UNIVERSITY OF CAPE COAST

SOME ASPECTS OF POLLINATION ECOLOGY AND EFFECT OF PESTICIDES ON THE FLOWER VISITORS AND YIELD OF THE WATERMELON CROP *Citrullus lanatus* (THUNB.) (CUCURBITALES: CUCURBITACEAE) IN THE SHAI-OSUDOKU DISTRICT OF GHANA

BY

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DECLARATION

CANDIDATE'S DECLARATION

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Emmanuel Joe Tettey-Enyo
(Candidate)

…………………………. Date …………………….

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

The purpose of the study was to investigate the influence of pesticide application on the abundance and diversity of watermelon flower visitors as well as its effect on the crop yield. This was to help identify the most beneficial insecticide application regime to ensure pollinator health and the control of insect pests whiles ensuring maximum yield. Insects that visited watermelon flowers were collected weekly with the use of sweep nets and pan traps from plots with pesticide application twice a week, once a week and no application. Phenologically the plants promoted male fitness by producing more male flowers than female flowers. The plot with no pesticide application had the highest diversity of flower visitors present with a value of 1.50 on the Shannon Weiner index, and the highest species richness of eight. The most abundant and most efficient pollinator of the watermelon plant according to this study was the honey bee *Apis mellifera* L. There was a significant difference between the number of insect flower visitors collected from the different treatments used in the study ($p < 0.05$). It was also established from the study that there was no significant difference ($p > 0.05$) in fruit yield from plots with different pesticide application regimes. In effect, the application of pesticides once a week after flowering is best to achieve protection of pollinators and still ensure maximum fruit yield.

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DEDICATION

I dedicate this work to my parents Mr. & Mrs. Tettey-Enyo, my siblings Mercy and Margaret as well as my nephew Jeremiah for their unflinching support.

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CHAPTER ONE

INTRODUCTION

Pollination is an indispensable ecosystem service that results in an increase in food security and the improvement of livelihoods (Kwapong, Aidoo, Combey, & Karikari, 2010). It is the transfer of pollen (male sex cells) from the anther to the stigma (female reproductive organ) of a flower.

This may occur by wind, water or biotic means and varies among plant species. Once viable pollen gets into contact with the stigma, pollen tube germination takes place leading to the fertilization of ovules and then the plant continues the path of producing seeds and fruit after being fertilized.

Pollination is therefore a requirement for seed and fruit production in most plants (Mayes, 2011) and many factors such as the flower physiology and morphology, pollinator characteristics as well as effects of weather influences the success of pollination (Kasina, 2007).

Estimates show that up to 90% of all flowering plant species rely on pollination by various kinds of animals (Richards, 1986; Buchmann & Nabhan, 1996).

Animal pollination requires an organism to transfer the plant's male sex cells to a receptive stigma and this is carried out by many different species ranging from vertebrates to invertebrates such as insects. Insects provide more than 80% of the animal pollination in crops, of which bees are the most agriculturally important pollinators worldwide (Calderone, 2012).

The most recent approximation of the global economic benefit of pollination amounts to €265 billion (Lautenbach, Seppelt, Liebscher & Dormann, 2012) and this is estimated as the value of crops dependent on natural pollination. This cannot be stated as a "real" value, because should natural pollination end, it will be impossible to replace it with this amount of money thereby making its true value infinitely high.

The estimated production value of one tonne of a pollinator dependent crop is approximately five times higher than its equivalent for one of those crop categories that do not depend on living organisms for fruit and seed production (Kluser, 2010) therefore much effort must be put into conserving at all cost the "producers" of our food.

Humans have relied on bees and other insects for long to provide pollination services to our crops (Kevan & Phillips, 2001) and this is because they possess many traits that make them good pollinators, e.g., their numerous body hairs, their foraging behaviour and the fact that they collect food for themselves and their young. This last trait is very important; as other insect pollinators just feed on nectar and or pollen, but do not collect them therefore they may not be reliable enough to cause pollination although they supplement bees in pollination (Free, 1993). A sufficient transfer of the pollen grains is likely to occur during the collection process because a larger number of flowers will be visited during floral resource collection.

Generally many staple crops such as wheat, maize and sorghum are wind pollinated but insects do visit these crops for pollen while most fruits and vegetables are pollinated solely by animals. Plants with anemophilous flowers can produce seeds without animal pollination because in most cases wind will provide sufficient transfer of pollen. This notwithstanding, the presence of insect visitors has been shown to significantly increase seed set in combination with wind effects (Soderstrom & Calderon, 1971; Adams, Perkins & Estes,

1981) mainly in areas where wind velocity is not strong enough to cause a sufficient transfer of pollen.

Cross pollination is necessary for most plants and occurs when pollen from a flower is deposited on the flower of another plant of the same species and even plants that undergo self-pollination often benefit from cross pollination.

There is an increasing sense of concern with regards to conservation of pollinators (Buchmann & Nabhan, 1996), as it is recognized that the productivity of many crops depends on the services of key pollinators. Insufficient pollinator service is of great concern in fruit production because when the flower receives too few visits from the pollinators; the quantity of pollen provided to the reproductive part of the plant is reduced leading to a reduction in the output or yield of the plant.

Worldwide declines in native and managed pollinators has led to an increased global discuss and focus on the potential factors that may be the underlying cause of these declines. Although a number of factors have been hypothesized as potential contributors to pollinator declines, no single factor has been isolated as the sole cause of the decrease in numbers. The available knowledge base suggests that pollinator declines are a result of multiple factors such as improper and elevated levels of pesticide use as well as habitat loss for pollinators (Kluser, 2010) which may be acting in various combinations. Research is being directed at identifying the individual and combined factors that are most strongly associated with pollinator declines but Walker (2013), identifies indiscriminate use of systemic pesticides, most notably a class of insecticides known as neonicotinoids as one of the major factors influencing pollinator decline.

According to the Ministry of Food and Agriculture (2011), the importation and use of pesticides in Ghana increased rapidly between 2007 and 2010 (Table 1). In spite of the high cost of the products relative to the financial capacity of majority of farmers, the use of pesticides increased all in the bid to reduce production losses and this has been associated with the high incidence of plant diseases and pest attacks.

This research is aimed at exploring some aspects of the pollination ecology of the watermelon plant *Citrullus lanatus* (Thunb.) and the effect of pesticide use.

Watermelon belongs to the family Cucurbitaceae which is largely described as a tropical plant, having 90% of the species in three main areas namely: Africa and Madagascar, Central and South America and Southeast Asia and Malaysia (Jeffrey, 1990). Economically, the family has many cultivated species and a number of wild species which are important for food, medicine and fodder (Njoroge, 1992; Njoroge & Newton, 1994). The watermelon plant has a short life span of between three to four months.

Citrullus lanatus is one of the cultivated cucurbitaceous species thought to have their origin in Africa (Cobley, 1965; Masefield, Wallis, Harrison & Nicholson, 1969; Kirkbried, 1993). Its cultivation began in ancient Egypt and India and spread from there to other countries via the Mediterranean, to Asia.

In 1857, David Livingstone reported the existence of a large wild species of watermelon in Botswana. As a result of prolonged cultivation and selection, new forms of watermelon have evolved that have no resemblance to the ancient African forms (Fehe'r, 1993).

Table 1. Pesticides Import Statistics for 2007 – 2010 in Ghana

YEAR	**2007**		**2008**		**2009**		**2010**	
Formulated Pesticide Product	Solids (Mt)	Liquids (Lt)	Solids (Mt)	Liquids (Lt)	Solids (Mt)	Liquids (Lt)	Solids (Mt)	Liquids (Lt)
Insecticides	5.900	969,944	273.000	3,269,000	60.430	3,388,275	40.666	3,028,724
Herbicides	500.170	1,581,190	1,429.000	6,102,000	998.147	8,981,102	323.580	13,161,585
Fungicides	588.558	365,100	1,561.000	179,000	325.932	947,656	242.926	697,913
Nematicides	287.030	-	-	-	-	-	-	-
Others e.g. Plant growth regulators e.t.c	62.700	34,464	-	-	-	-	7.096	5,061
Totals	1,444.358	2,950,698	3,263.000	9,550,000	1,384.509	13,317,033	614.268	16,893,283
Grand Total	4,395.056Mt		12,813.000Mt		14,701.542Mt		17,507.551Mt	

Source: MOFA, GCAP 2011

The plant is grown in Ghana for its flesh that is extremely refreshing mostly during the dry season because it contains abundant water and minerals and the fruit is also rich in α and β-carotene. In some other parts of Africa, especially West Africa, *C. lanatus* is grown for its seeds, which contain high levels of unsaturated linoleic acid and various amino acids (TCN, 1996).

Cultivation of watermelon is plagued with a number of pests and diseases. The main fungal diseases of this crop are anthracnose, powdery mildew *Sphaerotheca fuliginea* (Schlecht.) and downy mildew which is caused by the fungus *Pseudoperonospora cubensis* (Berkeley & Curtis). Other production problems are as a result of insect attacks, e.g. melon ladybird *Henosepilachna elateri* (Rossi.), aphids *Aphis gossypii* (Glover.), curcurbit fly *Dacus ciliatus* (Loew), red spider mite *Tetranychnus* sp. (Koch) and thrips *Cerathothripoides cameroni* (Boyhan, Darbie, Granberry & Kelley, 2000)

Statement of the Problem

Pollination of one third of the foods we consume require a living organism to unite the reproductive parts of the flowers (Mayes, 2011) but these organisms especially honey bees are gradually declining in population (Potts et al., 2010). This might be due to loss, modification, destruction or fragmentation of their habitat and the misuse of pesticides among others (Bhattacharya, 2010).

This decline in the population of pollinators has a negative effect on our food production as a nation. It leads to a reduction in the quantity and quality of food that can be produced because flowers that are not fertilized might end up producing no fruit at all.

Some plants require a specific number of visits by pollinators to ensure adequate pollination and fruit set. Eight or more bee visits to the watermelon flower is superior to four or fewer visits, as the former results in a high fruit yield and quality (Stanghellini, Ambrose, & Schultheis, 1997).

In a watermelon field, sufficient pollination is characterised by a high percentage of melons in the number 1 category i.e. symmetrical, completely developed throughout, and of satisfactory weight and sweetness (McGregor, 1976). Appearance such as the colour and shape of the fruit is often affected by pollination and this is important during marketing.

Although the cultivation of this crop is gradually gaining popularity in countries such as Kenya (Njoroge, Gemmill, Bussmann, Newton & Ngumi, 2004) and Ghana, there is lack of knowledge on the most efficient pollinators of watermelon as well as the effect of pesticide use on the pollinators and fruit yield in the region. According to Corbet, Williams & Osborne, (1997) pollination studies in other regions have shown that adequate pollinator visitation contributes positively to productivity of the plant hence the need to ensure consistent and sustainable pollinator populations.

Justification

Making adequate use of pollinators from the wild especially honeybees is considered as one of the cheapest and most eco-friendly approach in maximizing the yield of cross-pollinated crops (Free, 1993). Many investigations have consistently confirmed that yield levels can be increased by 50 to 60 per cent in fruits and plantation crops, 45 to 50 per cent in sunflower and sesame and 100 to 150 per cent in cucurbitaceous crops through good management of pollinators.

Insect pollination of crops is an essential crop management practice and should be utilized skilfully by harnessing the activity of honey bees, wild and domesticated bees as well as other pollinators including solitary bees. Achievement of desired pollination to increase the qualitative and quantitative parameters of crop yield lies in the planned and efficient utilization of the pollinators, as well as ensuring the safety and health of the various pollinators hence the need to identify through this research the impact of excessive pesticide use on the pollinator population.

According to Samnegard, Persson & Smith (2011), it was previously believed that the most limiting factors influencing the formation of seeds and fruit in plants were nutrients and water supply but in no way related to pollination because pollen is produced and spread in very large quantities. Nevertheless later research has revealed that pollen limitation occurs in many plant species and could be a major reason for reduced fruit and seed production (Burd, 1994; Larson & Barrett, 2000), especially for plants in fragmented landscapes (Aguilar, Ashworth, Galetto, & Aizen, 2006). This indicates the essential role pollinators play in many plants reproductive success.

Pollination failure can occur at different stages; before, during or after pollen dispersal (Wilcock & Neiland, 2002). Reasons for pollination failure can be pollen feeders depleting the pollen, not viable pollen, lack of pollinators or pollinator activity leading to a decline in the reproductive success of the plants involved.

The reproductive success of plants is related to whether progeny will survive into the future or not. A large number of unfertilized ovules results in a reduction of the reproductive success of plants and this could be a consequence of too few pollen grains arriving at the stigma or an excess of non-matching pollen (Wilcock & Neiland, 2002), which will be as a result of too few pollinators or non-efficient pollinators working the flowers.

To curb this, an identification of the most efficient pollinator is required and efforts made towards their conservation as is sought to be done through this work.

Main Objective

The main objective of this research is to understand some aspects of pollination ecology of the watermelon plant and how pesticide application can affect the diversity and abundance of pollinators.

Specific Objectives

1. To examine the phenology and behaviour of the watermelon plant.
2. To determine the diversity and abundance of watermelon flower visitors.
3. To determine the pollination efficiency of watermelon pollinators.
4. To examine the effect of pesticide use on the flower visitors and yield of watermelon plant.

Hypotheses

1. The diversity of watermelon pollinators is not influenced by pesticide application.
2. The abundance of watermelon pollinators is not influenced by pesticide application.
3. There are no significant differences in the yield of watermelon plants due to pesticide application.

CHAPTER TWO

LITERATURE REVIEW

Introduction

In this chapter literature related to the classification and morphology of the plant is examined. Pollinators and importance of pollination to the watermelon plant, the effect of declining pollinator populations and causes of pollinator pollination services decline and the benefits from the watermelon plant are examined.

The Watermelon Plant

Watermelon is a member of the cucurbit family (cucurbitaceae), a family of crops that includes cucumber, muskmelon, and squash (Wehner & Maynard, 2003).

The plant is mostly grown for fresh consumption of the juicy and sweet flesh of the mature fruit. The watermelon plant is a slender, aggressively sprawling, annual crop whose stems or runners can grow up to a length of between 3 to 5 meters depending on the cultivar. It is highly branched; forming secondary side shoots which in turn branch out. The vines, especially the younger shoots are covered with long woolly hairs protecting the plant from excessive heat (Department of Agriculture, Forestry & Fisheries, 2011). The leaves are dark green with prominent veins, possessing three large lobes each further divided into smaller lobes. The leaves measure between 2.5 to 5 centimetres wide and 3 to 8 centimetres long.

It is a warm season crop which grows best at mean temperatures above 20^{o}C hence the vine and the fruits are susceptible to extremely cold temperatures.

Proper fruit maturity occurs best at high temperatures between 35-40^oC with warm nights (McGregor, 1976).

The plant is dependent on insect pollinators for the formation of fruits and seeds due to its monoecious flowering condition made up of separate staminate (male) and pistillate (female) flowers (Adlerz, 1996; Free, 1993). Numerous studies have shown that watermelon plants not exposed to pollinators will not set fruits at all (Stanghellini, Ambrose, & Schultheis, 1998).

The root system is highly branched reaching up to 2m deep with some fifteen or occasionally more lateral roots branching from the main root.

Root formation begins before the emergence of cotyledons to the soil surface and it gets to its maximum length by the time of flowering. The plant produces one to three marketable melons during harvest (McGregor, 1976).

Watermelon Flowers

Watermelon flowers are yellow in colour with five petals measuring between 1-4 centimetres in diameter. The petals of the flower are united in a tiny tube, and are deeply lobed. The female flower has a three lobed stigma tightly crowded into the corolla tube attached to an inferior ovary.

There are separate male and female flowers on the same plant and flowering begins 4 to 5 weeks after seed germination with the male flowers looking paler than the female flowers. The receptacle of individual flowers differentiates a male from a female flower.

The receptacle of a female flower is enlarged due to the presence of the ovary, a feature absent in the male flower (Figure 1).

The flowers are borne singly in the axils, with the pistillate ones occurring in every fifth to seventh axil in many cultivars with the staminate ones occupying the intervening axils (McGregor, 1976).

Each female watermelon flower requires approximately 500 to 1000 or more viable pollen grains for complete fertilization of ovules (Stanghellini et al., 1997). Hence, each female watermelon flower has been found to require at least 6–8 honey bee (*Apis mellifera* L.; Hymenoptera: Apidae) visits for adequate pollination (Adlerz, 1996).

The flowers open 1 to 2 hours after sunrise each day, and begin closing around midday with a new flower opening the next day (Grubben & Denton, 2004).

The pistillate flower and the staminate flower just below it opens the same day (McGregor, 1976). The anthers split open when the corolla expands but the pollen remains on the anthers in sticky masses with the stigma being receptive throughout the day even though the transfer of most pollen grains take place in the early hours of the day. Large, sticky pollen grains and an adhesive stigma signal the necessity for active pollen transfer between flowers for pollination to occur (Kwon, Jaskani, Ko & Cho, 2005).

Figure 1: A watermelon plant showing male and female flowers
Source: Field work, 2014.

Watermelon Fruits

Fruit shape and appearance are quite varied, ranging from round to cylindrical or even square like in Japan where farmers have devised a means of growing square shaped watermelons and this was achieved by putting the young immature fruits in glass boxes and this result in the fruits naturally taking up the shape of the box at maturity. The square shape is intended to make the melons easier to stack and store (Cooperative Extension Service, 2000).

Rind colour of watermelons varies to a large extent from light green to dark green with or without stripes (Figure 2) whiles flesh colour can be deep red, light red, pink or yellow depending on the variety.

The edible part of the fruit is the endocarp which is usually red containing many flat, oval, black seeds throughout. Seedless varieties also exist, as well as types with orange, yellow or white flesh.

When ripe, the sweet juicy pulp is eaten fresh, and the rind is sometimes preserved (Dupree, Woodruff & Siewertet, 1953).

According to Wehner (2003), seeds germinate in 3 to 14 days depending on the cultivar, temperature and moisture conditions prevailing at planting.

Fruit enlargement in watermelon requires growth-promoting hormones that the developing seeds release in seeded varieties whiles in seedless watermelons, pollen provides these hormones hence the likelihood5757 to produce larger sized watermelon fruits in seeded varieties compared to seedless varieties.

Unfortunately, pollen is not abundant in the sterile seedless varieties therefore commercial fruit production requires growers to interplant diploid (seeded) varieties with triploid (seedless) varieties to ensure adequately sized melons at maturity (McGregor, 1976) or farmers will have to engage in hand pollination. This process which involves a person dusting pollen grains from male flowers to each female flower is slow, time consuming as well as very much capital intensive. The correct timing for dusting can also be missed as female flowers open for a specific space of time and are receptive to pollen only during this period.

Figure 2: Varieties of watermelon fruits

Seeds are roasted as a snack or ground into an ingredient in oils or sauces. Juice from the pulp of a watermelon contains 8 to 10% solids, of which 20 to 50% is sucrose (McGregor, 1976).

Watermelon is served fresh as juice, sliced into bits, as chunks (often in fruit salad), pickled rind, glacé candy, and as edible seeds (harvested from confectionary type cultivars). It is no longer just a warm season fruit but it is becoming an everyday fruit just like apples, bananas, and oranges.

The watermelon fruit is made up of 92% water, 6% sugar by weight with small amounts of protein, fat, minerals, and vitamins (Erhirhie & Ekene, 2013). In many dry regions, watermelon serves as a valuable source of water due to its high water content.

Watermelon contains water, energy protein, fat, carbohydrate, calcium, phosphorous, iron, thiamine, riboflavin, niacin, folate, ascorbic acid and lycopene in various quantities (Table 2) whiles the seeds are rich in fat and protein (Table 3) (United States Department of Agriculture, 2015).

Lycopene is a carotenoid that provides the red colour to tomatoes, watermelons, red pepper among other fruits and vegetables. Watermelon with red flesh is a significant source of lycopene and the lycopene content of the red watermelon cultivars is next to guava but higher than that in pepper, tomato and pink grapefruit (Mandel, Levy, Izkovitch, & Korman, 2005). According to the USDA nutrient database (2009), watermelons contain 40% more lycopene (per 100 g) than fresh ripe tomato. Also lycopene in fresh watermelons is more bio available than in fresh tomatoes (Bliss, 2002) making watermelon a very important source of the cancer fighting phytochemical.

Lycopene is a powerful antioxidant that helps reduce the risk of certain cancers, such as prostate, pancreas, and the stomach whiles fighting off heart diseases (Rao & Agarwal, 1999; Fadupin, Osadola, & Atinmo, 2012) as preliminary research indicates that the consumption of watermelon may have anti-hypertensive effects (Erhirhie & Ekene, 2013).

Orange flesh watermelons have only small amounts of lycopene, but the beta carotene content is similar to that of red flesh types whiles varieties with yellow flesh do not contain lycopene but do have a small amount of beta carotene (Wehner, 2003).

Worthy of note is the inner rind of the watermelon, which usually has a light green or white colour. This area is edible and contains many useful nutrients which are still being researched but most people avoid eating it due to its unappealing flavour.

Watermelon contains a significant amount of the amino acid citrulline whose beneficial functions are also being investigated. Among them is the ability to relax and dilate blood vessels, much like "Viagra" does to treat erectile dysfunction.

According to research, when watermelon is consumed citrulline is converted to arginine with the help of certain enzymes. The citrulline-arginine relationship helps heart health, the immune system and may prove to be very helpful for those who suffer from obesity and Type II diabetes (Texas A & M University, 2008).

Watermelon rinds are also edible and sometimes used as vegetable as well as livestock feed. In China, they are stir-fried, stewed or more often pickled. When stir-fried, the de-skinned and de-fruited rind is cooked with olive oil, garlic, chilli peppers, scallions, sugar and rum. Watermelon juice can also be made into wine though it is mildly diuretic (Wehner, 2003).

As a result of the required care and the time consumed in harvesting the perishable ripe melons (all harvesting is done by hand), vast acreages are seldom grown by individual farmers. Seven to eight weeks after flowering, watermelon begins to ripen and there are several ways to identify a ripe melon on the field without making the mistake of picking an unripe one.

One or all of these guides are used depending on the experience of the individual harvesting.

One way of identifying a ripe watermelon is to look at the tendril closest to the fruit. It dries up completely when the fruit is ready to be harvested. A ripe watermelon will also have its part which is in contact with the soil looking yellowish in colour (Figure 3) like most other ripe fruits and lastly a ripe watermelon fruit will produce a light metallic sound when tapped with the hand whereas an unripe one will produce a heavy sounding thud when tapped.

Figure 3: Mature watermelon fruits

Table 2: The nutritional composition of watermelon per 100 g edible portion

Nutrient	Unit	Value per 100 g
Water	g	91.45
Energy	kcal	30
Protein	g	0.61
Total lipid	g	0.15
Carbohydrate	g	7.55
Calcium	mg	7
Iron	mg	0.24
Phosphorus	mg	11
Potassium	mg	112
Vitamin C	mg	8.1
Thiamine	mg	0.033
Riboflavin	mg	0.021
Niacin	mg	0.178
Vitamin B-6	mg	0.045
Folate	µg	3
Vitamin A	µg	28
Vitamin E	mg	0.05
Vitamin K	µg	0.1

Source: USDA national nutrient database for standard reference (2015)

Table 3: The nutritional composition of watermelon seeds per 100 g seed flour

Nutrient	Unit	Value per 100 g
Water	g	5.05
Energy	kcal	557
Protein	g	28.33
Total lipid	g	47.37
Carbohydrate	g	15.31
Calcium	mg	54
Iron	mg	7.28
Magnesium	mg	515
Phosphorus	mg	755
Potassium	mg	648
Fatty acids, total saturated	g	9.779
Fatty acids, total monounsaturated	g	7.407
Fatty acids, total polyunsaturated	g	28.094

Source: USDA national nutrient database for standard reference (2015)

Watermelon Pollination and Pollinators

Due to research, *Apis mellifera* has been generally recognized as the most important pollinator for commercial crop production (Kremen et al., 2002; Stanghellini et al., 1997.) including watermelon. As a result of their manageability and large perennial colonies, *A. mellifera* is easily transported to different fields as needed (Kremen et al., 2002).

Many *A. mellifera* colonies have been significantly weakened or lost due to exotic parasites, diseases, loss of bee-keeping subsidies, colony collapse disorder and pesticide exposure (Stanghellini et al., 1999). It is on record that the supply of *A. mellifera* colonies has been reduced more than 50% since the 1950s despite a growing demand for honey bee pollination services (Kremen, Williams & Thorp, 2002).

Agriculturists and researchers have recently turned their attention to assessing the value of wild bee species as pollinators in crops that are heavily dependent on insect pollinators such as watermelon. (Winfree, Williams, Gaines, Ascher, & Kremen, 2008). Beetles, solitary bees (Jaycox, Guynn, Rhodes & Vandemark, 1975) flies and butterflies (Shawer, El-zawily, Metwally & Ghazy, 1981) have also been recorded as pollinators of watermelon.

Kremen, et al. (2002) found that organic farms in California located near native habitats (defined as having $\geq$ 30% native habitat within a 1 km radius of the farm) have a great likelihood of receiving adequate pollination from wild bees alone. However, as agricultural intensification increases, pollination services decrease by 3 to 6 fold (Kremen et al., 2002).

Klein, Steffan-Dewenter & Tscharntke (2003) successfully correlated increased yields of fruit with increased diversity and abundance of pollinators. Estimates in the 1980's on the value of insect crop pollination are as high as 18.9 billion dollars (Michener, 2000).

Pollination not only increases the number of seeds and size of fruit, it is also an important genetic provider, needed to improve cultivated strains (Fell, 2005; Michener, 2000).

Pollinators' essential role is to spread genetic information but at the most basic level, it is the transfer of pollen grains (the male gametes) to the plant carpel, the structure that contains the ovule (the female gamete) (Fell, 2005).

This process results in the provision of ecosystem services, provides honey for food, improves crop production and improves biodiversity in ecosystems (Millennium Ecosystem Assessment, 2005).

Ecosystem services are those that the natural environment produces, from which humans benefit (Kremen et al., 2004).

Watermelon has separate male and female flowers and do not undergo self-pollination not even seedless varieties. Therefore to ensure adequate pollination, a pollinator must transfer large, sticky pollen grains from male to female flowers during a period when its stigma is receptive.

Female watermelon flowers are open for between six to eight hours in one day only and during this time they must receive between and above 500 to 1000 pollen grains to produce a marketable melon (Stanghellini et al., 1997). Delivering this much pollen requires several bee visits. Bees visit flowers for rewards in the form of nectar, pollen and resins but in the process their bodies rub against the anther of the flower thereby collecting pollen grains.

During a subsequent visit to a female flower, the male sex cells are deposited resulting in the plant benefiting by being pollinated.

Importance of Pollination in Watermelon

Though it is well recognized that pollination is an ecosystem service of vital importance to human well-being through its role in food production, it is still saddening how little is known on a crop-by-crop basis about this role and the extent as well as the causes of the declines in this life sustaining service. In the absence of proper documentation of the specific contributions of pollination to crop yields, there has been increasing and unanswered questions about how relevant pollination might be to agricultural development and food security.

Fruit crops are especially susceptible to the decline of pollinators (Fell, 2005). In the absence of pollinators, 110-150 crop species, such as apples, peaches, blueberries, cranberries, squash, pumpkins, almonds, strawberries, and watermelons will be at risk with limited gene pools, reduced seed quantities and fruit qualities in the near future (Allen-Wardell et al., 1998).

Apart from the importance of pollination to fruit or seed set, the process enhances higher yields of better quality (McGregor, 1976; Free, 1993). Some crops benefit also in terms of uniform ripening, which reduces yield losses in the field. Plant vigour has also been shown to be enhanced by cross-pollination, e.g., in broad beans (*Vicia faba* L.), which requires flower tripping to produce viable seeds (Stoddard & Bond, 1987). Hence the preservation of pollinators is critical to efficient, continued agriculture, and biodiversity (Kremen et al., 2002).

Klein et al (2007) found that fruit, vegetable or seed production from 87 of the world's leading food crops depend upon animal pollination, representing 35 per cent of global food production.

Watermelon is completely dependent on multiple bee visits for pollination (Stanghellini et al., 1997). Beetles, solitary bees, flies and butterflies have been recorded as pollinators of watermelon. It is generally recognized that honey bee is the most important pollinator in commercial crop production (Free, 1993; Delaplane & Mayer, 2000) but the most efficient pollinator of the watermelon plant is yet to be identified and this is one of the goals this research seeks to achieve.

Stanghellini et al., (1997) noted that there was 100 per cent abortion for watermelon flowers receiving no insect visitation, as compared to flowers visited severally by pollinators of the plant thereby emphasizing the need for active transfer of pollen in this crop by insect pollinators.

There is a strong correlation between the weight of a mature watermelon and frequency of pollinator visit as this increases the likelihood of the deposition of a large quantity of pollen required for a well formed fruit.

Seedless watermelon require an even greater number of pollinator visits to set marketable fruit, because pollen must be carried from a polliniser variety further away and experiments have shown a positive effect of introducing honey bees to a melon farm on melon weight and or number of melons per plot (Stanghellini, Ambrose & Schultheis, 2002; Walters, 2005).

The Issue of Declining Pollinator Populations

Honey bees are believed to pollinate $1.8 - 8.3 billion of produce in the U.S.A. annually (Southwick & Southwick, 1992) but in recent years, there has been a reduction in pollinator populations the world over.

Pollination services are responsible for global biodiversity and maintenance of human food supplies (Allen-Wardell et al., 1998; Kearns et al., 1998; Michener, 2000 & Kremen et al., 2002).

Over the past two decades, bees have received increased attention by the scientific community because of population declines (Allen-Wardell et al.; Kearns, Inouye, & Waser, 1998) as pollination processes can be disrupted by declining pollinator abundance.

Scientific research has focused primarily on honey bee declines because this species is the most commonly used pollinator but significant declines have also occurred in native bees (Kevans & Phillips, 2001; Allen-Wardell, *et al*., 1998). The United States Department of Agriculture (USDA) bee research laboratory has charted a 25% decline in managed honey bee colonies since the 1980s (Greer, 1999) but estimates on native bee declines, on the other hand are disputed and vary (Williams, Minckley & Silveira, 2001).

The majority of global crops could display production loss owing to pollinator limitation (Klein et al., 2007). While the demand for pollinators remains constant or increases and the supply of commercial and wild honey bees decreases, native pollinators are being considered as viable options for mass crop pollination.

Honey bees are relatively dependable generalist pollinators that are easily managed and transported. However, although honey bees are usually sighted foraging in target crops like watermelon in order to enhance pollination, they often visit other crops or wild plant species due to the high incidence of pesticide usage for the control of insect pests and diseases on the fruit plant (Delaplane & Mayer, 2000).

Many native pollinators are present on farms and their value as pollinators is often underestimated or overlooked by farmers (Greer, 1999). Although these pollinators occur naturally on farms, many factors such as habitat fragmentation, agricultural destruction of habitat, grazing by livestock, and excessive pesticide application are decreasing the numbers of these beneficial hymenopterans (Kearns & Inouye, 1997).

The specific consequences of bee population decline on our food supply and global biodiversity is yet to be seen, but the effects will definitely be unpleasant (Allen-Wardell et al., 1998). The potential negative effects of pollinator declines include direct losses to the economy as an outcome of reduced crop yields as well as broader impacts on agricultural activity due to lower productivity in the ecosystem service such as nutrient cycling that sustains it.

Whiles there are concerns that the magnitude of the latter effect may be very large, the relevant ripple effect from reduced animal pollination to the population dynamics of wild plant species, changes in the structure of food webs, the health of ecosystems, and the supplies of their services to agriculture has yet to be systematically elaborated. In recognition of the enormity of this task, literature on the human impacts of pollinator declines has set focus greatly on the direct implications for crop production and global food security.

The magnitude of the direct impact of pollinator decline in itself is a subject of controversy (Ghazoul, 2005a; Steffan-Dewenter, Potts & Packer, 2005) as some people believe that pollinator populations are not in decline to levels which can cause any harm to the food security and existence of man. This notwithstanding, fears of food, economic and biological losses have provoked an increase in scientific literature that examines the causes, effect and solution to this global threat to human survival.

Klein et al. (2007) found that 75 per cent of primary global food crop species rely on some amount of animal pollination, but only 35 per cent of crop production is pollinator-dependent and at least 60 per cent of global food crop production comes from plant species that do not need animal pollination (e.g., cereals and grains), while 5 per cent of production comes from crops with unidentified pollinator dependency.

Hence comparing pollinator-dependent and pollinator independent crop production at the global level suggests that a larger part of the world relies greatly on pollinator non-dependent food crops as staples.

Aizen, Garibaldi, Cunningham, & Klein (2009) found similar results when dividing the world into developed and developing countries whiles Ashworth, Quesada, Casas, Aguilar, & Oyama (2009) found similar results for Mexico alone. Thus, from a consumption point of view, there does not appear to be a current risk to food security as a result of pollinator declines.

Some have argued however that there may be a global food security risk from a micro-nutrient perspective, as the majority of pollinator-dependent crops are fruits, vegetables, and nuts (Gallai, Salles, Settele, & Vaissiere, 2009b; Steffan-Dewenter et al., 2005) which are good sources of micro-nutrients.

Increased anthropogenic effects and exotic pests are impacting global bee populations (Kim, Williams & Kremen, 2006). This decline could also be as a result of changes in land use systems, harmful agricultural interventions such as the use of chemical fertilizers and herbicides as well as an increase in planting of single crop species over large acres of land (Verma & Partap, 1993; Partap & Partap, 1997; Partap & Partap, 2002).

Changes in climate might also affect pollinator numbers as these changes disrupt the timing for plant growing cycles.

The decline in pollinator populations and diversity presents a serious threat to agricultural production, conservation and maintenance of biodiversity in many parts of the world. One pointer to the decline in natural insect pollinators is the decrease in crop yields and quality despite increased mechanical and agronomic inputs. Such scenarios are cited in North West India, parts of China and Pakistan (Bauer & Wing, 2010).

In these places, the quality and quantity of cultivated fruit crops such as almonds, pears, almonds and apples are quickly depreciating. Farmers in these areas have failed to appreciate the importance of managed pollination as it is perceived as a venture for subsistent farmers (Partap, 2001).

According to Partap (2001), yields are so low in some apple growing areas of Pakistan due to poor pollination that some farmers have hewn down their apple trees.

Coffee is a very valuable export commodity from some developing countries and its yields on farms situated close to forest ecosystems in Mexico are 20% higher compared to yields from farms far from forest areas (Vergara & Badano, 2009).

In Costa Rica, the value of forests in term of pollination services was estimated to be slightly above $60,000 per year illustrating the economic benefits of pollination services, forest conservation and maintenance close to agricultural landscapes (Ricketts, Daily, Ehrlich & Michener, 2004).

In Brazil also coffee plantations close to forest fragments showed an increase of about 15% in production and this proportion of increase was attributed to pollinator services provided from the forests (Marco & Coelho, 2004).

It is suggested that adequate education of farmers concerning the role forests play in enhancing pollination services will promote the conservation of wild, unmanaged bee populations since the farmers are most often engaged in destroying the natural habitats of pollinators in the forests.

The significant reduction in pollinator diversity and abundance has created the avenue for managed pollination to help curb the incidence of low crop yields. This is done either with the use of managed pollinator pollutions or with hand pollination by human beings. For example, farmers in North West India use managed honey bees for pollination of their apples whiles in parts of China, their fruit crops are pollinated by hand (Partap, & Partap, 2000).

Hand pollination of crops provides employment for people serving as a source of income but it is an expensive procedure as farmers spend a large part of their income paying for the pollination to be done. It is a time consuming and slightly imperfect means of pollination as it doesn’t produce in all cases the desirable result provided by insect pollinators (Rickets et al., 2004; Klein et al., 2003a; Marco & Coelho, 2004).

The Effect of Monocropping on Pollinator Decline

Agricultural intensification which includes monoculture enables farmers to obtain greater yields within the same time frame and area through the cultivation of a single crop species on a field.

Before the advent of pesticides, cropping systems were such that they ensured the best relationship between plant health risks and the potential yield of the crop (Savini, 2005). But gradually due to the acquisition of knowledge on crop needs for mineral elements, the mastery of fertilization and insecticides which protects crops from insect damage, cropping systems never remained the same.

As a result of growers being able to directly influence the principal pests threatening their crops, farmers started to shy away from their choice of crop management sequence or cultivation systems that upheld this relationship and embraced those elements which contributed to achieving the highest yields and those which preserved this potential.

This decision led them to adopt farming practices as a function of a yield goal, even though they increased the plant health risk, and then treated the outcome of their deeds as and when they appeared the way they deemed fit.

Pesticides, which were effective, relatively inexpensive and easy to use, contributed to the development of intensive production systems (Savini, 2005), which also benefited from favourable market conditions and farm prices, as well as an under-evaluation of the environmental consequences which need to be managed today.

Unlike traditional poly culture cropping systems, which requires the cultivation of different crop varieties or that crops be interspersed with trees or domesticated animals, monoculture allows farmers to specialize in crops that have similar growing and maintenance requirements. Farmers around the globe have increasingly adopted monoculture to achieve higher yields (Gliessman, 2000).

Monoculture affects the composition, abundance and diversity of all organisms that depend upon the cultivated crops and provides a dwelling place for a narrow range of animal pollinators. Populations of pollinators tend to be lower in mono-cropped fields than in fields containing diverse forage and nesting sites (Killebrew & Wolff, 2010).

Farmers used to grow different crops which bloomed at different times of the year, preventing floral competition hence providing sufficient food (nectar and pollen) supplies for several pollinators of flowering plants as well as shelter. Planting a single crop on a vast land area incessantly requires the consistent use of chemicals that have proven harmful to the health of pollinators for the control of several pests and diseases. This is as a result of the build-up of the pest species associated with the single crop that is planted over the years.

The persistent and indiscriminate use of pesticides reduces the abundance and diversity of our insect pollinators which culminates to a reduction in pollinator population sizes.

Large scale monocropping reduces the amount of land available to support wild vegetation. With the increasing mechanization of agriculture, the number and area of hedgerows and uncultivated patches decreases reducing the number of native plants available as pollen and nectar sources (O'Toole, 1993).

The cultivation of single crop species poses serious effects to the ecosystem at large because of its destruction of local biodiversity. Vast areas of single crop plantations creates some kind of imbalance as this give rise to the increase of a particular insect species to the detriment of others by determining what pollinating insects can forage.

Honeybees are the most widely used pollinators of monoculture crops and have contributed immensely to the success of these crops (Brodschneider & Crailsheim, 2010). Unfortunately, this is not a mutually beneficial relationship as several studies have unravelled the detrimental effects of monocultures on the health of bees.

Feeding on pollen from only one plant species can lead to certain nutrient deficiencies in pollinators (Brodschneider & Crailsheim, 2010). Certain crops have short bloom times during which time nectar and pollen is available. When such crops are planted alone on large patches of land, there is food for the pollinators for a relatively short period of time after which they have nothing else to feed on. (Decourtye, Mader & Desneux, 2010).

Some popular monoculture crops such as wheat and corn do not provide adequately for the nectar or pollen needs of bees (Cane & Tepedino, 2001) therefore pollinators are required to fly over long distances to find food leading to the use up of energy store in their bodies. Too much stress and poor nutrition makes them vulnerable to the effects of pesticides and diseases leading to their death.

Bees fed pollen from a wide range of plants possess a stronger and more robust immune system than those dependent on monoculture diet. Diversity in diet therefore puts our crop pollinators especially bees in a safer position and increases their ability to protect themselves as well as their larvae from the harmful effects of chemicals, pathogens and microbes (Alaux, Ducloz, Crauser & Le Conte, 2010).

The Influence of Landscape Modification on Pollinators

Studies carried out in agricultural areas have enabled the evaluation of the effects of different land use practices on the abundance and species richness of pollinators. It has also helped in the identification of pollinators' responses to modification, fragmentation, and destruction of natural habitats and also helped with determining at what intensity these changes are felt by different species (Campos et al., 2006). This has brought to light the fact that ecological processes are most often affected by anthropogenic disturbance on a landscape scale rather than on a habitat scale (Turner, 2005).

Modification of landscape causes great effects on the ecology and survival of organisms living within the affected area (Fischer & Lindenmayer, 2007; Hobbs & Yates, 2003).

Various human activities have altered the landscape through destruction of natural habitats, degradation and fragmentation by changing their natural settings to create new anthropogenic habitats suitable to man.

Estimates of complete habitat conversion vary by biome from 0.4% (tundra) to 48.5% (tropical/subtropical dry, broad leaf forests), and a very large portion of this is directly influenced by human activities to some degree (Sanderson et al., 2002; Hoekstra, Boucher, Ricketts, & Roberts, 2005).

The alteration of a landscape structure as a result of a land-use pattern influences pollinators, target plants as well as their interactions at individual, population and community levels.

The response of bee individuals, populations and communities to land-use change is largely driven by the spatial and temporal distribution of floral, nesting and over-wintering resources in relation to foraging and dispersal capabilities of bees (Kremen et al., 2007). These components may occupy the same locality or may be dispersed across the landscape, resulting in a scattered group of partial habitats (Westrich, 1996).

Floral resources (pollen, nectar, oils and resins) are important deciding factors responsible for establishing and maintaining pollinator communities. Bee abundance and species richness therefore is positively connected with the abundance and richness of flowering plant species (Steffan-Dewenter & Tscharntke, 2001; Potts et al., 2003a).

More specifically, research has identified that the species richness of insect pollinators is affected by the diversity of nectar sources, the ratio of pollen to nectar energy content, and floral morphology of plants immediately available thereby implying that a greater floral diversity creates a wider array of foraging niches for different functional groups of flower visitors (Fenster, Armbruster, Wilson, Dudash & Thomson, 2004).

Environmental factors that alter the distribution of floral resources in a habitat at a given time, influences the pollinator community composition as well. For example, in a 50 year time followed study of a mediterranean pine-shrub community regenerating after a bush fire, bee community composition is observed to be directly proportional to the floral composition and rewards available (Potts et al., 2003b).

Nesting sites are also deciding factors for the presence of pollinator community and its composition. Some pollinators such as bees exhibit a variety of nesting behaviours which include tunnelling in bare ground, using already created cavities (e.g. pithy stems, small rock cavities or abandoned insect burrows), excavating dead wood, and constructing nests inside larger cavities in or on trees, rocks or rodent nests.

The diversity and specificity of nesting habits among insect pollinators show that the quantity and quality of nesting resources has a great influence on the pollinator community composition at any particular point in time.

Potts et al., (2005) showed that the composition of a diverse bee community in Israel was partially determined by the local presence of bare ground, potential nesting cavities, steeply sloping ground, plants with pithy stems and pre-existing holes. Similarly, the density of stingless bee nests was positively correlated with the local abundance, size and species of nest trees in tropical forests (Eltz, Bruhl, Van der kaars & Linsenmair, 2002; Samejima, Marzuki, Nagamitsu, & Nakasizuka, 2004).

Land-use change alters the distribution of both floral and nesting resources; this in turn affects individual behaviour, population dynamics and community composition of bees (Tscharntke, Klein, Kruess, Steffan-Dewenter & Thies, 2005).

Foraging from a fixed nest site results in individual pollinator foraging movements that are relative to resources which vary in space and time, and this is likely to increase pollinator's sensitivity to changes in habitat/landscape causing a reduction in the availability of resources.

Sensitivity to changes in the availability of resources will depend on species-specific flight capacity, which is positively correlated with bee body size (Gathmann & Tscharntke, 2002). Although larger bees can access resources further from their nests, such bees also have higher resource demands, resulting in the exclusion of larger sized species from areas with limited resources, as has been observed in some systems such as intensive agricultural areas as recorded by Larsen, Williams and Kremen, (2005).

Individual pollinators alter their foraging behaviour in response to changes in landscape structure. Examples include following corridors of vegetation to reach nectar or pollen sources (Haddad et al., 2003); avoiding edges created by roads or habitat boundaries (Rasmussen & Brodsgaard 1992; Ricketts, 2001), increasing foraging times in patches of simple landscapes with few alternative flower resources, or switching to locally available, non-preferred species if preferred plant hosts are too distant (Steffan-Dewenter & Tscharntke, 2001).

The quality of the vegetation surrounding the remnants of the original habitat has a strong influence on individual pollinator movements. A sufficiently large vegetation that is devoid of flowers may act as a barrier for pollinator movement, while one occupied by a mass-flowering crop can promote connectivity and provide nectar and pollen resources during periods of floral shortage in the habitat remnants (Chacoff & Aizen, 2006).

The loss and fragmentation of natural habitat could reduce gene flow and re-colonization rates among fragments, leading to lowered persistence of subpopulations and also of meta-population networks (Zayed et al., 2005).

This view of habitat fragmentation causes surrounding vegetation to seem empty of floral resources, and this is unfavourable for the survival of floral visitors.

Empirical studies of bee populations and communities, however, reveal a range of responses to fragment size, including positive, negative and neutral and this variability in response to fragmentation is likely due to differences in dispersal ability, habitat and floral specificity among pollinator species (Steffan-Dewenter, 2003; Zayed et al., 2005).

At the community level, pollinator richness may initially decline in response to disturbances in the landscape that are mild in intensity and/or frequency, but may become uncontrollably low under intense disturbance and relatively remain constant in climax habitats consisting of relatively few plant species (Chacoff & Aizen, 2006).

Pollinator species whose numbers are likely to increase due to a moderate level of landscape disturbance include those that use resources that occur in human-dominated habitats like agricultural or urban/suburban areas and ground-nesting bees that require patchy vegetation which is characteristic of early plant successional stages.

The plant pollinator relationship is reciprocally interwoven with each other, so that only a few plant species will possibly loose all their pollinator species as pollinator communities reduce in population and diversity due to habitat fragmentation. (Memmott, Waser & Price, 2004)

Studies offer alternative predictions of how rapidly pollination function would be affected if pollinator communities were lost non-randomly with respect to number of linkages or pollinator effectiveness (Memmott et al., 2004) but only one empirical example of community pollinator decline and its effect on pollination function exists (Larsen et al., 2005).

The study by Memmott et al. found that larger, more effective pollinators were also highly sensitive to land-use change, resulting in a rapid loss of pollination function rather than to population losses.

Predators, parasitoids and parasites of bee species also respond to land-use change at individual, population and community levels. Natural enemies of pollinators may alter searching behaviour and their attack rate of hosts in response to altered landscape structure or host density, as was recorded by With, Pavuk, Worchuck, Oates and Fisher (2002); Cronin, (2003) in crop monocultures and commercially managed bee colonies.

Predators and parasitoids of bee species reduced in species richness and caused less mortality for bees in isolation from natural habitat in several systems (Tscharntke, Gathmann, & Steffan-Dewenter, 1998), but changes in food web structure can also increase parasitism of solitary bees in highly modified landscapes (Tylianakis & Binzer, 2014) but little is known about the relative importance of top to down (predators, parasitoids and parasites) vs. bottom-up (floral and nesting resources) forces in determining bee population responses to land-use change.

Abiotic factors like pesticides are an additional aspect of land use that can increase mortality rates or alter foraging behaviour of floral visitors (Morandin, Winston, Franklin, & Abbott, 2005). Often, the intensity of pesticide use is correlated with decline in availability of floral and nesting resources (Kremen et al., 2002; Tscharntke et al., 2005), and separating the individual effect of either one on pollinator populations is an important challenge.

Agriculture has drastically changed landscapes. It has led to unequal partitioning of land surfaces and increased the number of small patches and line corridors. When a landscape is converted for agricultural use, the remaining habitats become fragmented and this leads to an increase in edge habitat which often increases the population of invasive plant species (With et al., 2002).

Fragmentation can also cause a decline in overall pollinator abundance and native bee species richness and of great concern is the loss of tropical forests where a large proportion of insects live and the conversion of forests into farmlands has a great impact on insect populations, particularly the primary forest specialists (Hill, Hamer, Lace & Banham, 1995).

Human action that leads to the fragmentation of natural landscapes occurs over a very short period of time, which creates a high risk to the ecosystem at large. The fragmentation of native forest areas certainly leads to changes in the shape and size of the fragments, increasing the isolation distance between these landscapes (Schelhas & Greemberg, 1996) and this may alter various processes and ecological functions of the affected ecosystem, as well as the loss of diversity of plant and animal species (Saunders, Hobbs & Margules, 1991).

Species richness and abundance tends to decrease with the fragmentation of natural environments, in which specialized pollinators are the most affected, revealing that most specialist species tend to be more susceptible to forest fragmentation than generalist foragers (Didham, Ghazoul, Stork & Davis, 1996). Therefore, plant species pollinated by specialist bees require to be connected to a variety of habitats in a restricted range for the promotion of pollinator populations.

During the disturbance of natural land patches, plants become isolated, and are distributed in homogeneous and fragmented landscapes, resulting in a dependence on generalist pollinators capable of covering great flight distances to transport pollen (Steffan-Dewenter & Tscharntke, 2002; Rathcke & Jules, 1993; Steffan-Dewenter & Tscharntke, 1999).

According to Patricio and Gomig (2008); Aguirre and Dirzo, (2008); Holzschuh, Dudenhoffer and Tscharntke,(2012); Klein, et al. (2003); Kremen et al., (2002) a strong relationship exists between the productivity of different crops such as understory palm, cherries, coffee, watermelon among others and the abundance of their pollinators.

The presence of fragments of native vegetation in its vicinity is very important as the remainder of the native vegetation offers lots of nesting sites for different groups of social and solitary bees and thus, ensures the presence of different pollinator species, which forage in the near surroundings in search of additional sources of food (Liow, Sodhi, & Elmqvist, 2001).

This shows that the closer the distance of cultivation to remnant forest is, the higher the reproductive success of plants. This correlation was confirmed for the cultivation of coffee in Indonesia by Klein et al., (2003), where in all cultivated areas studied there were remnants of native vegetation close by but at varying distances.

The results showed that in crops 250 meters close to fragments, the percentage of fruit set was 90%, whereas in crops distant from forest remnants around 900 meters, the percentage of fruit set was 70% (Klein et al., 2003).

In almond orchards located in California, the species richness of solitary bees, the frequency of visitation in flowers and fruit production was directly proportional to the presence of semi-natural habitats adjacent to crops (Klein et al., 2012). For coffee cultivation, in Costa Rica, mango in South Africa and plantations of passion fruit in Brazil, the distance of crops to the remaining forests was a determining factor in the rate of visitation of flowers, where crops closer to fragments received more visits that results to a greater seed set and fruit yield (Ricketts, 2004; Carvalheiro, Seymour, Veldtman, & Nicolson, 2010).

Hence it can be perceived that the abundance and diversity of insect pollinators as well as the efficiency of insect pollinators in pollination is impacted negatively by the isolation of crops.

In addition to the distance between fragments of remnant forests and isolation of cultivated areas, the percentage of groundcover with native vegetation surrounding the crops also influences the richness and abundance of pollinators as well as the entire pollination process (Patricio & Campos, 2014). A study conducted in Brazil by Patricio (2007) and another one conducted in Vera Cruz, Mexico by Vergara & Badano, (2009) evaluated the reproductive success of *Solanum viarum* Dun. & *Coffea arabica* L. respectively, using the hypothesis that more diversified habitats (heterogeneous landscapes) would support higher pollinator diversity and therefore warrant greater reproductive success of the plants involved in the study.

This hypothesis was rejected, however among the studied landscape types, only the percentage of forests' coverage showed a positive relationship with pollinator diversity and reproductive success of *S. viarum* Dun. & coffee. Despite the results obtained in these studies, several authors have reported that maintenance of native undisturbed habitats and landscapes provide enabling habitats for the establishment of pollinators which in turn is important for enhancing the pollination process.

Effect of Climatic Changes on Pollinator Decline

Animal pollination of both wild and cultivated plant species is under serious threat as a result of several environmental factors acting independently or in unison (Schweiger et al., 2010). Invasive species (Memmott & Waser 2002; Bjerknes, Totland, Hegland & Nielsen, 2007), pesticide use (Kearns et al., 1998; Kremen et al. 2002), land-use changes such as habitat fragmentation (Steffan-Dewenter & Tscharntke, 1999; Mustajarvi, Siikamaki, Rytkonen & Lammi, 2001; Aguilar et al., 2006) and agricultural intensification (Tscharntke et al., 2005; Ricketts et al., 2008) have all been shown to negatively affect plant-pollinator interactions.

Climate change may be a further threat to pollination services because one of the most important ecosystem services for continuously viable crop production: pollination is based on the mutualistic interaction between plants and animals. Changes in climatic factors is contributing greatly to a decrease in pollinator population thereby affecting pollination services (Memmott, Craze, Waser & Price, 2007; Schweiger et al., 2010; Hegland, Nielsen, Lázaro, Bjerknes, & Totland. 2009).

A great diversity of insect pollinators is necessary to help support the increased demand for food that will be brought about by future population increases. Insect pollinators are threatened by several environmental and anthropogenic factors, and several concerns have been raised over a looming potential pollination crisis. In terms of plant-pollinator interactions, the most important effect of climate change is an increase in temperatures (Mariken, Anders & Nils, 2011).

Hegland et al. (2009) studied the effects of temperature induced changes in plant-pollinator interactions. They found that both the timing of pollinator activity and plant flowering is strongly affected by temperature.

Insects and plants may react differently to changes in temperatures, leading to mismatches in blooming periods of plants and foraging times of pollinators as well as distributional mismatches which has great consequences on the survival rate and abundance of the species involved.

Mismatches affect plants by reducing insect visitation and pollen deposition due to a change in blooming periods of flowers leading to reduced yield and seed formation, while pollinators experience reduced food availability.

The outcome of three studies investigating how increased temperatures might create mismatches between wild and cultivated plants and their pollinators all buttress this point.

Gordo & Sanz, (2005) studied the nature of phenological responses of plants and their insect pollinators to increasing temperatures on the Iberian peninsula, finding that variations in the slopes of the responses indicate a potential mismatch between the mutualistic partners. When insect pollinators advance their activity period ahead of their preferred forage species, it results in a mismatch with some of their main plant resources.

However Kudo, Nishikawa, Kasagi, & Kosuge (2004) found that early-flowering plants in Japan advanced their flowering during a warm spring whereas bumble bee queen emergence appeared unaffected by spring temperatures. This cannot be generalised as direct temperature responses and the occurrence of mismatches in pollination interactions may vary among species and regions.

Memmot et al. (2007) tested the effects of increased temperatures on a plant-pollinator relationship and they found that shifts in the timings of biological changes in flowering plants which were due to climatic changes reduced the floral resources available for 17 to 50 per cent of the pollinator species.

A timing induced mismatch can be detrimental to both plants and pollinators. It is likely that pollinators will change their activity patterns as temperature increases, in turn affecting the efficiency of pollen removal and deposition (Mariken et al., 2011).

The survival rate and population size of the main pollinators will decrease if the foraging activity period is initiated earlier than the flowering period of the crop species as the period they set out in search of pollen and nectar, flowers have not blossomed yet. A loss of important pollinators early in the season will reduce crop pollination services later in the season.

In such cases, introducing alternative food sources might be an option for farmers. In more heterogeneous agro ecosystems, which are characterized by a higher diversity of crops and semi-natural habitats, pollinators may more readily survive on other crops and wild plants while waiting for their preferred food source to blossom.

Pollinators' Sensitivity to Elevated Temperatures

Bees are the most important pollinators' worldwide (Kearns et al., 1998) and like other insects, they are ectothermic, requiring elevated body temperatures for flying. The thermal properties of their environments determine the extent of their activity (Willmer & Stone, 2004).

The high surface-to-volume ratio of small bees leads to rapid absorption of heat at high surrounding temperatures and rapid cooling at low surrounding temperatures.

All bees with a body mass above the range of 35 and 50 mg are capable of endothermic heating, i.e. internal heat generation (Stone, 1993; Bishop & Armbruster, 1999).

Examples of bee pollinators with a body weight above 35 mg are found in the genera Apis, Bombus, Xylocopa and Megachile. Examples of small bee pollinators are found in the family Halictidae, including the genus Lasioglossum and all of these groups are important in crop pollination.

In addition to endothermy, many bees are also able to control the temperatures in their flight muscles before, during and after flight by physiological and behavioural means (Willmer & Stone, 1997). Examples of behavioural strategies for thermal regulation include long periods of basking in the sun to warm up and shade seeking or returning to the nest to cool down (Willmer & Stone, 2004).

In view of the potential effects of global warming, pollinator behavioural responses to avoid extreme temperatures have the potential to significantly reduce pollination services (Corbet et al., 1993).

Endothermic abilities and thermal requirements show a wide variation among different groups of bees. Most bee species have upper critical body temperatures (UCT) of 45-50°C (Willmer & Stone, 2004). Although desert and tropical bees face both high solar radiation and high air temperature, there seems to be no major difference in UCT between bees in different bio geographical regions (Pereboom & Biesmeijer, 2003). However, because of bees' contrasting abilities to generate heat when active, the maximum ambient temperature at which they can maintain activity may be somewhat below their UCT (Willmer & Stone, 1997). The activity patterns of bees during the day also depend on the bees' coloration and body size (Willmer & Stone, 1997; Bishop & Armbruster, 1999).

For example Willmer and Stone (2004) found that small, light-coloured Trigona bees in Costa Rica foraged on the flowers of *Justicia aurea* in full sunlight, while large, dark-coloured bees foraged in the morning and evening to avoid overheating hence the effect of climate change on pollinators depends upon their thermal tolerance and plasticity to temperature changes.

Elevated local temperatures can affect pollinator behaviour, changing the number of visits conducted by a single pollinator as well as the pollinators' behaviour within flowers. On a larger scale, changes in temperature over the entire season may alter the abundance and diversity of pollinators. For example, pollinators with a narrow temperature tolerance may be replaced by other pollinators that are less sensitive to temperature changes or have higher optimal temperatures (Mariken et al., 2011).

Entomophilous Crops' Sensitivity to Increased Temperatures

Plant development is mainly determined by mean temperature and photoperiod (Nigam, Rao & Wynne, 1998). As global temperatures increase, crops will be grown in warmer environments that have longer growing seasons (Rosenzweig et al., 2007). An increase in temperature of about 1-2°C may have a negative impact on crop growth and yield at low latitudes, and a small positive impact at higher latitudes (Challinor, Ewert, Arnold, Simelton & Fraser, 2008).

Extreme temperatures and drought are short-term events that will likely affect crops, particularly during anthesis (Conference on food and forestry, 2002).

High temperatures and water stress will negatively affect crop growth and yield and their impact on pollination functions are also established.

Akhalkatsi & Losch (2005) found reductions in inflorescence and flower numbers in the annual garden spice legume *Trigonella coerulea* when subjected to controlled drought conditions. Flowers with fewer attractants are less attractive to pollinators (Galloway, Cirigliano & Gremski, 2002; Pacini, Nepi, & Vesprini, 2003; Mitchell, Karron, Holmquist, & Bell, 2004; Hegland & Totland, 2005) and will experience reductions in pollination levels, with decreased seed quality and quantity (Philipp & Hansen, 2000; Kudo & Harder, 2005).

Crop species experiencing drought stress may also produce lower seed weight and seed number as well as reduced yield (Akhalkatsi & Losch, 2005). Yield reduction due to elevated temperatures may also result from a decrease in pollen viability along with an increase in flower abortion rates, which has been identified as the most important factors affecting seed set (Melser & Klinkhamer, 2001; Boyer & Westgate, 2003).

Pollinators and Pesticide Use

Increased demand for control of plant pests often results in the use of pesticides which has negative impacts on human health, the environment (Damalas, 2009), and ecosystem services such as pollination.

Pesticides are rarely specific to target species as less than 0.1% of pesticides applied to crops actually reach the intended pest (Arias-Estevez et al., 2008) with the remainder accumulating in soils, where it may filter into ground or surface water exposing micro-organisms, aquatic animals and humans to poison. Accumulated pesticides in soils may harm organisms that pose no threat to agricultural yields or public health such as arthropods, earthworms, fungi, bacteria, protozoa, and other organisms that contribute to the function and structure of soils. These organisms are killed as a result of being exposed to the toxic impacts of the application of these chemicals.

The use of agrochemicals has played a major role in increasing the yield of agricultural crops (Ntow, Gijzen, Kelderman, & Drechsel, 2006). Worldwide pesticide usage has increased tremendously over time and this has largely been responsible for the massive increase in food production obtained from the same surface of land with the help of mineral fertilizers (nitrogen, phosphorus, and potassium), more efficient machinery and intensive irrigation (Huber, Bach, & Frede, 2000).

The use of pesticides helped to significantly reduce crop losses and to improve the yield of crops such as corn, maize, vegetables, fruits, potatoes and cotton (Ntow, Drechsel, Botwe, Kelderman, & Gijzen, 2008).

This notwithstanding, the potential harm that will be caused as a result of the application of these chemicals greatly outweigh any assumed benefits of improved agricultural productivity from their role in pest control.

Despite the widespread application of pesticides in the United States at recommended dosages, it is documented that pests still destroy 37% of all potential crops with insects destroying 13%, plant pathogens 12%, and weeds 12% (Pimentel, 2005).

As farms have greatly increased in size, the challenges in keeping the plants free from pest damage have increased significantly as well. Hand-tilling weeds have become impractical, so also has been the reliance of farmers on the mechanism of natural enemies of pest species. This has caused the whole world to known an exponential increase in agrochemical usage both in types and quantities.

The poisoning of pollinators especially bees by pesticides is a major problem that influences the efficiency of bees not only in their production of honey but also in crop pollination. This problem is present in all countries that have developed agricultural systems and this is associated with insecticides applied to cultivated crops.

Damage also results from treatment of forests and rangelands, and even suburban areas, for the control of pests of man and animals.

Honey bees from a colony visit flowers over a distance of several square miles. The frequency of visitation in any one part of the area is as a result of the relative attractiveness of the flowers to the individual pollinators and the severity of damage caused to the colony by the pesticide application. Pollinator visitation patterns are influenced not only by the relative toxicity of the chemical but also by the methods and number of applications, the time of day, and the prevailing weather conditions at the time of application (Tirado, Simon, & Johnston, 2013).

The number of bees from individual colonies visiting the flowers in the treated area, the type of food (nectar or pollen) they are collecting are also determinants of the intensity of havoc caused as well as the type of flowers the resource is retrieved from, the season of the year the damage occurs, and even the forage the bees visited for weeks before and after the application.

Wild pollinators are also affected by pesticide use as well as managed ones. Poisoning may result from contaminated food as well as from florets, leaves, soil, or other material used by the bees in nesting (Fischer & Moriarty, 2011).

Intensity of Damage to Bees by Pesticides

Numerous surveys have been carried out to identify the quantum of the loss of bees due to pesticide poisoning. Levin & Anderson (1970) stated that some 500,000 colonies were killed or damaged in the United States in 1967, of which 70,000 were in Arizona and 76,000 in California and concluded that the major problem confronting the beekeeping industry was bee losses due to pesticide poisoning to which there is little disagreement by the beekeeping industry with losses in California in 1968 being the greatest running into 83,000 colonies.

All indications point to an annual loss by the industry in the range of 10 per cent caused by pesticides alone. Few industries can tolerate such losses and survive. Wherever pesticides are applied to plants there is a possibility of damage to bees.

How Poisoning of Pollinators Occur

Efforts to restrict pesticide application during the flowering period of plants provided some relief from the poisoning of pollinators but the residual effect of some pesticides was never effectively addressed hence the process of pollinator poisoning still existed (Johansen & Mayer, 1990).

The main situations leading to pollinators coming in contact with pesticides include but are not restricted to:

Exposure through feeding. Pollinators are exposed to harmful pesticides when they feed on contaminated food sources (nectar and pollen). Contaminated food is brought to the hive and fed to the entire colony. Poisoned food can contaminate all castes: worker bees, drones and queens (Villa, Vighi, Finizio, & Serini, 2000).

Exposure through contact. Pollinators may come in contact with pesticides in the air during flight just after the application of chemical treatments or with residues on treated plants (Desneux, Decourtye, & Delpuech, 2007).

Drinking contaminated water. Pollinators are also believed to get poisoned from drinking water in the form of dew on the plants or from water sources within the treated area, but there is little data to support this.

Utilization of contaminated, stored nectar and pollen. The pesticides applied to plants even if far from pollinator habitats can and frequently do reach the hive through pollen. Pollen collected from the field by bees requires fermentation for about a week in order to be digestible by honey bees therefore are stored over a period unlike nectar which is utilized almost immediately. Stored food will be used outside the period of harvest, especially in periods of unfavourable weather and this can result in severe poisoning if it is fed to the developing brood at this time, newly emerged bees can be poisoned from the food store (Tasei, 1996). This makes it possible for the actual time of contamination to be extended over long periods.

At extremely high temperatures, a colony can experience severe loss in numbers if the water supply is cut off for only a few hours. If the water supply is located far from the hive such that the water carriers became poisoned in flight, the colony could suffer both directly from the loss of the water carriers and indirectly from lack of water, even though the pesticide were applied to a totally unattractive crop.

Various pollinators react differently to the effect of different pesticides. The symptoms of arsenic poisoning are very pronounced. In the early stages, adult bees become sluggish and soon neglect their duties, so the brood apparently dies of starvation; later, their abdomens become greatly swollen, being filled with a yellowish watery liquid and later, the legs and wings become paralyzed then finally, the bees die in a state of coma.

In contrast, the symptoms of bees affected by DDT were described by McGregor and Vorhies, (2012). The bees acted as if they were cold, perching for long periods on leaves, twigs, or lumps of soil, selecting warm spots, and generally sitting motionless unless disturbed. Sometimes they fall from these perches, then regain their balance and depart slowly as a cold bee does.

Sometimes they are seen in rapid erratic flight only to alight again a few yards away.

In crawling they were much slower than arsenic poisoned bees. After becoming unable to crawl they would be helpless, sometimes for hours if protected from direct sun. They often lay on their backs or sides making feeble movement with their legs or antennae.

Other materials affect bees in other ways. When bees are exposed to the insecticide BHC, for example, they are much more inclined to sting.

Usually, the first noticeable effect of insecticide poisoning on the colony is recently dead or dying bees on the ground near the hive entrance, although this is not always the case.

If poisoning is severe, the affected or dead bees will pile up on the floor of the hive faster than the healthy bees can remove them.

Flight from the entrance decreases and fresh nectar can no longer be taken from the brood combs. As the cluster population decreases, its size and the concentration of bees within it also decreases. The brood is gradually abandoned, the smaller larvae begin to die, and many of the larger larvae crawl from their cells and fall to the floor of the hive before they die. The sealed brood begins to die and as it does so the colour of the capped cells becomes darker.

As the cluster continues to diminish and become disorganized, the combs in the colonies exposed to the hot sun begin to melt and soon liquid honey begins to ooze from the hive entrance and spreads among the dead bees on the ground. Frequently, the last individual to die is the queen. Wax moths quickly discover the deserted colony, lay their eggs within it and the developing larvae soon riddle and destroy the remaining combs.

Bees frequently store contaminated pollen in the combs and this contaminated pollen remains toxic for months, even in combs removed from weakened or destroyed colonies. Poisoning may result in complete destruction or the colony may be weakened to varying degrees.

If the colony is exposed to a single application that does not destroy it, the field force may be lost and if it has a large amount of brood emerging the colony’s apparent recovery is rapid. More severe poisoning may prevent rapid build-up, and the colony may go into winter without adequate reserves of food or young bees. Such colonies may die or survive the winter in such a weakened condition as to be of no value for much of the following year.

The grower is sometimes confused when he is told that colonies have been damaged by pesticides yet he or she sees apparently normal bees entering and leaving the hive entrance. He may be deceived by the fact that young bees take their orientation or "play" flight near the entrance before they reach the foraging age. This can give an impression of great activity whereas no food is being collected or stored.

Effect of Pesticide Application on Plants

The effect of pesticide application may not be confined only to the destruction of the pollinators of a distant crop or elimination of pollinators for the target crop alone. A previously overlooked factor associated with the effect of pesticide application may be that it can lead to a reduction in plants' productiveness.

Beekeepers frequently commented that they believed indiscriminate pesticide application influences the plant itself negatively from the bee foraging standpoint. This belief has received some experimental support as Sedivy (1970) reported that only 10.5 per cent of pollen grains germinated after they were dusted with Melipax 7 as compared to 62.1 per cent in the control pollen. When the pollen grains were treated with 0.3 per cent Fribal emulsion, only 28.2 per cent germinated as compared to 81.5 per cent of the control pollen. None of the grains treated with 0.7 per cent Fribal emulsion germinated as compared to 79.0 per cent of the control.

Gentile, Gallagher, & Santner, (1971) reported that the insecticide naled, at only 100 ppm, completely inhibited germination of both tomato and petunia pollen. They also reported that azinphosmethyl, DDT, dichlorvos, dicofol, endosulfan, and Gardona R caused reduction in pollen germination and/or pollen tube elongation. Carbaryl and methomyl had little or no deleterious effect on pollen, and xylene was non-injurious.

The separation of the toxic or repelling effect of the presence of the insecticide on the plant from the possible less attractiveness of affected pollen is difficult, but the idea merits further examination, both from the effect of pesticides on the plants and on the pollinating insects.

Dinham, (1993) estimates that 87% of farmers in Ghana use chemical pesticides to control pests and diseases on vegetables and fruits whiles Ntow et al. (2006) gave the proportions of pesticides used most often on vegetable farms as herbicides (44%), fungicides (23%) and insecticides (33%).

Notwithstanding the beneficial effects of pesticides, their adverse effects on environmental quality, human and pollinator health has been well documented worldwide and constitute a major issue that gives rise to concerns at local, regional, national and global scales (Ntow, 2001).

In a study encompassing 30 organized farms and 110 kraals distributed throughout the 10 regions of Ghana, Awumbila & Bokuma, (1994) found that 20 different pesticides were in use with the organochlorine lindane being the most widely distributed and used pesticide, accounting for 35% of those applied on farms. Of the 20 pesticides, 45% were organophosphorous, 30% were pyrethroids, 15% were carbamates and 10% were organochlorines (Awumbila & Bokuma, 1994).

A group of commonly used pesticides known as neonicotinoids are known to be systemic (Tirado et al., 2013), implying that they enter the plant's vascular system and travel through it spreading throughout the entire plant. Some neonicotinoid insecticides are coated around seeds when the coated seed starts to germinate and grow; the chemical is spread throughout the plants roots, stem and leaves, and later on the pollen and nectar.

The increased use of neonicotinoids means there is a great possibility that pollinators will be exposed to these chemicals over longer periods, as systemic insecticides can be found in various parts of the plant over its lifetime.

Pollen is the main protein source for honeybees, and it plays a crucial role in bee nutrition and colony health. According to Mullin et al. (2010), surviving on pollen with an average of at least seven different pesticides seems likely to have consequences some of which include impairment of foraging ability, impairment of learning ability (related to smell, memory etc. which are relevant to a bee's behaviour), increased mortality, and dysfunctional development in larvae and queen (Tirado et al., 2013).

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This chapter gives a description of the procedures followed, techniques and methods used in carrying out the research. It basically describes the study site, study design and sampling techniques/procedures. It also includes field and lab works, data collection, processing and analysis of the entire data collected.

Study Site

This research was carried out at Ayikuma (05^0 55.00' N; 00^0 03.00' W. 40m) in the Shai-Osudoku district of the Greater Accra region of Ghana. Watermelon cultivation is common here and is one of the main livelihood crops among the community members in Ayikuma.

The Study Area

Ayikuma is located in the Shai-Osudoku District (previously Dangme West district) in the Greater Accra region of Ghana (Figure 4).

Like many other communities in the Shai-Osudoku District, Ayikuma is a Dangme-speaking community as well as a predominantly farming community as this is the source of livelihood for most people in the town. It is ten to fifteen minutes drive from the district capital, Dodowa.

The town is predominantly rural though it is rapidly becoming urban as a result of the rapid sale of land in the area to estate agents, construction companies and individuals thus aiding a great amount of immigration and this is evidenced by the construction of many modern types of housing.

Major highways link the town to Accra, Akosombo, and Aflao but the local access roads within the township are either not tarred or usually poorly maintained.

It is bordered to the east by the Akwapim-Togo ranges leading up to Larteh in the Eastern Region of Ghana.

The town has a fair share of forest land extending up to the hills which makes it a scenic beauty though over time this is being degraded gradually as new settlements spring up.

It is bordered by Doryumu in the west, Dodowa and Somanya in the south and north respectively. It shares linguistic and cultural affinity with its neighbours, the communities in the district. The farmers Ayikuma make a living greatly because of the town's central location with respect to its surrounding neighbours. Farm produce from Ayikuma is easily transported to markets in Dodowa, Somanya, Lartey and Doryumu

The map below shows the location of Ayikuma within the Shai-Osudoku District (Figure 5). It also illustrates the major neighbouring communities surrounding the town.

Figure 4. A map of Ghana and the study area Google maps

Figure 5. A map of Shai-Osudoku district showing the study site in green

Field Work

Selection of plant variety

Variety selection is perhaps the most important management decision a farmer makes (Whalen, 1999). Planting a variety that is not suited for the available market and the particular production situation leads to lower profits or possibly crop failure. In addition to market acceptability, a variety must have acceptable yield, be adapted to the production area and have the highest level of needed pest resistance available (Department of Agriculture, Forestry & Fisheries, 2011).

The watermelon variety 'Kaolack' (Figure 6) was chosen because it is resistant to anthracnose and sun burns and widely patronised by consumers.

Figure 6: The watermelon variety Kaolack

Land preparation, planting of seeds and cultural practices

Three plots of land with dimensions 30.3m X 21.2m each were used for planting watermelon variety Kaolack. The plots were ploughed to allow easy penetration of the delicate roots of the watermelon plant into the soil for adequate absorption of water and nutrients for proper growth.

The study fields were adjacent to each other to ensure uniformity in soil nutrient available to the plants on the different treatment plots.

Un-cleared bush of width one meter was left separating each treatment plot from the other. This was to serve as a buffer during pesticide application.

Watermelon seeds were planted in rows 2 meters apart on each plot, with the plants 2 meters apart in each row with two seeds per hill which were thinned to one plant per hill upon germination.

One hundred and fifty (150) watermelon plants on each plot were used for the experiment. Cultural practices such as weeding and pest control were carried out.

Pesticides (Lambda-M and K-optimal) were used to control pests on the watermelon plants and fruits on the field by the use of a knapsack sprayer. Pesticide application started one week after flowering began and was carried out as follows: once every two weeks on one plot (controlled pesticide application); once a week on another plot (uncontrolled pesticide application) and no pesticide use on the third plot (no pesticide application). All pesticide application were done after 1500hrs to avoid the poisoning of pollinators.

Lambda-M is a pyrethroid whose active ingredient is lambda-cyhalothrin whiles K-optimal belongs to a group of insecticides known as neonicotinoids with acetamiprid as the active ingredient.

Data Collection

Phenology and behaviour of the watermelon plant

Twenty plants from each study plot were selected for observation; the observable changes in the plants from germination to maturity were noted and recorded. The length and branching pattern were recorded for each week to establish the growth pattern per time of the watermelon plant.

The number of male and female flowers produced each week were counted and recorded to determine the ratio of male to female flowers of the watermelon plant.

Collection of floral visitors using a sweep net

Once every week, flower visitors were sampled from watermelon flowers on the three treatment plots for eight weeks. One hour was spent on each plot collecting insects from flowers using a sweep net.

To prevent damage to the watermelon flowers and plants, the sweep net was tilted over the insect and allowed to move up the net (Figure7).

Insect sampling started at 0730hrs and ended at 1130hrs with the order of plot visitation being alternated each week.

All insects collected were killed by drowning in a bottle containing soapy water. Dead insects were washed and temporarily stored in pre-labelled vials containing 70% ethanol. The insects collected were then brought to the entomology museum of the University of Cape Coast for preparation, identification and recording as well as analysis.

Collection of insect visitors using pan traps

Five sets of pan traps of three colours each (white, yellow and blue) containing soapy water were set randomly in each plot to collect flower visitors (Figure 8). Insects trapped were collected every other day, the contents of each pan trap emptied, washed and placed in separate pre-labelled vials containing 70% ethanol.

In each set, the pan traps of individual colours were set apart at a distance of one meter from each other in a triangular form to ensure that flower visitors were collected based on their colour preferences and not by accident.

The diversity of the watermelon flower visitors collected from the study plots was determined using Shannon Wiener diversity index.

The Shannon Wiener diversity index is represented by the formulae

$$H' = -\sum (pi * \ln pi)$$

Where H'= Shannon Wiener diversity index

pi= Number of individuals of species i / total number of samples

$\ln pi$= Natural log of pi

Figure 7: Collecting insect flower visitors using a sweep net

Figure 8: Pan traps used for collecting insect flower visitors

Determination of the pollination efficiency of three main watermelon pollinators

Pollination efficiency is defined as the relative ability of an insect to pollinate flowers effectively, as measured by fruit production per some unit of measure such as per visit (Keys, Buchmann, & Steven, 1995).

Observations to determine pollination efficiency was done by bagging and tagging ten (10) female flowers at budding stage which were chosen by using the systematic random sampling method from each plot.

When the flowers opened, each one was exposed to a single visit by one pollinator then the flower was re-bagged. Each pollinator was assigned a colour tag that was attached to the plant for identification (Figure 9).

This was done because the single visit of a pollinator to a flower is the fundamental unit of analysis for the entire pollination process.

According to Mariken et al. (2011), visitation quality of observed pollinators should be investigated by presenting flowers for single visits to individual pollinator species and the shape, size and weight of resulting fruits formed be compared amongst different insect pollinators.

The pollinator that visited the individual flowers was recorded and the output (fruit formation and shape) was compared between individual flower visitors.

The ability of the female flower to form a fruit after a single visitation by individual pollinators was used as a criterion for determining the most efficient pollinator for the watermelon plant.

Figure 9: Female watermelon flowers covered with pollinator exclusion bags and tagged after single pollinator visits

Effect of pesticide use on the flower visitors and yield of watermelon

Abundance of the different pollinator species and diversity of the flower visitors collected from the individual plots was compared to identify the effect of the use of pesticide on watermelon flower visitors.

Diversity can be quantified in many different ways. The two main factors taken into account when measuring diversity are richness and evenness.

Richness is a measure of the number of different species present in a particular area. However, diversity does not depend solely on richness, but also on evenness. Evenness compares the similarity of the population size of each of the species present.

Evenness is determined using the formulae $E = H'/H_{max}$

E= Evenness

H'= Shannon Weiner diversity index

H_{max} = Maximum diversity possible

$H_{max} = \ln(S)$

S = Species richness

The diversity of insects that visited the watermelon flowers on the three fields used for the study was determined using the Shannon Wiener's diversity index. The diversities of flower visitors to the plots with controlled pesticide use (pesticide application once in two weeks), uncontrolled pesticide use (once a week) and no pesticide use (no pesticide application) were compared to show the effect of pesticide application on the diversity of insects that visited the watermelon flowers.

The species richness of flower visitors for each treatment was also deduced during the calculation of insect diversity. Species richness as a measure on its own does not take into account the number of individuals of each species present (Yadav & Mishra, 2013). It gives as much representation to those species which have very few individuals as to those which have many individuals per sample.

During harvest, fruits from the uncontrolled pesticide application plot, the controlled pesticide application plot and the no pesticide application plot were counted, and weighed.

A one way analysis of variance was used to compare the mean weight of fruits harvested from the three plots with different treatments. This was to help establish if there is a significant difference between the yields obtained from the plots with different treatments and to show the effect of pesticide application on watermelon fruit production.

Figure 10: A pollinator (*Apis mellifera*) foraging on a watermelon flower

Figure 11: A flower visitor (*Dactylurina staudingeri*) on a watermelon flower

Laboratory Work

At the entomological museum, insects collected were sorted, counted, identified, and then pinned in insect boxes. Data gathered from the collection was recorded and used to compute the percentage abundance of watermelon pollinators as well as the diversity of flower visitors of the watermelon crop in the individual treatment plots.

Identification of the insects was done in the laboratory with the help of an insect taxonomist, Dr. Rofela Combey.

Data Analysis

The mean number of flower visitors sampled from flowers and the mean weight of fruits harvested from the different study plots were analysed using a one way ANOVA at 95% confidence level interval, using Minitab Software version 16.

Fisher's method for least significant difference (LSD) test at 5% probability level was used to show which means were significantly different from each other.

Excel 2010 version of Microsoft Office suite was used to draw tables, graphs and charts to show recognisable trends and patterns.

CHAPTER FOUR

RESULTS

Introduction

The results presented in this chapter are a representation of data collected in relation to the objectives of this research. It consists of results of the relative abundance and the diversity of watermelon flower visitors collected from the study plots.

It also includes the mean number of flowers produced by the watermelon plants during the period of the study as well as its growth pattern, the effect of pesticide application on watermelon flower visitors and watermelon yield.

Pan trap colour preference of watermelon flower visitors and the most efficient pollinator from the experiment are presented in this chapter as well.

Phenology and Behaviour of the Watermelon Plant

The pattern of flowering of the watermelon plants observed showed the emergence of male flowers during the first week of flowering and female flowers in the second week of flowering with a continuous increase in the number of male and female flowers until the 6th week of flowering after which the number of flowers produced by the plants begins to decline. Female flowers emerge one week after male flowers had emerged.

The highest mean number of flowers counted per twenty (20) plants was 3.01 male and 1.75 female flowers from the plot with controlled pesticide use (Figure 12), 3.02 male and 1.33 female flowers from the plot with uncontrolled pesticide use (Figure 13) and 3.09 male and 1.75 female flowers from the plot with no pesticide use (Figure 14).

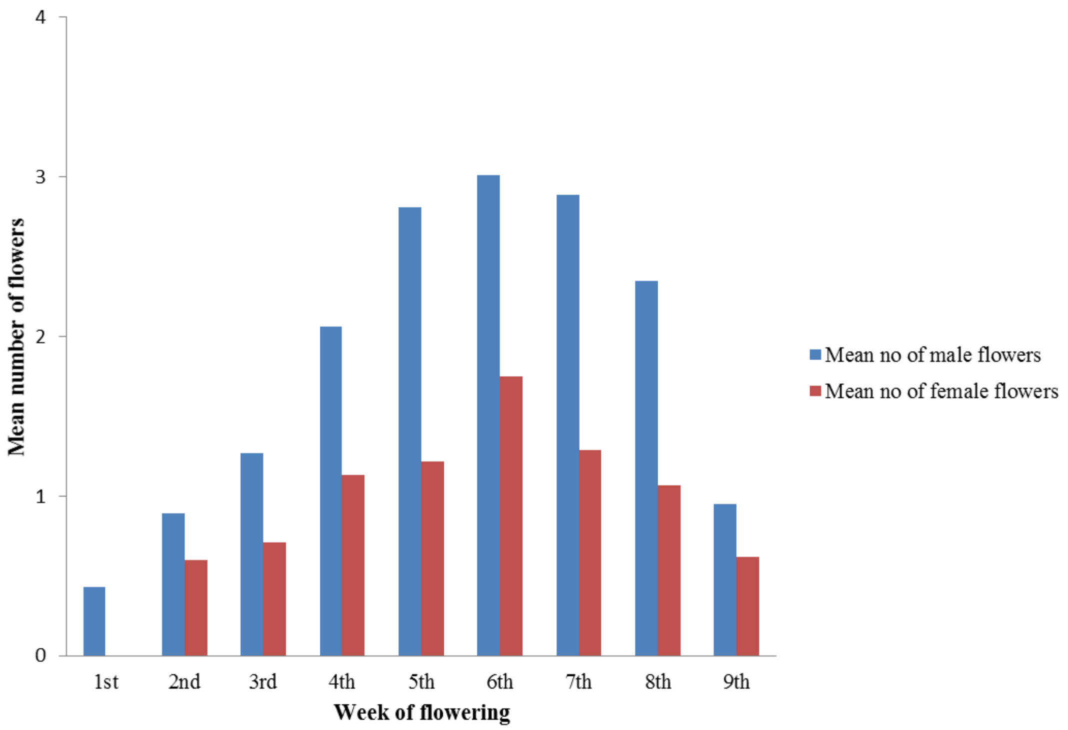

Figure 12: Mean number of male and female flowers on the plot with controlled pesticide use

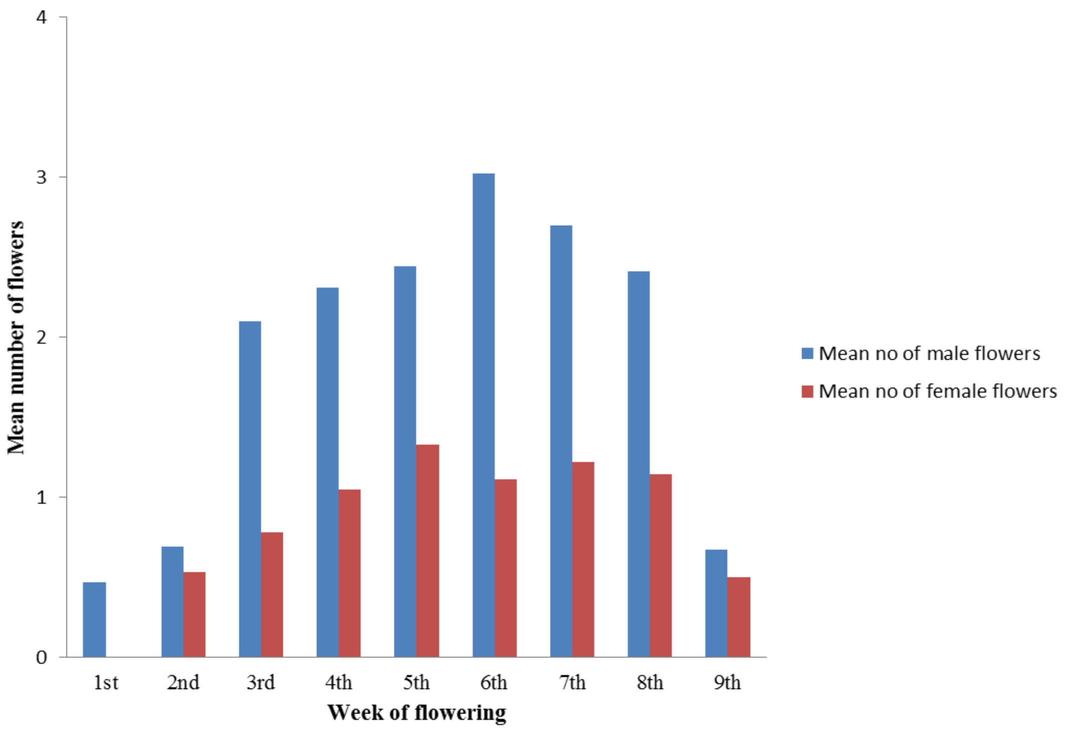

Figure 13: Mean number of male and female flowers on the plot with uncontrolled pesticide use

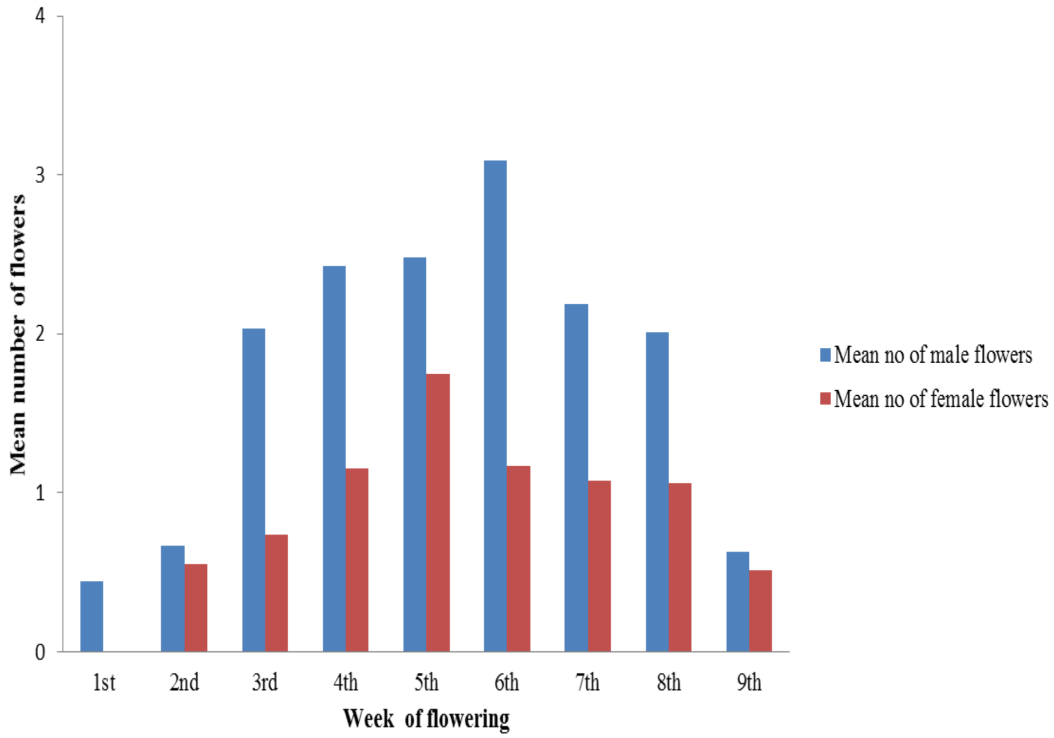

Figure 14: Mean number of male and female flowers on the plot with no pesticide use

The growth pattern (vine length and number of branches over time) observed showed a continuous progression (Table 4).

Table 4: Growth pattern of watermelon plant

Week after planting	Vine length (m)	Number of branches
1	0	0
2	0.30	0
3	0.82	0
4	1.46	1
5	1.86	1
6	2.23	1
7	2.41	2
8	2.65	2
9	2.87	2
10	3.00	3
11	3.14	3

Relative Abundance of Watermelon Flower Visitors

A total of 428 insect flower visitors were collected using a sweep net during the sampling period. This consists of 135 collected from the plot with controlled pesticide application, 76 from the plot with uncontrolled pesticide application and 217 from the plot with no pesticide application (Table 5).

The abundance of individual flower visitors collected from each plot is expressed as a percentage of the total number of floral visitors collected per plot.

Apis mellifera was the most abundant insect flower visitor collected from the three plots (Figure 15) with 88 collected from the field with controlled pesticide use, 55 from the field with uncontrolled pesticide use and 123 from the field with no pesticide use. This represents 65.2%, 72.4% and 56.7% of total collections from each field respectively.

The next most abundant flower visitor collected was *Lipotriches spp*, with 13 collected from the field with controlled pesticide use, 5 from the field with uncontrolled pesticide use and 29 from the field with no pesticide use representing 9.6%, 6.6% and 13.4% of total collections from each field respectively.

The least abundant flower visitors collected were *Amegilla spp* and *Epilachna spp* with 2 each collected from the field with no pesticide use. This represents 0.9% each of total collections from each field (Table 5).

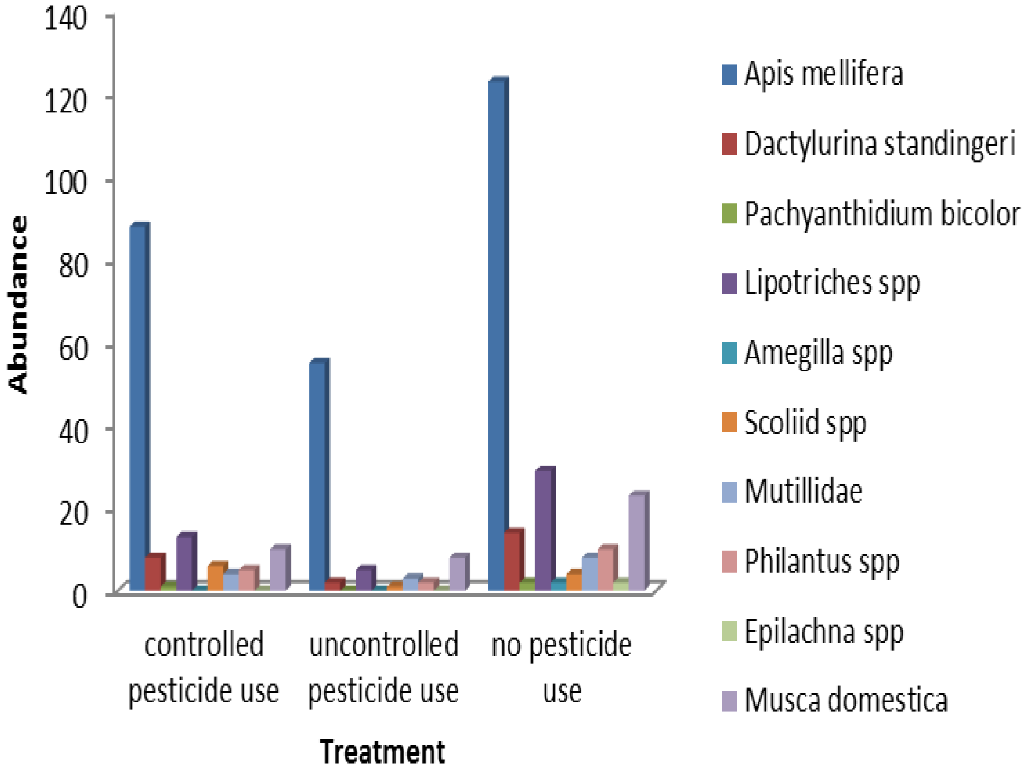

Figure 15: Abundance of insect flower visitors collected from watermelon flowers

Table 5: Relative abundance of insects sampled on watermelon flowers

Species	n , (%abundance)					
	Controlled pesticide use		Uncontrolled pesticide use		No pesticide use	
Apis mellifera	88	(65.2)	55	(72.4)	123	(56.7)
Dactylurina staudingeri	8	(5.9)	2	(2.6)	14	(6.5)
Pachyanthidium bicolor	1	(0.7)	0	(0.0)	2	(0.9)
Lipotriches spp	13	(9.6)	5	(6.6)	29	(13.4)
Amegilla spp	0	(0.0)	0	(0.0)	2	(0.9)
Scoliid spp	6	(4.4)	1	(1.3)	4	(1.8)
Multillidae	4	(3)	3	(3.9)	8	(3.7)
Philantus spp	5	(3.7)	2	(2.6)	10	(4.6)
Epilachna spp	0	(0)	0	(0)	2	(0.9)
Musca domestica	10	(7.4)	8	(10.5)	23	(10.6)
N	135	(100)	76	(100)	217	(100)

Values in parenthesis represent percentage abundance

Diversity of Watermelon Flower Visitors

The plot with no pesticide application had the highest diversity index of 1.50 for the flower visitors collected, the plot with controlled pesticide use and uncontrolled pesticide use had diversity indices of 1.36 and 1.07 respectively (Appendix H).

This shows that the plot with no pesticide application had the highest diversity of flower visitors present. This might be as a result of the absence of chemicals on that field as the plot with uncontrolled pesticide application had the lowest diversity of flower visitors.

Species Richness and Evenness of Flower Visitors

The study plot with controlled pesticide use had a species richness of eight (8) with insects such as *Apis mellifera* (Hymenoptera: Apidae), *Dactylurina staudingeri* (Hymenoptera: Apidae), *Pachyantidium bicolor, Lipotriches spp* (Hymenoptera: Halictidae), *Scoliid spp* (Hymenoptera: Scoliidae), *Philantus spp*, *Musca domestica* (Diptera: Muscidae) and wasp from the family Mutillidae collected from the plot.

This was higher compared to the plot with uncontrolled pesticide application which had a species richness of seven (7) with insect flower visitors such as *Apis mellifera, Lipotriches spp, Scoliid spp, Philantus spp, Musca domestica, Dactylurina standingeri* and wasp from the family Mutillidae present.

The control plot with no pesticide application recorded a species richness of ten (10) with insect species such as *Apis mellifera*, *Dactylurina staudingeri, Pachyantidium bicolor, Lipotriches spp, Scoliid spp, Philantus spp, Musca* *domestica*, wasps from the family Mutillidae, *Amegilla spp* (Hymenoptera: Anthophoridae) and *Epilachna spp* present.

The largest number of species collected was on the plot with no pesticide application suggesting that pesticide application had an impact on flower visitors.

Species evenness ranges from zero to one, with zero signifying no evenness and one; a complete evenness. The value of evenness using the Shannon Wiener's index for the plot with controlled pesticide use was 0.65 which showed a fairly evenly distributed flower visitor population. This value is higher than that obtained from the plot with uncontrolled pesticide application.

The plot with uncontrolled pesticide application also recorded a moderately distributed insect population with a value of 0.55 whiles the plot with no pesticide application had an equal value of evenness as the plot with controlled pesticide use. This plot showed a fairly evenly distributed flower visitor population with a value of 0.65 (Appendix H).

Efficiency of Watermelon Pollinators

After single visits from watermelon pollinators, the ability or inability of female flowers under observation to form fruits was recorded to establish the efficiency of individual pollinators visiting the watermelon flowers as this is a direct measure of pollinator efficiency.

Some studies have shown that the first pollinator visit deposits enough pollen to fertilize a large number of ovules and subsequent visits fertilize a much smaller number of ovules.

According to Spears (1983), in *Ipomoea trichocarpa* seed set from a single Bombus visit was indistinguishable from unlimited visitation therefore the first visit that a flower receives leads to the deposition of enough pollen to ensure a high level of seed set resulting in fruit formation.

The insect pollinators that were observed visiting the watermelon flowers were *A. mellifera, Lipotriches spp.* and *Dactylurina staudingeri.*

Of the ten (10) female flowers monitored on the plot with controlled pesticide application, five (5) were visited by *A. mellifera* and all five flowers developed into fruits. Three (3) flowers were visited by *Lipotriches spp.* but none of them developed into fruits and two (2) flowers were visited by *Dactylurina staudingeri* but none of them formed fruits.

On the plot with uncontrolled pesticide use, four (4) female watermelon flowers were visited by *A. mellifera* and all four flowers developed into fruits. Three (3) flowers were visited by *Lipotriches spp.* but none of them developed into fruits and three (3) female flowers were visited by *Dactylurina staudingeri* but were all aborted.

On the plot with no pesticide use, five (5) female watermelon flowers were visited by *A. mellifera* and four developed into fruits whiles one flower was aborted. Three (3) flowers were visited by *Lipotriches spp.* and none of them developed into fruits whiles two (2) female flowers were visited by *Dactylurina staudingeri* and were all aborted (Table 6).

Figure 16: Distorted watermelon fruits formed from single *A. mellifera* visit

Table 6: Efficiency of pollinators visiting ten watermelon flowers under different pesticide application regimes

	Controlled pesticide use		Uncontrolled pesticide use		No pesticide use	
Flower	Insect and result		Insect and result		Insect and result	
i.	*Apis mellifera*	Yes	*Lipotriches spp.*	No	*Apis mellifera*	No
ii.	*Apis mellifera*	Yes	*Apis mellifera*	Yes	*Lipotriches spp.*	No
iii.	*Apis mellifera*	Yes	*Apis mellifera*	Yes	*Apis mellifera*	Yes
iv.	*D. staudingeri*	No	*Apis mellifera*	Yes	*D. staudingeri*	No
v.	*Lipotriches spp.*	No	*D. staudingeri*	No	*Apis mellifera*	Yes
vi.	*Lipotriches spp.*	No	*Lipotriches spp.*	No	*Lipotriches spp.*	No
vii.	*Apis mellifera*	Yes	*Apis mellifera*	Yes	*Apis mellifera*	Yes
viii.	*D. staudingeri*	No	*Lipotriches spp.*	No	*Apis mellifera*	Yes
ix.	*Lipotriches spp.*	No	*D. staudingeri*	No	*D. staudingeri*	No
x.	*Apis mellifera*	Yes	*D. staudingeri*	No	*Lipotriches spp.*	No

Yes - fruit formed, No - no fruit formed

Effect of Pesticide Application on Flower Visitors

There was a significant difference between the mean number of insects collected from the three study plots with different treatments ($p < 0.05$).

As shown in Table 7, the mean number of honey bees collected from the plot with controlled pesticide use was 11.00 ± 1.20 which is greater than the mean number of honey bees collected from the plot with uncontrolled pesticide use which is 6.88 ± 0.64 but the highest mean number of honey bees collected was from the plot with no pesticide use which is 15.38 ± 1.92. ($F= 9.83$, $p = 0.001$).

For stingless bees collected, there was a significant difference in the mean numbers collected from the different treatments ($p < 0.05$). The highest mean number of stingless bees collected was 1.75 ± 0.37 and this was from the plot with no pesticide use, followed by a mean number of 1.00 ± 0.27 from the plot with controlled pesticide use and the least mean number of stingless bees collected being 0.25 ± 0.16 from the plot with uncontrolled pesticide use. ($F = 7.27$, $p = 0.004$).

A significant difference ($p < 0.05$) was observed between the mean number of other bees collected from the three different treatments. The highest mean number of other bees collected was 4.13 ± 0.97 from the plot with no pesticide use, followed by a mean number of 1.75 ± 0.37 from the plot with controlled pesticide use and the least mean number of other bees collected was 0.63 ± 0.18 from the plot with uncontrolled pesticide application ($F= 8.62$, $p = 0.002$).

A similar trend was observed for insects other than bees collected from the watermelon flowers. The highest mean number of other insects collected was 5.88 ± 0.74 from the plot with no pesticide use followed by a mean number of 3.13 ± 0.83 from the plot with controlled pesticide use and the least mean number of other insects collected was 1.75 ± 0.25 from the plot with uncontrolled pesticide use. ($F = 10.12$, $p = 0.001$).

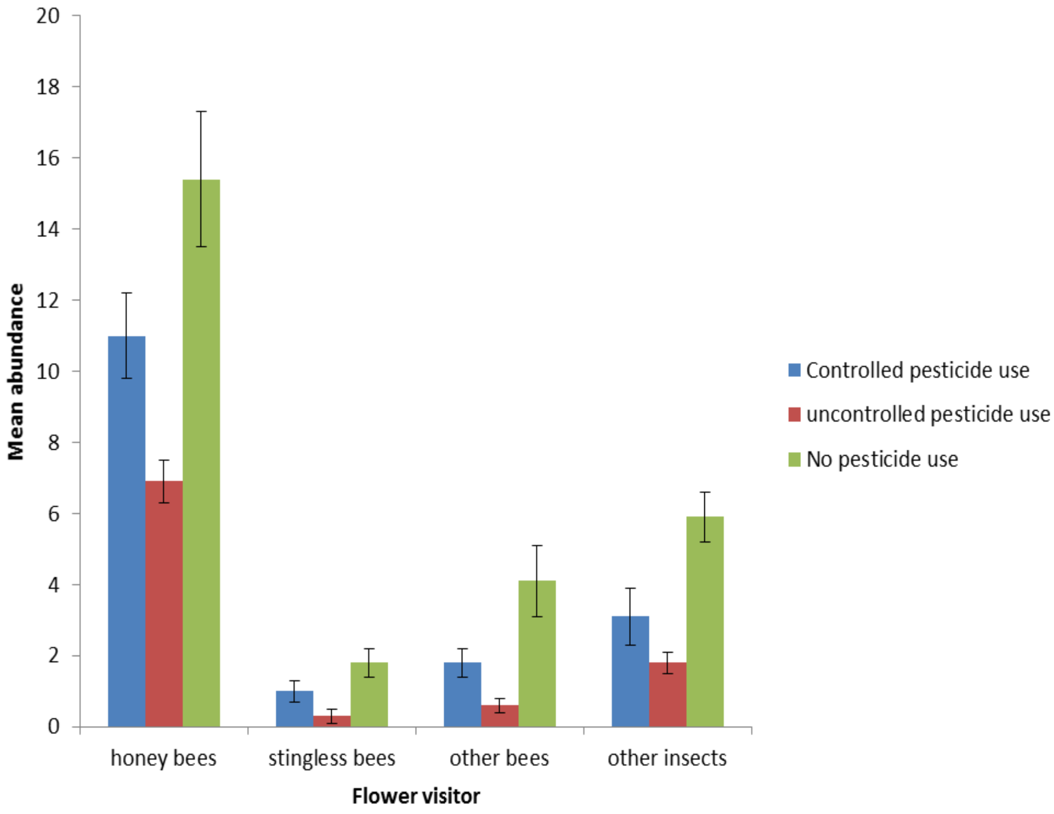

Figure 17. Mean abundance of flower visitors on the three treatment plots

Effect of Pesticide Application on Watermelon Yield

Analysis of the results showed no significant difference (p> 0.05) in the yield of watermelon plants due to pesticide application (Table 8). During the first harvest, twenty seven (27) watermelon fruits with a mean weight (kg) of 4.87 ± 0.24 were harvested from the plot with controlled pesticide use.

Fifty six (56) watermelon fruits with a mean weight (kg) of 4.55 ± 0.09 were harvested from the plot with uncontrolled pesticide use whiles from the plot with no pesticide use, seven (7) watermelon fruits with a mean weight (kg) of 5.36 ± 0.27 was harvested ($F = 3.04$, $p = 0.053$).

At the second harvest two weeks later, 16 fruits with a mean weight (kg) of 3.68 ± 0.22 were harvested from the plot with controlled pesticide use.

Twenty eight (28) fruits were harvested from the plot with uncontrolled pesticide use with a mean weight 3.39 ± 0.10 and a mean weight of 3.72 ± 0.36 from three (3) fruits harvested was recorded from the plot with no pesticide use ($F= 1.07$, $p = 0.351$).

The mean weights recorded from the third harvest four weeks after the initial harvest also showed no significant difference ($p> 0.05$) in the yield.

A mean weight of 2.75 ± 0.08 was recorded from the plot with controlled pesticide use from 11 fruits harvested.

Twenty seven (27) fruits were harvested from the plot with uncontrolled pesticide use and the mean weight recorded was 2.81 ± 0.07 and two (2) fruits with a mean weight of 2.33 ± 0.18 were harvested from the plot with no pesticide use ($F= 2.29$, $p = 0.117$).

Table 7: Effect of pesticide application on watermelon flower visitors

TREATMENT	HONEY BEES	STINGLESS BEES	OTHER BEES	OTHER INSECTS
	MEAN ± S.E.	MEAN ± S.E.	MEAN ± S.E.	MEAN ± S.E.
Controlled Pesticide use	11.00 ± 1.20b	1.00 ± 0.27ab	1.75 ± 0.366b	3.13 ± 0.833b
Uncontrolled Pesticide use	6.88 ± 0.64c	0.25 ± 0.16b	0.63 ± 0.183b	1.75 ± 0.250b
No Pesticide Use	15.38 ± 1.92a	1.75 ± 0.37a	4.13 ± 0.972a	5.88 ± 0.743a

S.E. = standard error. Means that do not share a letter are significantly different ($p< 0.05$) LSD

Table 8: Effect of pesticide application on watermelon yield

	FIRST HARVEST	SECOND HARVEST	THIRD HARVEST
TREATMENT	MEAN WEIGHT (± SE)	MEAN WEIGHT (± SE)	MEAN WEIGHT (±SE)
Controlled Pesticide Use	4.87 ± 0.24	3.68 ± 0.22	2.75 ± 0.09
Uncontrolled Pesticide Use	4.55 ± 0.09	3.39 ± 0.10	2.81 ± 0.07
No Pesticide Use	5.36 ± 0.27	3.72 ± 0.36	2.33 ± 0.18

S.E.= standard error (p>0.05)

Pan Trap Colour Preference of Watermelon Flower Visitors

Insects collected during the study using pan traps include *A. mellifera*, stingless bees, *hypotrigona* spp, *Lipotriches orientalis*, wasps, house flies, curcurbit fly (*Dacus ciliatus*), spotted cucumber beetles, a butterfly and moths. Individual insects showed different preferences for pan trap colours just as they would for flower colour.

On the plot with controlled pesticide use, no stingless bee was collected but flies were the most abundant insect collected. Seventy eight (78) flies, fifty five (55) beetles, six (6) wasps, six (6) other bees (besides honey bees and stingless bees), four (4) honey bees, one (1) butterfly and one (1) moth were collected by pan traps over the period of the study (Table 9).

On the plot with uncontrolled pesticide use, flies were the most abundant insect collected by pan trap and no stingless bee was collected. Eighty three (83) flies, Sixteen (16) beetles, Seven (7) wasps, Five (5) other bees (besides honey bees and stingless bees), two (2) stingless bees, two (2) honeybees, and one (1) moth were collected from this plot (Table 10).

Pan trap collections from the plot with no pesticide use also recorded flies as the most abundant insects. Insects collected consist of two hundred and seventeen (217) flies, thirty nine (39) beetles, fourteen (14) wasps, six (6) other bees (besides honey bees and stingless bees), five (5) honey bees and two (2) stingless bees (Table 11).

Flies were the most abundant insect collected by pan traps from all three treatments with a total number of three hundred and seventy eight (378) followed by one hundred and ten (110) beetles, twenty seven (27) wasps, seventeen (17) bees other than honeybees, eleven (11) honey bees, four (4) stingless bees, two (2) moths and one (1) butterfly (Table 12).

The yellow pan traps recorded the largest number of honey bees collected from all three treatments with the number collected by the blue and white pan traps being at par.

The total number of honey bees collected was eleven (11) out of which two (2) representing 18.2% was collected in white pan traps, seven (7) (63.6%) in yellow pan traps and two (18.2%) in blue pan traps respectively (Table 12).

The total number of stingless bees collected was four (4) out of which none (0%) was collected in white pan traps, three (3) representing 75% in yellow pan traps and one (1) representing 25% in blue pan traps.

In all, seventeen (17) other bees were collected out of which four (23.5%) was collected in white pan traps, 11 (64.7%) in yellow pan traps and 2 (11.8%) in blue pan traps respectively (Table 12).

Flies were the most abundant group of insects collected by pan traps with a total number of 378 from which 171 (45.2%) were collected in white pan traps, 78 (20.6%) in yellow pan traps and 129 (34.1%) in blue pan traps (Table 12).

110 beetles were collected in total and 42 (38.2%) were collected in white pan traps, 21 (19.1%) in yellow pan traps and 47 (42.7%) in blue pan traps (Table 12).

The least abundant insect collected was the butterfly, 1 butterfly was collected in total and it was collected in a yellow pan trap (Table 12).

The total number of moths collected was 2 and (50%) were collected in white pan traps and the other (50%) in a yellow pan trap (Table 12).

27 wasps were collected in total and 7 (25.9%) were collected in a white pan trap, 7 (25.9%) in a yellow pan trap and 13 (48.2%) in a white pan trap (Table 12).

It can be suggested from the study that bees were highly attracted to the colour yellow as compared to other colours whiles flies preferred very much the colour white to yellow and blue. Beetles preferred the colour blue to white and yellow, i also see that butterflies were attracted to the colour yellow more than white and blue but moths showed no preference for either white or yellow and were not attracted to the colour blue.

Table 9: Relative abundance of insects collected from the plot with controlled pesticide use by pan trap colours

INSECT GROUP	CONTROLLED PESTICIDE USE			
	PAN TRAP COLOUR			
	White	Yellow	Blue	Total
Honey bees	1	3	0	4
Stingless bees	0	0	0	0
Other bees	0	5	1	6
Flies	35	18	25	78
Beetles	24	10	21	55
Butterfly	0	1	0	1
Moth	1	0	0	1
Wasps	3	2	1	6
Total	64	39	48	151

Table 10: Relative abundance of insects collected from the plot with uncontrolled pesticide use by pan trap colours

INSECT GROUP	UNCONTROLLED PESTICIDE USE			
	PAN TRAP COLOUR			
	White	Yellow	Blue	Total
Honey bees	0	0	1	1
Stingless bees	0	2	0	2
Other bees	2	2	1	5
Flies	51	14	18	83
Beetles	3	3	10	16
Butterfly	0	0	0	0
Moth	0	1	0	1
Wasps	2	2	3	7
Total	58	24	33	115

Table 11: Relative abundance of insects collected from the plot with no pesticide use by pan trap colours

INSECT GROUP	NO PESTICIDE USE			
	PAN TRAP COLOUR			
	White	Yellow	Blue	Total
Honey bees	1	4	0	5
Stingless bees	0	1	1	2
Other bees	2	4	0	6
Flies	85	46	86	217
Beetles	15	8	16	39
Butterfly	0	0	0	0
Moth	0	0	0	0
Wasps	2	3	9	14
Total	105	66	112	283

Table 12: Relative abundance and percentage abundance of insects collected from the three treatments by pan traps

INSECT GROUP	PAN TRAP COLOUR AND PERCENTAGE					
	White	% of total	Yellow	% of total	Blue	% of total
Honey bees	2	18.2	7	63.6	2	18.2
Stingless bees	0	0	3	75	1	25
Other bees	4	23.5	11	64.7	2	11.8
Flies	171	45.2	78	20.6	129	34.1
Beetles	42	38.2	21	19.1	47	42.7
Butterfly	0	0	1	100	0	0
Moth	1	50	1	50	0	0
Wasps	7	25.9	7	25.9	13	48.2
Total	227		129		194	

CHAPTER FIVE

DISCUSSION

Introduction

This chapter discusses the results of the study in relation to existing literature and expectations.

Relative Abundance of Watermelon Flower Visitors

Results from the study showed that the most abundant insect collected from all three plots using sweep net was the honey bee *A. mellifera;* making up 65% of the total insects collected within the plot with controlled pesticide use, 72% of the total insects collected within the plot with uncontrolled pesticide use, and 57% of the total insects collected within the plot with no pesticide use. This is an indication that *A. mellifera* is the main pollinator of watermelon flowers.

Other solitary and stingless bees which were also identified during the study provided supplementary pollination for the watermelon flowers.

Henne, Rodriguez and Adamczyk (2012) in a survey of bee species found pollinating watermelons in the lower Rio Grande valley of Texas, also found *Apis mellifera* as the most abundant bee, comprising 46% of the total number of bees collected.

It was also observed from their study that even though there were approximately 3-4 managed hives of *Bombus impatiens* each around their study sites the abundance of this bee species observed and collected was still low compared to that of *A. mellifera*.

No managed hives of *A. mellifera* were placed in any of the study plots; hence the high number of this species collected and observed is likely derived from feral colonies living nearby.

Diversity and Effect of Pesticide Application on Watermelon Flower Visitors

The highest diversity of flower visitors was recorded from the plot with no pesticide use (1.50). This means some flower visitors might have been killed on the other plots with controlled and uncontrolled pesticide application. It shows how chemical application could affect the diversity of pollinators and in effect the efficiency of fruit set and yield.

Colignon, Hastir, Gaspar and Francis (2001) in their study of the effects of insecticide use on insect density and diversity in vegetable open fields observed that insect biodiversity was significantly higher in unsprayed plots compared to plots with chemical application.

Species richness is a function of the diversity of organisms and this is reflected in this study as the plot with no pesticide application recorded the highest number of different insect species of flower visitors.

Ten different insect species were collected from the plot with no application of pesticide. The absence of insecticides could be the reason for the greater diversity of insect flower visitors as they were not at risk of being killed during pollen or nectar collection.

The reduction in the number of different species collected from the treatment plots as the frequency of pesticide application increased might be as a result of the negative effect these pesticides had on the flower visitors.

This result agrees with the findings of Brittain, Vighi, Settele and Potts (2010), which showed that the diversity & richness of wild bee species declined as the frequency of pesticide applications increased.

The results of this study shows that an increase in the frequency of the application of pesticides mainly for the control of insect pests leads to a significant reduction in the abundance of flower visitors as seen from the comparison of the mean number of insects collected from different study plots. This leads to a rejection of the hypothesis that the abundance of watermelon pollinators is not significantly influenced by the indiscriminate use of pesticides.

This is in agreement with the results obtained by Goré, Baudoin & Zoro, (2011). Their study was carried out to identify the effect of the number of insecticide applications on *Citrullus lanatus* yield. It was recorded that fewer flower visitors were collected on the plots that were more frequently sprayed with insecticide as compared to the others.

Muratet and Fontaine (2015) in their study of the impact of pesticides on butterflies and bumble bee abundance in private gardens in France showed that the use of insecticides was negatively associated with butterfly and bumble bee abundance and that the frequent use of insecticides in gardens resulted in a decrease in insect abundance locally.

Efficiency of Watermelon Pollinators

The efficiencies of observed pollinators during their single visit to the flowers of the watermelon plant during this study were compared.

The honey bee was the most efficient as their single visit to female flowers, resulted in fruit formation though they were misshapen (Plate 12) compared to the female flowers visited by other species of bees.

Successful fruit set from a single visit usually implies that the visitor was able to successfully remove and transport sufficient pollen from a previously visited male flower of the same species making it both effective and efficient at pollination.

According to Spears (1983), in *Ipomoea trichocarpa* seed set from a single *Bombus spp* visit was indistinguishable from unlimited visitation therefore the first visit that a flower receives deposits enough pollen to ensure a high level of seed set resulting in fruit formation.

The female flowers visited by *D. staudingeri* and *Lipotriches spp* did not form fruits but 92.8% (13 out of 14) of the female watermelon flowers visited by *A. mellifera* were able to set fruits. This does not rule them out as pollinators of the plant but might mean that they are unable to collect enough pollen for transfer during their visit to the male flowers.

This result is in contrast with the findings of Njoroge, Gemmill, Bussmann, Newton and Ngumi (2010) in their study of the diversity and efficiency of wild pollinators of watermelon in Kenya. They discovered that besides honeybees, wild *Lasioglossium* bee species are better pollinators of watermelon in the region though this bee species was not identified as a pollinator of the watermelon plant during this study.

Effect of Pesticide Application on Watermelon Yield

Even though Steffan-Dewenter, Klein, Gaebele, Alfert, and Tscharntke (2006) had found that the abundance and diversity of pollinators improves the efficiency of pollination as well as fruit and seed production, the results of this study does not support it.

The highest diversity and abundance of flower visitors were obtained from the plot with no pesticide use but this plot had the lowest number of watermelon fruits at harvest (Appendix E, F, G) and this might be due to the action of pest species in the absence of chemical control.

This notwithstanding, there was no significant difference in the mean weight of fruits harvested from the three plots for which reason we fail to reject the null hypothesis that there are no differences in the yield of watermelon plants due to the use of pesticides.

This is in contrast with the results obtained by Foster & Brust (1995) from investigations carried out to determine the effect of insecticides applied to control cucumber beetles (Coleoptera: Chrysomelidae) on watermelon yields. Their study showed a significant negative correlation between the yield and the frequency of pesticide application, suggesting that the yield decreases when the frequency of the insecticide application increases.

Pan Trap Colour Preference of Watermelon Flower Visitors

Flowering plants use colour, fragrances, rewards (pollen or nectar), and size or shape of flowers to attract pollinators (Niesenbaum, Patselas & Weiner, 1998) with colour being one of the most important attractants. Due to this, coloured pan traps are a potential method of surveying and monitoring pollinator diversity and abundance (Campbell & Hanula, 2007).

Ten (10) insect species belonging to five (5) separate families were collected with the use of coloured pan traps. Using pan traps, 63.6% of all honey bees, 75% of all stingless bees and 64.7% of other bees were collected in yellow pan traps showing that bees were most attracted to the yellow pan traps.

This result agrees with the findings of Gollan (2011) in an experiment carried out in Australia which showed that yellow pan traps collected significantly larger and greater diversity of bees as compared to white coloured pan traps.

Munyuli (2013) also found out that bees collected by pan traps were significantly more abundant in yellow than in blue or white coloured pan traps.

The outcome of the study is contrary to the findings of Dafni et al. (1990); Stephen & Rao (2005); Nuttman et al. (2011) which stated that bees preferred the colour blue to white and yellow.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

Conclusion

A reduction in the population of beneficial floral visitors visiting our crops has a ripple effect on the entire ecosystem. This can lead to a decrease in the reproduction of a large number of entomophilous plants thereby reducing the regenerative ability of these plants which over time might fade into extinction.

A reduction in seed or fruit set resulting from this dip in pollinator numbers are unlikely to cause starvation because staple food sources such as grains and root crops do not depend on insect pollination. However, the balanced diets that we require for healthy nutrition will be threatened as fruits, nuts, vegetables and other plant sources of essential food nutrients are highly dependent on pollinators in order to be produced.

This study shows that different pesticide application regimes for the control of pests has a negative effect on the population and diversity of insect flower visitors of the watermelon plant but statistically leads to no difference in the crop yield.

Various species of insects visit the flowers of the plant even though they all do not contribute to the output of the plant. Although *A. mellifera* was identified as the most efficient pollinator, other floral visitors such as *Lipotriches spp* and *Dactylurina staudingeri* are believed to contribute to the pollination of the plant as they were observed visiting the flowers of the watermelon plant.

Recommendations

It is recommended that:

1. In order to prevent a loss of income due to a large number of misshapened and rotting fruits, the application of pesticide should be maintained at an interval of one spraying in two weeks. This is to ensure the promotion of pollinator health as well as sufficient pest control.

2. A measure such as the maintenance of natural vegetation around farms to provide habitats for essential pollinators like the honey bee and other beneficial insects should be encouraged by farmers.

3. Since honey bees are the main pollinators of watermelon, integrating beekeeping with watermelon farming can be encouraged to boost watermelon yields.

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APPENDICES

Appendix A:
One-way ANOVA: CONTROLLED PESTICIDE USE, UNCONTROLLED PESTICIDE USE, NO PESTICIDE USE (HONEY BEES)

```
Source  DF     SS     MS     F      P
Factor   2  289.1  144.5  9.83  0.001
Error   21  308.8   14.7
Total   23  597.8

S = 3.834   R-Sq = 48.36%   R-Sq(adj) = 43.44%



Level                       N    Mean  StDev
CONTROLLED PESTICIDE USE    8  11.000  3.381
UNCONTROLLED PESTICIDE U    8   6.875  1.808
NO PESTICIDE USE            8  15.375  5.423

                           Individual 95% CIs For Mean Based on Pooled
StDev
Level                        +---------+---------+---------+---------
CONTROLLED PESTICIDE USE               (--------*------)
UNCONTROLLED PESTICIDE U      (------*------)
NO PESTICIDE USE                                  (------*------)
                             +---------+---------+---------+---------
                           4.0       8.0      12.0      16.0

Pooled StDev = 3.834


Grouping Information Using Fisher Method

                             N    Mean  Grouping
NO PESTICIDE USE             8  15.375  A
CONTROLLED PESTICIDE USE     8  11.000    B
UNCONTROLLED PESTICIDE USE   8   6.875      C

Means that do not share a letter are significantly different.


Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons

Simultaneous confidence level = 88.16%
```

Appendix B:
One-way ANOVA: CONTROLLED PESTICIDE USE, UNCONTROLLED PESTICIDE USE, NO PESTICIDE USE (STINGLESS BEES)

Source	DF	SS	MS	F	P
Factor	2	9.000	4.500	7.27	0.004
Error	21	13.000	0.619		
Total	23	22.000			

S = 0.7868   R-Sq = 40.91%   R-Sq(adj) = 35.28%

Level	N	Mean	StDev
CONTROLLED PESTICIDE USE	8	1.0000	0.7559
UNCONTROLLED PESTICIDE U	8	0.2500	0.4629
NO PESTICIDE USE	8	1.7500	1.0351

```
                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level                       -----+---------+---------+---------+----
CONTROLLED PESTICIDE USE               (-------*--------)
UNCONTROLLED PESTICIDE U    (--------*-------)
NO PESTICIDE USE_1                                (-------*-------)
                            -----+---------+---------+---------+----
                               0.00      0.70      1.40      2.10
```

Pooled StDev = 0.7868

Grouping Information Using Fisher Method

	N	Mean	Grouping
NO PESTICIDE USE	8	1.7500	A
CONTROLLED PESTICIDE USE	8	1.0000	A B
UNCONTROLLED PESTICIDE USE	8	0.2500	B

Means that do not share a letter are significantly different.

Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons

Simultaneous confidence level = 88.16%

Appendix C:
One-way ANOVA: CONTROLLED PESTICIDE USE, UNCONTROLLED PESTICIDE USE, NO PESTICIDE USE (OTHER BEES)

Source	DF	SS	MS	F	P
Factor	2	51.08	25.54	8.62	0.002
Error	21	62.25	2.96		
Total	23	113.33			

S = 1.722   R-Sq = 45.07%   R-Sq(adj) = 39.84%

Level	N	Mean	StDev
CONTROLLED PESTICIDE USE	8	1.750	1.035
UNCONTROLLED PESTICIDE U	8	0.625	0.518
NO PESTICIDE USE	8	4.125	2.748

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level                     ----+---------+---------+---------+-----
CONTROLLED PESTICIDE USE         (--------*--------)
UNCONTROLLED PESTICIDE U  (--------*--------)
NO PESTICIDE USE                              (--------*--------)
                          ----+---------+---------+---------+-----
                            0.0       1.6       3.2       4.8
```

Pooled StDev = 1.722

Grouping Information Using Fisher Method

	N	Mean	Grouping
NO PESTICIDE USE_2	8	4.125	A
CONTROLLED PESTICIDE USE	8	1.750	B
UNCONTROLLED PESTICIDE USE	8	0.625	B

Means that do not share a letter are significantly different.

Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons

Simultaneous confidence level = 88.16%

Appendix D:
One-way ANOVA: CONTROLLED PESTICIDE USE, UNCONTROLLED PESTICIDE USE, NO PESTICIDE USE (OTHER INSECTS)

Source	DF	SS	MS	F	P
Factor	2	70.58	35.29	10.12	0.001
Error	21	73.25	3.49		
Total	23	143.83			

S = 1.868   R-Sq = 49.07%   R-Sq(adj) = 44.22%

Level	N	Mean	StDev
CONTROLLED PESTICIDE USE	8	3.125	2.357
UNCONTROLLED PESTICIDE U	8	1.750	0.707
NO PESTICIDE USE	8	5.875	2.100

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level                     --------+---------+---------+---------+-
CONTROLLED PESTICIDE USE         (------*-----)
UNCONTROLLED PESTICIDE U  (------*------)
NO PESTICIDE USE                                     (-----*------)
                          --------+---------+---------+---------+-
                                2.0       4.0       6.0       8.0
```

Pooled StDev = 1.868

Grouping Information Using Fisher Method

	N	Mean	Grouping
NO PESTICIDE USE	8	5.875	A
CONTROLLED PESTICIDE USE	8	3.125	B
UNCONTROLLED PESTICIDE USE	8	1.750	B

Means that do not share a letter are significantly different.

Fisher 95% Individual Confidence Intervals
All Pairwise Comparisons

Simultaneous confidence level = 88.16%

Appendix E:
One-way ANOVA: Controlled pesticide use, Uncontrolled pesticide use, No pesticide use (First harvest)

```
Source  DF      SS     MS     F      P
Factor   2   4.980  2.490  3.04  0.053
Error   87  71.208  0.818
Total   89  76.189

S = 0.9047   R-Sq = 6.54%   R-Sq(adj) = 4.39%



Level                       N    Mean   StDev
Controlled pesticide use   27  4.8685  1.2523
Uncontrolled pesticide u   56  4.5536  0.7061
No pesticide use            7  5.3571  0.7091

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level                      ----+---------+---------+---------+-----
Controlled pesticide use       (------*------)
Uncontrolled pesticide u   (----*----)
No pesticide use                   (-------------*-------------)
                           ----+---------+---------+---------+-----
                             4.50      5.00      5.50      6.00

Pooled StDev = 0.9047
```

Appendix F: One-way ANOVA: Controlled pesticide use, Uncontrolled pesticide use, No pesticide use (Second harvest)

Source	DF	SS	MS	F	P
Factor	2	0.995	0.498	1.07	0.351
Error	44	20.431	0.464		
Total	46	21.426			

S = 0.6814   R-Sq = 4.64%   R-Sq(adj) = 0.31%

Level	N	Mean	StDev
Controlled pesticide use	16	3.6750	0.8727
Uncontrolled pesticide u	28	3.3857	0.5519
No pesticide use	3	3.7167	0.6252

```
                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level                      -------+---------+---------+---------+--
Controlled pesticide use             (--------*-------)
Uncontrolled pesticide u        (------*-----)
No pesticide use           (-------------------*-------------------)
                           -------+---------+---------+---------+--
                                3.20      3.60      4.00      4.40
```

Pooled StDev = 0.6814

Appendix G:One-way ANOVA: Controlled pesticide use, Uncontrolled pesticide use, No pesticide use (Third harvest)

```
Source  DF      SS      MS     F      P
Factor   2  0.4377  0.2188  2.29  0.117
Error   34  3.2484  0.0955
Total   36  3.6861

S = 0.3091   R-Sq = 11.87%   R-Sq(adj) = 6.69%



Level                        N    Mean   StDev
Controlled pesticide use    11  2.7545  0.2919
Uncontrolled pesticide u    24  2.8104  0.3186
No pesticide use             2  2.3250  0.2475

                            Individual 95% CIs For Mean Based on
                            Pooled StDev
Level                       -------+---------+---------+---------+--
Controlled pesticide use                             (-----*-----)
Uncontrolled pesticide u                                (----*---)
No pesticide use            (--------------*-------------)
                            -------+---------+---------+---------+--
                                 2.10      2.40      2.70      3.00

Pooled StDev = 0.3091
```

Appendix H:

Diversity and evenness of flower visitors sampled from watermelon flowers

	Controlled pesticide use				Uncontrolled pesticide use				No pesticide use			
Species	N	pi	ln(pi)	pi*ln(pi)	n	pi	ln(pi)	pi*ln(pi)	n	pi	ln(pi)	pi*ln(pi)
Apis mellifera	88	0.65	-0.43	-0.28	55	0.72	-0.33	-0.24	123	0.57	-0.56	-0.32
Dactylurina standingeri	8	0.06	-2.81	-0.17	2	0.03	-3.51	-0.11	14	0.06	-2.81	-0.17
Pachyanthidium bicolor	1	0.01	-4.61	-0.05	0	0.00	0.00	0.00	2	0.01	-4.61	-0.05
Lipotriches spp	14	0.10	-2.30	-0.25	5	0.07	-2.66	-0.19	31	0.14	-1.97	-0.28
Amegilla spp	0	0.00	0.00	0.00	0	0.00	0.00	0.00	2	0.01	-4.61	-0.05
Scoliid spp	6	0.04	-3.22	-0.15	1	0.01	-4.61	-0.05	4	0.02	-3.91	-0.08
Mutillidae	4	0.03	-3.51	-0.11	3	0.04	-3.22	-0.13	8	0.04	-3.22	-0.13
Philantus spp	5	0.04	-3.22	-0.13	2	0.03	-3.51	-0.11	10	0.05	-3.00	-0.15
Epilachna spp	0	0.00	0.00	0.00	0	0.00	0.00	0.00	2	0.009	-4.71	-0.04
Musca domestica	9	0.07	-2.66	-0.22	8	0.11	-2.21	-0.24	21	0.10	-2.30	-0.23
N	135				76				217			
Σ (pi*lnpi)				-1.36				-1.07				-1.50
H_{max} = (lnS)				2.08				1.95				2.3
Evenness=H/H_{max}				0.65				0.55				0.65