

The study was carried in an experimental farm in Kikome village located inMakueni-Eastern Kenya (latitude S 02.14504°, longitude E 037. 80262°, altitude 803 m above sea level) from November 2017 to March 2018 (short rain season) and April 2018 to July 2018 (long rain season) (Figure 4.1). Makueni County is divided into six sub counties, namely, Makueni, Kilungu, Mukaa, Kibwezi, Kathonzweni, Makindu,

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Mbooni East, Mbooni West and Nzaui. Kikome village is located in Makueni sub-county and Kitise ward.

4.2.2. Land preparation

The experimental area was tilled using an oxen plough. Subsequently, manual hallowing was done to fix predetermined plots leaving 1m wide buffer lanes between the plots to allow data collection (Figure 4.1). Soil samples collected from the site were sent to Jomo Kenyatta University of Agriculture and Technology (JKUAT) laboratory for analysis of key nutrients required for plant growth. These included Phosphorous (P), Nitrogen (N), Potassium (K), Exchangeable Cations (EC), Ph, and moisture content (Appendix 2). Conditions at the experimental site were as follows: Soil pH: 7.4 Ec: 0.08 - 0.13 mS/cm, N: 0.03 %; available P: 114 mg/kg; available K: 0.3 me1/100 g, Cation Exchange Capacity (CEC): 12 meq/100g, soil moisture content: 2.7 %. The experimental plots measured 10 m x 7 m with a 1 m distance between them.

4.2.3. Crop establishment

To establish the plants, two seeds were directly sown in each planting hole at a depth of 2.5 cm in the field. The inter and intra-row spacing was 30 cm x 25 cm and 90 cm x 30 cm in cowpea and cucumber respectively. Di-ammonium Phosphate (DAP) fertilizer was incorporated into the soil while planting cucumber, while no fertilizer was used in cowpea plots. Two weeks after germination, the seedlings were thinned to one seed per planting hole while gapping was done where seeds failed to germinate. Plants were watered once per week by touching to feel the soil and irrigating before the topsoil dried to a greater depth using a surface water pump. Besides, weeding was done two times during the cropping cycle: the first and second weeding was done two and four weeks respectively after planting. Calcium Ammonium Nitrate (CAN) fertilizer at the rate of 100 kg/ha was applied in cucumber for top dressing to stimulate

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vegetative growth. Pests and diseases were controlled using bio-pesticides purchased from the Kenya Biologics.

4.2.4. Treatments and experimental layout

Experiments were laid out as a split plot within a randomized complete block design. A split plot design is basically a factorial treatment structure comprised of two levels of experimental units. In this case, the whole plot is divided into subplots and has two levels of randomization.

The treatments were replicated three times. Main plots comprised of bagging treatments at two levels; one bagged with an insect proof net (size 0.6 mm bought from Smaat enterprises Nairobi) and the other was left unbagged (Plates 4.1 and 4.2). A 1 m empty lane was left between the main plots. Sub-plots consisted of two plant species *viz.* cowpea variety Ken Kunde and cucumber variety Ashley.

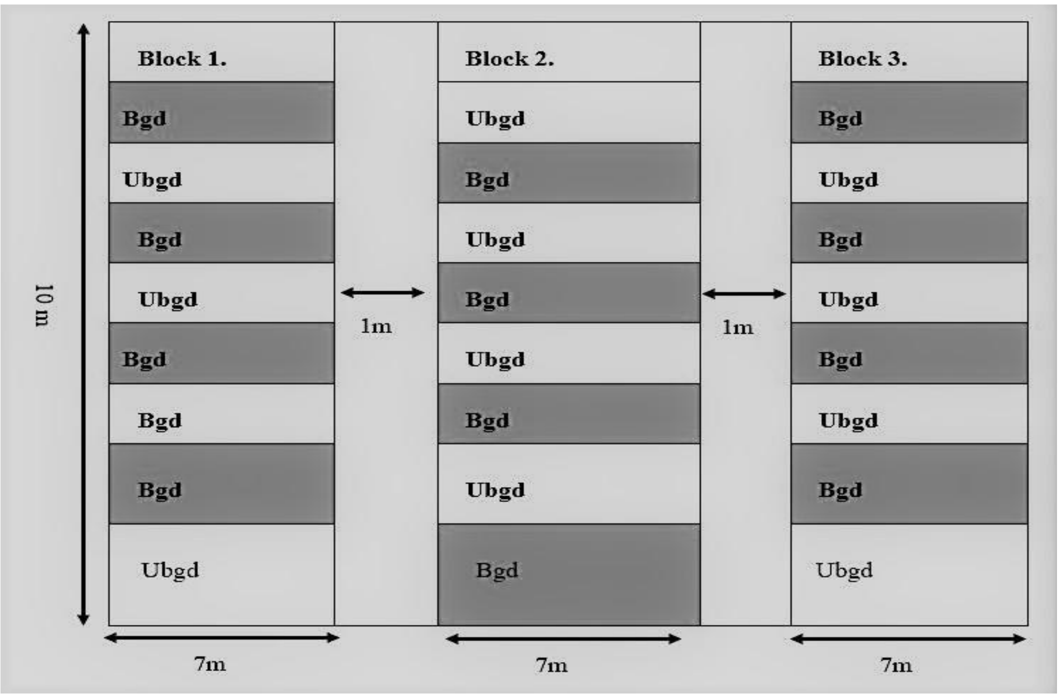

Figure 4.1: Experimental design and layout

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The ‘Ubgd’ and ‘Bgd’ refers to unbagged and bagged treatments respectively in respective experimental plot

Plate 4.1: Bagged (Bgd) and unbagged (Ubgd) treatments in cowpea experimental plot

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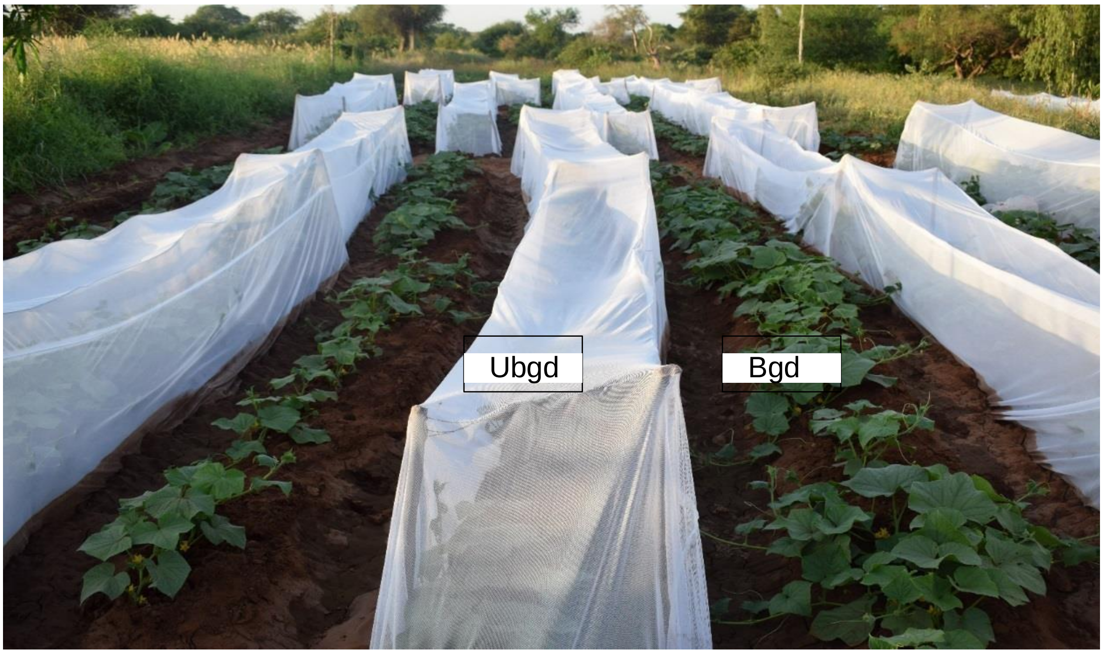

Plate 4.2: Bagged (Bgd) and unbagged (Ubgd) treatments in cucumber experimental plot.

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4.2.5. Insect pollinators' diversity and abundance assessment

Cowpea and cucumber plants started flowerings 35 and 45 days after planting respectively. Thus, the assessment of insect pollinators commenced when 50 % of the crops had flowered until the end of the blooming period which lasted for 28 days in cowpea and 32 days in cucumber. The timed visual search approach was used for sampling within both cowpea and cucumber experimental plots**.** It involved walking along the various experimental blocks searching for pollinators systematically. Precisely insect pollinators were observed at each replicate within the experimental block for fifteen minutes while walking along crop rows. Data on insect pollinators of respective crops were collected at four days' interval: four days on cowpea plots, then the next four days on cucumber plots. For cowpea, observations were done from 7:00 am - 10:00 am since its flowers have been reported to open between 6:00 am and 6:30 am and close between 11:30 am and 12:00 noon (Ige *et al*., 2011). Observations in cucumber plots were however done from 7:00 am to 5:00 pm since its flowers have been reported to open at 5:30 am and close between 6:00 pm and 6:30 pm (Khaja Rubina, 2010).

The number of individual insect pollinators visiting respective unbagged plants on each sampling day and during different times of the day was recorded. This was important to get visitation frequencies of the different insect pollinators. Samples of the insect pollinators observed and recorded were collected using a usual cone-shaped sweep net and stored in vials containing 70 % ethanol. Preserved insects were transported to a laboratory at the Zoology Department in the National Museums of Kenya, Nairobi for identification by the taxonomists using the taxonomic keys and reference collection. The diversity and abundance of insect pollinators of respective test crops was then determined.

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4.2.6. Effect of insect pollinators on the yield and quality of cowpea and cucumber.

Cowpea pods and cucumber fruits were harvested at physiological maturity (Kader, 1992). The yield and the germination percentage of the test crops harvested from bagged and unbagged treatments was compared to determine the contribution of insect pollinators to yield and quality improvement of respective test crops. Yield was determined by counting the average number of pods and fruits per plant sampled from five plants per plant row. The length, diameter and weight of cowpea pods and cucumber fruits was measured before the seeds were extracted. Seeds from each cowpea pod and cucumber fruit were counted and then weighed using a scale balance (model MA 40, manufactured in Germany).

The germination percentage of the harvested seeds was done in the National Museums of Kenya, Botany department, ex-situ laboratory, three weeks after seed extraction. The test was determined using procedures obtained from International Seed Testing Standards (2015). The seeds were placed on the surface of petri dishes that had been sterilized with 70 % ethanol. The Petri dishes and their covers were labeled taking note of the number of replicate, date and the crop variety. The growth substrate comprised of 10 % agar solution which was prepared by dissolving 10 g of agar powder in 100 ml of warm distilled water and heated on a hot plate.

The solution was allowed to boil to allow all the agar to dissolve completely, slightly cooled to 50 ^{o}C then poured into labeled petri dishes. The number of both cowpea and cucumber seeds used for the germination tests was 100. The seeds were arranged equidistantly in the petri dishes on the surface of the agar in 5 replicates each containing 20 cowpea seeds and 4 replicates each containing 25 cucumber seeds.

The petri dishes were covered with their lids then placed in an incubator at room temperature. The scores for germination were taken when the radicles were 2 mm long and the germination percentage calculated as the percentage of the total seeds that

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germinated out of total seeds sowed.

4.2.7. Data analysis

The frequency of visitation by each insect pollinator was recorded to identify the most abundant on cowpea and cucumber flowers and influencing their yield and quality using the equation as reported by Preston (1948) (Equation 4.2):

$$\text{Relative abundance of species } = \frac{\text{Number of individual visits on flowers}}{\text{Total number of pollinators}} X100$$

Equation 4.1

The diversity of the insect pollinators was measured by computing the Shannon Weiner index of diversity according to procedures established by Claude & Nobert, (1949) (Equation 3.3):

$$H = \sum[(\mathrm{Pi}) \times \ln(\mathrm{pi})] \qquad \text{Equation 4.2}$$

Where pi is the proportion of the i^{th} species of the pollinators.

4.3. Results

4.3.1. Diversity and abundance of insect pollinators associated with cowpea and cucumber

While 8 insect pollinator species were observed and recorded on cowpea flowers, 12 species were recorded on cucumber flowers during the short and long rain seasons (Table 4.1). *A. mellifera* was the most dominant insect pollinator during the two growing seasons in both test crops (Table 4.2). Whereas 75 % of the species found in cowpea belonged to the order Hymenoptera, only 33 % belonged to the order Hemiptera (Table 4.2). The study recorded a higher diversity of insect pollinator species during the long rain season (cowpea: H= 1.53; cucumber: H= 1.21), relative to the short rain season (cowpea H=0.18; cucumber: H=0.16) (Table 4.2). The Shannon Weiner index of diversity of the two crops during the two growing seasons was significantly different from each other (p=0.042, t=7.59) with a higher diversity recorded in cucumber (Table 4.2). The difference in the Shannon weiner index of diversity between the two growing seasons of each of the test crop was not statistically different from each other.

Table 4.1: Insect pollinators of cowpea and cucumber

		Cowpea	
Order	Family	Species	Common name
Hymenoptera	Apidae	*Apis mellifera*	*Honey bee*
		Xylocopa sp	*Carpenter bees*
	Vespidae	*Iphiaulax* sp	*Red paper wasp*
		Ichneumonid sp	*Paper wasp*
	Formicidae	*Camponotus* sp	*Carpenter ants*
Coleoptera	Meloidae	*Mylabris merefiensis*	*Blister beetle*
Lepidoptera	Lycaenidae	*Lampides boeticus*	*Pea blue butterfly*
Hemiptera	Pentatomidae	*Pentatomid* sp	*Stink bug*
		Cucumber	
Hymenoptera	Apidae	*Apis mellifera*	Honey bee
	Halictidae	*Lasioglossum* sp	Sweat bee
	Formicidae	*Camponotus* sp	Carpenter ant
Hemiptera	Miridae	*Mirid* sp	Plant bug
	Pyrrhocoridae	*Dysdercus cardinalis*	Cotton stainer bug
	Reduviidae	*Reduviid* sp	Assassin bug
	Lygidae	*Dieuches* sp	Apple red bug
Lepidoptera	Lycaenidae	*Lampides boeticus*	Pea blue butterfly
	Hesperidae	*Pelopidas mathias*	Black branded swift Butterfly

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Coleoptera	Coccinelidae	*Henesepilachna reticulata*	Ladybug
	Nitidulidae	*Carpophilus ligneous*	Sap beetle
Diptera	Syrphidae	*Episyrphus trisectus*	Marmalade hoverfly

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Table 4.2: Abundance of different insect pollinators of cowpea and cucumber during the two growing seasons

Mean ± S.E per Season				
Crop	**Cowpea**		**Cucumber**	
Season	**I**	**II**	**I**	**II**
Insect pollinators				
Apis mellifera	12.0± 1.8 (875)	4.5±0.7 (211)	5.1±2.2 (532)	3.3±0.2 (454)
Mylabris merefiensis	2±0.2 (39)	-	-	-
Ichneumonid sp	-	2.4±0.3 (93)	-	-
Camponotus sp	-	1.7±0.1 (48)	-	2.5±0.5 (5)
Iphiaulax sp	-	1.4±0.1 (20)	-	-
Lampides boeticus	-	1.8±0.3 (14)	-	1.5±0.1 (35)
Pentatomidn sp	-	1.4±0.3 (11)	-	-
Xylocopa sp	-	1(1)	-	-
Henesepilachna Reticulate	-	-	2.2±0.5 2.2±0.5	-

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			(13)	
Pelopidas mathias	-	-1	-	
			1.8±0.1	
Mirid sp	-	--	(126)	
				1.4±0.2
Episyrphus trisectus	-	--		(27)
			1.3±0.10	
Lasioglossum sp	-	--	(24)	
Dysdercus			1.5±0.14	
cardinalis)	-	--	(21)	
Carpophilus ligneus	-	--	1.7±0.4	(8)
Reduviid sp	-	--	1.7±0.3 (5)	
Dieuches sp	-	--	1	

[1] H values: Cowpea: 0.18 (Short rain season), 1.53 (Long rain season). Cucumber, 0.16 (Short rain season), 1.21 (Long rain season). The values in brackets represents the total number of individual insect pollinator

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4.3.2. Foraging activity of *A. mellifera* on cowpea and cucumber inflorescences

Observations were made between 7:00 am - 10:00 am in cowpea and 7:00 am -5:00 pm in cucumber flowers. In cowpea, *A. mellifera* foraged mainly at 9:00 am -10:00 am (Mean=13.05, p=0. 52) and 7:00 am – 8:00 am (Mean=7.5, p=0.021) during the short and long rain seasons respectively (Figure 4.2). However, in cucumber, the same species foraged more between 8:00 am - 9:00 am during the short (Mean=7.36, p<.001) and long rain (Mean=4.882, p<.001) seasons respectively (Figure 4.3). Except for the purposes of identification, all individuals other than *A. mellifera* were treated as a single population (non-*Apis* species). In cowpea, the foraging activity of non-*Apis* species peaked between 8:00 am and 9:00 am (p=0.019) and 9:00 am -10:00 am (0.370) during the short and long rain seasons respectively (Figure 4.2). In cucumber, the foraging activity of non-*Apis* species peaked between 7:00 am -8:00 am (p=0.366) and 8:00 am and 9:00 am (p=0.264) during the short and long rain seasons respectively (Figure 4.3)

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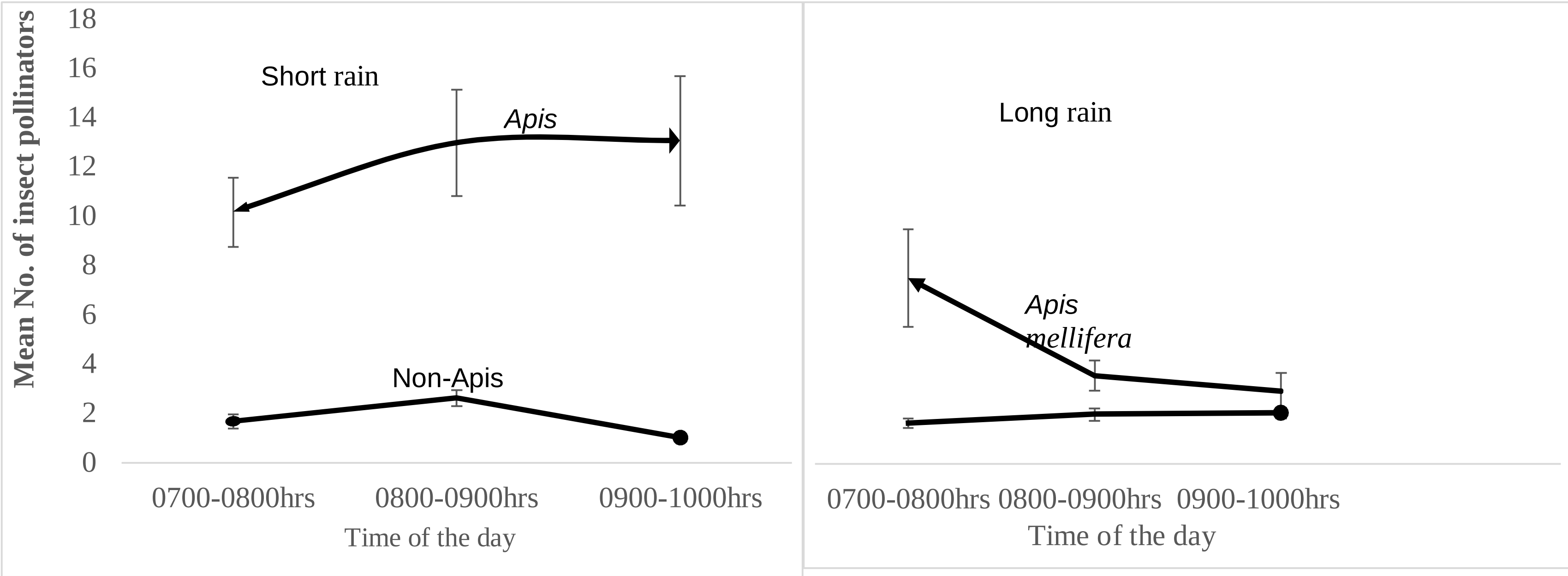

Figure 4.2: Changes in the mean (±S.E.) of insect pollinators per plot with time of the day in cowpea during the short rain (2017/2018) and long rain season (2018**)**

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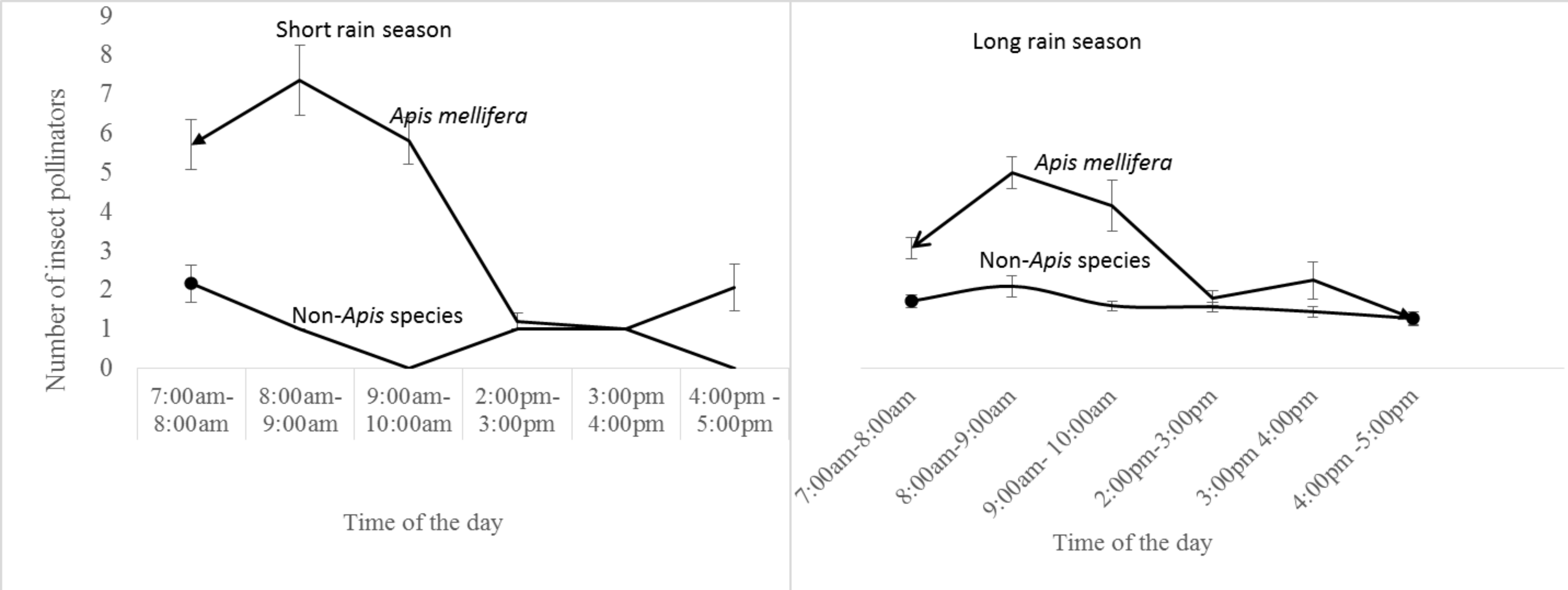

Figure 4.3. Changes in the mean (±S.E.) of insect pollinators per plot with time of the day in cucumber during the short rain (2017/2018) and long rain season (2018).

4.3.3. Effect of insect pollinators on the yield and quality of cowpea and cucumber

During the two seasons, cowpea and cucumber plants that were bagged had significantly higher number of crooked pods and fruits than the unbagged plants ($P < 0.001$). Bagged cowpea pods and cucumber fruits were of a lower mean weight significantly different from the unbagged plots ($p<0.001$). In addition, the number and the weight of the seeds were lower in bagged plots than the unbagged plots ($p<0.001$). Unbagged flowers yielded wider pods and fruits than the bagged flowers and the highest germination percentage in both seasons significantly different from bagged plants ($p<0.001$) (Table 4.3 and 4.4).

Generally, there was seasonal variation in the yield and quality of cowpea and cucumber. Both crops yielded higher during the long rain season and recorded a higher germination percentage (Table 4.3 and 4.4)

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Table 4.3: Mean (±S.E.) of cowpea yield and quality parameters assessed during the two growing seasons

Short rain season					Long rain season			
	Bagged	Unbagged			Bagged	Unbagged		
Parameters	Mean ± S.E.		T	P	Mean ± S.E.		T	P
Total pods/plant	7.53±0.52	9.11±0.31	-2.59	0.012	7.64±0.38	8.53±0.48	-1.44	0.154
Crooked pods/plant	5.25±0.31	0.56±0.12	13.9	< 0.001	3.94±0.25	0.25±0.09	13.93	< 0.001
Average pod weight(g)	3.08±0.1	3.87±0.19	-3.74	< 0.001	2.091±0.07	4.002±_0.22	-1.62	< 0.001
Pod length(cm)	12.99±0.11	14.82±0.13	-10.7	< 0.001	12.07±0.16	14.59±0.17	-10.6	< 0.001
Pod diameter(cm)	2.486±0.06	2.678±0.08	-5.12	< 0.001	2.38±0.03	2.96±0.03	-15	< 0.001
Number of seeds per pod	12.75±0.27	14.97±0.16	-7.15	< 0.001	11.61±0.24	15.78±0.34	-9.91	< 0.001
Seed weight(g)	2.50±0.11	3.52±0.08	-7.47	< 0.001	1.67±0.04	3.5±0.18	-9.83	< 0.001
Germination %	76.28±1.87	91.61±1.29	-6.75	< 0.001	79.19±1.26	99.86±1.10	-16.4	< 0.001

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Table 4.4: Mean (±S.E.) of cucumber yield and quality parameters assessed during the two growing seasons

Short rain season					Long rain season			
	Bagged	Unbagged			Bagged	Unbagged		
Parameters	Mean ± S.E.		T	P	Mean ± S.E.		T	P
Total fruits/plant	6.83±0.4	9.03±0.25	-4.64	< 0.001	5.75±0.34	11.72±0.58	-8.94	< 0.001
Crooked fruits/plant	5.5±0.37	0.78±0.16	11.59	< 0.001	4.22±0.41	0.14±0.07	9.85	< 0.001
Average fruit weight (kg)	0.25±0.01	0.43±0.04	-4.29	< 0.001	0.27±0.06	0.71±0.03	-6.17	< 0.001
Average length (cm)	19.55±0.38	22.01±0.45	-4.23	< 0.001	18.64±1.04	25.23±0.24	-6.15	< 0.001
Fruit diameter (cm)	15.11±0.2	18.74±0.45	-7.42	< 0.001	15.43±0.74	21.36±0.20	-7.75	< 0.001
Number of seeds /fruit	78.6±15.28	350.4±11.77	-14.09	< 0.001	19.8±4.2	552.2±34.13	-15.48	< 0.001
Seeds weight (g)	0.62±0.12	4.5±0.15	-20.74	< 0.001	0.27±0.06	6.78±0.21	-29.52	< 0.001
Germination %	0.28±1.19	82.25±2.6	-31.48	< 0.001	0.75±0.42	88.39±2.26	-38.16	< 0.001

4.4. Discussions

4.4.1. Diversity and abundance of insect pollinators of cowpea and cucumber

High visitation rates of honeybees relative to other insect pollinators demonstrates that honeybees are one of the most reliable insect pollinators of cowpea and cucumber within the study area. This is in agreement with other studies done worldwide. Previous studies indicated that *A. mellifera* were the major insect pollinators of cowpea and squash (Cucurbitaceae) in Kakamega (Kasina *et al*., 2009). This was also observed by Hordzi (2011) who reported that honeybees were the main insect pollinators of cowpeas in Ghana. Other studies also recorded *A. mellifera* as the most prominent of all insect pollinators observed in cowpea and that the pollinator visits cowpea immediately the flowers open (Ige *et al.*, 2011). Similar findings were made in cucumber in Western Kenya (Oronje *et al*., 2012) and Peshawar (Inam *et al*., 2015).

High abundance of *A. mellifera* is attributable to its feeding mechanism involving the engagement of several bee workers to exploit nutritional resources to the colony. Increase in population of non-bee species during the long rain season rather than *A. mellifera* was associated with an increase in yield and quality of cowpea and cucumber. According to Greenleaf & Kremen (2006), Non-*Apis* bees also increase foraging activities of honeybees. The authors recorded five-fold pollination efficiency of the honeybees in the presence of non-*Apis* bees. In another study, the non-bee species recorded were not efficient pollinators of sunflower (*Helianthus annuus* L., Asterale: Asteraceae) but were important in enhancing pollination by the honeybees (DeGrandi-Hoffman & Watkins, 2000).

4.4.2. Foraging activity of *A. mellifera* on cowpea and cucumber inflorescences

In cowpea, the peak foraging activity of insect pollinators was between 8:00 am - 9:00 am and 7:00 am - 8:00 am during the short and long rain seasons respectively. These findings agree with those of Fohouo *et al*., (2009) in Cameroon, who recorded the maximum foraging activity of *A. mellifera* on cowpea between 7:00 am -8:00 am. Similar observations were made by (Naeem *et al.*, 2018) who recorded the peak

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foraging activity of *A. mellifera* on *Pisum sativum* L., (Fabaceae) flowers in the morning hours between 9:00 am - 12:00 pm and the lowest in the evening hours between 3:00 pm - 5:30 pm. In pigeon pea (Fabaceae), Prashanth (2009) in Bangalore recorded the overall activity of insect pollinators in the morning, afternoon and evening as 15.74 %, 33.87 % and 50.82 % respectively.

The present study recorded the maximum foraging activity of *A. mellifera* in cucumber between 8:00 am and 9:00 am during the short and long rain seasons. Other studies have reported on the maximum foraging activity of insect pollinators of cucumber and other members of Cucurbitaceae family. Other studies concur with these findings.

The peak foraging activity of honeybee in *Cucurbita pepo* L.,(Cucurbitaceae) in Italy was recorded between 7:00 am -9:00 am (Nepi *et al*., 1996). Similarly, Thakur (2007) recorded peak foraging activity of honeybees on cucumber between 9:00 am - 10:00 am. In Peshawar, Inam *et al.,* (2005) recorded the peak foraging activity of honeybees in cucumber flowers in the evening (1.03bees/plot), and the lowest population in the afternoon (0.78 bees/plot). This is also in agreement with finding reported by Dorjay *et al.,* (2017), in Jammu, who recorded the highest activity of *A. mellifera* on cucumber flowers between 9:00 am - 10:00 am.

Though not determined in the present study, the differences in foraging activity of *A. mellifera* on the test crops from other studies could be due to changes in temperature and humidity, which affects the activities of insect pollinators (Bhattacharya, 2017).

4.4.3. Effect of insect pollinators on the yield and quality of cowpea and cucumber

Yield results from this study indicate that the yield recorded in the unbagged plots was higher and significantly different from bagged treatments. This is attributed to the contribution of insect pollinators on yield and quality improvement of the test crops. The number of pods per plant, pod length, pod weight, seed weight per pod, number of seeds per pod and germination percentage in cowpea were highest in unbagged plots

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and significantly different from the bagged plots.

Studies done by Kasina *et al*., (2007) indicated that cowpea seed yield per pod from bagged and unbagged treatments per year was 1.33 kg and 0.78 kg respectively recording an annual income of 45.05 US$ attributed to insect pollination. Research conducted by Prashanth (2009) recorded a significant difference in number of pods per plant, pod weight, total seeds, and seed weight per pod ($p<0.05$) between caged and uncaged plots of *Cajanus cajan* L., (Fabaceae). The author also recorded a higher germination percentage in uncaged plots (90 %) relative to caged plots (82 %). Similar findings were reported by Aouar-Sadli *et al*., (2008).

Likewise, fruit set occurred in both bagged and unbagged plots of cucumber. The unbagged treatments, however, recorded higher yield and quality relative to the bagged treatments. The difference in yield is attributed to frequent visitation by insect pollinators in unbagged plots where there was open access to all kinds of insect pollinators, unlike bagged plots where the insect pollinators were excluded. This is in agreement with previous studies such as Shah *et al.*, (2015) who recorded fruit set in bagged plots of cucumber and attributed it to chances of wind pollination. It, however, contradicts with studies done by Oronje *et al*., (2012) who observed that all caged *Momordica charantia* L., (Cucurbitaceae) flowers aborted without setting fruits. Fruit set in bagged cucumber could be attributed to chances of wind pollination (Shah *et al.*, 2015).

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CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECCOMENDATIONS

5.1.General discussion

The study showed that all the respondents interviewed during the study used chemical pesticides in pest management. This is possibly because pests are the major limitation in crop production as shown from the study results. Effective use of cultural and biological approaches in pest management can be used to suppress pests population and reduce the inputs of pesticides (Held & Potter, 2012). Amongst various pesticides used by farmers, pyrethroid, neonicotinoid, and carbamate-based pesticides were the most frequently used mostly during the flowering stage. It was noted that most of the farmers had no access to extension services. According to Nderitu *et al., (*2017), farmers should manage pests earlier before the blooming period and adopt pest management practices that are bee friendly

Eight and twelve insect pollinators were recorded as insect pollinators of cowpea and cucumber A higher diversity of insect pollinators ensures the inclusion of species of different pollination efficiencies. Insufficient pollination can be a limiting factor causing reductions in crop yield (Free, 1999). In both test crops, *A. mellifera* was the most dominant insect pollinator. Similar findings have been found by other authors (Kasina *et al*., 2009; Hordzi, 2011; Ige *et al.*, 2011) and cucumber (Oronje *et al*., 2012; Inam *et al*., 2015).

Unbagged treatments had significantly higher yield and germination percentage than the bagged treatments during the two growing seasons in both test crops ($p<0.05$). Fruit set occurred inside bagged plots of the test crops. In cowpea, self-pollination took place leading to pod set, but the yield was considerably lower than that recorded in unbagged plots. Yield in bagged treatments could be attributed to chances of wind and self-pollination as reported by Shah *et al*., (2015).

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5.2.Conclusion

From the study, farmers' pesticide uses and application practices poses a risk to the health of insect pollinators. Additionally, insect pollinators identified during the study are important in the improvement of yield and quality of cowpea and cucumber in Makueni County, Kenya.

The following conclusions can be derived from the study:

1. There is overreliance on the use of chemical pesticides as all respondents were using chemical pesticides as the sole method of pest management. There was frequent use of relatively toxic chemical group of pesticides mostly the pyrethroid, carbamate and ne nicotinoid based pesticides during the flowering stage which is a risk to the insect pollinators feeding on the nectar and pollen.

2. There is a diverse population of insect pollinators important in pollination of cowpea and cucumber in Makueni-Eastern Kenya. *A.mellifera* was however the most dominant insect pollinator of both cowpea and cucumber.

3. Insect pollinators contribute to yield and quality improvement of cowpea and cucumber in Makueni County, Kenya.

5.3 Recommendations

The study makes the following recommendations:

1. Bodies as the National Museums of Kenya and the Bayer Bee Care should train extension officers on the importance of insect pollinators' conservation so that they can train the farmers.

2. A study on the effects of the most frequently used chemical pesticides and application practices on the diversity and abundance of insect pollinators should be carried out.

3. Effects of weather parameters notably temperature, humidity, and rainfall on the activity of insect pollinators of cowpea and cucumber should be studied

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APPENDICES

Appendix I: Questionnaire used for assessment of farmers' pesticide use and application practices

1. GENERAL PROFILE OF RESPOMDENTS

a. Date …………………………………

b. Age of respondent …………………………………

c. Gender of respondent …………………………………

d. Education level of respondent …………………………………

e. Level of education (Tick against the level of education where you fall)

Primary	
Secondary	
University/ college	

f. Size of the farm…………………………………

g. Number of household members …………………………………

h. Does the respondent use pesticide(s)? …………………………………

i. What crops does the respondent grow?

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j. What are the major problematic pests influencing yield and quality of crops?

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2. KNOWLEDGE OF PESTICIDE

a. What types of pesticides does the respondent use? List in the table and (indicate class in brackets where possible)

b. What are the major pests that you control in your field? (indicate in the table)

3. PRACTICES ON PESTICIDES

a. Do you integrate pesticide use with other methods?

Yes ☐ ☐ No

b. What other methods do you use? (List down)

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c (i). Do you get trained on pesticide use?

Yes ☐ ☐ No

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c (ii)What is the frequency of the training?

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…

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d. At what stage of crop growth do you mostly spray ?

…………………………………………………………………………………………
…

………………………………………………

e. How often do you spray pesticides?

…………………………………………………………………………………………
…

…………………………………………………

3. ATTITUDE ON PESTICIDES

a. Do you think pesticides are harmful to humans and the environment?

Yes ☐ ☐ No

b. What negative effects caused by pesticides use do you know?

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c. Why do you prefer to use pesticides to other methods of pests management?

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Àppendix II: Soil analysis report.

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
DEPARTMENT OF HORTICULTURE

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K
ENYA.

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20/11/2017. Laboratory Data (SOIL ANALYSIS)

Sample brought by: SUSAN NJERI DAN. Certificate of Analysis

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Field No/ID.../2017 Place	0-30cm	30-60cm	REMARKS
Laboratory No.	1	2	
pH- H_2O (1:2.5 v/v)	7.2	7.5	Slightly Alkaline
Ec (mS/cm)	0.13	0.08	No salinity effect
% N	0.05	0.10	LOW
Available P (mg/kg)	114	113	LOW
Exchangeable K (meq/100g)	0.32	0.27	Moderate
CEC(meq/100g)	11	12	Ideal
% Moisture	2.3	3.0	

METHODS OF ANALYSIS

PH-Soil; H_2O (1:2.5) -------------------------------Electric pH meter method

Ec (H2O 1:2.5)------------------------------------- Electric Conductivity meter method

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Available Phosphorous ---- -------------Colorimetric or uv-vis spectrophotometer by Ammonium molybdate/Vanad at 400nm

% N --- Kjeldahl method Exchangeable K

-- Flame photometry

CEC -- Ammonium acetate Ph 7.0

Moisture..Oven met