

UNIVERSITY OF CAPE COAST

THE INSECT TAXA ON CASHEW (*ANACARDIUM OCCIDENTALE* L.)
PLANTS DURING THE FLOWERING AND FRUITING PERIODS IN THE
NORTHERN REGION, GHANA

FLORENCE SUMALA-ANG KUUKYI

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NORTHERN REGION, GHANA

BY

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Thesis submitted to the Department of Conservation Biology and Entomology, School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast in partial fulfilment of the requirements for the award of Master of Philosophy Degree in Entomology.

JUNE 2016

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.

Candidate's Signature..... Date.....

Name: Florence Sumala-ang Kuukyi

Supervisors' Declaration

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

Principal Supervisor's Signature..... Date.....

Name: Prof. Mrs Mary Botchey

Co-Supervisor's Signature..... Date.....

Name: Dr. John Abraham

ABSTRACT

There have been debates whether insects that visit cashew during the flowering and fruiting periods are the same. The main problem arises as whether the insects that visit the plant during the flowering are the same that visit during the fruiting period. Field survey was conducted in ten farms in the Northern Region from December 2014 to April 2015 to identify and assess insects taxa on cashew in farms close to natural forest and farms away from natural forest, during cashew flowering and fruiting periods. Total insect species enumerated in farms close to the forest during the flowering period was 6161, with a mean number of 1232.2 (SD = 250.7) and diversity of 3.34. In farms greater than 5km away from the forest, the total number of insect species enumerated was 2745, with a mean of 549 (SD = 103.2) and diversity of 3.56. During the fruiting period, total insect species collected in farms close to the forest was 4665, with a mean number of 933 (SD = 143.5) and diversity of 3.13. In farms away from the forest, total insect species enumerated was 2056, mean 411.2 (SD = 52.1) and diversity 3.14. Insect diversity was greater during the flowering period in farms close to the forest than the fruiting period. Also, no significant difference was found between the diversity of insects on cashew plant in farms close and away from the forest during both the flowering and the fruiting periods. Most of the species that occurred during the flowering period were not the same as those that occurred during the fruiting period though some shared the same family. The result also shows that insect composition was not influenced by closeness to forest.

KEY WORDS

Cashew

Flowering period

Fruiting period

Insect behaviour

Insect density

Insect diversity

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DEDICATION

To my husband and daughter,

Dr. Edward Debrah Wiafe and Janice Enmengteh Kuukyi

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CHAPTER ONE

INTRODUCTION

Background of the Study

The development of plants has changed the global environment into an extremely useful resource for the herbivore community. In the natural ecosystems, plants and insects are constantly interacting with each other in a complex way. These two organisms are closely connected such that, insects provide several beneficial services including defence, dispersal and pollination to plants while plants provide shelter, oviposition sites and food, which are the three main factors necessary for insect reproduction (Mello & Silva-Filho, 2002).

On the other hand, depending on the amount of insect attack, herbivorous insects might be enormously detrimental to plants leading to death. Plant-insect interaction is a dynamic system, subjected to a repeated disparity and change (Mello & Silva-Filho, 2002). Numerous plants devote their resources in protecting their flowers against insects because some insects are usually unproductive pollinators (Bleil, Blüthgen, & Junker 2011).

Impending enemies of pollinators might chemically inhibit pollen germination, may reduce pollen viability or may be floral nectar thieves because most ants cause pollen damage.

In some cases, the more a plant invests in growth, the more it invests in resources such as nesting structures and extra floral nectar for insects. Insect selection might help mechanisms that add to the plant's allotment to growth at the outflow of its allocation to reproduction. Insect-pollinator conflicts or direct insect-plant conflicts have seldom been documented in mutualistic

insect–plant systems (Gómez, Bosch, Perfectti, Fernández & Abdelaziz, 2007). However, many plants have evolved chemical or physical devices against insects on their flowers which are pollinator's or fruit eaters(Gómez et al., 2007).

Plants development set up a number of defences against herbivores including herbivores insect. A principal defence is the production of toxins to poison the attackers. Other strategies comprise the growth of thorns and tough inedible tissue to put off herbivores, and the enrolment of parasitoids and predators that attack herbivores (Meunier, Dalecky, Berticat, Gaum& McKey, 1999). Chemical defences are all over and more or less undoubtedly vital for plant survival, but other defences are also important, varied, and not always obvious. Plants build up tough polymers such as cellulose, lignin, tannins and silicates, which reduce palatability. Furthermore, by minimizing the nutritive value of their tissues plants may power an herbivore (particularly an insect) to consume more (Bhattacharya, Viswakarma, Bhat, Kirti & Chopra. 2002).

Although this strategy may not appear beneficial, it really forces the herbivore to consume larger amounts of plant toxins. Thorns, barbs, stings and sticky resins exuded from resin ducts, lactifers, or trichomes physically interfere with herbivory and trap or kill herbivores. Lectins and proteinase inhibitors produced in response to grazing hinder digestion (Fürstenberg-Hägg, Zagrobelny, & Bak, 2013). The benefit of a defence would emerge to be apparent. Energy and photosynthetic assimilates of the plant leave a resource for survival and reproduction of the plant relatively than that of the secondary consumers.

However, the defence itself requires expenditures of these resources. Consequently, if a plant suffers comparatively with little herbivory, the rate of the defence may not be recovered in increased fitness. Furthermore, if one of numerous possible herbivores is undeterred by the plant's defences, the advantage of the defence might not be realized. Thus, several strategies must be working that are more complicated than simple attack with toxic chemicals (Bleil, Blüthgen, & Junker, 2011).

Cashew (*Anacardium occidentale* L.) was introduced into Ghana by the Government in the 1960s for a forestation in the savannah (Northern region), coastal savannah (Volta, Greater Accra and Cape Coast) and forest-savannah transition zone (Brong Ahafo region). Its cultivation was also deemed necessary for tree cover in degraded areas where land recovery programmes were under way to put off more erosion (Dwomoh, 2008). Large scale farming of this crop started in 1991 and by 1997, the section under cashew cultivation nation-wide was covering 12,500 ha. Between 2000 and 2004, incentives were provided to farmers in the form of loans and improved planting materials to establish new and rehabilitate old plantations.

Consequently, there was a marked increase in acreage from 18,000 ha to 51,831 ha, with a corresponding rise in nut yield from 3,600 MT to 25,915 MT. Cashew is potentially an enormous socio-economic crop to Ghana (Opoku-Ameyaw & Appiah, 2000). The product of commercial significance is the nut, it contains 47% fat, 21% protein and 22% carbohydrate, as well as some vitamins, especially thiamine (Soares et al., 2013).

The proteins in cashew nut are whole; having all the essential amino acids, as compared to a kilogram of the nut yields about 6000 calories to 3600

from cereals, 1800 from meat and 650 from fresh citrus fruit (America & Brazil, 2008). As bulk of the fatty acids present in the nuts is unsaturated, they are easy to digest, and can therefore, be consumed safely by young and old alike (Soares et al., 2013).

A liquid obtained from the cashew, known as cashew nut shell liquid (CNSL), is used broadly in brake linings of motor vehicles, paints, varnishes and laminated products (Opoku-Ameyaw & Appiah, 2000). It is also used as a plywood adhesive and a low-cost substitute for phenol in resole resins, as a constituent to boost the tensile properties, as blaze retardants of natural rubber and as a long-life, highly bioactive, antifouling shell for marine vessels (Noix & Afrique, 2002). CNSL and other extracts from the shell are larvicidal, molluscicidal, and antifungal and antibacterial (Mitchell & Mitchell, 2004).

However, several insects are found on the cashew plant, both beneficial and non-beneficial insects at the various stages of its development (Burgio, Ferrari, Boriani, Pozzati, & Van Lenteren, 2006). There has not been much information on insect species associated with cashew in Ghana regarding either the flowers or the fruits in respect to either there are beneficial species and none beneficial. Also, at what time is an insect species referred to as beneficial or none beneficial. There is therefore the need to identify insect species that visit cashew plant during the flowering and the fruiting periods in order to close this gap. In a previous study by Aidoo (2008) who worked on cashew insect pollinators but his protocol deviated a bit from this study and it will be so bias to build on his protocol. This is because this research is more about insect taxa on cashew plants during the flowering and fruiting periods.

Furthermore, it is necessary to investigate the density, diversity, distribution of and species composition of insects that visits the cashew plant during the flowering and fruiting periods.

Statement of the Problem

The issue of insect control to boost the productivity of cashew plant leaves much to be desired. The yield of cashew has been low whether there is lack of appropriate pollinators and possible role of ants in pollen damage. Also, flower visitors assessment on flora rewards for pollination and the role of flower visitors on fruit set in Ghana is scant. The main problem arises as whether the insects that visit the plant during the flowering period are the same that visit during the fruiting period. Moreover, the knowledge of the insect behaviour on cashew and the part they are found is not enough. There is no documentary evidence to show whether all the insects that visits the cashew plant has a positive or negative impact on the plant.

Justification

Information on the insect complex connected with any crop is necessary for the developing pest control strategies for the crop. Literature on insects that visit cashew during the flowering and fruiting periods in Ghana is lacking (Abid et al., 2013). Though Dwomoh et al. (2008) conducted a survey on insects that associate with cashew plants in Ghana, the insects were not categorised into periods.

There have been several debates whether insects that visit cashew during the flowering and fruiting seasons are the same (Bhattacharya, 2004 & Navarro, 2001). This study is not only meant to shed light on this debate, but to identify the economic importance of different insects that visits cashew

plant during the flowering and fruiting periods. Aidoo (2009) studied cashew pollinators through Ghana just as Dwomoh (2008) did, but there are differences among these studies and this present study. The two authors (Dwomoh, 2008 & Aidoo 2009) did different studies as well, for example Dwomoh studied the general insect composition on cashew through Ghana while Aidoo studied cashew pollinators through Ghana. However, this study is concern about insect taxa on cashew during the flowering and the fruiting periods in the Northern region specifically and not throughout Ghana.

There is an information gap pertaining insects that visits cashew during the flowering and fruiting periods. Very recently, the concept of pollination syndrome has been questioned by Garibaldi et al. (2013), whether the insects that visit flowers pollinate them in order to consume the fruits in future or they do so purposely for the mutualism existing between them (i.e. in search of their resources). A study on insects that visit cashew plant in Ghana was done by Dwomoh,& Aidoo (2008, 2009) who reported that insect order associated with cashew plant comprises of Hemiptera, Coleoptera, Hymenoptera, Dictyoptera, Orthoptera, Lepidoptera, Homoptera, Diptera and Thysanoptera. However, there was no distinction in these recorded insect orders during the flowering and fruiting periods.

Activities of insects generally affect the tree; depending on where the insect is located will either affect the whole plant or part of the plant. Meanwhile, these activities of insects like predating,sucking sap, sucking nectar, leaves mining, twigs and stem girdling, and juice have not clearly been defined on periodical bases (flowering and fruiting). There is therefore the need to study aspects of ecology of insect taxa that visit the cashew plant

during the flowering and the fruiting periods. It will be a great contribution to knowledge if the differences and similarities of insect species and activities among the insects are found during flowering and fruiting periods as well as the part of the plant the insect is located.

Goals and Objectives

The goal of this research is to determine the type of insect species that visit the cashew plant and their interactions during the flowering and fruiting periods in different locations.

The objectives of the study are as follows:

1. To identify the type of insect species that visit cashew plant during flowering and fruiting periods in farms close to natural forest and farms away from the forest.
2. To determine the density and diversity of insects that visit cashew during flowering and fruiting periods.
3. To determine the status of insects that visits the cashew plant.
4. To investigate the insects activities on cashew plant during the flowering and fruiting periods.

Hypotheses

The following hypotheses were tested to guide the research

1. Insects that visit cashew during the flowering period are not the same species during fruiting period.
2. Abundance and diversity of insects during flowering and fruiting periods are not the same.
3. Natural forest did not influence the insect composition during the flowering and the fruiting periods.

Organization of the Study

This thesis consists of six chapters which starts with introduction including the background, justification, objectives and hypotheses of the research in chapter one. Chapter two provides some related information and previous research done by other researchers in the same subject area. Chapter three covers the description and background of the study area and methods used in the data collection. Chapter four presents the results and chapter five discusses the results whilst chapter six deals with major conclusions of the research as well as some recommendations.

CHAPTER TWO

LITERATURE REVIEW

Animal Plant Inter-relationship

Biologists and naturalists have long been fascinated about plant animal interactions (PAI), the relationships between organisms in the kingdoms Animalia and Plantae (Holopainen, 2003). The seeming simplicity of the formulation of insects conceals an enormous number and diversity of ecological relationships and fundamental processes, ranging from the obscure to the ubiquitous. As a result, there is an extensive history of investigation into these often fascinating relationships among these living organisms (Mitter & Farrell, 1991).

The evolution of plants transformed the terrestrial environment into a highly valuable resource for the herbivore community. In the natural ecosystems, plants and insects are just some of the living organisms that are continuously interacting in a complex way (Mello & Silva-Filho, 2002).

Plant-animal interactions range from the general to those that are highly specific and involve elaborate evolutionary adaptations, an example of a general PAI is a tree that provides critical habitat for a nesting bird (Mello & Silva-Filho, 2002). Some animals are flexible in their choice of plants; in contrast, some insects are highly specialized, living and laying eggs on only one plant species (Archer & Pyke 1992).

In an attempt to categorize and describe the plethora of PAI, biologists further categorize PAI into three: (1) commensalism, in which one partner benefits while the other is unaffected; (2) Antagonistic, in which the

interaction is detrimental to at least one of the partner and (3) Mutualistic, in which both the plant and animal partners benefit (Interactions, 2012a).

Interactions are classified by whether an individual partner has more, less, or the same number of offspring as a result of the relationship, in terms of higher or lower fitness. Although the ultimate value is the reproductive success (fitness) of the interacting plants and animals, this can be quite difficult to measure (Holopainen, 2003).

Commensalism in plant-animal interactions is straightforward in theory and somewhat difficult to demonstrate. This is because there is always some question whether an interaction has a completely neutral effect on one of the species involved. For example, bird nesting in a tree which clearly benefits the bird but may or may not influence the tree (Vaissière, Freitas, & Gemmill-Herren, 2011). If the presence of the nest has no effect on the tree's growth and reproduction, then the relationship is truly commensal (Holopainen, 2003).

The bird may eat herbivorous insects that feed on the tree, thus having a positive effect, but the nest may block sunlight or weigh down branches away from sunlight exposure, thus having a negative effect (Althoff, Segraves & Pellmyr, 2005). The task of conclusively demonstrating commensalisms in this type of interaction involves experimentally removing nesting birds from some trees and leaving others unchanged and comparing the fitness of the two groups.

A study conducted by Cazetta, Galetti, Rezende & Schaefer (2012) reports that, the most common plant-animal interactions are antagonistic and involve the direct consumption of plants by animals (called

herbivores) for food. This PAI general serves as the fundamental process for transferring the energy from sunlight to the animal biomass in all ecosystems.

Herbivores can be highly specialized or unselective generalists and span a huge range of body sizes, from tiny leaf-eating and sap-sucking insects to large herbivores such as elephants, or the selective Chinese giant panda whose diet consists almost entirely of bamboo (Owen-Smith & Chafota, 2012). Herbivores have evolved a variety of feeding styles to consume plants. For example, insects in the order Hemiptera, such as aphids, leafhoppers and scale insects, have piercing and sucking mouth parts specialized to suck fluids directly from the vascular system of the plant (Teixido, Méndez, & Valladares, 2011). Other insects, such as those belonging to the orders Orthoptera (grasshoppers and crickets) and the larvae of Lepidoptera (moths and butterflies), have chewing mouthparts that allow them to bite and tear leaf material (Archer & Pyke, 1992).

Plants have evolved a broad spectrum of defences against herbivory, ranging from tolerance to resistance of defoliation. Herbivory-tolerant plants have high growth rates and are able to reallocate, stored carbohydrates to defoliated stems rapidly (Fox, 1981).

Additionally, plants tolerant of herbivory often have architectures that protect carbohydrate-rich storage organs, found below ground or out of the bite range of herbivores (Schardl, 2002). In a study conducted by (Pacini, Viegi & Franchi, 2008), it was shown that plants that are resistant to herbivory employ either structural or chemical defences that deter or even harm herbivores.

The most basic structural defence of plants is the production of cell walls and fibrous tissues composed of cellulose and lignin. A main component of wood, which are difficult for herbivores to chew and digest(Dejean et al., 2004).

More specialized structures include: thorns, barbed spines, hooks, and hairs that protect especially the photosynthetic tissue of plants. Plant chemical defences, also known as secondary compounds or metabolites and metabolic products not necessary for primary growth and reproduction(Endara & Coley, 2011).

The chemistry of plant secondary compounds is complex but well studied because of the deep historical connection with humans.Herrera et al.(2002) reports that not all antagonistic relationships involve animals eating plants but one of the more deviations from the typical pattern is that of the carnivorous plants.

Currently there are more than six hundred species of carnivorous plants described, including the well-known Venus fly trap and pitcher plant, which trap and slowly extract nutrients from decomposing arthropods(Abid et al., 2013).

Plants and animals also engage in a wide diversity of interactions that benefit both partners. One example is pollination, in which animals feed on nectar and pollen from flowers, transferring pollen to other plants, the foundation of the highly successful sexual reproduction of flowering plants (Gabriel & Tschamtkke, 2007). A form of mutualism involves animals that protect plants from other animal herbivores. This relationship is classic in that, it provides an example of extreme specificity between partners andrelationship

in which mutualism and antagonism are balanced in a strong co-evolutionary relationship (Kariyat et al., 2014).

The PAI involving ants and acacias is one of the best-known examples of mutualism. In tropical woodlands and savannahs throughout the world, trees belonging to the genus *Acacia* produce hollow, swollen structures on their twigs that provide shelter for stinging ants (Robinson, 2005).

Moreover, these trees also have glands at the base of their leaves that secrete carbohydrate-rich nectar on which the ants feed, thus, the ants benefit by receiving both a place to live and a source of energy rich food. This relationship is mutualistic because the trees benefit in return: the ants swarm to attack leaf-eating mammal and insect herbivores (Lewinsohn, Novotny & Basset, 2005).

Importance of Plants and Animals Interactions

The sustainability of ecosystems throughout the world depends on an elaborate network of plant-animal interactions that facilitate ecosystem function (energy flow and nutrient cycling) (Scherber et al. 2013). Habitat destruction and the loss of biodiversity brought about by rapid expansion of human populations and increased resource consumption, is threatening to unravel these core plant-animal interactions to the detriment of natural ecosystems and at great cost to human societies (Kremen et al., 2007).

Moreover, it has been found that, plant-animal interactions are also at the heart of natural processes that threaten human well-being and economic stability, such as the long history of crop damage by insect pests (Abid et al. 2013).

Consequently, understanding and preserving the co-evolutionary relationships between plants and animals is a critical component for a responsible (Kremen et al., 2007). Networks of interactions depict the essence of community assembly. Relationships among component species can take an enormous diversity of patterns and outcomes. However, we still have a limited understanding of the consequences of network patterns for ecosystem stability and evolution. These generalized patterns, especially the power-law (or scale-free) topologies lead to small-world patterns with important implications for the evolution, stability, and resilience to perturbations of these networks (Nicholls & Altieri, 2013). Plant–animal mutualistic interactions have a pervasive influence in the community dynamics and diversity, where they play a central role in the reproduction of the plants and the life histories of the animals (Kaiser Bunbury, Traveset & Hansen, 2010).

Animal-plant interactions associated with rainforests may bring economic benefits, for example, if a rainforest patch provided a source of insects that pollinated tree crops in adjacent farmland, or if a restoration planting reduced rodent predation in adjacent crops (Ebeling, Klein, Schumacher, Weisser & Tschardtke, 2008).

Some rainforest animals may also adversely affect production systems: for example, as a result of their depredations on fruits and seeds. Interactions such as these are a fascinating and exciting facet of rainforest biodiversity, and continue to intrigue scientists and the general public alike (Nair, 2007).

Describing and understanding these interactions and their consequences has been a major challenge for biologists (Tschardtke, Klein, Kruess, Steffan-Dewenter & Thies, 2005). For example, can the multiple

animal-plant interactions that determine the dispersal and regeneration of plants provide an explanation for the high diversity of plant species in tropical rainforests? The answer to this and other related questions remains the subject of intense scientific debate (Abid et al., 2013).

Understanding the ecological and evolutionary processes which underlie the generation and maintenance of high diversity and complex interactions of living organisms will also influence future approaches to the conservation and management of rainforests. Plants represent a significant amount of biomass on Earth, and are subject to a variety of interactions.

As mentioned previously, phytophagous insects target plants and represent a parasitic type of interaction. However, plants attract and utilize insects, such as bees and butterflies, for pollination and these interactions distribute plant genetic material in the form of pollen. Ants also play important mutualistic role with dispersion of plant seeds (*myrmecochory*) in the terrestrial ecosystem, particularly for flowering plants (Kaiser-Bunbury et al., 2010).

Animals have evolved to exploit plants as well, and in a balanced ecosystem, this interaction can be viewed as commensal to animals, if not possibly mutual to both plant and animal. Animals differ in their dietary adaptations. Carnivores are predominantly meat eaters and have little capacity to utilize plant material, but omnivores, which also cannot digest plant material, may feed on fruiting bodies of plants and consequently, distribute seeds in their stool (Howe, 1989). Herbivores in contrast and ruminants in particular, have developed the capacity to digest and utilize plant biomass for their own nutrient needs.

These latter adaptations involve microbial symbioses, but in relation to the plant, they can be commensal in nature. The negative implications of animals on plants are widely recognized (Hagen et al., 2012). Animal movements can trample plants and grazing by herbivores can result in plant injury and loss of the plants' reproductive organs.

However, omnivores and mammalian herbivores can benefit plants by dispersing seeds (Herrera et al. 2002). Some plants have evolved structures such as hooks to facilitate attachment to animals for dispersion by *exozoochory*, or transport outside the animal, whereas other plants have evolved to utilize *endozoochory*, or transport by animal ingestion.

Fruit-bearing plants often have fleshy fruit to attract a variety of birds and mammals that consume (*frugivory*), transport and defecate the seeds, a process known as *direct endozoochory*. Whether or not seeds are dispersed by an animal, hoof action by animals disrupts the soil surface and can serve to bury seeds for later germination (Herrera et al., 2002).

In agriculture, properly managing forage lands and foraging animals will minimize the environmental impact of animal agriculture and sustain a productive system (Herrera et al., 2002).

Insect Plant Relationship

Insect herbivores have traditionally been divided into generalists (polyphagous) that feed on several hosts from different plant families, or specialists (monophagous and oligophagous), which feed on one or a few plant types from the same family (Saha, Srivastava & Ramani, 2013). The generalists tolerate a wide array of defences present in most plants, while they cannot feed on certain plants that have evolved more unique defense

mechanisms. Specialists on the other hand, use a specific range of host plants releasing defense compounds that at the same time may function as feeding stimulants and provide ovipositioning cues (Capinera, 2005).

However, this view has recently been challenged (Mitter & Farrell, 1991), since it focuses only on the extremes, while in reality the distribution of insects feeding on one to several plants is a continuum. The paradigm is further based on the fact that feeding generalists and specialists would elicit differential plant responses, which is difficult to prove. It is recommended that such experiments contain at least four species, having the same feeding guild and being in two taxonomic pairs.

However, so far no such experiment has been reported (Hochkirch, Mertes & Rautenberg, 2012). The herbivory defences of plants may be expressed constitutively or they may be induced and developed only after attack. This is a question of benefit versus cost, since plant defense mechanisms are expensive.

Plants are constantly in the dilemma of combining growth and development with defense. This is a problem especially when fitness-limiting resources, like nitrogen, are invested (Rickson & Rickson, 1998) or if the compounds produced are toxic to the plant itself, and not only the herbivores. The attempt to cover the whole chain of defense against insect herbivores from the recognition of feeding insect, through the production of defense compounds or utilization of physical defences to the rejection of the plant as food by the insect. The early events that induce the defense responses are described, beginning with the interaction in the plant/insect interface, the

complex intracellular signalling cascades with a particular focus on their pathway.

The different defense responses are explained as majority of insect herbivores feed on ground tissues (Hossaert-McKey et al., 2001). The main focus is therefore on plant defense against insect herbivory.

Insect feeding can inflict other pathogens on the plant. The defence against pathogens share several features with the defence against insect attacks, but is beyond this and elsewhere (Althoff et al., 2005, García, 1998). More than one million herbivorous insect species have been described so far, with different feeding strategies leading to different quantity and quality of mechanical damage on plant tissue. Two thirds of all known herbivores are leaf-eating beetles (Coleoptera) or caterpillars (Lepidoptera) that cause damage with mouthparts evolved for chewing, snipping or tearing (Althoff et al., 2005).

Leaf miners feed on the soft tissue between the epidermal cell layers, while piercing-sucking herbivores, such as spiders and trips, have a tube-like structure used to suck the liquid content from lateral cells. Phloem-suckers such as aphids, whiteflies and other Hemiptera have special stylets that are inserted between the cells and into the phloem. The feeding guilds among root feeding insect herbivores are not as well reviewed as above ground herbivores, but the majority are root-chewers and a few root borers/piercers have also been reported (Ebeling et al., 2008). Plants can evaluate the quality and quantity of leaf tissue damage, a feature studied especially using caterpillars. Caterpillars follow a special pattern when feeding, removing similarly sized pieces of leaf tissue in a highly choreographed and predictable manner.

Simulation of repetitive caterpillar wounding by mechanical wounding of *Phaseolus lunatus* (lima bean) resulted in the release of volatiles qualitatively similar to those released by an actual caterpillar attack (Scherber et al., 2013).

Land plants and insects have coexisted for more than 400 million years (Bennett & O'Grady, 2012). During this time, they have developed refined interactions that affect organisms at all levels, from basic biochemical to population genetics levels (War & Interaction, 2005). Some of these relationships are mutually beneficial, such as pollination, but most interactions involve insect predation of plants, and plant defence against herbivorous insects (Althoff et al., 2005).

Fürstenberg-hägg, Zagrobelny, & Bak (2013), reports in their study that predator-host relationship is so common that almost every plant species is eaten by at least one insect species. This has given rise to the co-evolutionary theory, which proposed that insect feeding on plants has been a determining factor in increasing species diversity in both herbivores and hosts (Gabriel & Tschamtkke, 2007).

Insect herbivores have traditionally been divided into generalists (polyphagous) that feed on several hosts from different plant families or specialists (monophagous and oligophagous), which feed on one or a few plant types from the same family (Lewinsohn et al., 2005). The generalists tolerate a wide array of defences present in most plants, while they cannot feed on certain plants that have evolved more unique defence mechanisms (Abraham et al., 2015a).

Specialists, on the other hand, use a specific range of host plants volatile compounds as cues on locating their specific host for food and provide

ovipositioning sites(Fürstenberg-hägg et al., 2013). The herbivory defences of plants may be expressed constitutively or they may be induced and developed only after attack(Abraham et al., 2015). This is a question of benefit versus cost, since plant defence mechanisms are expensive(Abid et al., 2013). Plants are constantly in the dilemma of combining growth and development with defence. This is a problem especially when fitness-limiting resources, like nitrogen, are invested or if the compounds produced are toxic to the plant itself, and not only the herbivores(Silvius & Fragoso, 2002).Herrera et al., (2002) pointed out that insect feeding can inflict other pathogens on the plant and the defence against pathogens share several features with the defence against insect attacks.

As soon as an insect herbivore starts to feed on a plant, several defence signals are induced, leading to different defence responses. Plants have the ability to distinguish between herbivory and mechanical damage, such as hail and wind, as well as to recognize ovipositioning(Zakir, 2011). This feature is needed to avoid wasting expensive defence resources, since production and release of defence responses only benefits herbivore-challenged plants. It is also important to point out the ability of the plant to recognize the feeding of an insect herbivore (Fürstenberg-Hägg et al., 2013).

Two thirds of all known herbivores are leaf-eating beetles (Coleoptera) or caterpillars (Lepidoptera) that cause damage with mouthparts evolved for chewing, snipping or tearing(Wilson, 2008). Leaf miners feed on the soft tissue between the epidermal cell layers, while piercing-sucking herbivores, such as spiders and trips, have a tube-like structure used to suck the liquid content from lateral cells(Endara & Coley, 2011). Phloem-suckers such as

aphids, whiteflies and other Hemiptera have special stylets that are inserted between the cells and into the phloem (Fürstenberg-hägg, Zagrobelny, & Bak, 2013; Abid et al., 2013). The feeding guilds among root feeding insect herbivores are not as well reviewed as above ground herbivores, but the majority is root-chewers and a few root borers/piercers have also been reported (Kariyat et al., 2014; Abraham et al., 2015b).

Plants are also able to recognize compounds in insect oral secretions, which elicit more intense volatile responses than mechanical damage alone, insect oviposition fluids can give rise to defence responses in the plant as well, making the plant attract egg-eating predators or strengthen its defence in case of a potential future insect herbivore attack (Fürstenberg-Hägg et al., 2013). Oviposition by *Diprion pini* (sawfly) on *Pinus sylvestris* (Scots pine) leads to increased production of terpenoid volatiles and decreased ethylene release, (Herrera, 1989). Oviposition by *P. brassicae* on *A. thaliana* triggers the expression of defense-related genes as well. However, the chemicals responsible for the defense response have only been identified in *Brassica Pisorum* (War & Interaction, 2005). Its oviposition fluid contains bruchins that, when added to *Pisum sativum* (pea), elicit tumor-like growths that inhibit the larvae from entering the pod. Furthermore, oviposition of *P. brassicae* on leaves of *B. oleracea* (Brussels sprouts) changes the leaf surface chemicals leading to attraction of the egg parasitoid *Trichogramma brassicae* (Herrera, 1989).

One of the most appealing applications of molecular markers in insect studies is probably on those for insect–plant interaction. DNA markers provide utility in tagging and mapping genes in important crop plants that provide

resistance to damaging insect pests, and are also useful in characterizing avirulence genes in insects interacting with the host plants (Behura, 2006). The molecular genetic information generated by marker data is used to characterize phenotypic ability of insect to attack specific plant varieties (Behura, 2006).

Insect-pollination Relationship

Insect pollination is a vital ecosystem service; a large proportion of the human diet either directly or indirectly depends on animal-based pollination. It is also essential for the conservation of wild plants. Pollination by animals is an essential ecological process, which ensures plant reproduction in 60-90 % of angiosperms (Patrício-Roberto & Campos, 2014), and provides products and food for human mankind and animals (Scaven & Rafferty, 2013). Entomophilous pollination describes a mutualistic interaction between plants and insect pollinators. Pollinators forage on flowers for resources such as nectar and pollen, and shelter (Nicholls & Altieri, 2013), in the process they distribute pollen among flowers and thereby fertilize them. The quantity and quality of transferred pollen contributes to plant reproductive success. There are, however, factors outside (extrinsic) and inside (intrinsic) the system of interactions between plants, and between plants and pollinators, which influence pollen exchange and deposition in many plants (Junker, Chung, & Blüthgen, 2007).

As deposition of larger pollen quantities is more likely when more pollinators are visiting flowers (Abid et al., 2013), plants can facilitate each other by increasing pollinator diversity and visit frequency. For example, a single highly attractive plant may benefit co-occurring hetero-specifics by

enhancing their visitation frequency (Hammond & Miller, 1998). Higher species richness of plants at a local level can also increase pollinator visits to individual plants by supporting a broad spectrum of pollinators (Francisco Ornelas, 2002).

However, a larger diversity of pollinators can cause interference among flower visitors, displacing some pollinator species and possibly affecting the quality of the pollination services (Hagen et al., 2012). Diverse or dense plant communities can counterbalance competition among pollinators by providing visitation alternatives, which are not or less visited by the dominating pollinator which is competitor-free-space, (Eardley, Roth, Clarke, Buchmann, & Gemmill, 2006).

Animal-mediated pollination boosts the reproduction of wild plants on which other services or service-providing organisms depend. Some commercial plants, such as almonds or blueberries, do not produce any fruit without pollinators (Habitat & Leaflet, 2005). For many, a well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit (Vaissière, Freitas, & Gemmill-Herren, 2011). Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruit to pests, disease, bad weather, agro-chemicals and saving on water (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005).

Mutually beneficial relationships have developed over time between pollinator anatomy and plant flower structures as well as mechanisms that plants use to attract reproductive assistants in exchange for food rewards. These co-adaptations can be so specialized that the loss of one species

threatens the existence of another (Sekercioglu, 2010). Many insects including social and solitary bees, flies, wasps, beetles, butterflies and moths provide an ecosystem service by pollinating crops worldwide (Kjohl, Nielsen, & Stenseth, 2011).

Insect pollination has been shown to increase or stabilize yields of fruit, vegetable, oil, seed and nut crops (Tscharntke et al., 2005). Global cultivation of insect-pollinated crops has expanded since the 1960s, leading to about a 300% increase in demand for pollination services (Review, 2005). While honey bees are managed for both crop pollination services and honey production (Gómez et al., 2007). Honey bee pollination by itself is often unable to deliver sufficient pollen to crops where they are most needed (Cameron et al., 2011).

A diversity of pollinators, however, can contribute to sustainable crop pollination. Natural habitats support a range of wild pollinators that can increase crop yield through provision of a resilient and complementary pollination service (Puterbaugh & Prince, 2001). Given the multiple threats facing pollinators, any dependence on individual species for agricultural crop pollination is risky (Thies & Kalko, 2004). In a global economy, changes in pollination services are likely to have ramifications for geographically distant markets and human responses, such as developing new suppliers, may simply transfer the environmental impacts elsewhere in the globe (Millennium Ecosystem Assessment, 2003). Aside from the monetary impacts, and the possible consequences for the socio-economics of human societies, loss of pollination may also affect human nutrition (Ghazoul, 2008).

For example, vitamin A deficiency is a major human health concern worldwide. Insect-pollinated crops provide about 70% of this vitamin and pollination increases yields of these crops by about 43% (Brittain, Kremen & Klein, 2013).

Loss of pollinators and the service they provide will thus produce problems for human nutrition, although the magnitude of the problem will often depend on geographical location and degree of societal development (Ebeling, Klein, Schumacher, Weisser, & Tschardtke, 2008).

In the richer developed countries, the impact of pollinator losses on human health will be less profound but has the potential to erode the quality of human nutrition, or increase the reliance on synthetic micronutrients (e.g., vitamin supplements). Pollinator declines could also have very serious ecological consequences because insect pollination of wild plants (Teixeira-martins & Page, 2013), is a key supporting mechanism for many other organisms. The dependence of flowering plants on animal (mostly insect) pollination is estimated to range from 78% in temperate regions to 94% in the tropics (Vaissière, Freitas, & Gemmill-Herren, 2011).

Pollination processes are relatively resilient to loss of species because certain ecological characteristics (e.g. behavioural flexibility, species redundancy) confer robustness to networks of plant-pollinator interactions (FAO, 2014).

Consequently, reduced abundance and loss of pollinators would have serious ecological implications not only for individual plant species but also the wider community of organisms associated with plant and pollinator, and ultimately ecosystem function (Roubik, 2002).

Insect activities mostly relates to plant floral morphology, which largely determines pollinator composition among insect-pollinated plants (Thies & Kalko, 2004). Non-structural traits, however, may also in making floral rewards available to pollinators at different times of the daily cycle, plants might be able to 'select out' a subset of pollinators from the broad taxonomic array potentially available (Capinera, 2005). Foraging activity of insect floral visitors depends on combination of extrinsic and intrinsic factors.

The species-specific environmental tolerances set by these intrinsic factors, in relation to the daily course of extrinsic ones, determine definite 'daily activity windows' for different pollinators (Capinera, 2005). Inter-specific differences in timing of activity windows lead to a succession of pollinators ordinarily visiting the flowers of a given plant species in the course of a day (Herrera, 1990). As the bee forages, crosspollination occurs and genetic information is widely transferred (Kwapong, Aidoo, Combey, & Karikari, 2010).

Some pollen grains are deposited on the sticky surface of each stigma and each compatible pollen grain sends a tube through the style to the ovule to complete fertilization. Within three days of fertilization, petals drop and the pistil begins to elongate to form a pod as the seeds develop inside (Thies & Kalko, 2004). In order for pollen germination and fertilization to occur, pollen must travel from one brassica plant to the stigma of a different brassica plant in the process of cross-pollination.

Bees are members of the insect family Apidae, which are unique in that their bodies are covered with feather-like hairs (setae). The bright yellow flower petals act as both beacon and landing pad for the bees, attracting them

to the flower and guiding them to the nectarines (Ghazoul, 2001). The bee drives its head deep into the flower to reach the sweet nectar secreted by the nectarines and brushes against the anthers and stigma. Quantities of pollen are entrapped in its body hairs (Abid et al., 2013). Bees depend on the flower for their survival. Sugars in the nectar provide carbohydrates to power flight and life activities. *Symbiosis* is the close association of two or more dissimilar organisms (Hoffmann, Vierheilig, Riegler, & Schausberger, 2009).

Such associations can be beneficial to both organisms (*mutualistic*) or detrimental to one (*parasitic*). Symbiotic relationships among species occur frequently in nature. When the two or more species in symbiosis evolve in response to each other, they are said to *coevolve*. Under close examination each symbiotic relationship stands out as an example of miraculous complexity which has emerged. The *co evolution* of bees and brassicas, each dependent upon the other for survival, is such a relationship (Stone et al., 1999).

However, conflicts exist in such mutualisms, and some plant-insects are even parasites of myrmecophytes (Gaume, Zacharias, & Borges, 2005). Because the more the plant invests in growth, the more it invests in resources for the insects such as nesting structures and extra floral nectar (Mill, 1993), selection on insect might favour mechanisms that increase the plant's allocation to growth at the expense of its allocation to reproduction.

Human activity in the biosphere has altered ecosystems and often threatens their capacity to provide services that are essential to human survival (Witter et al., 2014). One of these services is pollination, which is fundamental to the maintenance of biodiversity, floristic composition (Hochkirch, Mertes,

& Rautenberg, 2012) and food production (Althoff, Seagraves, & Pellmyr, 2005). In this context, the decline in native (Hochkirch et al., 2012) and managed (Carlos Herrera, 1989) bee populations can pose a threat to pollination services globally and, consequently, to agriculture.

Native pollinators can increase the productivity of crops and thus constitute an important natural resource, even though their populations are sometimes insufficient to adequately pollinate crops in environments of intensive agriculture (Goulson, 2003).

According to Abid et al. (2013), areas of intensive agriculture that exhibit homogeneous landscape structures are detrimental to native bee populations and have lower potential for canola production, for example, than areas with diverse vegetation. Canola production is greatly influenced by pollen vectors such as wind, gravity and insects, especially *Apis mellifera* (Witter et al., 2014; Teixido, Méndez & Valladares, 2011; Miller, 1993). Recent studies have shown that native bees are also efficient pollinators of canola flowers (Pellmyr, 2003; Masiga et al., 2014) and that the elevated abundance of these bees increases the productivity of crops (Adjaloo, Odur, & Mochiah, 2012).

Invasions of alien plant species can have severe consequences for native ecosystems, as they often lead to massive changes in the structure and function of indigenous biotic communities (Fürstenberg-Hägg et al., 2013; Kaiser-Bunbury et al., 2010; Holland & DeAngelis, 2002). One major mechanism threatening native plant species is displacement by alien plants, which is usually explained by resource competition (Losey & Vaughan, 2006).

However, after establishment exotic plant species also need to interact with other members of the native ecosystem. For example, a stronger resistance to herbivory can represent a key advantage of alien plant species (Hoehn et al., 2008; Losey & Vaughan, 2006).

Furthermore, invasive plants often rely on mutualistic interactions with seed dispersers and pollinators and might disrupt such interactions in native communities (Willmer et al., 2009). Much of the empirical and theoretical research on mutualism has treated the interaction as a pair wise relationship. In most mutualistic interactions, however, there are multiple mutualistic and non-mutualistic species that simultaneously interact with the focal participants (Dalecky, Gaume, Schatz, Mckey, & Kjellberg, 2005). This complexity of interactions among mutualistic and non-mutualistic species coupled with changes in community composition over the geographic range of an interaction present a much more dynamic and realistic picture of mutualism. Relatively little research; however, has been directed at expanding the study of mutualism to understand the ecological and evolutionary roles of other species (Gabriel & Tschardtke, 2007).

Species engaged in obligate pollination mutualisms are also part of a larger community, and they interact with many other species in addition to their mutualistic partners (Junker, Heidinger & Blüthgen, 2010; Herrera et al., 2002). These interactions may not necessarily influence the outcome of the mutualism, but they may shape the cost-benefit ratio, impact selection on traits important to the mutualism, and influence co-evolutionary dynamics (Grundon, 1999).

In addition to interacting with their mutualist pollinator moths, yuccas are also visited by a suite of other non-pollinating lepidopterans, xylophagous and florivorous beetles, and phloem-feeding hemipterans (Gabriel & Tschamtko, 2007).

Most of these species feed on or within the inflorescence, flowers, or fruits and have the potential to impact both yucca and pollinator fitness. For example, Carlos, Herrera, (1990) demonstrated that feeding by a bogus yucca moth species benefited the plant by reducing the number of yucca seeds eaten by pollinator larvae. Understanding plant-pollinator community interactions are critical for the conservation of biodiversity. Enhanced plant species richness has been hypothesized to promote richness of pollinators because of plant species-specific pollinator preferences and a better pollen and nectar resource availability over space and time (Kasai, 1951). Enhanced pollinator richness should also increase functional redundancy, so that potential extinctions may be compensated by remaining species (Grundon, 1999). In addition to species richness, floral abundance is another important variable structuring pollinator communities (Patrício-Roberto & Campos, 2014). Greater floral abundance means higher resource availability for pollinators, which may also contribute to temporal variability.

Accordingly, floral resources should often be toxic, unpalatable or unreachable for exploiters that would otherwise consume nectar, pollen or petals without transferring pollen from one plant individual to another (Smith, López Quintero, Moreno Patiño, Roubik, & Weislo, 2012). Different mechanisms involving floral scents that have the potential to exclude certain taxa from florivory have been proposed (Garratt et al., 2014) to demonstrate

that certain floral secondary metabolites are produced at different locations in *Nicotiana attenuata* (Solanaceae) and that these interact with different types of flower visitors are defensive nicotine at a basal part and the attractive benzyl acetone at the outer corolla.

The emission of floral scents that would attract both pollinators and antagonists may be reduced at times when the latter are most active (Nieh et al., 2004). The same floral scent compounds may serve both functions together: attract pollinators and repel antagonists. For instance, linalool attracts bees (Capinera, 2005) and butterflies, but also efficiently repels ants from stealing nectar (Gitay, Brown, Easterling & Jallow, 2001), suggesting a dual function of this floral scent compound (Vélez, 2006).

The literature examining the biodiversity–ecosystem functioning relationship suggests that diverse assemblages might function better due to niche complementarities (Herrera et al., 2002), whereby a combination of many different species can extract more resources in space and time than can a species-poor community (Raine, Willmer & Stone, 2002). The importance of this mechanism in natural pollinator communities is unknown, but evidence of a stronger diversity–pollination relationship when flowers are heterogeneously distributed (Bhattacharya et al., 2002) suggests that an analogous mechanism may operate. Pollinator species within a community may have behaviourally partitioned niches, but little is known about the mechanisms of complementarity between the bee species.

Impact of Insects on Flowers and Fruit Set

Pollinator specialization in communities is often discussed in terms of classic examples of evolutionary adaptations through plant–pollinator co-

evolution (Hochkirch, Mertes, & Rautenberg, 2012). Nevertheless, the observed level of pollinator specialization also has an ecological component in that, it is influenced by changes in the diversity and composition of the local plant community (Hoehn, Tschardtke, Tylianakis, & Steffan-Dewenter, 2008).

Recent studies indicate that the evolution of pollinator specialization can be influenced by coexisting plant species (Arun & Vijayan, 2004), to some extent driven by the level of inefficiency in pollen transfer when pollinators are visiting numerous plant species (Kaiser-Bunbury, Traveset, & Hansen, 2010). These models assume that pollinator sharing between plant species occurs though little is known regarding the determinants of pollinator sharing (Sargent & Ackerly, 2008).

The extent to which plants will lose pollen to other plant species (or individuals) are present but also by the choices pollinators make, which may be affected by the overall similarity of co-flowering species. Overall similarity, in turn, is determined to some extent by shared ancestry (Holland & DeAngelis, 2002). For instance, the prevalence of certain floral adaptations that act as barrier traits that restrict certain pollinators will affect the mean level of generalization in the community as well as the mean level of pollinator sharing. Pollinator guilds that can only access unrestrictive floral resources (open flowers) exploit a subset of the resources exploited compared with more “versatile” pollinators e.g. pollinators with long tongues that allow access to nectar tubes but may also visit open flowers (Wratten, Gillespie, Decourtye, Mader, & Desneux, 2012). If unrestrictive plant species within a community tend to be more closely related than expected by chance, it would be predict that non-versatile pollinators, or those that are more strongly

constrained by traits, plant species will not only be influenced by how many would have a high propensity for visiting closely related plants (clade specialization), (Capinera, 2005).

This prediction can be addressed by employing phylogenetic community structure metrics (Hoehn et al., 2008). Pollination communities are founded on the basis of both mutualism between plants and their pollinators and the competitively interacting systems of plants for pollinators and pollinators for floral resources (Teixido, Méndez, & Valladares, 2011).

The ideal design of studying the pattern of the community organization is study of both flowering phenology and the community structure of flower-visiting animals on individual flower species: Sampling should be made periodically with a quantitative method (Bartomeus et al., 2014) in a primary vegetation where co-evolutionary relationship has been formed (Teixido et al., 2011). All flower visitors and their floral hosts should be distinguished and identified. Sampling is preferably continued at least for several years because the community structure of flower visiting animals sometimes greatly varies among years (Tschardtke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005).

The study of insects is necessary to know their life history, habit and habitat, as well as their role in the ecosystem. Bees are insects of highly economic importance, which feed on pollen and nectar that are natural plant in origin. Study on the relationship between flowering plants and the flower-visiting insects are of great importance to conserve terrestrial ecosystem by conserving plant pollinator mutualism(Herrera, 1989).

Definitely they have very important role in the ecosystem as natural pollinators of various plant species. Recently, their use in the field of crop pollination is a matter of growing demand and high prospect.

The flowers of fruit-bearing hedgerow plants provide a succession of forage for insects for much of the year. The fruits of plant species found in British hedges provide a winter food resource for small mammals (Potts et al., 2010) and form a large part of the winter diet of resident and migratory frugivorous birds on farmland (Kremen et al., 2007). Loss of hedgerows in UK farmland will have reduced the availability of hedgerow fruit. Many farmland birds have declined in recent decades (Kaiser-Bunbury et al., 2010), but it is unclear whether changes in availability of hedgerow fruit have contributed to this. The flowers of blackthorn (*Prunus spinosa*), hawthorn (*Crataegus monogyna*), dog rose (*Rosa canin agg.*), bramble (*Rubus fruticosus agg.*) and ivy (*Hedera helix*) are visited for pollen or nectar (or both) by several insect species, mainly Aculeate Hymenoptera (bees and wasps), Diptera (true flies) and Lepidoptera (moths and butterflies) (Brasileiro & Daninhas, 2010).

It is likely that these visits result in pollination, seed set and fruit-set, but the importance of insects for hedgerow fruit-set depends on the reproductive system of the plant. Pollen limitation is observed as a common phenomenon in plants (Goulson, 2003) and supplemental pollination experiments have demonstrated its occurrence for several plant species (Garibaldi et al., 2013). Factors that could contribute to sub-optimal fruit- or seed-set are the delivery of incompatible pollen (Tschardt et al., 2005) or the delivery of insufficient numbers of pollen grains due to low pollination

services (Breeze, Roberts, & Potts, 2012). Resource limitation can also reduce seed- and fruit-set and can operate in conjunction with pollen delivery to influence seed-set or fruit size (Tscharntke et al., 2005). If fruit-set is reduced in the absence of insects and pollen limitation is occurring it might be predicted that reducing the time of exposure of flowers to insects would have an effect on fruit-set. For example, Potts et al., (2010) found that even partial exclusion of pollinators resulted in a decrease in fruit yield in both self-incompatible and self-fertile cultivars of orchard trees.

Arboreal ants can benefit their host plant through the consumption of herbivorous insects. Plants have developed an array of strategies, such as providing ants with food or shelter, to attract them (Navarro, 2001), leading to tight mutualistic relationships between both taxonomic groups (Abid et al., 2013). Ants, however, are likely to attack all insects visiting the plant, and their presence risks deterring pollinators from visiting flowers (Gaume, Zacharias, Grosbois & Borges, 2005), potentially decreasing the plant's reproductive success.

To counteract this negative effect, some plant species produce ant-repellent substances during the flower's fertile period (Herrera et al., 2002), ensuring pollination without losing the protection of ants. Ants are not alone in interfering between plants and their pollinators. Other predators, notably crab spiders, ambush visiting insects at flowers (Bhattacharya et al., 2002), affecting the foraging choices of pollinators (Willmer et al., 2009) and sometimes reducing plant reproductive success. It has been suggested, however, that plants may benefit from the presence of ants on flowers or other ambush predators.

This would be the case if their negative effect (reduction in pollinator visits) is compensated by the protection they offer by removing florivorous insects and seed predators (Crawley, 1989). Pollination of crop flowers by wild insects is one such vulnerable ecosystem service, as the abundance and diversity of these insects are declining in many agricultural landscapes. Globally, yields of insect-pollinated crops are often managed for greater pollination through the addition of honey bees (*Apis mellifera* L.).

Therefore, the potential impact of wild pollinator decline on crop yields is largely unknown. Nor is it known whether increasing application of honey bees compensates for losses of wild pollinators, or even promotes these losses. Fruit set, the proportion of a plant's flowers that develop into mature fruits or seeds, is a key component of crop yield (Breeze et al., 2012).

Wild insects may increase fruit set by contributing to pollinator abundance, species number (richness), equity in relative species abundance (evenness), or some combination of these factors (Garibaldi et al., 2013). Increased pollinator abundance, and therefore the rate of visitation to crop flowers, should augment fruit set at a decelerating rate until additional individuals do not further increase fruit set e.g., pollen saturation or even decrease fruit set e.g., pollen excess (Breeze et al., 2012). Richness of pollinator species should increase the mean, and reduce the variance, of fruit set because of complementary pollination among species, facilitation, or "sampling effects", among other mechanisms (Navarro, 2001).

Pollinator evenness may enhance fruit set via complementarities, or diminish it if a dominant species e.g. honey bee is the most effective pollinator.

To date, the few studies on the importance of pollinator richness for crop pollination have revealed mixed results, the effects of evenness on pollination services remain largely unknown, and the impact of wild insect loss on fruit set has not been evaluated globally for animal-pollinated crops (Garibaldi et al., 2013). For most crops, both wild insect and honey bee visitation enhance pollen deposition on stigmas of flowers; consequently, for most crops, wild insect and honey bee visitation both improve fruit set, visitation by wild insects promotes fruit set only when honey bees visit infrequently (Tschardt et al., 2005).

Insect Fruit Relationship

Insect herbivores may eat virtually all types of plant tissue and herbivore damage may occur at any stage of a plant's life cycle (Schutze et al., 2015). However, because herbivores consume both vegetative and reproductive tissue, the impact of herbivory on plant fitness may depend largely on the type of tissue being consumed (Levey, Tewksbury, Izhaki, Tsahar, & Haak, 2007). A number of plant characteristics are hypothesized to have evolved as responses to selective pressure exerted by herbivores, including structural, chemical, physiological and life-history traits (Schutze et al., 2015).

Mutualistic associations with ants constitute one such defence strategy, and hundreds of plant species produce domatia (structures that house ant colonies) and/or food rewards (food bodies, extrafloral nectar) to attract ants which in turn provide the plant with some protection against herbivores (Levey & Soy, 1989). Extra floral nectaries (EFNs) are nectar-secreting organs not directly involved in pollination which are found on virtually all above-

ground plant parts (Hoehn et al., 2008). Plants bearing EFNs are widely distributed around the world, and available evidence supports the general contention that they are more common in tropical than in temperate environments ((Rodríguez, Alquézar, & Peña, 2013). Although EFNs attract a variety of nectar-feeding insects (Rodríguez et al., 2013), ants are by far the most frequent visitors to EFN-bearing plants both in temperate and tropical habitats (Herrera, Herrera, & Espadaler, 1984).

In the past two decades, a number of experimental field studies have demonstrated that ant visitation to EFNs may increase plant fitness by deterring leaf herbivores (Willmer et al., 2009), bud or flower herbivores (Dadzie et al., 2014) and seed predators (Ioriatti & Altindisli, 2013). Some studies, however, have found no apparent benefit to the plant from ant visitation (Schutze et al., 2015). As stressed by Holland & DeAngelis, (2002), ant-plant mutualisms mediated by EFNs are facultative and non-specialized, as indicated by the wide variety of associated ant visitors (Tschardt et al., 2005).

In fact, ant-derived benefits to EFN-bearing plants can be conditioned by factors such as time (Armesto, Rozzi, Miranda, & Sabag, 1987), habitat type (Thies & Kalko, 2004), aggressiveness of ant visitors (Yu & Pierce, 1998), as well as the capacity of herbivores to overcome ant predation (Vogler, Rott, Gessler, & Dorn, 2010). Although Vogler et al., (2010) showed that herbivore deterrence by visiting ants can increase fruit production by plants of *Opuntia acanthocarpa* in greenhouse conditions, the authors were not able to show such an effect in the species' natural habitat. The flowers of fruit-bearing hedgerow plants provide a succession of forage for insects for

much of the year. The fruits of plant species found in British hedges provide a winter food resource for small mammals (Rickson & Rickson, 1998) and form a large part of the winter diet of resident and migratory frugivorous birds on farmland (Wilson, 2008). Loss of hedgerows in UK farmland (Ebeling et al., 2008) will have reduced the availability of hedgerow fruit.

Many farmland birds have declined in recent decades (Silva & Barr, 2006), but it is unclear whether changes in availability of hedgerow fruit have contributed to this. There is growing evidence that ecosystem services, such as biological pest control and crop pollination, benefit food production (York & At, 1992). Indeed, 75% of the crop species used for food depends on insect pollination to some degree (Altieri, 1999).

More than a decade of active pollination research has led to a greatly improved general understanding on animal pollination benefits to crop yields worldwide (Bartomeus et al., 2014). However, major knowledge gaps remain. While some crops depend entirely on insect pollinator visits to set fruit, many others are only partly dependent on animal pollination and can produce more than 90% of the maximum seed or fruit yield without pollinators (Krenn, Plant, & Szucsich, 2005). The role of pollinators for crop production has mainly been examined in observational studies, relying primarily on natural variation in visitation rates among observed sites.

Fruit number can be a good proxy for yield (Kaiser-Bunbury, Traveset, & Hansen, 2010), which is the amount of produce harvested per unit area. However, the correlation between the number of fruit produced and yield may be low in some crops. For example, inter-specific plant competition can lead to high variability in plant size and thereby fruit production among plants.

This is especially critical for crops with indeterminate flowering and a high compensation capacity such as soybean (*Glycine max*) and oilseed rape (*Brassica napus*). For these, fruit set measured on a limited number of isolated plants is unlikely to be representative of the real production in a crop stand (Harren & Cristescu, 2013).

Moreover, plants can allocate resources for producing fruits of variable size based on the number of fruits per plant and the level of pollination received (Tarnita, Palmer, & Pringle, 2014) in kiwifruit *Actinidia deliciosa*, such that similar levels of fruit set can differ in total crop yield because of difference in fruit size (Harren & Cristescu, 2013). Again, the use of proper control plants from which pollinators are excluded is a way to better estimate the actual contribution of pollinators to yield in such crops.

Most insect are attracted to fermenting fruit (Levey, Tewksbury, Izhaki, Tsahar, & Haak, 2007). Micro-organisms like *Saccharomyces* yeasts growing on fruit occupy a commonly overlooked trophic level between fruit and insects. Insects from several orders, including beetles, flies, ants and bees interact with yeasts (Wilson, 2008). Many insects feeding on flowers or fruit encounter yeasts, and yeasts that use insects as hosts and vectors are widespread.

Furthermore, Rodríguez, Alquézar, & Peña, (2013) found that at certain seasons in the year especially late summer and autumn, the availability of ripe fruit allows wild yeasts to flourish. Niches with freely available fruit sugars are predominantly exploited by *Saccharomyces cerevisiae* and its close relatives that are able to out-compete other micro-organisms by the accumulation of ethanol (Levey et al., 2007).

For *Drosophila* flies, the presence of yeast in larval diet substrates is fundamental for the occupation of niches. Separation of species and interactions between yeast and fruit flies have led to mutual co-adaptations (Becher et al., 2012). Nutritional gains or detoxification of harmful chemicals sustain larval development while feeding and vectoring by flies mediate dispersal and out breeding of yeast strains (Ayscough, 2005).

A typical example of plant insect interaction was illustrated by Vogler, Rott, Gessler, & Dorn, (2010) as follows: several species of mango plant hoppers live on mango trees all year round. Adults lay oval-shaped egg rafts on the surface of leaves or fruits. Adults and nymphs prefer to stay and feed on the fruit peduncles at the bottom level of the tree canopy, and their secretion drops on the base of fruits, which promotes the growth of sooty mould (Peng & Christian, 2005). This indirect damage has a great effect on fruit quality.

In addition, Willmer et al., (2009) concluded that although green ants are very effective in controlling a range of mango insect pests, they have been regarded as a pest by many mango growers. This is because of the mutual relationship between the ant's scales and mealybugs; black spots on fruits caused by the ant formic acid; and disturbance to people while picking fruits (Robinson, 2005).

Seed consumption by herbivorous invertebrates, mainly insects, dates back to the Devonian (c. 416 million yr ago). However, those insects were probably granivorous and contributed little to the evolution of fleshy fruits (Rodríguez, Alquézar, & Peña, 2013). Frugivorous insects comprise mainly taxa from the orders Lepidoptera, Hemiptera, Coleoptera, Hymenoptera and Diptera (Armesto, Rozzi, Miranda, & Sabag, 1987).

Fruit location is a key issue for feeding, mating and reproduction of specialist insects, and involves the perception of a sequence of olfactory and visual cues (Burkhardt, Delph, & Bernasconi, 2009). Generally, specialized insects are able to distinguish the VOCs (volatile organic compounds) emitted by vegetative tissues and unripe and ripe fruits; they are mainly attracted by particular VOC blends of ripe fleshy fruits and, in some cases, they are repelled by green tissues (Burkhardt et al., 2009). For example, the codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) is attracted by mature apple fruits, but repelled by green fruits, probably through the emission of benzaldehyde and butyl acetate (Morton, 1973).

The preference for mature fruits has also been shown for females of the oriental fruit moth (*Cydia molesta*; Lepidoptera: Tortricidae) in apple and peach fruits, whereas VOCs released by vegetative tissue are behaviorally ineffective (Huth & Pellmyr, 1999). For *Ceratitis capitata* (Diptera: Tephritidae) females, the odor of ripe or almost ripe coffee drupes is more attractive than that of unripe drupes, leaves or stems (York & At, 1992).

Host fruit recognition usually depends on specific blends of VOCs and not just on the detection of a single compound; however, some blend components are biologically more important than others for the interaction (Holland & DeAngelis, 2002).

Moreover, the recognition of a host plant by insects could occur using either specific ratios of ubiquitous compounds or species-specific compounds (Peigné et al., 2009). For example, polyphagous insects, such as *Anastrepha obliqua* and *C. capitata* fruit flies (Diptera: Tephritidae), are attracted by

different blends of monoterpene compounds emitted by mango and citrus fruits (Birds, 2009).

In contrast, monophagous insects, such as the olive fly *Bactrocera oleae* (Diptera: Tephritidae), are attracted by a specific VOC blend present in ripening fruits and in leaves. Therefore, these specific VOC cues may have evolutionary significance for monophagous insects. In addition, insects are sensitive to volatiles for social communication, and some acquire host plant compounds to use as sex pheromones or sex pheromone precursors (Zhao et al., 2010).

Insects such as Tephritidae and Drosophilae Diptera release sex pheromones in response to host fruit chemical emissions that additionally enhance the response of insects to sex pheromones. For example, the combination of male pheromone and host fruit odor is more attractive to female papaya fruit flies, *Toxotrypana curvicauda* (Diptera: Tephritidae), than is either male pheromone or host fruit aroma alone (Varel, 2011). Oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) males are attracted to and feed on methyl eugenol, a VOC emitted by *Terminalia catappa* ripe fruits (Zhao, Xu, Zhang, & Zhang, 2012). Males that have eaten methyl eugenol are more successful in courting and mating with females than males that have not (Huth & Pellmyr, 1999).

Fleshy fruits provide food for several kinds of frugivorous animals, which are beneficial to plants by dispersing their seeds (Peigné et al., 2009). However, fruits also attract pests, which, contrary to dispersers, harm plants by damaging fruits (Birds, 2009).

Pre-dispersal seed predators destroy seeds developing within fruits, directly decreasing plant offspring (Zhao et al., 2010), and pest insects, by consuming fruit pulp, make fruit less attractive to vertebrate frugivores (Zhao et al., 2012). Fleshy-fruited plants, vertebrate dispersers and fruit pests are described as a complex ecological triad in which each component interacts simultaneously with the other two (Abid et al., 2013).

As a consequence of these pair-wise interactions, the balance of disperser and pest effects on plant reproduction will determine whether or not the maintenance of fleshy fruit is a benefit for the plant (Huth & Pellmyr, 1999). In an evolutionary sense, the fruit is the meeting point of selective pressures of both pest and disperser. Due to the dependence in the interaction, selective pressures of one type of frugivore (pest or disperser) upon fruit-dispersal traits can dilute evolutionary effects of the other type of fruits (Armesto et al., 1987).

Fruits constitute an unusual kind of "prey" insects. These structures are usually the units of dissemination of a plant's offspring and, consequently, they benefit from being carried away from the parent by a dispersal agent (Nair, 2007). A fleshy fruit can be described as a nutritious "package", containing the seeds inside and "designed" to be eaten by insects and others (Holland & DeAngelis, 2002).

The insects may act as dispersers when they ingest the entire fruit, thus gaining a meal, and transport the seeds undamaged to a different place where germination may occur. Mutualistic interactions between plants and fruit eaters, most commonly invertebrates, have probably evolved from a relationship that was originally predatory in nature (York & At, 1992). This

sequence is suggested by the various cases where either the seeds are harmed by the piercing of the fruits with their piercing mouth parts, or insects suffer from the predator-deterrent chemicals present in the fruit flesh. In this review we will concentrate on potentially mutualistic interactions between fruit eaters and plants, keeping in mind that many situations are hard to classify unequivocally as purely mutualistic (Morton, 1973). These features of tropical areas, among others, have attracted researchers interested in exploring the relationship between fruit eaters and seed dispersal.

However, by no means should this imply that biotic interactions are less frequent in the dispersal of temperate forest plants, or that fruit eaters are unimportant within temperate invertebrate assemblages. In recent years, an increasing number of studies have begun to unravel the patterns of interaction between plants and insect dispersers, particularly ants, in temperate and Mediterranean regions of North America and Europe (Armesto et al., 1987).

Impact of Insects on Fruit Production

Insect pollinators play a fundamental role in the production of many fruits, vegetables and field crops and numerous studies have valued insect pollination as an ecosystem service for agricultural food production at both global and national scales (Garratt et al., 2014). There is, however, increasing evidence of global and localised declines in the abundance and diversity of both managed and wild insect pollinators threatening the stability of this ecosystem service (Potts, 2010).

Understanding the economic benefits of an important agricultural ecosystem service such as crop pollination by insects is fundamental to sustainable food production. Valuation of the services provided by pollinators

will allow potential consequences of continued insect pollinator decline for food production and food security to be understood. It can also illustrate how appropriate management of insect pollination services can reduce production risks and increase rewards by addressing pollination deficits within cultivated areas (Nicholls & Altieri, 2013). Insects, such as bees and hoverflies, are the predominant pollination vector for apples and thus their activity in orchards is essential for apple production globally.

Experimentally increasing insect pollinator numbers in apple orchards has shown improved fruit set and yield but the influence of insect pollination on the quality of apple production in terms of size, shape, marketability and storability is poorly understood (Hoehn, Tschardtke, Tylianakis, & Steffan-Dewenter, 2008).

There is some evidence that levels of pollination affect seed number with associated impacts on size and calcium concentration but direct links between insect pollination and apple quality are equivocal (Garratt et al., 2014). Identifying the production value that is currently limited by sub-optimal pollination is necessary and potentially could provide an economic benchmark indicating how much could be sensibly invested in management of insect pollination services to address these deficits. Such pollination deficits have been found in several tree crops including apples (Losey & Vaughan, 2006).

Density and Diversity of Insects in other Countries

According to Herrera, (1989), insects are important components in most natural and transformed landscapes. They play crucial functional roles that ensure delivery of various ecosystem services which are important for

some aspects of human livelihood such as agriculture, tourism, natural resource use. Holopainen, (2003) reveals that Nigeria is an afro-tropical country endowed with rich flora and fauna biodiversity, typical of most tropical countries of the world. The tropics which has been reported to house approximately 70% of global biodiversity is also a treasure trove of insect diversity which is estimated to parallel the extent of plant diversity of this region (Raine, Willmer, & Stone, 2002).

The majority of insects are herbivorous, and high numbers of species in a food web are dependent on autotrophic plants. As a result, factors that disturb plant physiology have effects on insect fauna relying on plants. Ample amount of literature indicates that insect herbivore abundance often increases when the host plant is subjected to some abiotic stress. Breeze, Roberts, & Potts, (2012) specified that, plant stress-induced alteration in insect herbivores is a result of variation in both plant responses to stress and insect sensitivity to changes in stressed plants.

Reports from Regions & Results, (2003) indicates the host plant environment is taken to be the whole ecosystem around the target plant. An alteration in volatile organic compound (VOC) emissions from stressed plants might affect the orientation behaviour of herbivorous insects that are specialized on a few host plant species. Such insects use specific plant odours to localize the proper host plant species. Insect damage to fruit and seed crops causes heavy losses of seed every year. Borges, Bessière, & Ranganathan,(2013) explains that, destruction of seed crops may be caused either by insects directly infesting the reproductive structures (flowers, fruits and seeds) or by insects attacking other parts of the tree, e.g. defoliators,

which cause exhaustion of nutrient reserves, which in turn may diminish nutrient allocation for seed production. Only insect problems of the former type will be dealt with in this note.

Furthermore, Harren & Cristescu, (2013) claims some insects attack flower buds or flowers and may thus cause complete failure of fruit setting, other species attack during the later phase of seed development, but before the seeds mature. Still others are able to attack after maturity and continue both feeding and infestation after harvest provided the external environment is suitable, e.g. temperature. Meanwhile, Borges et al., (2013) indicates the attack takes place in a heavy infestation may cause almost complete seed-crop destruction and certainly make seed collection inefficient and uneconomical. Seed predation or infestation rate varies from species to species, from location to location and from year to year. It is often correlated with seed-crop size in the way that small seed crops are heavily attacked while the percentage of infested seeds in large crops is significantly smaller (Bhattacharya et al., 2002).

CHAPTER THREE

MATERIALS AND METHODS

This chapter discusses the various methods used in carrying out the research from sampling of the study farms, insect counts, collection of representatives, presentation of data and findings.

The study Area and Description of Farms

To evaluate the impact of natural forest and agricultural land on insect species that visit cashew during the flowering and the fruiting periods, the study area was stratified into two. The areas are farms close to Kanikani forest (< 1km) and farms away from Kanikani forest (> 5km) in the Sawla and Bole districts respectively in the Western part of the Northern Region (Table 1). The study towns are located in the western part of the Northern Region, (Table 1 and Figure 1) between latitudes 8° 40' and 9° 40' North, longitudes 1° 50' and 2° 45' West.

Table 1: Towns where the Experiment was carried out

Farms closer to the forest (Sawla)	Farms away from the forest (Bole)
Sogoyire	Serepe
Sonyon	Dagnewure
Klanpobile	Bole
Mankuma	Kakiase
Bordaa	Mandire

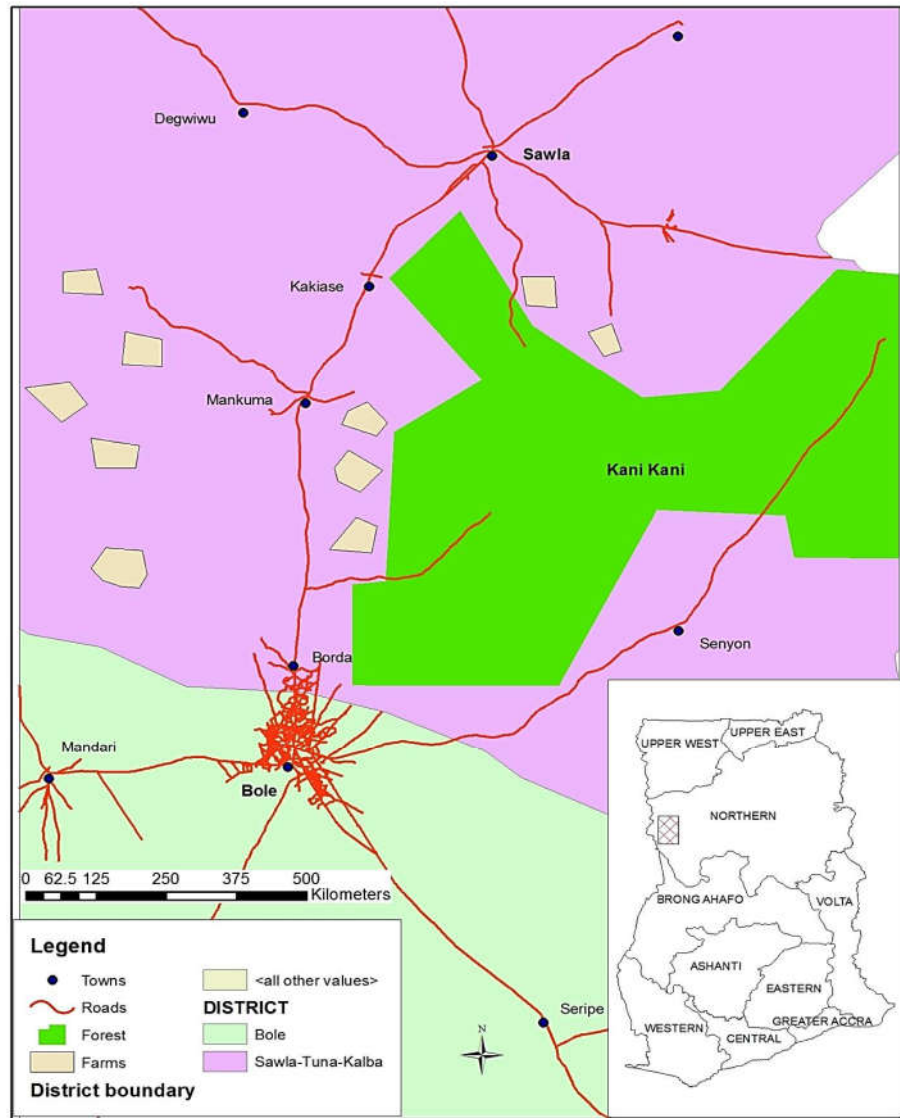


Figure 1: Map of the Study Area indicating the Farms Distributions (farmsPositions not up to scale)

Farms studied were cultivated with dwarf cashew variety CCP76. The trees were 10-20 years old, spaced 7.5 x 7.5 m, with a maximum number of 178 trees per ha. All farms were managed in accordance with the standard agricultural practices for cashew crops such as pruning, soil clearing, and weed control prior to blooming periods by the farmers. A global positioning system (G.P.S) Garmin 60C manufactured in 1989 by American multinational technology was used to pick and record coordinates of the each plot, sweep net with a long handle was used for collection of insects, tubes were used to preserve insect specimen, forceps was used to pick specimen into the preserving tubes, field note book and pencil were used for taking the recordings of the data, paper envelopes were used to preserve butterflies, vials with alcohol were used for preservation of the specimen and lap top computer was used for computing and storing information from the field.

Experimental Design and Data Collection Procedure

The study area was stratified into two areas as follows: (1) farms close to Kanikani forest reserve (< 1km) and (2) farms away from Kanikani forest reserve (> 5km). Five farms measuring averagely about 1ha were selected in each stratified area.

The study follows the methodology proposed by (Vaissière, Freitas, & Gemmill-Herren, 2011). Therefore, in each farm two plots of an area measuring 25 m x 50 m (1,250 m²) were established in all the ten cashew farms with approximately 30 trees per plot. The enumeration team was made up of three members: one person served as a recorder and the two others scanned through the cashew trees, identified insects, count and inform the recorder. This procedure was carried out on all the trees in the plots.

Representatives of all insects were captured, killed in a killing jars and preserve in 70% alcohol. These species were sent to the University of Cape Cost and Cocoa Research Institute (CRIG) Tafo Entomology museums for further confirmation of already identified specimen and identification of unidentified. The nomenclature of the insects was after (Picker, Griffiths & Weaving, 2002).

This procedure was carried out in two separate periods: (1) the flowering period (mid December to mid January 2015) and (2) the fruiting period (March to April 2015).

In addition, the activity of insects at the time of capture on the plant part at which they were captured was recorded.

Data Analysis

The data collected were analyzed as follows:

- a. **Density** was calculated using the formula:

$$density = \frac{total\ number\ of\ all\ insects}{total\ sampled\ area}$$

- b. **Diversity** was calculated using Shannon (H):

$$H = \sum_{t=1}^s p_i \ln p_i$$

Where p_i = the proportion of the population belonging to the i th of s species.

- c. **Abundance** was calculated by adding the number of individuals per species encountered in both seasons.

- d. **Relative abundance** (%) was calculated as follows:

$$Relative\ abundance = \frac{number\ of\ individual\ species}{total\ number\ of\ all\ species} (100)$$

e. **Frequency of occurrence** was determined from the raw data by dividing the number of farms where a particular species was collected by the total number of farms occupied by each species in question and multiply by 100Wright, David Hamilton (1991). The relative status of each species based on its frequency of occurrence was defined as follows:

(1) Species that occurred in 70-100% of the farms were classified as abundant

(2) Species that occurred in 30-70% of the farms were classified as common

(3) Insects that occurred in 0-30% of the farms were classified as rare.

f. **Turnover index** is a way of expressing the similarity or dissimilarity in species assemblage between two sites and was calculated as follows:

$$\textit{turnoverindex} = 1 - \left[\frac{C(T_1 + T_2)}{2T_1T_2} \right]$$

Where C = the number of species shared between two sites

T₁ = the number of species at site one

T₂ = the number of species at site two

Mann-Whitney U test was used to test the differences in abundance of species between two variables (size and periods).

Student's 't' test was used to evaluate differences between diversity of species between any two sites and the means of species in farms close to the forest and farms away from the forest.

All the statistical analysis and other calculations were done using Paleontological Statistics software package for education and data analysis, PAST (Hammer, Harper, & Ryan, 2001) and Microsoft excel.

CHAPTER FOUR

RESULTS

This chapter introduces the findings of the study in the form of sentences, charts and tables in accordance with the objectives.

Type, Density and Status of Insects Encountered in the Flowering Period

During the flowering period in the five farms close to the forest reserve, the total number of insects recorded was 6161. The mean number of insects per plot was 1232.2 (SD=250.7, N=40). Density of insects was found to be 6161/ha (density per ha was equal to the total number of insects because the total area enumerated in farm was equal to 1ha) in the farms close to forest reserve, which comprises 46 different species belonging to 20 families and 6 orders (Table 2). Higher number of insects were counted among the following species; *Apis mellifera*, *Oecophylla longinola*, *Cataulacus guineensis*, *Dactylurina staudingeni* and *Euchrysops malathana* in farms closer to the forest (Table 2).

On the other hand, the total number of insects enumerated in the five farms away from the forest reserve during the flowering period was 4665, the mean number of species per plot was 933 (SD=143.5, N=40). The density of insects were found to be 4665/ha (density per ha was equal to the total number of insects because the total area enumerated in farm was equal to 1ha) comprising 41 species belonging to 22 families and 7 orders. The following species were found to be relatively higher in numbers: *Apis mellifera*, *Oecophylla longinola*, *Atelocera* sp. *Atractomorpha aberrans* and *Chilomenes lunata* (Table 2).

The local conservational status of insects was assessed and calculated in farms close to forest reserve. The following were the results: 77% of insect species were classified as abundant, 13% of insect species were classified as common and 10% of insect species were classified as rare (Figure 2).

The same was calculated in the five farms away from forest reserve. The following were also the results: 94% of insects encountered were classified as abundant and 6% of them were classified as common (Figure 2), there were none of the insects classified as rare in the farms away from the forest reserve during the flowering period.

There were highly significant more insects species in farms closer to the forest than farms away from the forest ($t = -3.25$, $P = 0.001$) during the flowering period. Moreover, there was more abundance of insects in farms away from the forest than farms closer to the forest ($t = -2.30$, $P = 0.005$).

Table 2: Insects Species Identified during Flowering Period in Farms close to Forest

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
Hemiptera	Coreidae	<i>Anoplocnemis curvipe</i>	60	1.2	100	72	1.7	100
		<i>Pseudotheraptus devastans</i>	37	0.8	100	68	1.1	100
		<i>Homoeocerus pallens</i>	58	1.2	100	70	1.1	100
		<i>Clavigralla shadabi</i>	103	2.2	100	91	1.5	100
		<i>Clavigralla tomentosicollis</i>	0	0.0	0	68	1.1	100
		Pentatomidae	<i>Piezodorus rubrofasciatus</i>	103	2.2	100	80	1.3

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Nezara viridula</i>	58	1.2	80	75	1.2	80
		<i>Atelocera sp.</i>	70	1.5	100	82	1.3	100
Coleoptera	Cetoniidae	<i>Diplognatha gagates</i>	96	2.1	80	55	0.9	80
		<i>Pachnoda cordata</i>	129	2.8	100	492	8.0	100
		<i>Mylabris bifasciata</i>	0	0.0	0	63	1.0	100
		<i>Chilomenes lunata</i> F	97	2.1	100	198	3.2	100
		<i>Pachnoda marginata</i>	110	2.4	100	109	1.8	100

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
	Bostrychidae	<i>Apate telebrans</i> Pall.	57	1.2	80	119	1.9	80
	Cerambycidae	<i>Philematium festivum</i>	74	1.6	100	98	1.6	100
		<i>Analeptes trifasciata</i> F	98	2.1	80	128	2.1	100
		<i>Prosopocera lactators</i>	35	0.8	100	33	0.5	80
	Buprestidae	<i>Zographus regalis</i> B.	33	0.7	40	35	0.6	80
	Meloidae	<i>Mylabris bifasciata</i>	42	0.9	80	62	1.0	80

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
	Galerucidae	<i>Asbecesta cyanipennis</i>	87	1.9	100	111	1.8	100
	Coccinellidae	<i>Chilomenes lunata</i> F	70	1.5	40	94	1.5	40
Lepidoptera	Lycaenidae	<i>Euchrysops malathana</i>	93	2.0	100	197	3.2	100
	Gracilariidae	<i>Acrocerops sp.</i>	112	2.4	80	122	2.0	80
		<i>Apate terebrans</i>	0	0.0	0	36	0.6	100
Diptera	Calliphoridae	<i>Calliphora vomitoria</i>	166	3.3	80	272	4.4	100
Dictyoptera	Mantidae	<i>Sphodromantis lineola</i>	0	0.0	0	40	0.6	80

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Tarachodes afzelii</i> R.	51	1.1	100	81	1.3	80
		<i>Amorphoscelis sp</i>	95	2.0	100	264	4.3	100
Homoptera	Cocidae	<i>Stictococcus sp</i>	30	0.6	100	43	0.7	100
	Pseudococidae	<i>Stictococcus sp</i>	67	1.4	100	120	1.9	100
		<i>Planococcoides njalensis</i>	71	1.5	80	133	2.2	80
		<i>Toxoptera aurantii</i> B.	75	1.6	100	81	1.3	100
	Aphididae	<i>Aphis sp.</i>	78	1.7	60	113	1.8	60
	Miridae	<i>Helopeltis antonii</i> S.	18	0.4	80	21	0.3	100

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Apate terebrans</i>	72	1.5	100	118	1.9	100
		<i>Mecocorynus loripes</i>	78	1.7	60	73	1.2	80
		<i>Analeptis trifasciata</i>	45	1.0	80	66	1.1	100
Hymenoptera	Formicidae	<i>Pheidole megacephala</i>	65	1.4	80	99	1.6	80
		<i>CreMATogaster africana</i>	32	0.7	100	51	0.8	100
		<i>CreMATogaster striatula</i>	35	0.8	80	59	1.0	80

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Oecophylla longinoda</i>	97	2.1	60	134	2.2	60
		<i>Cataulacus guineensis</i>	45	1.0	80	74	1.2	80
		<i>Camponotus olivieri</i> F	20	0.4	60	40	0.6	80
		<i>Polyrachis laboriosa</i>	0	0.0	0	105	1.7	100
	Apidae	<i>Apis mellifera</i>	298	6.4	80	49	0.8	100
		<i>X. varipuncta</i>	33	0.7	40	37	0.6	60
		<i>Meliponula ferruginea</i>	190	4.1	100	28	0.5	100

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Hypotrigona sp</i>	129	2.8	80	55	0.9	30
	Halictidae	<i>Myiobris bifasciata</i>	51	1.1	100	241	3.9	100
	Megachilidae	<i>Amorphoscelis sp</i>	70	1.5	60	69	1.1	80
	Sphecidae	<i>Sphex pensylvanicus</i>	33	0.7	80	86	1.4	100
	Braconidae	<i>Aleiodes sp.</i>	58	1.2	60	46	0.7	100
		<i>Apanteles sp.</i>	46	1.0	100	98	1.6	80
		<i>Braunsia sp.</i>	89	1.9	60	34	0.6	100
		<i>Bassus sp.</i>	55	1.2	100	82	1.3	30
		<i>Chelonus sp.</i>	78	1.7	80	31	0.5	20
Orthoptera	Tettigoniidae	<i>Phaneroptera sparsa</i>	69	1.5	80	29	0.5	40

Table 2 Continued

Order	Family	Species	Farms close to forest			Farms away from forest		
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	Frequency of Occurrence %
		<i>Conocephalus longipennis</i> L.	37	0.8	60	94	1.5	100
	Acrididae	<i>Anacridium</i> sp.	71	1.5	100	96	1.6	70
		<i>Polyspilota variegata</i>	48	1.0	100	59	1.0	50
		<i>Atractomorpha aberrans</i>	95	2.0	100	81	1.3	100
		<i>Acrida turrita</i> L.	38	0.8	30	70	1.1	60
	Pyrgomorphidae	<i>Zonocerus variegatus</i>	57	1.2	40	30	0.5	20
	Tetrigidae	<i>Pantelia horrenda</i>	69	1.5	100	27	0.4	60
	Total		4665	100.0		6161	100.0	

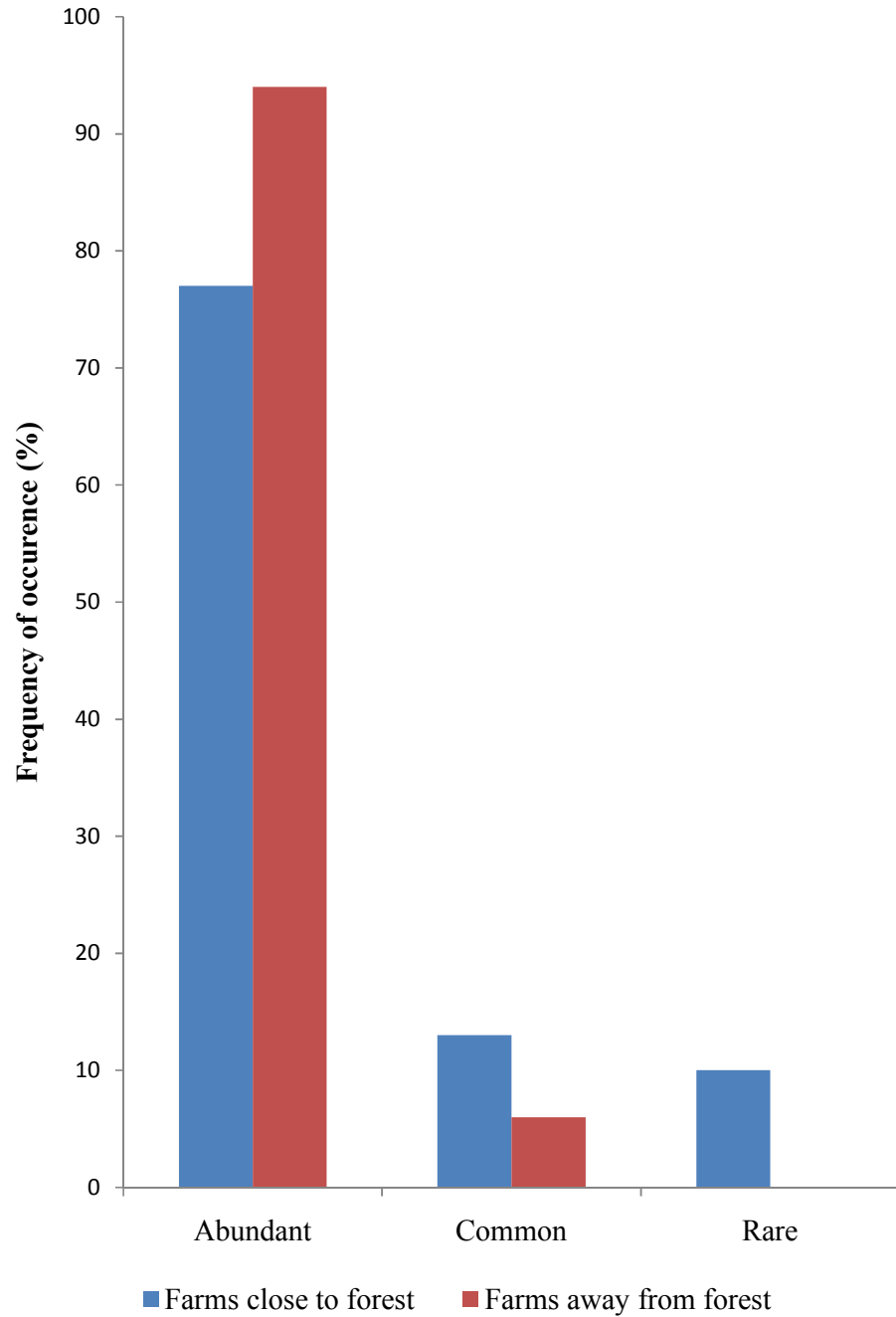


Figure 2: Frequency of Insect Species Occurrence Enumerated for Farms close to the Forest and away from the Forest during the Flowering Period

Taxa, Density and Status of Insects Encountered in the Fruiting Period

The total number of insects enumerated in the five farms closer to the forest during the fruiting period was 2745 and the mean number of insects per plot was 549 (SD=103.2, N=40).

The density of insects was found to be 2745/ha in farms closer to the forest, this comprises of 48 different species belonging to 21 families and 6 orders (Table 3). Higher number of insects was counted among the following species; *Apis mellifera*, *Oecophylla longinola*, *Mylabri bifasciata*, *Crematogaster striatula* and *Crematogaster africana* in farms closer to the forest (Table 3).

Similarly, the total number of insects identified in the other five farms away from the forest was 2056 and the mean number of species per plot was 411.2 (SD=52.1, N=40).

The density of insects found was 2056/ha in farms away from the forest, comprises of 29 species belonging to 22 families and 7 orders (Table 3).

The following insect species: *Apis mellifera*, *Oecophylla longinola*, *Anancriidim* sp. *Mylabri bifasciata* and *Crematogaster striatula* recorded higher number of individual with respect to all other insects encountered during the fruiting period in farms away from the forest.

The local conservation status of insect species enumerated in farms close to the forest was as follows: 82.7% of insect species were classified as abundant and 17.3% of insect species were classified as common (Figure 3).

The local conservation status of insects in farms away from the forest was as follows: 89.2% of insects were classified as abundant and 10.8% of

insects were reclassified as common. There was no insect species classified rare in farms close or away from the forest during the fruiting period (Figure 3).

There was no significant difference between insect numbers in farms close to the forest and farms away from the forest during the fruiting period ($t = 0.22$, $P = 0.82$). Also, insect abundance in farms close to forest and farms away from the forest during the fruiting period has no significance as well ($t = -2.30$, $P = 0.03$).

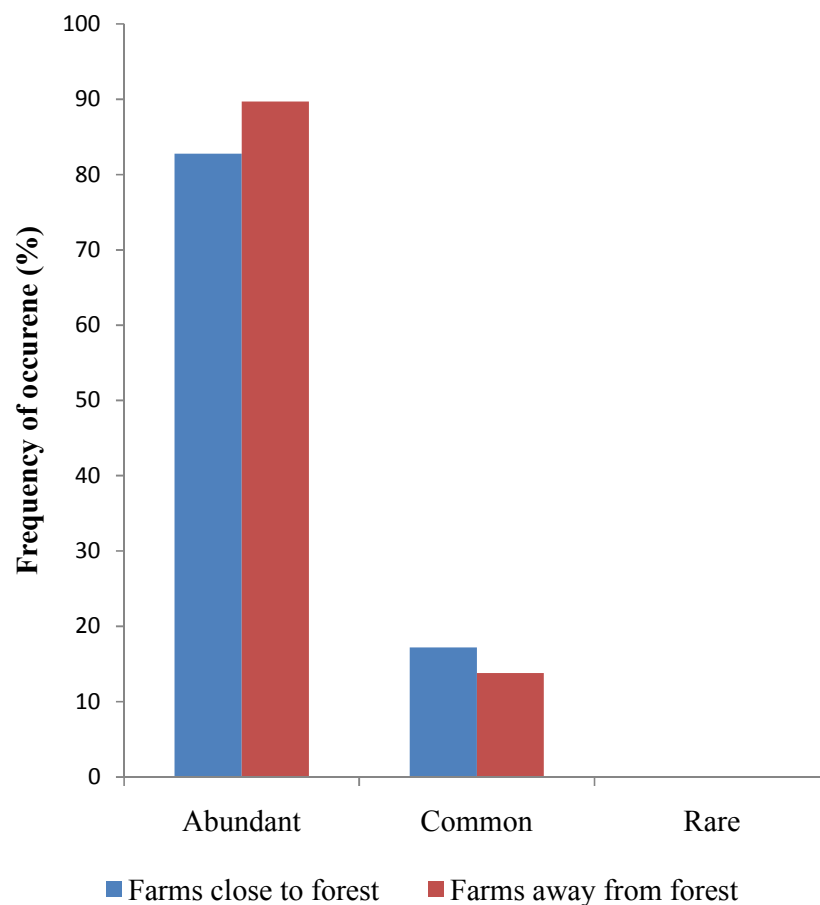


Figure 3: Frequency of Insect Occurrence Identified in Farms close and Farms away from the Forest during the Fruiting Period

Table 3: Insects Species Identified during Fruiting Period in Farms close and away from the Forest

Order	Family	Species	Farms close to forest			Farms away from Forest		Frequency of Occurrence %
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	
Hemiptera	Coreidae	<i>Pseudotheraptus devastans</i>	56	2.7	100	20	0.7	100
		<i>Homoeocerus pallens</i> (F)	22	1.1	100	43	1.6	100
		<i>Clavigralla shadabi</i> D	13	0.6	60	10	0.4	80
		<i>Clavigralla tomentosicollis</i>	18	0.9	100	34	1.2	100
		<i>Nezara viridula</i> Linn.	26	1.3	60	10	0.4	60
Coleoptera	Cetoniidae	<i>Diplognatha gagates</i> F.	28	1.4	80	9	0.3	80
		<i>Pachnoda cordata</i>	36	1.8	100	40	1.5	100
		<i>Mylabris bifasciata</i>	20	1.0	100	13	0.5	100
		<i>Chilomenes lunata</i> F.	49	2.4	80	30	1.1	80

Table 3: Continued

Order	Family	Species	Farms close to forest		Frequency of Occurrence %	Farms away from Forest		Frequency of Occurrence %
			Abundance	Relative Abundance		Abundance	Relative Abundance	
		<i>Pachnoda marginata</i> D.	15	0.7	100	12	0.4	100
	Bostrychidae	<i>Apate telebrans</i> Pall.	33	1.6	100	40	1.5	100
	Cerambycidae	<i>Philematium festivum</i> F.	37	1.8	100	9	0.3	100
		<i>Analeptes trifasciata</i> F.	25	1.2	80	22	0.8	80
		<i>Prosopocera lactators</i> F	37	1.8	80	11	0.4	80
	Buprestidae	<i>Zographus regalis</i> B.	31	1.5	100	21	0.8	100
	Galerucidae	<i>Asbecesta cyanipennis</i>	30	1.5	100	50	1.8	100
	Coccinellidae	<i>Chilomenes lunata</i> F	39	1.9	100	21	0.8	100
Lepidoptera	Lycaenidae	<i>Euchrysops malathana</i> B.	36	1.8	80	14	0.5	80
	Gracilariidae	<i>Acrocerops</i> sp.	39	1.9	100	40	1.5	100

Table 3: Continued

Order	Family	Species	Farms close to forest			Farms away from Forest		Frequency of Occurrence %
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	
		<i>Apate terebrans</i>	17	0.8	60	10	0.4	40
Diptera	Calliphoridae	<i>Calliphora vomitoria</i>	67	3.3	100	149	5.4	100
		<i>Musca domestica</i>	28	1.4	100	96	3.5	100
		<i>Sphex pensylvanicus</i>	39	1.9	100	53	1.9	100
Dictyoptera	Mantidae	<i>Sphodromantis lineola</i> B.	24	1.2	100	83	3.0	100
		<i>Tarachodes afzelii</i> Roy.	42	2.0	100	25	0.9	100
		<i>Amorphoscelis</i> sp	15	0.7	40	22	0.8	40
Homoptera	Cocidae	<i>Stictococcus</i> sp	36	1.8	100	95	3.5	100
		Pseudococidae	<i>Stictococcus</i> sp	8	0.4	60	9	0.3
		<i>Planococcoides njalensis</i>	18	0.9	80	70	2.6	60
		<i>Toxoptera aurantii</i> B.	33	1.6	40	66	2.4	70
		Aphididae	<i>Aphis</i> sp.	22	1.1	20	18	0.7

Table 3: Continued

Order	Family	Species	Farms close to forest			Farms away from Forest		Frequency of Occurrence %
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	
	Miridae	<i>Helopeltis antonii</i> Sign	40	2	10	50	1.8	100
		<i>Apate terebrans</i>	20	1	100	40	1.5	60
Hymenoptera	Formicidae	<i>Pheidole megacephala</i> F.	68	3.3	100	53	1.9	100
		<i>Crematogaster africana</i>	38	1.8	100	22	0.8	100
		<i>Crematogaster striatula</i>	31	1.5	100	40	1.5	100
		<i>Oecophylla longinoda</i>	123	4.2	100	171	4.5	100
		<i>Cataulacus guineensis</i> F.	41	2	90	61	2.2	100
		<i>Camponotus olivieri</i> F.	33	1.6	100	30	1.1	100
		<i>Polyrachis laboriosa</i>	37	1.8	100	70	2.6	90
	Apidae	<i>Apis mellifera</i>	86	4.3	100	127	4.6	100
		<i>X. varipuncta</i>	13	0.6	80	15	0.5	60
		<i>Dactylurina staudingeri</i>	60	3	100	95	3.5	100

Table 3: Continued

Order	Family	Species	Farms close to forest			Farms away from Forest		Frequency of Occurrence %
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Relative Abundance	
		<i>Meliponula ferruginea</i>	62	3	100	111	4	100
		<i>Hypotrigena sp</i>	75	3.6	100	98	3.6	100
	Halictidae	<i>Mylabris bifasciata</i>	13	0.6	70	20	0.7	60
	Megachilidae	<i>Amorphoscelis sp</i>	28	1.4	60	37	1.4	50
	Sphecidae	<i>Sphex pensylvanicus</i>	48	2.3	70	20	0.7	70
	Braconidae	<i>Aleiodes sp.</i>	31	1.5	40	40	1.5	80
		<i>Apanteles sp.</i>	25	1.2	40	50	1.8	80
		<i>Ascogaster sp.</i>	15	0.7	80	42	1.5	60
		<i>Bracon sp.</i>	39	1.9	30	57	2.1	70
		<i>Braunsia sp.</i>	15	0.7	40	38	1.4	80
		<i>Bassus sp.</i>	24	1.2	70	45	1.6	60
		<i>Chelonus sp.</i>	15	0.7	60	41	1.5	40

Table 3: Continued

Order	Family	Species	Farms close to forest			Farms away from		Frequency of Occurrence %
			Abundance	Relative Abundance	Frequency of Occurrence %	Abundance	Forest Relative Abundance	
Orthoptera	Tettigoniidae	<i>Phaneroptera sparsa</i> F.	16	0.7	80	60	2.2	80
		<i>Conocephalus longipennis</i>	14	0.7	60	51	1.9	70
		<i>Acrididae</i>						
		<i>Anacridium sp.</i>	35	1.7	100	30	1.1	70
		<i>Polyspilota variegata</i> O.	27	1.3	100	20	0.7	60
		<i>Atractomorpha aberrans</i>	21	1.2	80	30	1.1	30
		<i>Acrida turrata</i> L.	28	1.4	80	45	1.6	50
		Pyrgomorphidae	<i>Zonocerus variegatus</i>	18	1.8	40	40	1.5
	Tetrigidae	<i>Pantelia horrenda</i> Wlk.	15	0.7	60	32	1.2	40
Total			2056	100		2745	100	

Diversity of Insects during Flowering and Fruiting Periods

Diversity of insects found during the flowering period in farms close to the forest was 3.34 and during the period fruiting in farms close to the forest diversity was 3.56 (Table 4). The difference between the diversity of insects in the flowering and the fruiting periods were highly significant ($t= 11.148$, $p < 0.001$).

However, insects diversity for farms away from the forest during the flowering period, was 3.13, while during the fruiting period insects diversity was found to be 3.14 (Table 5). A significance difference was found between the flowering and the fruiting periods ($t= 28.097$, $p < 0.005$).

Table 4: Diversity Index of Insects in Farms closer and Farms away from Forest in during the Flowering and Fruiting Periods

Farms	Period	Diversity (H)	Evenness	Confidence intervals	
				Upper	Lower
Farms close to forest	Flowering	3.34	0.67	3.59	3.55
	Fruiting	3.56	0.75	3.59	3.55
Farms away from forest	Flowering	3.13	0.79	3.59	3.53
	Fruiting	3.14	0.79	3.59	3.54

Table 5: Diversity 't' Test between Insects in Farms close and away from Forest

Farms close to forest	Farms away from forest	T value	P value
Flowering close to forest	Flowering away from forest	-0.3818	0.70263
Flowering close to forest	Fruiting close to forest	11.148	1.4749E-28**
Fruiting close to forest	Fruiting away from forest	-0.3818	0.70263
Flowering away from forest	Fruiting close to forest	25.48	1.8868E-133**
Flowering close to forest	Fruiting away from forest	-11.773	1.0368E-31**
Flowering away from forest	Fruiting away from forest	28.097	3.5278E-164**

** Highly significance at 0.001

Table 6: Determination of Statistical Differences in Abundance of Insects in Cashew Farms close and away from the Forest with Mann-Whitney U test during Flowering and Fruiting Periods

Farms close to forest	Farms away from forest	U value	P value
Flowering close to forest	Flowering away from forest	804	0.0232*
Flowering close to forest	Fruiting close forest	681.5	0.001287*
Flowering close to forest	Fruiting away from forest	802	0.0212*
Flowering away from forest	Fruiting close to forest	408	1.279E-07**
Fruiting close to forest	Fruiting away from forest	1007	0.449
Flowering away from forest	Fruiting away from forest	564.5	2.33E-05**

* Significant at 0.005, ** significant at 0.001

Comparisons in Insects Abundance in Farms close and away from the Forest during the Flowering and Fruiting Periods

With reference to Table 6, the following observations were made: comparing the abundance of insects in farms close and away from the forest during the flowering period, insects abundance differed significantly between them ($U = 804, P < 0.005$).

Furthermore, the difference in abundance of insects during the flowering period in farms close to the forest and the fruiting period in farms close to the forest was also significant ($U = 681.5, P < 0.005$).

Again, the insects abundance during the flowering period in farms closer and the fruiting period in farms away from the forest was significant ($U = 802, P < 0.005$).

Meanwhile, the abundance of insects during the flowering period on farms away from the forest was highly significant from the abundance of insects during the fruiting period on farm close to the forest ($U = 408, P < 0.001$).

Also, there were no significant differences between insect abundance during the fruiting period in farms close to the forest and away from the forest.

Lastly, there was highly significant difference between insects abundance during the flowering period in farms away from the forest and during the fruiting period in farms away from the forest ($U = 564, P < 0.001$).

Contribution of Insects Family that Visit Cashew during the Flowering and Fruiting Periods

During the flowering period, the family Formacidae contributed high number of insect species with a percentage of 3.6%, the family Coreidae

followed with 2.6%, the family Apidae was third with 2.6% and the family contributed less with Acrididae 2.1%.

However, comparing the flowering period to the fruiting period the family Pentatomidae contributed high number of insect species in the fruiting period with a percentage of 3.1%, the family Coreidae was second with 2.6%, the family Formicidae also followed with 2.6% and then the family Apidae had the less number of insect species in contribution 2.6%.

Furthermore, in the flowering period, the family's Aphididae and Terigodae contributed less insect species with a percentage of 0.5% respectively (Table 7).

Also, during the fruiting period the family's Pyrgomorphidae, Meloidae and Coccididae contributed less insect species with a percentage of 0.5% respectively (Table 8).

Table 7: Family of Insects Identified during Flowering Period in Farms close and Farms away from the Forest

Family	Flowering close to forest		flowering away from forest	
	No. of species	Percentage	No. of species	percentage
Formicidae	7	3.6	7	3.6
Coreidae	5	2.6	5	2.6
Apidae	5	2.6	5	2.6
Acrididae	4	2.1	4	2.1
Cerambycidae	3	1.5	3	1.5
Mantidae	3	1.5	3	1.5
Pentatomidae	2	1.0	2	1.0
Gracilariidae	2	1.0	2	1.0
Tettigoniidae	2	1.0	2	1.0
Cetoniidae	1	0.5	1	0.5
Bostrychidae	1	0.5	1	0.5
Buprestidae	1	0.5	1	0.5
Meloidae	1	0.5	1	0.5
Galerucidae	1	0.5	1	0.5
Lycaenidae	1	0.5	1	0.5
Halictidae	1	0.5	1	0.5
Megachilidae	1	0.5	1	0.5

Table 7 continued

Family	Flowering close to forest		Flowering away from forest	
	No. of species	Percentage	No. of species	percentage
Sphecidae	1	0.5	1	0.5
Pyrgomorphidae	1	0.5	1	0.5
Tetrigidae	1	0.5	1	0.5
Aphididae	1	0.5	1	0.5

Table 8: Family Contribution of Insects during Fruiting Period in both Farms closer and away from Forest Reserve

Family	Fruiting close to forest		Fruiting away from forest	
	number of species	percentage	numberof species	percentage
Pentatomidae	6	3.1	6	3.1
Coreidae	5	2.6	5	2.6
Formicidae	5	2.6	5	2.6
Aphidae	5	2.6	5	2.6
Mantidae	4	2.1	4	2.1
Acrididae	4	2.1	4	2.1
Cerambycidae	3	1.5	3	1.5
Gracilariidae	2	1.0	2	1.0
Drosophilidae	2	1.0	2	1.0
Pseudococidae	2	1.0	2	1.0
Miridae	2	1.0	2	1.0
Tettigoniidae	2	1.0	2	1.0
Bostrychidae	1	0.5	1	0.5
Buprestidae	1	0.5	1	0.5
Meloidae	1	0.5	1	0.5
Galerucidae	1	0.5	1	0.5
Coccinellidae	1	0.5	1	0.5
Lycaenidae	1	0.5	1	0.5
Cocidae	1	0.5	1	0.5

Table 8: Continued

Family	Fruiting close to forest		Fruiting away from forest	
	number of species	percentage	number of species	percentage
Aphididae	1	0.5	1	0.5
Pyrgomorphidae	1	0.5	1	0.5
Tetrigidae	1	0.5	1	0.5
Aphididae	1	0.5	1	0.5
Pyrgomorphidae	1	0.5	1	0.5
Tetrigidae	1	0.5	1	0.5

Similarities and Dissimilarities of Insects during the Flowering and Fruiting Periods Farms close and Farms away from the Forest

Insect species similarities and dissimilarities in farms close and farms away from forest during the flowering and the fruiting period was investigated to determine insect species shared between the farms close and the farms away from the forest. This is to see insect species that are found only during the flowering and the fruiting periods in farms close and farms away from the forest or insect species shared between the farms and the periods (Tab: 9).

Table 9: Similarities and Dissimilarities (Turnover indices) of Insects in Farms close and Farms away from Forest during the Flowering and Fruiting Periods

Farms/location	Farms/location	Turnover Indices (TI)
Flowering close to forest	Flowering away from forest	0.86
Flowering close to forest	Fruiting close to forest	0.47
Fruiting close to forest	Fruiting away from forest	0.36
Flowering away from forest	Fruiting close to forest	0.47
Flowering close to forest	Fruiting away from forest	1
Flowering away from forest	Fruiting away from forest	0.57

Insects Observed on Cashew Plant Part during the Flowering Period

During the flowering period, it was noticed that 33% of insect species were found on the cashew leaves foliage, 18% were found on the leaves and branches, 15% on the flushing shoots, 13% were found on the both flowers and leaves, 13% were also found on only the flowers, 5% on the growing tips and flushing shoots, then 3% were found on the leaves, trunk, and twigs respectively (Figure 4).

Insects Observed on Cashew Plant Part during the Fruiting Period

Also, in the fruiting season insects behaviours and activities were also different upon the plant part the insect is found. 47% of insect species were found on the leaves, 25% were on only fruits, 19% were found on the fruits

and nuts while 6% were found on fruits and twigs, leaves and fruits, then 3% were found on the leaves, trunk and twigs (Figure 5).

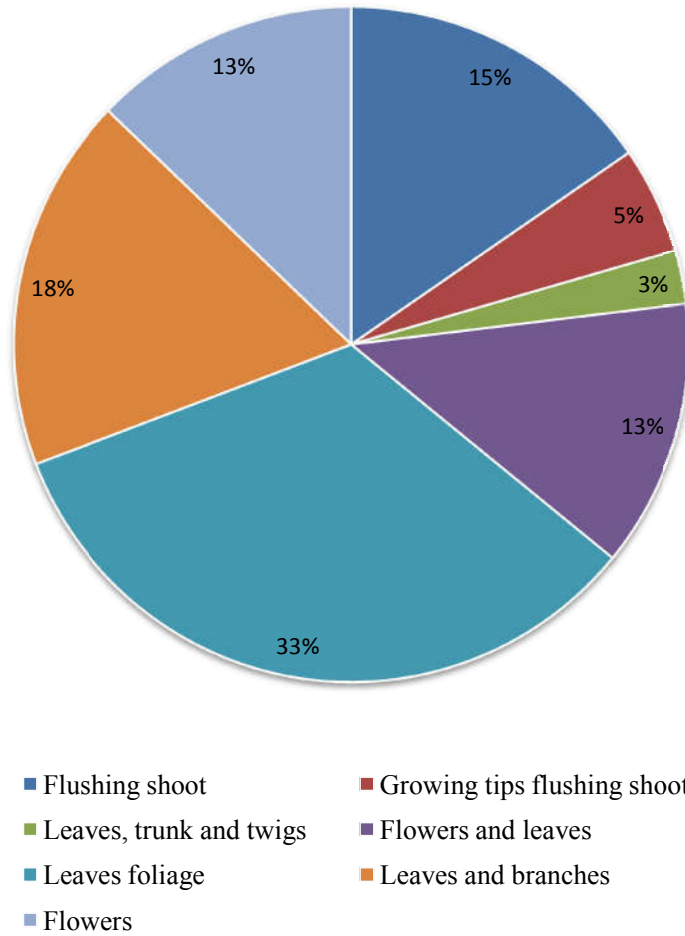


Figure 4: Insects Observed on Different Cashew Plant Part during Flowering Period

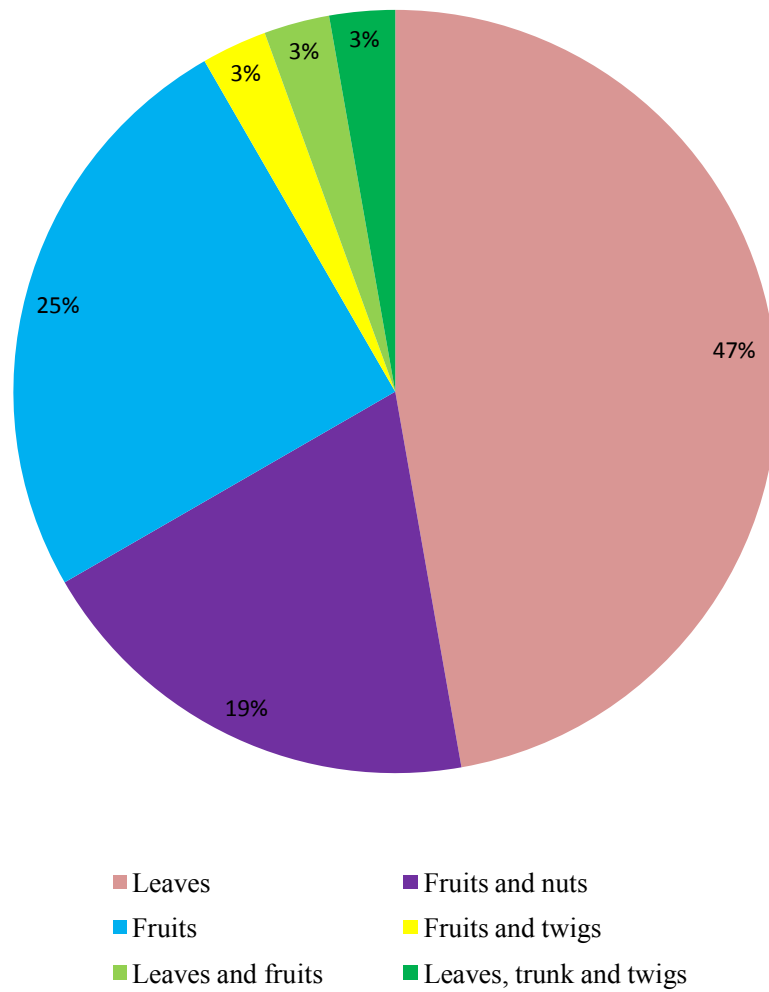


Figure 5: Insects Observed on Different Cashew Plant Part during Fruiting Period

Table 10: Insect Species Activities on Cashew Plant during the Flowering Period

Family	Species	Plant part found	Activity observed
Coreidae	<i>Anoplocnemis curvipes</i> (F)	Flushing shoots	Sucking sap
	<i>Pseudotheraptus devastans</i> (Dist.)	Shoots	Sucking sap
	<i>Homoeocerus pallens</i> (F)	Shoots	Sucking sap
	<i>Clavigralla shadabi</i> Dolling	Flushing shoots	Sucking sap
	<i>Clavigralla tomentosicollis</i> Stal	Flushing shoots	Sucking sap
Pentatomidae	<i>Piezodorus rubrofasciatus</i>	Flushing shoots	Sucking sap
	<i>Atelocera</i> sp.	Growing tips and flushing shoots	Sucking sap
Bostrychidae	<i>Apate telebrans</i> Pall.	Leaves trunks and twigs	Sucking sap

Table 10 continued

Family	Species	Plant part found	Activity observed
Cerambycidae	<i>Philematium festivum</i> F	Leaves trunks and twigs	Sucking sap
	<i>Analeptes trifasciata</i> F	Mature tree trunks and twigs	Girdling trunks and branches
	<i>Prosopocera lactators</i> F	Mature tree trunks and twigs	Sucking sap
Buprestidae	<i>Zographus regalis</i> Brown.	Mature tree trunks and twigs	Sucking sap
Meloidae	<i>Mylabris bifasciata</i> Deg	Flowers and leaves	Feeding on inflorescence and tender foliage
Galerucidae	<i>Asbecesta cyanipennis</i> Har	Leave foliage	Feeds on foliage
Coccinellidae	<i>Chilomenes lunata</i> F.	Young and mature trees	Prey on aphids and early nymphs of H.
Tettigoniidae	<i>Phaneroptera sparsa</i> F	Leaves foliage	Feeds on foliage
	<i>Conocephalus longipennis</i> L.	Leaves foliage	Feeds on foliage

Table 10 continued

Family	Species	Plant part found	Activity observed
Acrididae	<i>Anacridium sp.</i>	Leaves foliage	Feeds on foliage
	<i>Polyspilota variegata Oliv.</i>	Leaves foliage	Feeds on foliage
	<i>Atractomorpha aberrans K</i>	Leaves foliage	Feeds on foliage
	<i>Acrida turrita L</i>	Leaves foliage	Feeds on foliage
Pyrgomorphidae	<i>Zonocerus variegatus (L.)</i>	Leaves foliage	Feeds on foliage
Tetrigidae	<i>Pantelia horrenda Wlk.</i>	Leaves foliage	Feeds on foliage
Gracilariidae	<i>Acrocerops sp.</i>	Leaves	Leaf miners
Lycaenidae	<i>Euchrysops malathana</i> Boisd.	Leaves foliage and flower	Feeds on foliage and flowers
Mantidae	<i>Sphodromantis lineola (Burm)</i>	Leaves and flowers	Predator of nymphs of flying insects

Table 10 continued

Family	Species	Plant part found	Activity observed
	<i>Tarachodes afzelii</i> Roy.	Leaves and flowers	Predator of nymphs of flying insects
	<i>Amorphoscelis</i> sp.	Leaves and flowers	Predator of nymphs of flying insects
Pseudococcidae	<i>Planococcoides njalensis</i> (Laing)	Twigs	sucking Sap
Aphididae	<i>Aphis</i> sp.	Leaves	sucking Sap
Formicidae	<i>Pheidole megacephala</i> F	Leaves, branches	Predators and caring debris of ruminants
	<i>Crematogaster africana</i> Mayr	Leaves, branches	Predators and caring debris of ruminants
	<i>Crematogaster striatula</i> Emery	Leaves, branches	Predators and caring debris of ruminants
	<i>Oecophylla longinoda</i> Latr	Leaves, branches	Predators and caring debris of ruminants

Table 10 continued

Family	Species	Plant part found	Activity observed
	<i>Cataulacus guineensis</i> F. Smith	Leaves, branches	Caring debris and ruminants'
	<i>Polyrachis laboriosa</i> Smith	Leaves, branches	Caring debris and ruminants
	<i>Camponotus olivieri</i> F.	Leaves	Honey dew harvesters
Apidae	<i>Apis mellifera</i> F	Flowers	Collecting pollen on cashew inflorescence
	<i>X. varipuncta</i>	Flowers	Collecting pollen on cashew inflorescence
	<i>Dactylurina staudingeri</i>	Flowers	Collecting pollen on cashew inflorescence
	<i>Meliponula ferruginea</i>	Flowers	Collecting pollen on cashew inflorescence
	<i>Hypotrigona</i> sp	Flowers	Collecting pollen on cashew inflorescence
Thripidae	<i>Selenothrips rubrocinctus</i> (Giard)	Leaves	Suck sap and scrape leave

Table 11: Summary of Insects Activities on Cashew Plant Part during the Fruiting Period

Family	Species	Plant part found	Activity observed
Coreidae	<i>Anoplocnemis curvipes</i> (F)	Developin apples and nuts	Sucking juice
	<i>Pseudotheraptus devastans</i> (Dist.)	Apples and nuts	Sucking juice
	<i>Homoeocerus pallens</i> (F)	Apples and nuts	Sucking juice
	<i>Clavigralla shadabi</i> Dolling	Apples and nuts	Sucking juice
	<i>Clavigralla tomentosicollis</i> Stal	Apples and nuts	Sucking juice
Pentatomidae	<i>Nezara viridula</i> Linn.	Cashew nuts	Sucking sap/preying
Cetoniidae	<i>Diplognatha gagates</i> (Forst.)	Young and mature apples	Feed and pierces holes
	<i>Pachnoda cordata</i> (Drury)	Young and mature apples	Feed and pierces holes
Cerambycidae	<i>Analeptes trifasciata</i> F.	Mature trees	Girdling trunks and branches

Table 11 continued

Family	Species	Plant part found	Activity observed
	<i>Philematium festivum</i> F.	Leaves, trunk and twigs	Sucking sap
	<i>Prosopocera lactators</i> F	Mature trees	Sucking sap
Buprestidae	<i>Zographus regalis</i> Brown	Mature trees	Sucking sap
Meloidae	<i>Mylabris bifasciata</i> Deg	Leaves	Tender foliage
Galerucidae	<i>Asbecesta cyanipennis</i> Har	Leave foliage	Feeds on foliage
Coccinellidae	<i>Chilomenes lunata</i> F.	Young and mature trees	Prey on aphids and early Nymphs
Tettigoniidae	<i>Phaneroptera sparsa</i> F	Leaves foliage	feeds on foliage
	<i>Conocephalus longipennis</i> L.	Leaves foliage	Feeds on foliage
Acrididae	<i>Anacridium</i> sp.	Leaves foliage	Feeds on foliage
	<i>Polyspilota variegata</i> Oliv	Leaves foliage	Feeds on foliage

Table 11 continued

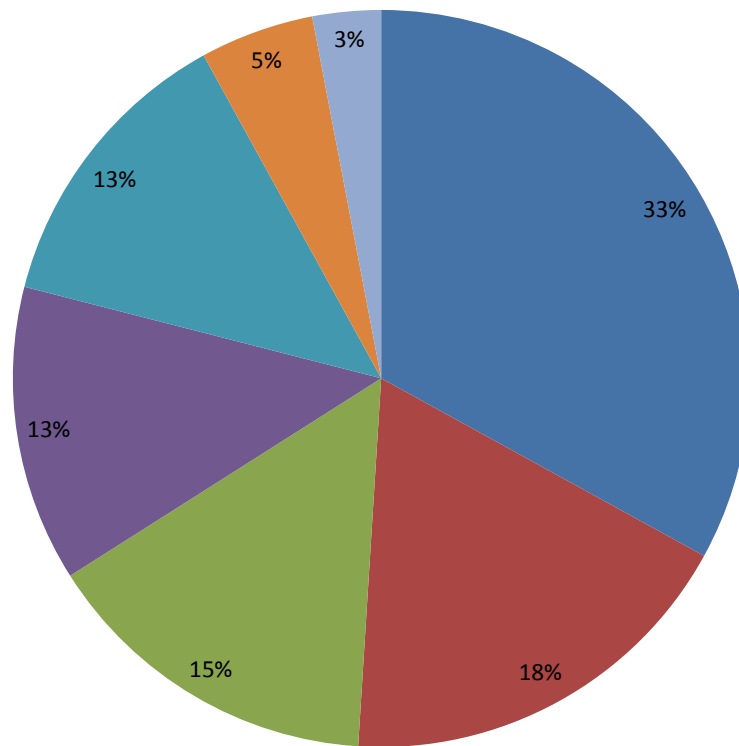
Family	Species	Plant part found	Activity observed
	<i>Atractomorpha aberrans</i> K	Leaves foliage	Feeds on foliage
	<i>Acrida turrita</i> L	Leaves foliage	Feeds on foliage
Pyrgomorphidae	<i>Zonocerus variegatus</i> (L.)	Leaves foliage	Feeds on foliage
Tetrigidae	<i>Pantelia horrenda</i> Wlk.	Leaves foliage	Feeds on foliage
Gracilariidae	<i>Acrocerops</i> sp.	Leaves	Leaf miners
Lycaenidae	<i>Euchrysops malathana</i> Boisd.	Leaves foliage	Feeds on foliage
Drosophilidae	<i>Drosophila melanogaster</i> (Meigen)	Fruits	Feed on apples
Mantidae	<i>Sphodromantis lineola</i> (Burm)	Leaves	Predator of nymphs of flying insects
	<i>Tarachodes afzelii</i> Roy.	Leaves	Predator of nymphs of flying insects
	<i>Amorphoscelis</i> sp.	Leaves	Predator of nymphs of flying insects

Table 11 continued

Family	Species	Plant part found	Activity observed
Pseudococcidae	<i>Planococcoides njalensis</i> (Laing)	young fruits and twigs	Sap suckers
	<i>Toxoptera aurantii</i> (Boy.)	Young fruits	Sap suckers
Aphididae	<i>Aphis</i> sp.	Leaves and fruits	Sap suckers
Formicidae	<i>Pheidole megacephala</i> F	Leaves and branches	Predators and debris of ruminants
	<i>Crematogaster africana</i> Mayr	Leaves and branches	Predators and debris of ruminants'
	<i>Crematogaster striatula</i> Emery	Leaves and branches	Predators and debris of ruminants
	<i>Oecophylla longinoda</i> Latr.	Leaves and branches	Predators and debris of ruminants
	<i>Cataulacus guineensis</i> F. Smith	Leaves and branches	Predators and debris of remnants
	<i>Polyrachis laboriosa</i> Smith	Leaves and branches	Predators and debris of ruminants'
	<i>Camponotus olivieri</i> F.	Leaves	Honey dew harvesters

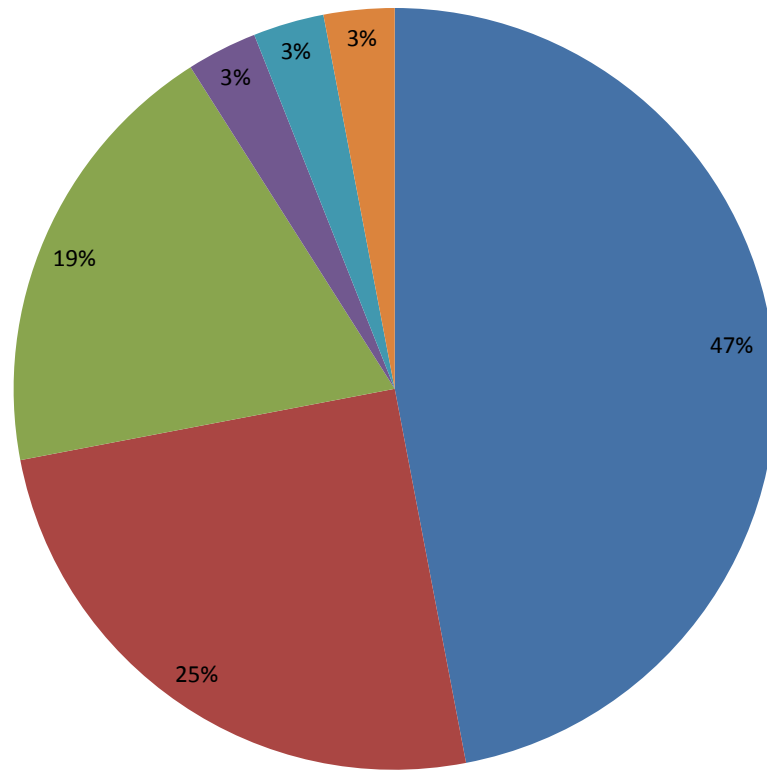
Table 11 continued

Family	Species	Plant part found	Activity observed
Apidae	<i>Apis mellifera</i> F	Fruits	Sucking juice from fruits
	<i>X. varipuncta</i>	Fruits	Sucking juice from fruits
	<i>Dactylurina staudingeri</i>	Fruits	Sucking juice from fruits
	<i>Meliponula ferruginea</i>	Fruits	Sucking juice from fruits
	<i>Hypotrigona</i> sp	Fruits	Sucking juice from fruits
Thripidae	<i>Selenothrips rubrocinctus</i> (Giard)	Leaves	Suck sap and scrape leave



- Collecting pollen
- Carrying remnants
- Sucking nectar
- Sucking sap
- Preying
- Feeding on foliage
- Girdling trunk and twigs

Figure 6: Proportion of Activities of Insects during the Flowering Period



- Feeding on foliage
 - Preying
 - Girdling trunk and twigs
- Sucking juice
 - Piercing holes and feeding on fruits
 - Carrying remnants

Figure 7: Proportion of Activities of Insects during the Fruiting Period

CHAPTER FIVE

DISCUSSIONS

Species Composition of Insects that Visit Cashew

The study identified a number of different insect species on the cashew plant during the flowering and fruiting periods in farms close and away from the forest reserve. The phenology of the plant can be said to determine the type of insects that can be attracted to the plant. Though the variation of species that visit the cashew plant during the flowering and fruiting periods were not wide, the density differed significantly.

The species that visit the cashew plant during the flowering period were found to belong to six insect orders namely: Hemiptera, Coleoptera, Lepidoptera, Dictyoptera, Hymenoptera, and Diptera.

Among these insect orders encountered during the flowering and the fruiting periods, there were some family contributions that occurred and the following were the family contributions occurred by these insect orders.

Order Hemiptera contributed two insect families namely: Coreidae and Pentatomidae. Order Coleoptera contributed seven insect families namely; Cetoniidae, Bostrychidae, Cerambycidae, Buprestidae, Meloidae, Galerucidae and Coccinellidae. Order Lepidoptera contributed three insect families namely; Lycaenidae, Gracilariidae, Lycaenidae. Order Dictyoptera contributed one insect family namely; Mantidae. Order Diptera contributed two insect families namely; Mucidae and Drosophilidae. Then the Order Hymenoptera contributed six insect families namely; Formicidae, Apidae, Halictidae, Megachilidae, Sphecidae and Braconidae.

The families Formicidae and Apidae dominated numbers in terms of different insect species and some of them were as follows: *Crematogaster striatula*, *Camponotus olivieri*, *Pheidole megacephala*, *Cataulacus guineensis*, *Polyrachis laboriosa*, *Oecophylla longinoda*, *Crematogaster striatula* and *Camponotus olivieri*, *Apis mellifera*, *Dactylurina staudingeni* and *Euchrysops malathana*.

On the other hand, during the fruiting period the species that visited the cashew plant were found to belong to seven insect orders namely: Hemiptera, Coleoptera, Lepidoptera, Dictyoptera, Hymenoptera, Homoptera and Diptera.

Again among the insect orders identified, all the insect orders have some insect family contributions in the cashew orchard. The order Hemiptera comprises of two insect families namely; Coreidae and Pentatomidae. Order Coleoptera comprises of seven insect families namely; Cetoniidae, Bostrychidae, Cerambycidae, Buprestidae, Meloidae, Galerucidae and Coccinellidae. Order Lepidoptera comprises of three insect families namely; Lycaenidae, Gracilariidae and Lycaenidae. The order Diptera contributed two insect families namely; Drosophilidae and Mucidae. The order Dictyoptera contributed one insect family namely; Mantidae. The order Homoptera contributed four insect families namely; Coccidae, Pseudococcidae, Aphididae and Miridae. Order Hymenoptera contributed six insect families namely; Formicidae, Apidae, Halictidae, Megachilidae, Sphecidae and Braconidae. Then order Orthoptera also comprises of four insect families namely; Tettigoniidae, Acrididae, Pyrgomorphidae, and Tetrigidae.

Comparing the insect composition in both flowering and the fruiting period, it was noticed that though the same family may occur in both periods

species occurrence may differ. For example, during the flowering period the family Pentatomidae presented these insect species; *Piezodorus rubrofasciatus* and *Atelocera sp.*

However, during the fruiting period the same family: Pentatomidae presented different insect species like the *Nezara viridula* Linn. The family Pentatomidae has been noted to belong to the predators and sap suckers family, but these differences might have occurred because the different species have their own different prey requirements.

There were some insect species found to be visiting cashew in all the periods (flowering and fruiting) not because they were interested in the flowers or the fruits. This may be because they have different resources they required and these resources could be acquired throughout both periods.

It could be deduced that a thin gap occurred between the flowering and the fruiting periods. This is because flowers and fruits develop concurrently at the same time, so there were some overlaps of insect species during the flowering and the fruiting periods.

For instance, *Oecophylla longinoda* was found throughout both periods not because there were there to collect or suck nectar from flowers nor to suck juice or sap from the fruits or nuts, but probably because they were interested in making their nest on the plant, as they are canivorous insects they harvest and bring their booty into the nest as drive many insects from the cashew plant. Crimatogasta on the other hand also tender some Homopteran species like the Mealybugs or scale insects from other predators and collecting honeydew secreted by these Homopteran species (Abid et al., 2013 & America & Brazil, 2008)

Insect Distribution and Frequency of Occurrence on Cashew

Insects distributions in farms close and farms away from the forest reserve during the flowering period presented the following outcome: The density of insects recorded in farms close to the forest reserve during the flowering period differed from during the fruiting period ($P < 0.001$). A similar observation was also made in farms away from the forest reserve during the flowering and the fruiting period ($P < 0.001$).

This indicates that, the resources that attract the number of insects to the plant during flowering period such as; nectar, pollen, colour of petals and scent differ from resources that attract them during the fruiting period like; Colour of fruit, scent, fermentation and yeast.

This was similar to González, Santamaría, Corlett, & Rodríguez-Gironés, (2013) who reported that flowers of plant normally serves as attractant to several categories of insects because of the different benefits attained. Insects like the weaver ants (*Oecophylla smaragdina*), are attracted to the plant not to pollinate the flower directly but to deter insects that attack some pollinators.

Moreover, during the fruiting period some volatile compounds such as methyl benzoate and methyl salicylate have been reported to attract insects to the plant. For example, volatile compounds have been reported by Warthen, Lee, Jang, Lance, & McInnis, (1997) to serve as insects attractant to ripen fruits of coffee.

In terms of frequency at which species occurred in all the farms during the flowering period; in farms close to the forest reserve, 77% of insect species were classified as abundant, this means insect species occurred in almost all

the farms. 13% insect species were classified common in the farms, which means insects species occurred in half (70% below of farms) of the farms while 10% of insects species were classified rare this also means insects species occurred in few of the farms (30% below of farms).

In farms away from the forest during the flowering period, 94% of insect species were classified abundant, it means more insects species occurred in almost all the farms only few (6%) of insect species were classified common which means less than 30% of insect species occurred in the rest of the farms. There were no species classified rare during the flowering period, this shows that during the flowering period in farms away from the forest there were no insect species that could be in scares.

During the fruiting period in farms close to the forest reserve, 82.7% (more than 70%) of insect were classified as abundant, 17.2% (less than 70%) of insects were classified as common, and none of the species were classified rare.

In farms away from the forest reserve still during the fruiting period, 89.7% (greater than 70%) of insect were classified as abundant 13.8% (less than 70%) of insects were classified as common and there were none classified as rare.

In this instance, it can be said that, the forest has little influence on the insect species frequency of occurrence in farms close and away from the forest during flowering and fruiting periods.

Diversity of insects recorded in farms closer to the forest reserve during the flowering period also differed from the fruiting period ($P < 0.01$). The

same observation was made in farms away from the forest reserve during the flowering and the fruiting period ($P < 0.01$).

This supports the hypotheses that, diversity of insects during the flowering and the fruiting periods in the cashew orchard are not the same. It shows that the forest has less influence on insect that attracts the cashew plant during the flowering and the fruiting periods.

There are differences of conditions that attract insects to visit cashew during the flowering and fruiting periods some of which has been mentioned earlier above. In addition, insects that visit the cashew orchard during the fruiting period were more diverse than those that visit during the flowering period.

This supports the hypotheses that insect's diversity on cashew flowers and fruits are not the same. This is because, individual species have specific resource requirement from the cashew orchard.

Most insects visit cashew orchard purposely for any of the following; food, shelter, oviposition, chemical for pheromone or for all. Colour differences between the flowers and the fruits of cashew might influence the type and number of insects that visit the plant. This can bring about the differences in insect diversity during both periods as the colour of cashew fruit is more conspicuous than the colour of cashew flowers.

Furthermore, it has been shown that flowers are more conspicuous to pollinators and fruits are also more conspicuous to fruits dispersers, yet despite the differences in visual systems of the insect, flower and fruit colours have evolved to attract multiple and distinct mutualists (Renoult, Valido, Jordano, & Schaefer, 2014).

In addition, another study has reported that yeast production also attract insects to the flowers and fruits as well(Encinas-Viso, Revilla, van Velzen, & Etienne, 2014).

During the fruiting period, apart from colour, the fermentation of fruits can also be a major attractant of insects to the plant in the fruiting period. this has also been supported by Levey, Tewksbury, Izhaki, Tsahar, & Haak (2007) that many insects have been attracted to fermenting fruit and also the growth of some micro-organisms like *Saccharomyces* yeasts growing on fruit occupy a trophic level between fruit and insects.

Also, Levey et al., (2007) continued to support the fact that *Drosophila* flies also used immature fruits for their oviposition place due to the presence of yeast in the fruits for better growth of their larvae.

Insects Found on Cashew during Flowering and Fruiting Periods in Farms close and Farms away from Forest Reserve

Common insects shared between the flowering and fruiting periods in farms closer to the forest and farms away from the forest reserve was also calculated. In farms close and farms away from the forest reserve during the flowering and the fruiting period, 86% of insects were found to be shared between both farms and both periods. This implies that,insects shared between the two periods were high.

During the flowering period in farms close to the forest and the fruiting period in farms away from the forest,insects shared between them were 47%.This indicates that less than half of the insects were shared between the flowering and the fruiting period.

Furthermore, during the flowering period in farms away from the forest reserve and the fruiting period in farms close to the forest we recorded 36% of insects that shared between the two periods in the different farms. It means that more than half of the insects were shared between the two periods in farms close and in farms away from the forest reserve.

However, during the fruiting period in farms close to the forest and farms away from the forest reserve, 100% of insects were shared between the two farms in the fruiting period. This shows that, all the insects found during the fruiting period in farms close to the forest was also found in farms away from the forest. Therefore, this truly supports the hypotheses that the forest has no influence on insect richness in terms of flowering or fruiting.

Finally, during the flowering period in farms away from the forest and during the fruiting period also in farm away from the forest we released that, 37% of insects were sheared between the two periods and farms as well. This implies that few insects were shared when we came to farms away from the forest in both periods. Also, this could mean there were limited resources for these insect or there were natural enemies that might lead to the limited insect sharing in these period and farms.

Family of Insects that Visit Cashew during Flowering and Fruiting Periods

Insects' family contribution to cashew during the flowering and fruiting periods shows the different kinds of insect families that dominate in both periods. This might indicate that depending on the resource available at the time will depend on the kind of insect family that will contribute much or less species.

Meanwhile, there were some particular insect families which were found in all the two periods (flowering and fruiting). During the flowering period the following insect families were collected, identified and documented: Formicidae, Coreidae, Apidae, Acrididae, Cerambycidae, Mantidae, Pentatomidae, Gracilariidae, Tettigoniidae, Cetoniidae, Bostrychidae, Buprestidae, Meloidae, Galerucidae, Lycaenidae, Halictidae, Megachilidae, Sphecidae, Pyrgomorphidae, Tetrigidae and Aphididae.

With this, the family Formicidae contributed high number of insect species with 3.6% in both farms close and farms away from the forest reserve. This indicates that, the family Formicidae were either nectarivorous, pollinators, scavengers or honeydew suckers.

Therefore, the presence of nectar or pollen on the flowers will draw all the kinds of different insect species to the plant. Also, may be the presence of some Homoptera species which may be said to be producing honeydew could also attract some of these insect families too to the plant.

This could also contribute to their (Formicidae) high number in the flowering period, though some of the insect species from this family might be predators some too might be biological controllers. This could mean that, they might be there because of the presence of their enemies (to prey and to scare).

The family Tetterigoidae contributed less during the flowering period and similarly this might be that there were some species that might be preying on them that lead to their reduction in numbers during the flowering period.

During the fruiting period the same families that were recorded in the flowering period were also recorded. However, the family Pentatomidae

recorded higher number of species with 3.1% in both farms (closer and away from forest reserve). It must be noted that this family is frugivorous as well as a predator and for that matter, it could be deduced that these insects were there because of the presence of either the smell of fermented fruits, yeast or the colour of the fruits and also, they may be there because their prey were attracted to the fruits hence their dominance (Abid et al., 2013). It could also be that since they are sap suckers their presences may be of the cashew fruits, nuts or the stem.

Similarly, there might be no predators which prey on these insects family during the fruiting period hence their increment in numbers. Moreover, the family Aphididae contributed less during the fruiting period. This could be that the presence of predators for these insects during the fruiting period preying on them might contribute to the decrease in number.

Also, the family Apidae was the second highest in number with (2.6%) on both flowering and fruiting periods in farms close and farms away from the forest reserve. This is simply because; the family Apidae are insects that depend much on pollen and nectar for their survival.

In addition, they can also roam everywhere within their vicinity in search of resources. This is similar to Garibaldi et al. (2013) who reported about pollination syndrome as insects that visit flowers are the same that visit fruits. They emphasized that the family Apidae pollinates the flowers through their search for pollen and nectar and during the fruiting period, they can get a different supplementary food resources like juice from the rape fruits to depend on when the flowers are not in session. This association can be

described as mutualism because both the family Apidae and the cashew plant benefits without harming each other.

Some Major Activities of Insects Observed during Flowering and Fruiting Periods in the Cashew Orchard

In the cashew orchard, insects visits cashew plant because of a particular resource which may attract them to the plant. Others visits cashew in search of pollen and nectar, some goes there to prey on other insects yet some others are there to protect some insects from predators and in turn get what they want. For example, some ants protect mealybugs from predators and also collect honeydew secreted by the mealybugs. This brought about insects categorizations into three different set.

Commensalism, antagonistic and mutualism as mentioned in (Archer & Pyke 1992). Therefore, insects are spread on the plant parts depending on where each resource needed is located on the cashew plant. During the flowering season insects that visit the plant goes there for the resources attached to the flowers and during the fruiting they go there because of the resources attached to the fruits. This supports the study conducted by Archer & Pyke (1992), he states that flowers and fruits visitors are documented in a mutualistic and antagonistic insect-plant system as during the flowering period both plant and insects benefit from each other. Meanwhile, antagonistic because during the fruiting period the insect only benefit from the plant but at end destroy the fruit either through feeding or piercing holes on the fruit with their ovipositor to lay eggs inside the fruit.

During the flowering period, a greater number 33% of insect's species were found on the cashew leave foliage. We observed that insects found on the

leave foliage were feeding on the young foliage and inflorescence of the cashew and some were also observed undertaking predating and feeding on their booties during these periods.

Similarly, during the fruiting period, higher number 47% of the insects were found to be on the leaves. It must still be noted that, not all insects that visit the cashew during the flowering and fruiting periods go there because of the flowers or the fruits but for other resources they could derive during these periods.

During the flowering and fruiting periods, there were some predators, leave miners, flower feeders, fruits feeders, fruits piercers and so many other activities goes on by these insects in the cashew orchard. For example, during the flowering period were predominantly observed and recorded rating from the highest to the lowest. Insect species found sucking saps on older and flushing shoots, insect species mining leaves, those that were found (predators) attacking nymphs of flying insects e.g. Mirids, insect species found collecting pollen and nectar on flowers, insect species found carrying debris and remnants up and down the cashew plant. There were few insect species noticed collecting honeydew from the secretion of some Homoptera species (mealey bugs) and also observed girdling around the trunk and twigs of the cashew tree and this activity was found to be more dangerous to plant health .

In the fruiting period the following observations were also recorded as major activity. There were so many different insect species noticed to be sucking juice from the fruits, mining leaves and preying. There were of them noticed sucking sap from the cashew leaves, nuts and stem then those that were found girdling and harvesting honeydew respectively.

In previous studies conducted in Ghana by(Dwomoh, 2008), in Nigeria by (Eguagie 1972) in Cote d'ivoire, Guinea Bissau and in Guinea by (Topper et al 2001) recorded the same insects.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Field survey was conducted in ten farms in the Northern Region from December 2014 to April 2015 to collect, identify and access insects distribution on cashew farms close to natural forest and close to agricultural farm land, during the flowering and the fruiting periods of cashew. There has been scant research documentation on this area of study. Some hypothesis was tested to see if the natural forest or agricultural farm land has significant influence on insect distribution in the cashew orchard, whether the activities of insects during the flowering and the fruiting periods were the same.

Five farms close to the forest and five farms close to the agricultural lands. Four plots measuring 20 m x 25 m were established in each of them. Insects that were found on the cashew orchard during the flowering and the fruiting periods were identified and counted.

Insects recorded in the farms close to the forest during the flowering period was 6161 with a mean of 1232.2 (SD=250.7, N=40) Density of insects was found to be 6161/ha in the farms close to forest, which comprises 46 different species belonging to 20 families and 6 orders. The local conservational status of insects species occurrence was access and calculated. The following were the results: 77% of insects species were classified abundant, 13% were classified common and 10% were classified rare.

Insects recorded in the five farms away from the forest was 4665 with a mean of 933 (SD=143.5, N=40). The density of insects were found to be 4665/ha comprising 41 species belonging to 22 families and 7 orders. The local

conservational status of insects was also access and calculated with the following results: 94% of insect species were classified abundant and 6% classified common.

Total number of insect species recorded in farms close to the forest during the fruiting period was 2745 with a mean of 549 (SD=103.2, N=40) insects per plot. Density of insects was 2745/ha. In the five farms away from the forest total insect species was 2056 with a mean of 411.2 (SD=52.1, N=40) species per plot. Density of insects was 2056/ha and diversity was 3.14.

The local conservational status of insect species occurrence was access and calculated. The following were the results: 82.7% of insect species were classified abundant, 17.3% classified common. In the five farms away from forest the following were the results: 89.2% of insect species were classified abundant and 10.8% were classified common.

The difference between the diversity of insects in the flowering and fruiting periods were highly significant ($t= 11.148, p < 0.001$).

Insect activities during the flowering period were different from the fruiting period except few which were performing the same activities. For example, frugivorous and nectarivorous insects were performing different activities while predators, leaf miners and tree girdlers were performing the same activities during the flowering and fruiting periods.

Conclusions

Based on the results of the study, the following conclusions were made: The study revealed a number of insects that visit cashew during the flowering period from the orders Hemiptera, Lepidoptera, Coleoptera, Dictyoptera, Hymenoptera, Orthoptera and Diptera. During the flowering

period, insects encountered in farms close to the forest were 6161 comprising 46 different species belonging to 20 families and 6 orders. In farms away from the forest reserve, 4665 individual insects were identified also comprising 41 species belonging to 22 families and 7 orders during the flowering period.

During the fruiting period, the same orders occurred except the order Homoptera. Insects encountered and recorded in farms close to the forest were 2745, which comprises 48 different species belonging to 21 families and 6 orders. While in farms away from the forest insect recorded were 2056 comprising 55 species belonging to 22 families and 7 orders.

The density of insects on cashew farms during the flowering period in farms close and away from the forest was higher than that of the fruiting period. In terms of diversity, insect species were lower in the flowering period than the fruiting period in farms close to forest and farms away from the forest.

On the local conservational status of insect species occurrence, most of the insects were ranked either as abundant or common in the flowering and fruiting periods just a few were classified rare only in the flowering period.

During the flowering period, the family Formacidae recorded high number of species with the family Terigodae recording less number of species in the flowering period. The family Pentatomidae recorded high number of insect species during the fruiting period and the family Aphididae recorded less during the fruiting period.

The activity of insects on cashew differs during the flowering and fruiting seasons. Insects were found on all parts of the cashew plant with different activities, some were found on the leave foliage, nuts, flowers, fruits,

and leaves performing different functions. Foliage feeders were feeding on fresh foliage, sap suckers were sucking sap from the nuts, pollen seekers collecting pollen from flowers, fruits feeders also feeding on fruits yet predators were also attacking their prey. Some of the insects carried out their functions on the flower in order to enhance their survival when the flowers are no more in season and all these activities show that, the natural forest or the agricultural farms land has no influence on the insects on the cashew orchard. It was observed that some insects were mostly found on matured seed during the flowering period but during the fruiting period none was found on the matured seed.

Recommendations

The following recommendations were made:

1. Further studies should be conducted throughout the year in order to differentiate resident insects from insects that were attracted to the plant because of the flowers and fruits.
2. Further studies should be conducted with laboratory test to determine nutrients content in insects that visit cashew during flowering and fruiting periods.
3. Integrated pest management strategy should be adopted by farmers to manage insects, because not all insects seen during the flowering and fruiting periods might be harmful to the plant.
4. Insect's conservation should be integrated into the national biodiversity conservation policy and implemented; emphasis should be made on insects that visit the cashew orchard.

5. Studies should be conducted to find out why insects are found on mature seed during the flowering period.

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APPENDIX 1

Detailed calculation of Turnover Index

Calculation of turn over index

$$\text{Turn over index} = 1 - [c (T_1 + T_2) / 2T_1 T_2]$$

Where C = Number shared between the sites

T_1 = Number of species at site 1

T_2 = Number of species at site 2

$$\text{TI} = 1 - [23(47+29)/247 \times 29]$$

$$\text{TI} = 1 - [22(44+29)/244 \times 29]$$

$$\text{TI} = 1 - [23(76)/2(1363)]$$

$$\text{TI} = 1 - [22(73)/2(1276)]$$

$$\text{TI} = 1 - [1748/22726]$$

$$\text{TI} = 1 - [1606/2552]$$

$$\text{TI} = 1 - 0.641$$

$$\text{TI} = 1 - 0.629$$

$$\text{TI} = 0.36$$

$$\text{TI} = 0.37$$

$$\text{TI} = 36\%$$

$$\text{TI} = 37\%$$

$$\text{TI} = 1 - [0(29+29)/29 \times 29]$$

$$\text{TI} = 1 - [6(41+47)/41 \times 47]$$

$$\text{TI} = 1 - [0(58)/2(841)]$$

$$\text{TI} = 1 - [6(88)/2(1927)]$$

$$\text{TI} = 1 - [0/1682]$$

$$\text{TI} = 1 - [528/3854]$$

$$\text{TI} = 1 - 0$$

$$\text{TI} = 1 - 0.137$$

$$\text{TI} = 1$$

$$\text{TI} = 0.86$$

$$\text{TI} = 1\%$$

$$\text{TI} = 86\%$$

$$TI = 1 - [18(41+29)/41 \times 29]$$

$$TI = 1 - [18(70)/2(1189)]$$

$$TI = 1 - [1260/2378]$$

$$TI = 1 - 0.521$$

$$TI = 0.47$$

$$TI = 47\% \quad TI = 57\%$$

$$TI = 1 - [25(41+47)/41 \times 47]$$

$$TI = 1 - [25(88)/2(1927)]$$

$$TI = 1 - [2200/3854]$$

$$TI = 1 - 0.57$$

$$TI = 0.57$$

$$TI = 1 - [19(47+29)/47 \times 29]$$

$$TI = 1 - [19(76)/2(1363)]$$

$$TI = 1 - [1444/2726]$$

$$TI = 1 - 0.53$$

$$TI = 0.47$$

$$TI = 47\%$$

$$TI = 1 - [25(41+29)/41 \times 29]$$

$$TI = 1 - [25(70)/2(1189)]$$

$$TI = 1 - [1750/2378]$$

$$TI = 1 - 0.73$$

$$TI = 0.27$$

$$TI = 27\%$$

$$TI = 1 - [22(48+29)/48 \times 29]$$

$$TI = 1 - [22(77)/2(1392)]$$

$$TI = 1 - [1694/2784]$$

$$TI = 1 - 0.61$$

$$TI = 0.39$$

$$TI = 39\%$$

$$TI = 1 - [26(29+29)/29 \times 29]$$

$$TI = 1 - [26(58)/22(841)]$$

$$TI = 1 - [1508/1682]$$

$$TI = 1 - 0.90$$

$$TI = 0.1$$

$$TI = 1\%$$

