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The effect of pollinators and pollination on fruit set and fruit yields of okra (*Abelmoschus esculentus* (L) Moench) in the forest region of Ghana.

BY

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SEPTEMBER, 2012

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BY

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SEPTEMBER, 2012

DECLARATION

I hereby declare that this submission is my own work towards the MSc. Degree and to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the Kwame Nkrumah University of Science and Technology or any other university, except where due acknowledgement has been made in the text.

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(Head of Department) Signature Date

DEDICATION

This thesis is dedicated to my parents Mr. and Mrs. Angbanyere Kyemuo of blessed memory who passed away 26 and 10 years ago respectively for their love and tender care given to me during my primary and secondary school days and my daughter Carolina Angbanyere who did not receive the full fatherly care during the period I was undertaking this research.

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ABSTRACT

The indiscriminate application of chemical insecticides on crops has resulted in reduction of the numbers of beneficiary insects which provide pollination services. The reduction in pollination services has led to reduction in crop yields of which okra is no exception. This study investigated the effect of pollinators and pollination on the reproductive performance of okra (*Abelmoschus esculentus* (L) Moench). The experimental design used was the randomized complete block design (RCBD) involving three treatments with three replications. The Statistical Analysis System (SAS) using the General Linear Module procedure was used to analyze the data. The treatments were control, insecticide application and net covering. The parameters studied were the number of flowers per plant, number of aborted flowers per plant, number fruits per plant, yield per plant, number of seeds per pod and number of honeybee visitation in a day. The results indicated no significant differences ($p > 0.05$) in number of flowers per plant and number of aborted flowers per plant but significant differences ($p < 0.05$) were shown in the number of pods harvested per plant, yield per plant and number of seeds per pod. The bee visitation also showed significant differences between treatments. The number of aborted flowers did not show significant difference but very high abortion rates were recorded in all the treatments with figures as 40%, 43% and 51% for control, insecticide and net respectively for the major season and 41%, 41% and 50% in the same order for the minor season. The study indicated that insect pollination helps to improve the yield in okra. I therefore recommend the use of bee hives in future research in order to determine the real potential of insect pollination in the yield of okra.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
API	African Pollinators Initiative
CNRS	Natural Resources Conservation Service
CSIR	Centre for Science and Industrial Research
EC	Emulsifiable Concentrate
ESA	Ecological Society of America
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization the United Nations
GLM	Global Linear Module
GMO	Genetically Modified Organisms
INRA	French National Institute for Agricultural Research
KES	Kenyan Shilling
MABES	Mobile agent-based ecosystem services
NARP	National Agriculture Research Project
No.	Number
NPK	Nitrogen, Phosphorus, Potassium
Pt	Plant
SAS	Statistical Analysis System
SNK	Student's Newman Kuel's
UFZ	Helmholtz Centre for Environmental Research
UNEP	United Nations Environmental Programme
US	United States
US$	United States Dollar
USA	United States of America
USDA	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND

Okra (*Abelmoschus esculentus* (L.) Moench) is a member of the family Malvaceae. It is an annual fruit vegetable crop grown in tropical and subtropical parts of the world. Although okra is primarily a rain fed crop, it also does well under irrigated conditions during the dry season (Pushpalatha, 2008). It is primarily a garden vegetable plant, grown for its immature fruits, which are consumed when cooked either alone or in combination with other foods (McGregor, 1976).

The green tender fruits of okra are highly nutritious, containing 107 mg of calcium and 8.9 mg of Iron for every 1000 g edible portion and fair amounts of vitamins A, B and C. It is also rich in protein and crude fibre (Sona Thampi and Indira, 2000). The fruits are very mucilaginous and are used to thicken soup (Vickery and Vickery, 1979). The immature okra pods are used in soups, stir-fries, and stews. Recently attention has been given to the use of okra seeds as a source of proteins (about 20% of dry matter) and vegetable oil (about 14% of dry matter) [Martin and Rhodes, 1983]. Seeds contain mainly monounsaturated fatty acids (oleic) and palmitic acid (Martin and Rhodes, 1983) and have high lysine level (Al-Wondawi, 1983). Sometimes, the seeds are roasted and used as a substitute for coffee and dried fruits are ground into powder, stored and used in stews and soups (Siemonsma, 1982). Okra seeds are reportedly used as substitutes or additives in feed compounds

(Purseglove, 1974), in the preparation of okra seed meal and a number of baked products (Martin and Roberts, 1990) and in blood plasma replacement (Vickery and Vickery, 1979). Apart from its nutritive value the stem and fruit sheath are used in the manufacture of paper as they contain some crude fibre (Sharma and Arora, 1993). In Ghana, it is the fourth most popular vegetable after tomatoes, pepper, and garden eggs (Sinnadurai, 1973). The world okra production, as of 2007, was estimated at 4.8 million tons with India leading the production by 70% followed by Nigeria (15%), Pakistan (2%), Ghana (2%), Egypt (1.7%) and Iraq (1.7%) (Gulsen *et al.*, 2007). In West Africa, okra ranks second in vegetable production after tomato (Anon, 2002). Brong Ahafo, Ashanti, Northern, Volta, Greater Accra and Central Regions are the bulk producers in Ghana (NARP, 1993). About 10 - 15 t /ha of yield can be obtained under good management (NARP, 1993). Okra is a vegetable which one finds in a fresh state in almost all markets in Ghana, during the rainy season and in a dehydrated form during the dry season, particularly in Northern Ghana due to its strong commercial value for poor women farmers and its vital importance as food diet among the inhabitants of the cities and villages (Oppong-Sekyere *et al.*, 2011).

Well drained sandy to clay soils supplied with enough organic matter are good for okra cultivation. However, loose, friable and well-manured loam soils with the pH range between 6.0 - 6.8 are the best. Being a warm season crop it is susceptible to cold and frost. It thrives well during warm, moist season although it grows fairly well in the hottest summer. The seeds do not germinate below 17°C. Okra flowers drop at 42°C day temperature (Chauhan, 1972). Mbagwu and Adesipe (1987) reported the greatest reduction (70%) in yield when stress was imposed at flowering and pod filling stage. Welby and McGregor (1997) observed an improvement in the performance of okra when rainfall was about 750 mm, evenly distributed and relative humidity was between 90-95%. However, low temperatures of 28.9 ^{o}C-29.2 ^{o}C (maximum) and 17.9-19.8 ^{o}C (min) and short day-lengths of 5.2-5.7 hrs resulted in a largest number of flowers (Thamburaj, 1972).

Many fruit vegetables require some cross pollination by insects and other arthropods for effective fruiting and high yields. Where insect associated pollination is not achieved, yields achieved may only reflect that proportion that is mediated by selfing or pollination by other means. This indicates that, although self-compatible plants do not require outcross pollen for fertilization, they often produce more seeds and/or larger fruits (Greenleaf and Kremen, 2006), more vigorous offspring (Marshall, 1991) and/or show greater transformation into the next generation when cross-pollinated (Herrera, 2000).

Flowering plants and their pollinators started co-evolution about 225 million years ago (Price, 1975). As early as 800 B.C, stone carvings and bricks from the palace of Assyrian kings depict the significance of pollen and pollination of fruits that pollination enhances quality and yield of seeds and fruits (Thapa, 2006). Lack of sufficient number of suitable pollinators causes decline in fruit and seed production (Partap, 2001). Of the total pollination activities, over 80% is performed by insects, and bees contribute nearly 80% of the total insect pollination, and therefore, they are considered the best pollinators (Robinson and Morse, 1989).

Another value of pollination lies in its effect on quality and efficiency of crop production. Inadequate pollination can result not only in reduced yields but also in delayed yield and a high percentage of culls or inferior fruits. Insect pollination is so important that the grower may fertilize, and cultivate the soil, prune, thin and spray the trees, in a word, he may do all of those things which modern practice advocates, yet without his pollinating agents, chief among which are the honey bees, to transfer the pollen from the stamens to the pistil of the blooms, his crop may fail (Belize Ag Report, 2010).

Okra is self-fertile, and when the anthers come in contact with the stigmas, self pollination may result; however, cross-pollination also occurs. It is freely visited by honey bees and bumble bees, but the value of insect pollinator visitation is unknown (McGregor, 1976).

In okra, there is a positive correlation between the number of seeds in a pod and its weight, and insect pollination increased the number of seeds present in a pod (Free, 1976). Nineteen percent increase in yield in Punjab, India, was reported by Tanda (1984, 1985) due to intensive bee pollination. Mishra *et al.* (1987) found that the weight and length of capsules and seed number per capsule were significantly higher in open pollinated than in bagged flowers. Azo'o *et al.* (2011) reported that the mean number of matured seeds is higher in open-pollinated plants and smaller in self-pollinated plants.

However, the knowledge of farmers in pollination is limited: many farmers lump pollinators together with insect pests, and do not explicitly manage to conserve them, although pollinators may contribute substantially to yields at no cost to the farmer. In Ghana, farmers would appreciate more extension information on pollination services in order for them to understand the importance of insect pollinators in yields of farm crops (API, 2007). However, little or no study has been done in Ghana on the contribution of pollinators to the yield of okra especially in the forest region of Ghana.

Cane and Tepedino (2001) advocate that if pollinators are in decline it should be possible to measure the results of their absence as reductions in fruit or seed production in natural or agricultural ecosystems. This study therefore sought to determine the effect of pollinators and pollination on reproductive performance (flower set, fruit set, fruit yield and fruit quality) of okra cultivated in the forest region of Ghana.

1.2. OBJECTIVES

The main objective of the study was to study the effect of pollinators and pollination on the reproductive performance (flower set, fruit set, fruit yield and fruit quality) of Okra cultivated in the forest region of Ghana.

1.2.1 The specific objectives were to:

- determine the effect of caging on the reproductive performance of okra.
- assess the effect of insecticides on the insect pollinators.
- evaluate the flower abortion rates in the various treatments.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 The mechanics of pollination

Pollination is the movement of the male gametes in plant pollen to female gametes of the same species, which leads to sexual reproduction if fertilization (fusion of the male and female gametes) occurs. Sexual reproduction ensures mixing of genes, which does not occur when plants propagate themselves through asexual means, such as budding or division. Abiotic factors such as wind (anemophily) and water (hydrophily), aid pollination, but insects and other animals (biotic pollination) provide the vast majority of terrestrial plant pollination (Adamson, 2011). Pollination occurs in two different ways, either cross or self pollination.

2.1.1. Cross-pollination

This is the transfer of pollen from the anther of a flower to the stigma of a flower on another plant of the same species. A plant is cross-compatible if it can normally be pollinated with pollen of another cultivar, but it is cross-incompatible if it is not receptive to pollen of certain cultivars (Mcgregor, 1976).

According to Shrestha (2008) not only the self-sterile varieties require cross-pollination, but also the self-fertile forms need it by means of which they are able to produce more and better quality seeds and fruits if pollinated preferably by honeybees or by other insects. For example, Kasina (2009) reported that beans and cowpeas usually have about 17% and 23% protein content when not pollinated by the carpenter bees but when pollinated, the protein content increases to 19% and 25% respectively. Sunflower oil content increases from 35% to 45% after pollination by honey bees while well pollinated melon and butternut is large, sweeter and juicy. According to Gustafson and Bergh (1966) cross-pollination is necessary for the best setting of fruit in avocados.

2.1.2. Self-pollination

This is the transfer of pollen from an anther to a stigma of the same flower or to the stigmas of flowers on the same plant. A plant is said to be self-fertile or self-compatible if it can produce fruits without the need for the transfer of pollen to it from another cultivar so that no interplanting of cultivars is necessary (Snow *et al*., 1996). Such a plant may not necessarily be self- pollinating. An external agent, such as the wind or insects, may be necessary to transfer the pollen from the anthers to the stigma within the flower or between flowers on the same plant (Mcgregor, 1976). If the plant is not receptive to its own pollen, it is self-sterile. Even self-pollinating plants are frequently benefited by cross-pollination, the transfer of pollen from one flower to another. They may also benefit from having the pollen more thoroughly transferred and distributed over the stigma at the most receptive period (Mcgregor, 1976).

2.2. Ecosystem services of insects

Ecosystem services are functions provided by nature that improve and sustain human wellbeing (Daily, 1997). Some ecosystem services, such as pollination, pest control and seed dispersal, are produced on a local scale by mobile animals foraging within or between habitats (Gilbert, 1980; Lundberg and Moberg, 2003; Sekercioglu, 2006). These are called mobile agent-based ecosystem services (MABES). Although these mobile organisms deliver services locally, their individual behaviour, population biology and community dynamics are often affected by the spatial distribution of resources on a larger landscape scale. Managing mobile animals and the services they provide therefore requires considering not only the local scale where services are delivered, but also a landscape scale that reflects both the spatial distribution of resources and the foraging and dispersal movements of the animals themselves. MABES have both direct (immediate) and indirect (via other ecosystem services) values, corresponding respectively, to their regulating and supporting roles (Millennium Ecosystem Assessment, 2005). For example, the direct (regulating) value of pollination services to humans is the marginal increase in production of market-based or subsistence crops, fibre, forage, timber and non-timber forest products (e.g. firewood, medicinal products and wild fruits) resulting from animal pollination. For example, Azo'Ela *et al.* (2012) conducted studies on the importance of a single floral visit of *Eucara macrognatha* (Gerstaecker) and *Tetralonia fraterna* (Hymenoptera: Apidae) in the pollination and the yields of *Abelmoschus esculentus* and found that the mean number of aborted seeds differed with the treatments; it was higher in the fruits from flowers that were isolated for autonomous self-pollination than those that received a single visit of *T. fraterna* and *E. macrognatha*. The indirect (supporting) value is the marginal increase, due to animal pollination, in reproduction of wild plants that play a role in other ecosystem services.

Losey and Vaughan (2006) estimated the value of ecosystem services provided by insects at $57 billion. These services included dung burial, pollination, wildlife nutrition and pest control.

Pollinators provide an essential ecosystem service, namely pollination. Approximately 80% of all flowering plant species are pollinated by animals, including vertebrates and mammals - but the main pollinators are insects (FAO, 2011). Wuver and Attuquayefio (2006) reported that, the important roles of wildlife in the ecosystem food web as pollinators, predators, seed dispersers or prey species of other animals did not seem to have been appreciated by a majority of the local people in Ghana.

2.3. Knowledge of pollination in Ghana

API (2007) reported that, interviews with farmers, extension agents, and agricultural lecturers in Ghana indicated that all of these groups are aware of pollination and pollinators, to varying degrees. All respondents agreed that pollination is important in agriculture and that the absence of pollination will not result in fruit and seed formation. Only a few believed that plants can reproduce vegetatively. Eighty-three percent of the respondents thought that crop yield increases when flowers are sufficiently pollinated. But ninty-three percent of people sampled thought that humans have a major role to play in ensuring adequate pollination and only a few understood that it is a natural ecosystem service that should be allowed to go on unaided (API, 2007). With respect to pollinators, most of the farmers said, according to the study, that they left any insect found on plants during flowering not because they really understand their role but they think bees provide honey for medicinal purposes and also form part of God's creation and must be left alone. A few farmers however claimed that they sprayed bees found on their crops for fear of attack. The report indicated that extension agents had more knowledge on pollination: for example, 75% of Agricultural agents thought that pollinators need to be protected from sprays compared to 31% of farmers who think the same. According to the report, farmers felt that the Ministry of Agriculture had done little or almost nothing to promote the awareness and occurrence of pollination and the need to protect the service (API, 2007).

A number of studies however, have taken place on the type of pollinators for certain crops and the efficiency of pollination of these pollinators. Mensah and Kudom (2011), reported that *Xylocopa olivacea* was more efficient in the pollination of *Luffa aegyptiaca* than *Apis mellifera* in terms of number of fruit set per single visit. Kudom and Kwapong (2010) also indicated that pollination is not required for fruit set in *Ananas comosus* L.

2.4. Pollinator behaviour and plant mating patterns

Flowering plants cannot directly control gamete receipt or export. Instead, nearly three-quarters of Angiosperms rely on animal vectors to move pollen among flowers (National Research Council, 2007), a form of indirect control mediated through pollinators. The resulting patterns of pollen dispersal often reflect pollinator foraging behaviour, and may not optimize the quality or quantity of matings (Campbell and Dooley, 1992). For example, foraging pollinators typically move short distances between flowers, often visiting neighbouring plants (Levin and Kerster, 1969) and probing several flowers in sequence on multi-flower displays (Robertson, 1992). These foraging behaviours have important implications for plant mating. Short pollinator flights may limit the extent of pollen-mediated gene dispersal, influencing the genetic structure of populations (Turner *et al*., 1982), neighbourhood size (Levin and Kerster, 1968; Crawford, 1984; Levin, 1988), and the frequency of bi-parental inbreeding (Ellstrand *et al*., 1978; Griffin and Eckert, 2003). For example, Azo'Ela *et al.* (2012) reported that the number of matured seeds per pod and the mean length of fruits were higher in the flowers that received a single visit of *E. macrognatha* than those that received a single visit of *T. fraterna* and those that were isolated for autonomous self-pollination in okra.

In self-compatible species the tendency of pollinators to visit several flowers in sequence on a single plant also increases the opportunity for geitonogamous (among-flower) self-pollination and a resulting increase in the selfing rate (Harder and Barrett, 1995, 1996; Snow *et al*., 1996; Karron *et al*., 2009). In self-incompatible species, geitonogamous pollination can reduce seed production if self-pollen clogs stigmas, interferes with outcrossed pollentube growth, usurps ovules, or increases fruit abortion, and can reduce siring success through pollen discounting (Snow *et al*., 1996).

2.5. Economic value of pollination services

In agriculture, pollination is an important input of crop production, comparable to any other input such as fertilizer, labour or pesticides. The best management practices of pollinators in crops mean best economic value. Costanza *et al*. (1997) estimated the value of pollination at US$ 120 billion annually for all ecosystem pollination services. Richards (1993) stated a value of US$ 200 billion for the role of pollination in global agriculture alone.

French scientists and a UFZ German scientist found that the worldwide economic value of pollination service provided by insect pollinators, bees mainly was €153 billion (217 billion US dollars) in 2005 for the main crops that feed the world. This figure amounted to 9.5% of the total value of the world agricultural food production (Helmholtz Association of German Research Centres, 2008). Estimates vary in large measure because different underlying approaches were used for establishing values. For example, Muth and Thurman (1995) stated that the value of commercial pollination services is the amount farmers pay to beekeepers to rent bees, and critisized other studies for inflated estimates of pollination service values.

Kasina (2009) saw pollination to be a goldmine for both Kenyan families and the country's economy. He reported that farmers growing beans would harvest 60 bags but if they provide their beans with carpenter bees during the flowering period, they will get additional 40 bags. Those growing sunflower will harvest 43 bags but get additional 57 bags if honeybees visit their flowers when in bloom. Farmers who grow cucurbits such as melon and butternut will harvest nothing if they do not have honeybees. He also stated that 10% (KES 19 billion) of the value of crop production in Kenya in 2005 was due to pollination by insects. Kenya in 2001 reported US $ 200 billion as the direct gain from pollination of crops (Kasina, 2009).

Crop pollination by honeybees (*Apis mellifera*) alone is estimated to be €4.25 billion per year in Europe (Luig *et al.*, 2005). About 30% of the food consumed by humans is derived from pollinated crops (O'Toole 1993), and thousands of wild plants depend on the services of bees for seed and fruit formation. In many crop plant species, the honey bee (*Apis mellifera*) seems to be the main pollinator insect (Klein *et al*., 2007). Thus reduction in the abundance of bees could have serious implications for both natural and agricultural ecosystems.

2.6. Contribution of insect pollinators to increase in yield

Insects are viewed from the harmful perspectives and are usually being killed through several means including indiscriminate use of deadly chemicals. Insects are important component of the ecosystem and their beneficial aspects are immense. In fact, pollinators such as bees, birds and bats affect 35 % of the world's crop production, increasing outputs of 87 of the leading food crops worldwide, as well as many plant-derived medicines (FAO, 2011). Some commercial plants, such as almonds or blueberries, do not produce any fruits without pollinators. For many, a well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit. Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruits to pests, diseases, bad weather, agro-chemicals and reduction in the quantity of water used in irrigating farms (UNEP, 2010). A significant reduction in the pollinating force may have serious effects on fruit and seed set in insect-pollinated flowers which are in bloom at, or shortly after, the time of spraying (Miliczky and Osgood, 1979). In nature, many wild plant populations are 'pollen-limited', meaning that untreated individuals set fewer fruits or seeds than experimental plants supplemented with cross-pollen (Burd, 1994; Ashman *et al.*, 2004).

Manzoor-ul-haq *et al.* (1978) in their investigation on the effect of insect pollinators mostly *A. dorsata* and *A. florea* on fruit bearing in kinnow mandarin (*Citrus reticulate* L) found significantly more fruit set and matured on branches accessible to insect pollinators than from where insects were repelled or excluded. Effects on fruit size and the number of seeds were also significant. Abrol (1989) in his studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality revealed that the percentage of fruit set and well formed fruits were much higher in open pollinated plants as compared to those where pollinating insects were not allowed access.

Kitroo and Abrol (1996) conducted studies on abundance, diversity and importance of native pollinators for fruit production in litchi (*Litchi chinensis* Sonn.), and found that honeybees *Apis dorsata*, *A. mellifera*, *A. cerana*, and *Apis florea* were the most important and efficient pollinators. According to them insect pollination was responsible for the increase in fruit production and fruits resulting from open pollination were significantly largest in size and weight.

In the developed countries, insect pollination has increased considerably during the past few decades and arrangements for insect pollination are now part of standard management practices when growing many crops. For example, in the USA alone, over one million honeybee colonies are rented annually for pollination services and that the feral Africanized bees increased coffee production in Central America (Thapa, 2006; Roubik, 2002). In coffee plantation, De Marco and Coelho (2004), in Brazil, found that the farms near forest fragments had an increase of 14.6% in production, that could be related to pollinating services; Ricketts (2004) and Ricketts *et al.* (2004) pointed out the importance of tropical forest fragments to enhance pollinator's activity in nearby coffee crops. The self-pollinated crop species occupy less than 15% and the remainders are cross-pollinated crops that need help of pollinating agents like wind, water or insects for fertilization. Even self-pollinated crops benefit from insect pollination because pollinated crops produce higher yields with good quality seeds showing their hybrid vigour without any desertion in the innate properties of fruits and seeds (Thapa, 2006). Addition of honey bees increased fruit number per hectare of C. *moschata* and C. *maxima* cultivars of pumkin. Honey bee pollination resulted in larger-sized fruit, increasing individual fruit size of all but small-sized pumpkins. Individual pumpkin fruit weights of the *Cucurbita pepo*, C. *moschata*, and C. *maxima* cultivars evaluated, increased by about 26%, 70%, and

78%, respectively, when honey bee colonies were included (Walters and Taylor, 2006). On the contrary, Azo'Ela *et al.* (2012) reported that each flower of okra turned into fruits regardless of the treatment received.

2.7. Effect of human activities on insect pollinators

Human activity, based on the assumption that pollination is a free and abundantly available ecological service, has put a large pressure on pollinators by both increasing their demand and removing their habitat (FAO, 2011). Biodiversity, therefore, is being exploited at much faster rates than ever before with negative implications for sustainable human livelihood (Turner *et al.*, 1990).

Changing fire and grazing regimes are putting increased pressure on many plant-pollinator communities, especially around the Mediterranean. More frequent fires (Potts *et al*., 2003) and excessive grazing (Kreuss and Tscharntke, 2002) can lead to habitats supporting fewer pollinators. The extensive agricultural activity of coastal meadows and increasing summer cottage building and leisure activity on the dune areas along the coastal areas of Finland affect wild bee populations (Soderman and Leinonen, 2003).

Kasina (2009) also reported that some of the farm activities that affect pollinators include lack of hedges (to provide food and shelter), use of pesticides (which eliminates their food or kills them directly) and lack of safe sites for them to dwell.

According to Thapa (2006), the manmade agro-ecosystem exerted pressure and forced to reduced pollinators and their diversity, which resulted in reduced agricultural productivity. The economic gains due to beekeeping and agricultural pollination might be reduced by intoxication of colonies with pesticides (Desneux *et al*., 2007). Excessive use or inappropriate application of pesticides is known to have negative impacts on a range of pollinators (Batra, 1981; Kevan, 1975; O'Toole, 1993). A study conducted in eastern Canada indicated that, blueberry production, which depends largely on pollination by as many as 70 species of native insects, failed in 1970, and subsequent years, because of aerial spraying of fenitrothion (Kevan , 1991). A report by Wuver and Attuquayefio (2006) indicated that major human activities that impact on the biodiversity are bushfires, hunting, fuelwood harvesting and farming.

Luig *et al*. (2005) classified the most significant pressures on pollinators and pollinator services into five groups: land use practices, agrochemicals, parasites and diseases and introduction of genetically modified organisms (GMO) plants and invasive species. Consequently, for several decades, bee researchers and beekeepers have tried to conserve pollinating insects like honeybees providing nesting sites and good forage, and protecting them from pesticides (Thapa, 2006).

2.8. The decline in pollinator activities

The decline in biodiversity results in decline in pollinators. About 75% of the genetic diversity of agricultural crops lost since the beginning of 20th century from the earth and 25% of the world's species present in the mid 1980 will be lost by 2015 (Thapa, 2006).

Concerns about the loss of pollinators and the services they provide have grown over the last decades (Allen-Wardell *et al*., 1998; Kearns *et al*., 1998), but relatively little information exists on the status of pollinators or of pollination function. These concerns are warranted, based on recent evidence of declines at local or regional scales (Larsen *et al*., 2005; Biesmeijer *et al*., 2006) and evidence for elevated extinction rates across all taxa (Dunn 2005; Millennium Ecosystem Assessment 2005). In addition, declines in abundance of the most important commercially managed crop pollinator (*Apis mellifera*) are well documented in the USA (National Research Council of the National Academies, 2006). These declines are due mainly to the establishment of a disease-carrying mite, *Varroa destructor* L, and have led to pollination shortages and price increases for pollination rental fees for selected crops, for example, almond, (Sumner and Boriss, 2006).

Declines in pollinator activity could have serious economic repercussions throughout the world. In 1994, for example, honeybee shortages caused by parasites and pesticides forced almond growers in California to import bees from distant states to ensure adequate pollination of their $800 million crop (ESA, 2008). World Conservation Union predicts that 20,000 flowering plant species will disappear in the next few decades. Significant causes of the declines in flowering plants and pollinators are: habitat loss, fragmentation and modification; agricultural and grazing practices; pesticide use; and the introduction of nonnative species (ESA, 2008).

Among the various human activities undertaken in the coastal wetlands of Ghana, fuelwood harvesting, bushfire setting, hunting, and farming had the greatest impact on biodiversity conservation through degradation of the wetland over the years (Wuver and Attuquayefio, 2006).

2.9. Causes of pollinator decline

Report from USDA (1980) showed that, native pollinators and honey bees are declining in the United States of America. Both are necessary for the health of the environment and for a large proportion of our food production. The numbers of honeybee colonies, both domesticated and feral, have declined by 50 and 70%, respectively, since 1946 (USDA 1980; data from 1980–2001). One of the major factors behind the decline in native pollinators is the increasing loss of pollinator habitat. Pollinators can usually find all that they need for survival when the natural environment is not disturbed. They require food, water, protective cover, and space, as do all animals. Modern agricultural practices often remove pollinator habitat from field margins. Our efforts to clean up the landscape of the cities and suburbs also tend to destroy pollinator habitats (Underhill, 2009). Even natural herbicides and botanical insecticides can harm bees and other pollinators (USDA and NRCS, 2009).

Agriculture increasingly replaces natural plant communities with monocultures, some of which are incapable of sustaining pollinator populations. For instance, grains such as wheat and corn, which are planted every year across 6% of the continental U.S. land area and up to 20% of some midwestern states do not provide for the nectar or pollen needs of any bee species (Cane and Tepedino, 2001). Undocumented acreages of hedgerows, field margins, embankments, and other "waste places" provide nesting habitat for some native bees. Removal of these often unappreciated habitats has been associated with dramatic declines in Germany's native bee fauna since the 1960s (Westrich, 1989). Conversely, retention of some of these features has been associated with persistently rich native bee faunas in some Polish agricultural landscapes (Banaszak, 1995).

Cane and Tepedino (2001) reported that, more than 3% of the U.S. land area has been urbanized converting rich arrays of habitats into highways, houses, strip malls, office complexes, and industrial parks. Urbanization not only removes habitat directly but also isolates and fragments the land that it does not degrade or assimilate. The attributes, extent, and permanency of fragmentation effects for native bee faunas and their flowers, however, are barely understood (Cane, 2001).

Evidence in Ghana has shown that the rate of environmental degradation has increased in recent times (Gyasi *et al.*, 1995), in such a way that previously rich forests are being converted to savanna woodland whilst existing savanna woodlands are being converted into near desert (Hawthorne and Abu-Juam, 1995). It has been estimated that Ghana's high forest area of 8.2 million hectares at the turn of last century had dwindled to about 1.7 million hectares by the mid-1980s (Hall, 1987), and about one million hectares by the mid-1990s (Forest Services Division, 1996). This obviously, leads to the decline of pollinators.

2.10. Life history of honey bee.

Honeybees originated in Tropical Africa and spread from South Africa to Northern Europe and East into India and China (Otis, 1990). The first bees appear in the fossil record in deposits dating about 40 million years ago in the Eocene. Honeybees belong to the order Hymenoptera, superorder Apocrita, infraorder Acuelata, superfamily Apoidea, family Apidae, subfamily Apinae, tribe Apini. There are more than 11 extant species of *Apis* worldwide (Michener, 2000). The genus *Apis* is evidently tropical in origin. It is native to Asia, Africa and Europe including such continental islands as Japan, Taiwan and the Philippines (Seeley, 1985). Perhaps due to high temperature, the native tropical bees generally build their nest as a single air open nest and rely upon aggressive behavior to defend these exposed nests (Collins and Kubasek, 1982). Adult bees are divided into a queen, female workers and male drones. The queen will leave the hive only once to mate with several drones, storing sperm in her spermatheca to last her lifetime. In order to rear and defend the eggs lain by the queen, worker bees develop stinging mechanisms, pollen baskets, dance languages and labor divisions (Tammy, 2008). Younger worker bees tend to the queen, and older worker bees forage, construct wax cells, convert nectar into honey, clean cells and guard the hive. Ideally, a healthy hive is a collection of overlapping generations (Tammy, 2008).

Honeybees are hymenopterans, a group that generally feed on pollen and nectar and constitute about 20,000 species throughout the world, known taxonomically as the superfamily Apoidea (Michener, 2000). The genus *Apis* are the most studied because of their fascinating and complex lifestyle, communication systems (Nieh, 1998; Nieh and Roubik, 1998), role as keystone pollinators of native plants, pollination of agricultural crops, and the valuable hive products that they produce, such as honey, royal jelly, bee wax, bee pollen, propolis and even bee venom. Honey bees are such efficient pollinators that industrialized countries developed specialized agriculture dependent upon migratory pollination and the *Apis mellifera* (Tammy, 2008). In many crop plant species, the honey bee (*Apis mellifera*) seems to be the main pollinator insect (Klein *et al.*, 2007). In India for instance, honeybees *Apis cerana* and solitary bees *Halictus* spp. appeared as the main okra pollinators (Crane, 1991; Free, 1993) and preliminary observations indicated that okra flowers were fully visited by the two wild bee species between 7:00 and 10:00 am (Azo'o *et al.*, 2011).

2.11. Origin and botany of okra

Okra is a native of West Africa (Joshi *et al.*, 1974; Kochhar, 1986). It is grown on a large scale in Africa, especially in the Sudan, Egypt, Ghana and Nigeria. It is also very important in other tropical areas including Asia, Central and South America (Joshi *et al.*, 1974; FAOSTAT, 2008). The Nile Basin seems to have been the route by which this plant spread through North Africa, the Eastern Mediterranean, Asia and to India. Okra reached the new world through Brazil and Dutch Guinea. African slaves brought okra to North America by way of New Orleans (Hamon *et al*., 1990; Bish *et al*., 1995). There are a number of varieties, both wild and cultivated. Some of these are *A. esculentus*, *A. caillei*, *A. moschatus*, *A. manihot*, *A. ficulneus* and *A. tetraphyllus*. The cultivated species in the genus *Abelmoschus* are: A. *manihot* L. and A. *moschatus* L. (Stevels, 1988; Siemonsma, 1991).

Okra is an amphidiploid-having a complete diploid set of chromosomes derived from each parent form (Siemonsma, 1982) with varieties displaying a tremendous variation in plant size, shape, fruit type and colour. Okra plant is a semi woody, fibrous herbaceous annual with an indeterminate growth habit (Nonnecke, 1989). The plants form a deeply penetrating taproot with dense shallow feeder roots reaching out in all direction in the upper 45cm of the soil. The seeds are dicotyledonous and they vary in shape; round, kidney or spherical with epigeal germination (Hamon *et al.*, 1991; Ariyo, 1993). The monoic flowers of okra are self-compatible (Martin, 1983; Hamon *et al*., 1990). About 35-60 days after emergence, the plant begins to flower. The flower usually remains open for a day. It is mostly self-fertilized; however, insects such as honeybees and bumble bees can cross-pollinate. Okra is self-compatible, and passive self-pollination can take place in its hermaphrodite flowers (Al-Ghzawi *et al*., 2003). Its pollen grains are very large and echinate, 156 µm in diameter with spines over 20 µm in length (Vaissière and Vinson, 1994) so that pollination with both self and cross-pollen is possibly achieved by insects (Hamon and Koechlin, 1991; Al-Ghzawi *et al.*, 2003). Anthesis takes place at dawn, and the flower remains open all morning and closes by noon or early afternoon. Cross pollination can occur in okra up to a maximum of 42.2% (Mitidieri and Vencovsky, 1974). The extent of cross-pollination in a particular place will depend upon the cultivar, competitive flora, insect population and season. Al Ghzawi *et al.* (2003) reported that, no significant differences were found between insect- and self-pollinated plants for the number of flowers. Immature fruits of 8-9 cm long are ready for harvest 4-6 days after anthesis. Harvesting is recommended at least every other day for size and quality (Ramu, 1976). About 35-40 days are required from anthesis to seed maturity. If fruits are allowed to mature, plant growth declines and few flowers develop, but with continuous harvesting, the plant continues to set fruit (Norman, 1992). Fruits are harvested 4 to 7 days after the flower has opened, and the fruits are not fibrous (fruits 2 to 4 inches. long). Mature fruits should be removed and discarded as they reduce the plant growth and decrease yield (Ramu, 1976). The rate of allogamy differs according to varieties and ecological conditions (Hamon *et al.*, 1991). When ripe the fruit becomes fibrous and splits longitudinally in five parts, showing 5 rows of seeds, with 50 – 100 seeds per fruit (Norman, 1992).

Okra has alternate palmate broad leaves and the flowers have five large yellow petals with a large purple area covering the base. The fruit, which is harvested immature, are pale green, green, or purplish fruits and in many cultivars are ridged (Hamon *et al.*, 1990). When mature, they are dark brown dehiscent or indehiscent capsules. Fruit shapes range from round to ridged and short to long (Siemonsma, 1982). The plant and fruits may have small spines on them that create allergies in some people (Ariyo, 1993; Düzyaman, 1997).

2.12. Environmental requirements of okra

Okra is sensitive to low temperatures and develop poorly below 15^{o}C (Marsh, 1992). Studies on the optimum weather requirement for high yield okra in the tropics showed that okra does best when the minimum and maximum temperatures are 18^{o}C and 35^{o}C respectively (Martin, 1982, Ezeakunne, 1984). Grubben (1997) observed temperatures of between 25-40^{o}C for optimum growth and yield of okra, while Oyolu (1977) recorded a critical day length of 12½ hours for flower initiation and fruit yield. An improvement in the performance of okra was observed when rainfall was about 750 mm, evenly distributed and relative humidity was between 90-95% (Anon., 1982; Welby and McGregor, 1997). Hussein *et al.* (2011) reported an increase in the number of fruit yield in okra when the irrigation interval was reduced. Mbagwu and Adesipe (1987) found the greatest reduction (70%) in yield when stress was imposed at flowering and pod filling stage. It can be grown on a wide range of soil types provided the drainage is good. It does not tolerate wet, poorly drained and acidic soils. Okra does not do well in tight, water logged soils, but will tolerate a soil pH range from 6.0 to 7.5. The addition of lime or dolomite may be necessary during soil preparation to bring the pH to about 6.0 to 6.5 (Incalcaterra and Curatolo, 1997). The optimum soil temperature for germination of seeds is between 24°C-32°C (Martin, 1982). Germination is poor at 20°C (68°F). However, low temperatures of 28.9^{o}C-29.2^{o}C (maximum) and 17.9-19.8^{o}C (min) [Thamburaj, 1972] and short day-lengths resulted in a larger number of flowers (Thamburaj, 1972; Martin, 1982). Flowering begins at a very early stage of growth at day lengths of less than 11 hr; under long days, the flower buds tend to abort (Chauhan, 1972). Germination will take 5-14 days (Hamon and Nairot, 1991). Okra is best eaten just after it is picked but it can be stored for several days and will keep for 7-10 days if kept at 45°C-50°C with a relative humidity of 90%-95% (Martin, 1982).

2.13. Nutritional Values and Health Benefits of okra

The okra fruit is a reservoir of valuable nutrients (Grubben *et al*., 1977; Candlish *et al*., 1987), nearly half of which is soluble fibre in the form of gums and pectins. Soluble fibre helps to lower serum cholesterol, reducing the risk of heart disease (Brown *et al*., 1999). The other half is insoluble fibre which helps to keep the intestinal tract healthy, decreasing the risk of some forms of cancer, especially colorectal cancer (Schneeman, 1998). Okra has several heath benefits, as it is rich in vitamin A, thiamin, vitamin B6, vitamin C, folic acid, riboflavin, calcium, zinc and dietary fibre (Norman, 1992). Okra is recommended for pregnant women, as it is rich in folic acid, which is essential in the neural tube formation of the foetus between the 4^{th} and 12^{th} week of pregnancy (Allen, 2007). It is also enriched with amino acids, with the likes of tryptophan, cystine and other sulphur amino acids. Nearly 10% of the recommended levels of vitamin B6 and folic acid are present in a half cup of cooked okra. It is the ideal vegetable for weight loss and is a storehouse of health benefits, provided it is cooked over low flame to retain its properties (Hamon and Charrier., 1997).

Justo (2011) reported that, a 100g edible portion of okra fruit contains 90g water, 2g protein, 1g fibre and 7g carbohydrates. Its energy value is 145 kJ/100g and is a good source of vitamins and minerals. It is also **very rich in calcium (70-90 mg/100g).**

2.14. Economic importance of okra

Okra *Abelmoschus esculentus* (L.) Moench, is an annual crop, which requires warm conditions for growth and is available in almost every market all over Africa (Schippers, 2000). It is grown mainly for its leaves and young pods which are frequently eaten green as vegetable. Okra contains carbohydrates, proteins and vitamin C in large quantities and also essential and non essential amino acids which are comparable to that of soybean (Adeboye and Oputa, 1996).

Okra leaves are considered good cattle feed, but this is seldom compatible with the primary use of the plant. Okra mucilage is suitable for medicinal and industrial applications. In the medical field, the mucilage is used as a plasma replacement or blood volume expander (Purseglove, 1974). Industrially, okra mucilage is usually used to glace certain papers and is also useful in confectionery among other uses (Farinde *et al.*, 2007). Therefore, the consumption of okra plays an important role in human nutrition. Worldwide production of okra as fruit vegetable was estimated at 6,000000 tons per year. In West Africa, it was estimated at 500,000 to 600,000 tons per year (Burkill, 1997). Schippers (2000) observed a great diversification of okra with the most important production regions localized in Ghana, Burkina Faso and Nigeria. The West and Central Africa region accounts for more than 75% of okra produced in Africa, but the average productivity in the region is very low (2.5 t/ha) compared to East Africa (6.2 t/ha) and North Africa (8.8 t/ha) (FAOSTAT, 2006). Nigeria is the largest producer (1,039,000 t) followed by Cote d'Ivoire, Ghana and others (FAOSTAT, 2008). The three most important vegetables grown by 28% of the rural poor in Ghana include pepper tomato and okra (Diao, 2010). Oppong-Sekyere *et al.* (2011) reported that okra is a vegetable which one finds in a fresh state in almost all markets in Ghana, during the rainy season and in a dehydrated form during the dry season, particularly in Northern Ghana due to its strong commercial value for poor women farmers and its vital importance as food diet among the inhabitants of the cities and villages.

2.15. The status of okra in the local and export markets in Ghana

Sefa-Dedeh (2006) stated that, the horticultural export industry in Ghana is one of Africa's success stories, growing at 20% annually. Ghana ranks among the top six suppliers of horticultural produce to the European Union markets. Figures from Ghana Export Promotion Council suggest that vegetable exports have grown from 886 metric tonnes, valued at $439,000 in 1993 to 34,764 metric tonnes valued at $7,700,000 in 2003 (Sefa-Dedeh, 2006). The vegetables exported included chilli pepper, mini aubergine, tinda, okra, cluster beans, yard long beans, greenpepper and sponge gourds. Ghana contributes 2% to the total world production of 4.8 million tons of okra pods produced annually (Gulsen *et al.*, 2007). Okra has a strong commercial value for poor women farmers particularly in Northern Ghana (Oppong-Sekyere *et al.*, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

This study was conducted on the experimental farm of the Department of Horticulture of the Kwame Nkrumah University of Science and Technology during the minor, August-November, 2011 and major season, Febraury-May, 2012. The experimental farm is located near the University campus in the forest ecological zone (06^o 41' N, 01^o 33' W) of Ghana, and is 361.4 m above sea level. The area is characterized by a bimodal rainfall pattern. The site experiences the major season from March-Mid July, and the minor season from August-November with peaks in June and September and a dry spell between mid-July and August. The minor season receives less rain comparatively but is often enough for the cultivation of short season crops. Following the minor season is a short dry season from late November to Early March. The annual average rainfall of the area is 1,250-1,500 mm and a mean temperature range of 19^oC-33^oC. The soil belongs to the oxisols and typically represented by sandy loam (Meteorological Services Department, Personal communication).

3.2. Meteorological Data

Data on the weather conditions were collected on the experimental site to evaluate how they would affect yield performance of okra.

3.3. Experimental Design

The study was conducted in a randomized complete block design (RCBD) with three treatments and three replications. The research had three blocks representing the three replications of the treatments. Each block was divided into three sub-plots (a sub-plot for a treatment). The three treatments were: Control (no insecticide application at flowering stage and no net covering); Insecticide application and Net covering (caging). A subplot measured 4m x 6m with 2m between plots and blocks giving a total area of 24m^2 per subplot and an overall area of 308m^2 for the whole experiment. The variety of okra used for the research was the 'asontem', an early variety developed by the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR).

3.4. Cultural practices

3.4.1. Land preparation

Land clearing was done manually with a cutlass. A single tractor ploughing and harrowing operation was then carried out before sowing.

3.4.2. Sowing

In both the minor and major planting seasons, seeds were sown after a single ploughing and harrowing operation. Two seeds were sown per hole and thinned to one plant per stand one week after germination. The okra seeds were sown at a spacing of 80cm x 60cm per stand to give an approximate plant density of 70 plants per subplot and 29,167 plants per hectare. Sowing was done on the 6th of August, 2011 and 17th of February, 2012 for the minor and major seasons respectively.

3.4.3. Weeding

Two manual weeding operations were carried out in each season, minor and major seasons in 2011 and 2012 respectively using the hand-hoe. The first weeding was done two weeks after germination and the second weeding operation was carried out in the fourth week after germination. Subsequent weed growth was easily controlled by hand pulling.

3.4.4. Pest control

At about two weeks after germination, flea beetle (*podagrica spp*) was found on the leaves of the young plants. This was controlled by the application of Cymethoate super EC at the rate of 10mls per 15 litres of water.

3.4.5. Fertilizer application

Basal NPK fertilizer (15-15-15) was applied to all plots including the control at the rate of 233kg per hectare four weeks after planting. This was done to take care of any possible nutrient deficiencies.

3.5. Treatment Details

Flowering of the plants started 6 weeks after germination and actual treatments commenced at this time. The three plots in each block were treated with either insecticide, covered with net (caging) and control (no insecticide application and no net covering) on the 6th week after germination when flower buds started appearing. The insecticide used for the treatment was Cymethoate Super EC (consisting of 36g Cypermethrin and 400g Dimethoate in litre). Application of the insecticide was done every other week starting from the 6th week after germination when flower buds started appearing up to the 12th week after germination at the rate of 10mls of insecticide per 7.5 litres of water in both the minor and major seasons.

Plate 1. Field layout

The picture above shows the experimental field indicating the three treatments which started 6 weeks after germination when flower bud formation had just begun.

3. 6. Data collection

3.6.1 Number of Insects/honey bees

The honeybees (*Apis mellifera*) which are the main pollinators of okra were counted starting from the 6th week after germination at the time when flower bud formation had just begun. Other insects which were seen on the plant were also counted separately. This was done whilst taking a transect walk and observing along the field. Counting was done weekly between the hours of 8:00-9:00 AM, 1:00-2:00 PM, and 5:00-6:00 PM up to the 12th week after germination in both seasons.

3.6.2 Number of flower sets

Ten plants from each plot were randomly selected from the two middle rows and their flowers counted over a five week period. Counting started in the 6th week after germination. The total number of flowers on the ten plants in each experimental plot was summed up and the average number of flowers per plant calculated.

$$\textbf{Average number of flowers per plant} = \frac{\text{Total number of flowers on the ten plants}}{\text{Total number of plants used in plot}}$$

3. 6.3. Harvesting

Harvesting was done five times over a period of one month starting from the 7th week after germination in both seasons. Ten plants from each plot were randomly selected and fruits harvested every four days interval. The weight of fruits was taken using a top-pan balance scale and the yield per plant calculated in kilograms.

3.6.4 Number of fruit sets per plant

Mature fruits from ten randomly selected plants in each plot were counted at each harvest. The average number of fruits per plant was calculated at the end of the harvesting period.

$$\textbf{Average number of fruits per plant} = \frac{\text{Total number of fruits}}{\text{Total number of plants}}$$

3.6.5 Number of seeds per pod

At the end of the harvesting period, 10 dry fruits were selected from each plot. The fruits were split open and the seeds removed. The seeds of the 10 dry fruits from each plot were then counted and the mean seeds per pod calculated.

$$\textbf{Average seeds per pod} = \frac{\text{Total number of seeds}}{\text{Total number of pods}}$$

3.6.6 Number of aborted flowers per plant

The number of aborted flowers per plant was obtained by counting all the flowers that did not develop into mature fruits in the randomly selected ten plants in each of the plots. The average number of aborted flowers was calculated as follows:

$$\textbf{Average number of aborted flowers} = \frac{\text{Total Number of aborted flowers x 100}}{\text{Total number of flowers}}$$

3.6.7. Weight of fruits per plant

The fruits in each plot were harvested every four days from ten randomly selected plants and weighed. This was done over a period of five weeks. At the end of the harvesting period, the total weight of fruits in each plot was determined and the average yield per plant in each treatment calculated using the following formula.

$$\textbf{Yield per plant} = \frac{\text{Total yield in kg}}{\text{Number of plants}}$$

3.7. Data Analysis

Data collected were analyzed using the Statistical Analysis Systems (SAS, 2011) using the General Linear Module (GLM) Procedure. Analysis of variance (ANOVA) was performed and where the difference was significant the means were separated using the Student Newman Keul's (SNK) test. Significant difference was set at $p \leq 0.05$.

CHAPTER FOUR

RESULTS

4.1. Meteorological data during the period of cultivation

The meteorological data collected from a station at Kwame Nkrumah University of Science and Technology where the study was carried out from August to December, 2011 and January to May, 2012 are shown in tables 1 and 2 below. The data collected indicated that the minor season (August to December, 2011), had higher rainfall figures than that of the major season (February to May, 2012). The general climatic conditions were relatively better in the minor season than in the major season (Tables 1 and 2) below.

Table 1. Meteorological data (August-December 2011)

Month	Rainfall(mm)	Temperature (^oC)		Relative (%)	Humidity	Sunshine duration (days)
		Max	Min	0900	1500	
August	71.5	28.9	21.7	92	73	2.0
September	231.7	29.8	22.0	92	73	2.8
October	241.0	31.2	22.4	89	67	5.5
November	44.9	32.4	23.0	86	54	7.5
December	0.0	32.9	21.4	80	41	6.4

Table 2. Meteorological data (January-May 2012)

Month	Rainfall(mm)	Temperature (^oC)		Relative (%)	Humidity	Sunshine duration (days)
		Max	Min	0900	1500	
January	18.5	33.8	20.4	72	36	5.9
February	48.5	33.7	22.2	82	49	6.5
March	126.1	33.6	23.1	83	54	6.3
April	163.0	33.0	23.5	80	60	6.0
May	**221.6**	**32.8**	**23.0**	**88**	**65**	**6.4**

4.2. Major season okra reproductive performance

4.2.1. Mean number of flowers per plant

Mean number of flowers per plant ranged from 17.63 on the control plots to 16.77 on the insecticide sprayed plots (Table 3). The means calculated indicated that, there was no significant difference between the treatments (p = 0.8550). However, the largest mean was recorded on the control whilst the net covered plots and the insecticide sprayed treatments recorded virtually the same values (Table 3).

4.2.2. Mean number of pods harvested per plant

Mean number of pods harvested recorded the largest on the control plots and the least on the net covered plots (Table 3). The means calculated showed that there was significant difference in the number of pods harvested between net covered plots and that of control, and insecticide sprayed plots (p = 0.0384). However, no significant difference was observed between control and insecticide sprayed plots (Table 3).

4.2.3. Mean number of aborted flowers per plant

Flower abortion rate in the three treatments indicated that, in the major season there was no significant difference between all the treatments (p = 0.2347). The control, insecticide and net treated plots recorded 7.07, 7.17 and 8.67 respectively (Table 3).

4.2.4. Yield of okra per plant

The means of okra yield in the three treatments showed significant difference among the control, insecticide sprayed plots and the net (p = 0.0001,). The highest mean yield was recorded in the control whilst the least was recorded in plots covered with nets.

4.2.5. Mean number of seeds per pod

The mean number of seeds indicated significant difference among net, control and insecticide sprayed plots in the major season (p = 0.0008). Control had the largest number of seeds whilst the net covered plots recorded the least. However, between the control and insecticide sprayed plots, there was no significant difference (Table 3).

Table 3. Mean reproductive performance of okra during the major season, 2012

Treatment	No. of flowers/plt	No. of pods harvested/plt	No. of aborted flowers/plt	Yield/plt	No. of seeds/pod
Control	17.63 ±1.65[a]	10.40 ±0.85[a]	7.07 ±0.86[a]	0.24±0.01[a]	76.57±1.84[a]
Insecticide	16.87 ±1.00[a]	9.60 ±0.47[a]	7.17 ±0.56[a]	0.21±0.00[b]	74.17 ±1.95[a]
Net	16.77 ±0.75[a]	8.23 ±0.34[b]	8.67 ±0.76[a]	0.14±0.00[c]	66.27±2.01[b]

Within column means with different letters are significantly different ($P < 0.05$)

4.3. Reproductive performance of okra in the minor season, 2011

4.3.1. Mean number of flowers per plant

Results obtained from the study on number of flowers per plant indicated no significant difference among control, insecticide sprayed plots and net covered plots in the minor season ($p = 0.7984$). The mean values recorded were 18.50, 18.47, and 17.60 for control, insecticide and net plots respectively (Table 4).

4.3.2. Mean number of pods harvested per plant

The mean values for the number of pods harvested per pod were 10.77, 10.77 and 8.70 for the control, insecticide and net treatments respectively. This showed significant difference in the results ($p = 0.0334$). The figures showed that control and insecticide treated plots were the same whilst the net covered plots recorded the least figure (Table 4).

4.3.3. Mean number of aborted flowers per plant

The mean number of aborted flowers in the minor season showed no significant difference ($p = 0.3114$). The largest number of aborted flowers was recorded in the plots covered with net whilst the least number of aborted flowers were recorded in the control plots. The control and insecticide applied plots were virtually the same (Table 4).

4.3.4. Yield per plant

Mean yield in the treatments indicated significant difference (p = 0.0001) between net covered plots, control and insecticide sprayed plots. Values in the control and insecticide applied plots were 0.34 and 0.30 respectively which did not show any significant difference between them. The least figure was recorded in the net covered plots which were significantly different from that of the control and the insecticide sprayed plots (Table 4).

4.3.5. Mean number of seeds per pod

With regards to the number of seeds per pod, significant difference was recorded (p = 0.0041) among the net covered plots, control and insecticide sprayed plots. The largest value was recorded in the (control) but there was no significant difference between the control and the insecticide treated plots. However, significant difference was recorded between the net covered plots and that of the control, and insecticide sprayed plots (Table 4).

Table 4. Mean reproductive performance of okra during the minor season, 2011

Treatment	No. of flowers/plt	No. of pods harvested/plt	No. of aborted flowers/plt	Yield/plt	No. of seeds/pod
Control	18.50±1.30[a]	10.77±0.74[a]	7.67±0.68[a]	0.34±0.03[a]	79.43±2.17[a]
Insecticide	18.47±0.98[a]	10.77±0.68[a]	7.70±0.61[a]	0.30±0.02[a]	78.17±2.02[a]
Net	7.60±0.91a	8.70±0.44[b]	8.90±0.65[a]	0.20±0.01[b]	69.86±2.24b

Within column means with different letters are significantly different (P < 0.05)

4.4. Insects visiting the okra plant in the major season, 2012

4.4.1. Honeybee visitation to the okra plant

Honeybees counted in the three treatments indicated significant differences in the bee population among the treatments ($p < 0.05$) in all the three periods of the day as shown in the (figure 1). However, there was no significant difference between the control and the insecticide applied plots. The control plots recorded the largest number of bees in all the periods within the day whilst no bees were recorded on the plants covered with net at all the periods. During the period of observation, that is 8:00-9:00 AM, 1:00-2:00 PM and 5:00-6:00 PM, the largest number of bees was recorded between 8:00-9:00 AM and the lowest between 1:00-2:00 PM on all the three treatments.

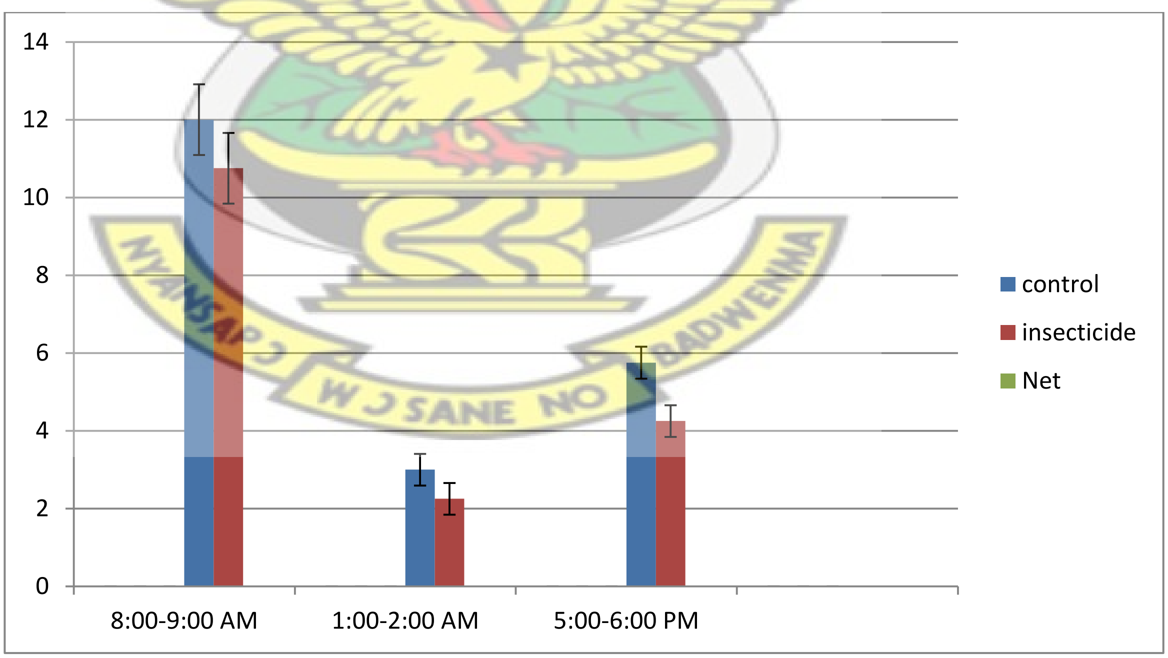

Figure 1. Daily Means of honeybee numbers in the major season

4.4.2. Other insects' visitation to the okra plant

Several insect species were found visiting the okra plant. Notable among them apart from the Honeybee (*Apis mellifera*, Lin) were; Flower beetle (*Chiloloba acuta*, Wied), Golden wasp (*Vespa magnifica* (Smith)), Carpenter bee (*Xylocopa* spp.), House fly (*Diptera* spp.), Cotton stainer (*Dysdercus superstitiosus*, Fabr.), Flea beetle (*Podagrica* spp.), Bumble bee (*Bumbus* spp.) and Lemon butterfly (*Papolio machon* Lin). Apart from the house fly, the numbers of the other insects were, however, very insignificant as compared to that of the honeybees and they did not play any role in the pollination of the okra flower. The honeybee however was found to be the main pollinator of the okra flower. The daily average numbers of these insects recorded in the major season are shown in the figure 2 below. It indicated figures of 5, 4, and 0 for the time between 8:00-9:00 AM; 2, 2, and 0 between 1:00-2:00 PM; and 3, 2, and 0 between 5:00-6:00 PM in the control, insecticide sprayed and net covered plots respectively.

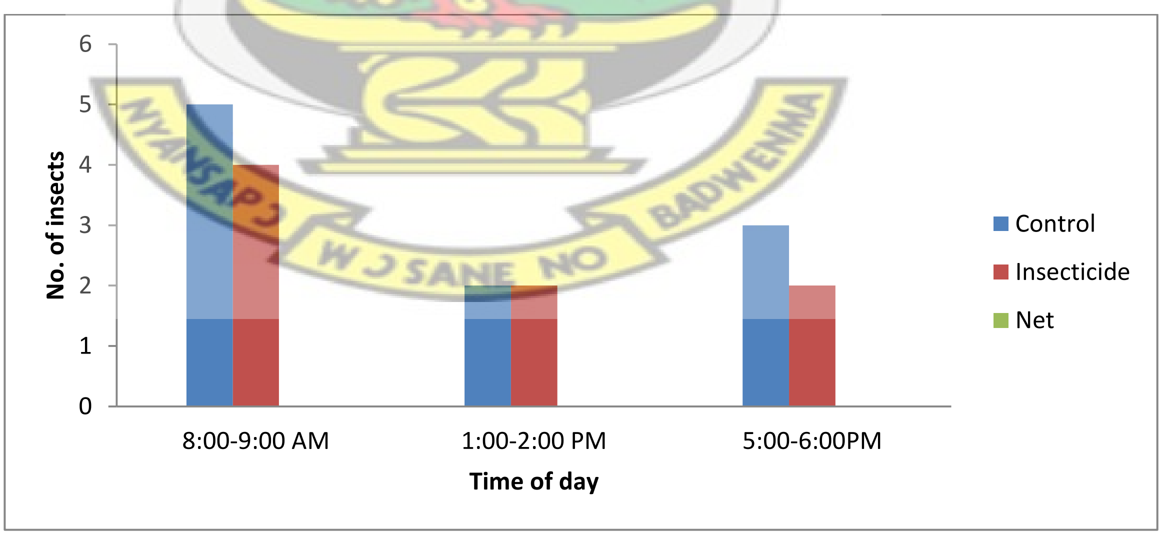

Figure 2. Number of other insects on okra plant in the major season, 2012

4.4.3. Honeybee visitation to the okra flower in the minor season, 2011

In figure 3, the honeybee count in the three treatments of 11.5, 10.75, and 0 between 8:00-9:00 AM; 2, 2.5 and 0 between 1:00-2:00 PM; and 7, 6.5 and 0 between 5:00-6:00 PM on control, insecticide sprayed plots and net covered plots respectively, indicated that there was a significant difference in the bee numbers among the treatments ($p < 0.05$) in all the three periods of the day. The difference existed between the net and the other two treatments whilst there was no significant difference between the control and the insecticide applied plots. The control plots recorded the largest number of bees in all the periods within the day whilst no bee was recorded in the plants covered with net. The largest number of honeybees was recorded between 8:00-9:00 AM whilst the least was recorded between 1:00-2:00 PM in all the three treatments within the three periods of the day.

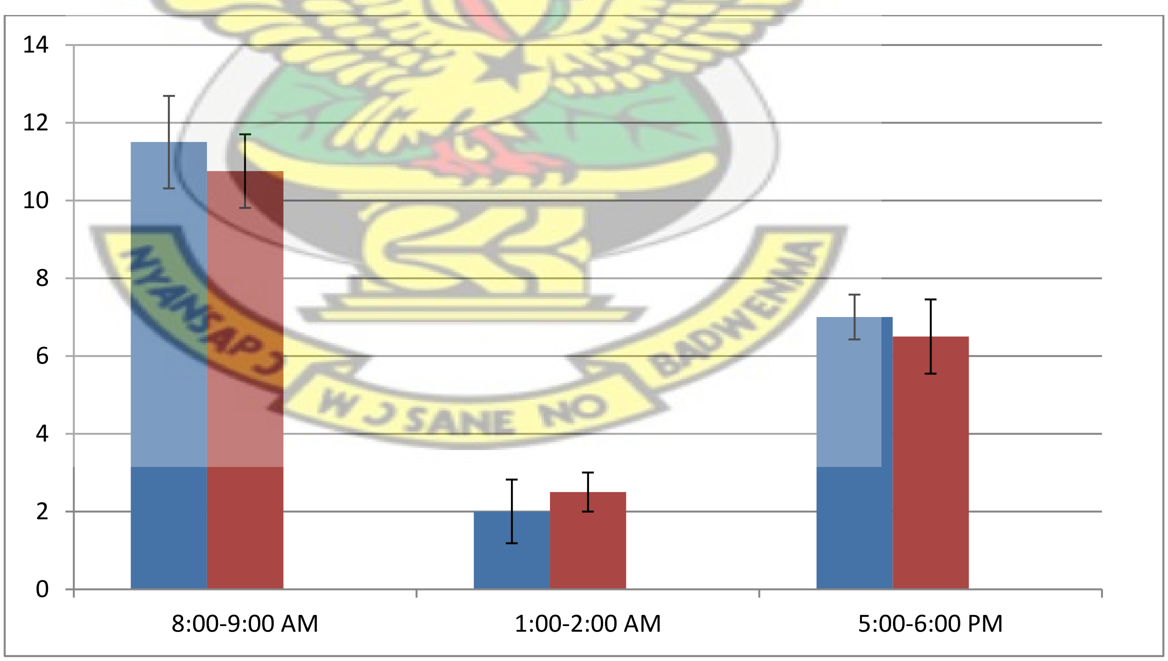

Figure 3. Daily Means of honeybees numbers in the minor season, 2011

4.4.4. Other insects' visitation to the okra plant in the minor season, 2011

The same species of insects that visited the okra plant in the major season were recorded in the minor season. They included, Flower beetle (*Chiloloba acuta*, Wied), Golden wasp (*Vespa magnifica* (Smith)), Carpenter bee (*Xylocopa* spp.), House fly (*Dipteral* spp.), Cotton stainer (*Dysdercus superstitious,s* Fabr.), Flea beetle (*Podagrica* spp.), Bumble bee (*Bumbus* spp.) and Lemon butterfly (*Papolio machon* Lin). The numbers of house flies were so numerous that they could not be counted probably as a result of aphids' infestation on the farm. However, the others recorded very insignificant numbers and were therefore lumped together as one unit. Usually, 8:00-9:00 AM recorded the largest numbers whilst 1:00-2:00 PM recorded the least.

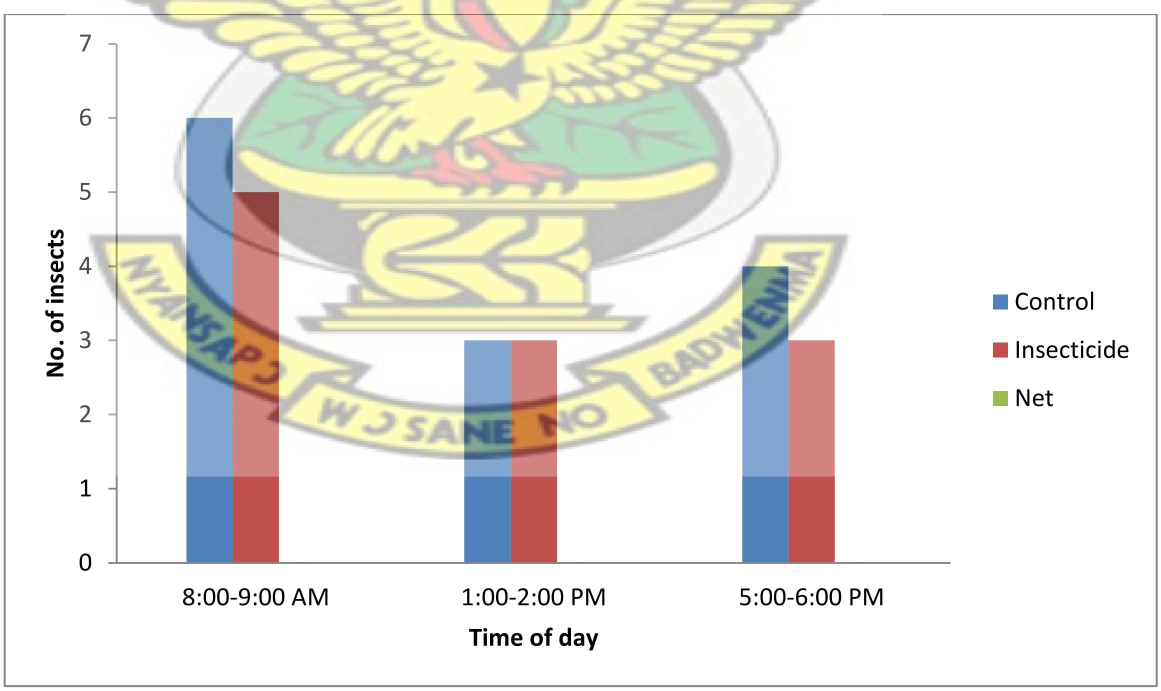

Figure 4. Number of other insects on okra plant in the minor season, 2011

CHAPTER FIVE

DISCUSSION

5.1. Okra reproductive performance

5.1.1. Number of flowers per plant

The number of flowers per plant was not affected by insecticide application or covering the plants with net, indicating the varietal attributes of the okra used. This was in conformity with Al-Ghzawi *et al.* (2003) who reported no significant difference between insect and self-pollinated flowers with regards to number of flowers per plant. Differences in the number of flowers might occur in different varieties as reported by Al Ghzawi *et al.* (2003) but within the same variety there was no difference in the number of flowers per plant. In this study, only one variety (asontem) was used, that explained why there was no difference in the number of flowers.

The minor season however recorded a slightly larger numbers of flowers in all the treatments than the major season. This could be attributed to the fact that, rainfall pattern within the first three months after planting was better in the minor season than in the major with values of 71.5mm, 231.7mm and 241.0mm for the month of August, September and October respectively whilst 48.5mm, 126.1mm, 163.0mm were recorded for February, March and April respectively in the major season (Tables 1 and 2) [Ghana Meteorological Service, personal communication]. Drought at the flowering stage might probably have detrimental effect on pod yield (Ahmad *et al.*, 2003; Sawadogo *et al.*, 2006, Seghatoleslami, *et al.*, 2007). Literature again indicated that improvement in the performance of okra was observed when rainfall was about 750 mm, evenly distributed and relative humidity was between 90-95% (Anon., 1982; Welby and McGregor, 1997). The results obtained in the study were also in agreement with that of Mbagwu and Adesipe (1987) who found the greatest reduction (70%) in yield when water stress was imposed at flowering and pod filling stage. Low temperatures of 28.9^{o}C-29.2^{o}C (maximum) and 17.9-19.8^{o}C (min) (Thamburaj, 1972) and short day-lengths resulted in a larger number of flowers (Thamburaj, 1972; Martin, 1982). For flowering in the okra plant to reach the optimum level, rainfall should be regularly and evenly distributed throughout the growing season.

Okra flowers are sensitive to drought and therefore might wither when there is drought condition. Studies on the optimum weather requirement for high yield in okra in the tropics showed that okra does best when the minimum and maximum temperatures are 18^{o}C and 35^{o}C respectively (Martin, 1982 and Ezeakunne, 1984). Observation from the study showed that for commercial cultivation, farmers should be ready to irrigate their farms as and when there is absence of rainfall for more than a week in order to obtain maximum yield. Reduction in yield could have been worse off as a result of the drought situation if water was not applied to the plants any time it was found necessary. Considering the low level of rainfall, high temperatures and the low humidity in the early part of the major season (Table 2), the application of water helped improve yield since these conditions did not favour the reproductive performance of okra.

5.1.2. Number of pods harvested per plant

The mean number of pods harvested showed that the number of pods in the control and insecticide treated plots in both major and minor seasons were larger than that of the net. In both seasons, the significant difference which occurred between the net and the other two treatments (control and insecticide sprayed plots) indicated that honeybee pollination had an effect on the number of flowers that were transformed into mature pods. However, with figures of 10.40 and 9.60 for control and insecticide sprayed plots respectively, meant that there was no significant difference between the control and insecticide treated plots as both were exposed to insect (honeybee) pollination. This was in line with the observation made by Al Ghzawi *et al.* (2003) who stated that, insect-pollinated plants showed a greater number of young pods and mature pods due to greater transformation of flowers into young pods. But it was also realized that the number of pods harvested in the control was a little larger than that of the insecticide sprayed plots. This reduction in number of pods harvested could be attributed to the spraying of the insecticide which might have expelled some insects (honeybees) from the sprayed flowers. So, some of the flowers which did not receive insect pollination as a result of the insecticide that was sprayed, got aborted and hence the reduction in the number of pods harvested in insecticide sprayed plots. This results from the study affirmed the study by Miliczky and Osgood (1979) who reported that, a significant reduction in pollinating force may have serious effects on fruit and seed set in insect-pollinated plants which are in bloom at, or shortly after, the time of spraying. It was however in contrast with the findings of Azo'Ela *et al.* (2012) who stated that all flowers turned into fruits no matter the treatment received.

The data showed that the number of aborted flowers was larger in the net covered plants than in the open-pollinated plants which therefore resulted in the larger numbers of young pods in the open-pollinated plants. Al-Ghzawi *et al.* (2003) reported that, insect-pollinated plants showed a greater number of young pods and mature pods due to greater transformation of flowers into young pods. The reason could be that some flowers in okra plant need insect-pollination to develop into young pods, the absence of which results in those flowers being aborted. It could therefore be said that insect pollination reduces flower abortion in okra. Also, spraying of crops with insecticides reduced the number of pollination agents visiting the flowers for pollination which eventually led to the reduction in the number of flowers that transformed into fruits.

As the weather conditions in the major season were not as favourable as that of the minor season, as indicated in (Table 2) and (Table 1), the number of pods harvested showed that the minor season had a slightly larger number of pods than that of the major season. The increase in number of pods in the minor season could be due to the more favourable weather conditions which prevailed in the minor season. Another reason could also be the seasonal variation of the climatic factors. This assertion was supported by the findings of Olasantan (2003) who reported that; season markedly influenced both the vegetative and yields of fresh pods of okra in South-Western Nigeria. The application of water whenever necessary to improve the weather conditions in the major season helped to improve the yield. This had been confirmed by the findings of Hussein *et al.* (2011) who reported an increase in the number of fruit yield in okra when the irrigation interval was reduced. The study in general indicated that yield of okra with regards to number of pods harvested was affected by insect pollination and also influenced by the season.

5.1.3. Number of aborted flowers per plant

No significant difference ($p > 0.05$) was observed in number of aborted flowers per plant in all the treatments in both the major and minor seasons. This was rather contrary to previous literature as Mesquida *et al.* (1990) reported lower flower abortion rates in insect-pollinated plants than in self-pollinated plants. This however, could also happen as a result of varietal difference. For a particular crop, whilst certain varieties may be affected by entomophilous pollination, others may not. Mesquida *et al.* (1990) reported that, entomophilous pollination had an effect on Line D-23 of faba beans but Line D-27 of the same faba beans was not. It is also contrary to a study carried out by Stanghellini *et al.* (1997) on the effects of honeybee (*A. mellifera* L.) and bumblebee (*Bombus impatiens* Cresson) pollination on fruit set and abortion of cucumber (*C. sativus* L.) and watermelon, *C. lanatus* Thunb.), who revealed that as the number of bee visits to flowers increased, the number of fruits aborted decreased..

It was also observed that percentage flower abortion was generally very high ranging from 40%-51% and 41-50% in the major and minor seasons respectively. This was due to the harsh weather conditions in the two seasons. The reason being that, in the minor season, the rains stopped abruptly at the time flowering was still going on resulting in greater number of flowers being aborted. Also, the beginning of major season initially experienced low rains, high temperatures and low humidity all of which probably favoured flower abortion. This was in agreement with studies done by Abdul (2009) who stated that, water stress develops during bud formation, flowering and grain filling period reduces yield due to abortion of ovule, embryo and sterility of pollen. Mbagwu and Adesipe (1987) found the greatest reduction (70%) in yield when water stress was imposed at flowering and pod filling stage. Several days or nights with temperatures outside the ideal range will cause the plant to abort fruit set and focus on survival (Mills, 1988). A study conducted by Mann and Jaworski (1970) results showed that pod formation was severely limited at temperatures above 40°C (104° F). Chauhan (1972) also observed that flowering begins at a very early stage of growth at day lengths of less than 11 hours; under longer days lengths, the flower buds tend to abort.

There was no seasonal variation as far as the numbers of aborted flowers were concerned. With figures of 8.90, 7.70 and 7.67 for minor season and 8.67, 7.17 and 7.07 for major season representing net covered plants, insecticide sprayed plants and control respectively in both seasons, revealed no seasonal effect on number of aborted flowers. The reason could be that, in both seasons, approximately the same weather conditions prevailed. Under normal circumstances, the major season should have experienced more rains and lower temperatures which would result in better reproductive performance than the minor season. But probably because planting was done as early as February, climate change might have contributed to the low performance in the major season and but for the application of water any time it was found necessary, worse conditions would have been experienced in the major season.

5.1.4. Yield in kilogramme per plant

The weight of okra harvested from the three treatments in the study indicated significant difference ($p < 0.0001$) in all the treatments in the major and minor seasons. The results in both seasons showed that yield of okra in open pollinated plants were higher than the yields of plants which were covered with the net. It showed that even though okra may be self-pollinated, yield improved when there was insect pollination. This observation was similar to the study conducted by Manzoor-ul-haq *et al.* (1978) who in their investigation on the effect of insect pollinators mostly *A. dorsata* and *A. florea* on fruit bearing in kinnow mandarin (*Citrus reticulata*, L) found significantly more fruit set, bigger fruit size, and larger number of seeds that are matured, on branches accessible to insect pollinators than on those where insects were repelled or excluded. Also, Abrol (1989) in his studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality revealed that the percentage of fruit set and well formed fruits were much higher in open pollinated plants as compared to those where pollinating insects were not allowed access. Kitroo and Abrol (1996) conducted studies on abundance, diversity and importance of native pollinators for fruit production in litchi (*Litchi chinensis* Sonn.), and found that honeybees *Apis dorsata*, *A. mellifera* L, *A. cerana* and *Apis florea* were the most important and efficient pollinators. According to them insect pollination was responsible for the increase in fruit production and the fruits resulting from open pollination were significantly larger in size and weight. Since the net covered plots excluded the pollinators from the plants, entomophilous pollination which helps increase fruit size and number, was absence and hence the reduction in yield experienced in the net covered plots.

Comparing the two seasons, there was only a slight difference in yield with the minor season recording higher yield than the major season. This difference could be as a result of better weather conditions in the minor season than in the major season because in the major season, the drought was so severe that water was applied to crops any time it became necessary. But in the minor season no water was applied to the plants. The minor season experienced rather less harsh climatic conditions than the major season. This result also confirmed the findings of Anon. (1982), Welby and McGregor (1997) who in their study realized improvement in the performance of okra when rainfall was about 750 mm, evenly distributed and relative humidity was between 90-95%.

The major season recorded significant difference in yield between the insecticide sprayed plots and the control but there was no difference between the two in the minor season. The control in the major season reason recorded a mean of 0.24kg which was significantly different from the insecticide sprayed plots with mean of 0.21kg. The reason might be that the insecticide application coupled might have reduced the pollinating efficiency of insects and therefore reduced yield in the insecticide sprayed plots.

5.1.5. Number of seeds per pod

The mean number of seeds obtained in this study indicated significant difference between treatments in both the major and minor seasons. The largest number of seeds per pod was recorded in the open pollinated plants (control and insecticide - treated plots) whilst the least was in the plants covered with net. The reason could be that the open pollinated plants had adequate pollination which resulted in fertilization of more ovules that developed into more matured seeds in the open-pollinated plants than the net covered plants which did get adequate pollination from insects. This was similar to the study conducted by Azo'Ela *et al.* (2012) who found that the pollination rate, the number of matured seeds per pod and the mean length of fruits were higher in the flowers that received a single visit of *Eucara macrognatha* (Gerstaecker) than those that were isolated for autonomous self-pollination. The results from the study was also in line with that of Njoya *et al.* (2005) who reported that hand and insect pollination of okra flowers gave seed sets varying between 73-84% per pod which differ significantly ($p < 0.05$) from that of the bagged flowers (spontaneous self pollination) which just rendered 57% seed sets per pod.

In both seasons the control recorded figures that are a little larger than that of the insecticide sprayed plots but the figures did not show any significant difference between them. The larger figures in the control showed that there was more insect pollination in the control which resulted in the formation of more seeds than in the insecticide sprayed plots. But since the difference was just very marginal, it could be due to the fact that the insecticide used was not able to expel all the insects from the plants, therefore allowing a reasonable level of pollination to take place in the insecticide sprayed plants or the insecticide was only effective some few days after application since application was done forth nightly.

It was also noted that net covered plots recorded the least number of seeds per pod. The small number of seeds per pod in the plants covered with net could be as a result of seed abortion due to lack of fertilization resulting from inadequate pollination. This was in line with the findings by Azo'Ela *et al.* (2012) who stated that, the mean number of aborted seeds was larger in the fruits from flowers that were isolated for autonomous self-pollination than those that received a single visit of *T. fraterna* and *Eucara macrognatha* (Gerstaecker). The results from the study indicated that some amount of insect pollination was necessary even in self pollinated plants. The results confirmed the study by Thapa (2006) who stated that, even self-pollinated crops benefit from insect pollination because insect-pollinated crops produce higher yields with good quality seeds showing their hybrid vigour without any desertion in the innate properties of fruits and seeds. Seasonal variation did not have any significant effect on the yield of okra as the major season recorded 66.27-76.57 seeds per pod and the minor season recorded 69.87-79.43 seeds per pod. However, there was a marginal increase in seed number in the minor season. This could be attributed to the relatively better rainfall figures in minor season than in the major season.

5.2. The honeybee and other Insects' visitation to the okra plant

Several insects were found on the plants but their numbers were insignificant as compared to the honeybee. Together, their total number recorded was not more than 5 in any particular time of the day. It was only the house fly which dominated in numbers at all times of the day and it was not even possible counting them. Their main activities or purpose for visiting the plant could be mainly for feeding purposes. They did not seem to play any role in the pollination of the okra flowers because they were found on the leaves or on the periphery of the flowers. The honeybee was the main pollinator of the okra flower because it was usually found deep inside the flower. This agrees with Singh (1984) who conducted studies on the activity of some insect pollinators on jujube (*Zizyphus mauritiana* Lamk.) and found that honeybees were the more efficient pollinators while frequency of visits of houseflies to receptive flowers was more. This also conformed to the study conducted by Klein *et al.* (2007) who stated that in many crop plant species, the honey bee (*Apis mellifera* L) seems to be the main pollinator insect.

There was significant difference in the number of bees visiting the plants in the treatments in both the major and minor seasons ($p < 0.05$). The plants covered with nets received no bee visitation through out the study period. Bee visitation only took place on the control and insecticide treated plots. With daily total means of 20.75 and 20.5 on the control, 17.25 and 19.75 on insecticide sprayed plots, in the major and minor seasons respectively, the honeybee count was virtually the same in the two seasons. The insecticide did not have any serious effect on the bee population since they did not expel large number of bees from the plots. The possible of the insecticide on the bee population could be that after taking the nectar and subsequent pollination, the bees might go and die which could lead to the reduction in the bee population. This would reduce the pollinating force on future crops and consequently lead to reduction in the yield of crops in the future.

Bee counts at different periods within the day indicated variation in the bee population in the morning, afternoon and in the evening. The largest number of bees was recorded in the morning and the least in the afternoon in both seasons. The difference could be due to temperature differences at these times of the day. This agrees with studies on temperature and pollinating activity of social bees, by Corbet *et al*. (1993) which showed that thermal constraints on flight activity limit the pollinating effectiveness of bees. Similar findings were also reported by Abrol (1987) on the influence of thermal and energetic constraints on the pollination activity of carpenter bee *Xylocopa pubescens* Spinola. The bees' activities were negatively correlated with temperature and solar radiation. Maximum pollination was accomplished early in the morning and late afternoon. Studies on the abundance and daily visitation patterns of bees on oil seed sunflower, *Helianthus annuus* L. in

Southeastern Arkansas showed that peak activity of bees occurred at 0800 hr. and 0900 hr. with greatly reduced numbers during afternoon hours (Posey *et al*., 1986).

On the basis of seasonal variation in bee population, there appeared to be no difference in the number of bees for the two seasons. This observation was similar to that of Arita and Fujii (1992) who conducted studies on quantity and seasonal variation of pollen types collected by honeybees, which showed no relationship between rainfall and the amounts of pollen collected.

In general, the observation from the study was that open pollinated plots improved in all the parameters measured as compared to the net covered plots. The conclusion therefore was that insect pollination improved the yield of okra and it would be necessary for crops which are even self-pollinated.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study showed no significant difference between the treatments in number of flower per plant. This meant that there was no effect on flowering with regards to net covering or spraying with insecticides. So far as seeds are concerned, the number of flowers in each treatment according to the study was virtually the same; however, number of pods harvested per plant indicated significant differences between the plants covered with net on one hand, and the control and insecticide on the other. The point therefore is that, when flowers are covered with net, some of the flowers which do not receive insect pollination, are not transformed into fruits because they are aborted. The study however, revealed that okra is self-compatible, and passive self-pollination can take place in its hermaphrodite flowers because nearly 50-60% of fruits were formed in the net without insect pollination. It was however, clear that insects play a role in the transformation of flowers into fruits and seeds. Insecticide application however, did not have any significant effect on flower abortion since the insecticide treated plants and the control did not show any difference in number of aborted flowers.

As more flowers were transformed into fruits, yields of okra showed significant difference between the net covered and the open pollinated plants. Therefore insects probably play a role in improving the yield of okra. It was also evident that the number of seeds per pod was larger in open pollinated plants than those covered with the net. It can therefore be concluded that insect pollination leads to larger number of ovules being fertilized than the non-insect pollinated plants. The results indicated that bees which are the main pollinators of okra were active during the morning and in the evening than in the afternoon. A lot of the pollination therefore took place in the mornings and evenings.

6.2. Recommendation

For future research work, it is recommended that the following be considered:

- Bee hives should be used to determine the real potential of insect pollination on the yield of okra.
- There should be a study to determine differences in the viability and growth vigor between open pollinated and self pollinated seeds.

Further recommendations are:

- Government should provide resources to the Ministry of food and Agriculture for the sensitization of farmers on the importance of insect pollinators.
- Stakeholders in Agriculture should institute spraying regimes that will be less harmful to insect pollinators.
- integration of both traditional and modern knowledge systems of biodiversity conservation into school curricula
- Initiation of afforestation programmes in order to provide habitats for bees and other insect pollinators so that they can provide the necessary pollination services on farms.

REFERENCES

Abdul, N. (2009). The potential for breeding okra (*Abelmoschus esculentus* (L) Moench) for stress tolerance. PhD thesis, University of Agriculture, *Faisalabad*, Pakistan. pp54-67. Online at URL:prr.hec.gov.pk/Thesis/136S.pdf.

Abrol, D. P. (1987). Influence of thermal and energetic constraints on the pollinating activity of carpenter bee, *Xylocopa pubescens*. *Environ. Ecol*., 5(1): 90-93

Abrol, D. P. (1989). Studies on ecology and behaviour of insect pollinators frequenting strawberry blossoms and their impact on yield and fruit quality. *Trop. Ecol*., 30(1): 96-100.

Adamson, N.L. (2011). An assessment of non-*apis* bees as fruit and vegetable crop pollinators in southwest Virginia. *Blacksburg*, Virginia, 9(1): 4-5.

Adeboye, O.C and Oputa, C.O (1996). Effects of galex on growth and fruit nutrient composition of Okra (*Abelmoschus esculentus* L. Moench) *Ife J. Agric*., 18(1,2): 1-9.

Ahmad, S., Mahmood,A., Malik, A.J., Karim A. and Kumbha, M.B. (2003). Response of okra to water stress. *Sarhad J. Agri.* 19(1):73-79.

Al- Ghzawi, A.M., Zaittoun, S.T., Makadmeh, I. and Al –Tawaha, A.R.M. (2003). The impact of wild bee on the pollination of eight okra genotypes under semi-arid Mediterranean conditions. *Int. J. Agric. Biol.*, 5: 409-411.

Allen, B. (2007). Knowledge-base of Hispanic Women about Neural Tube Defects and Folic Acid Supplementation. Honors thesis. *Texas State University*. Online: https://digital.library.txstate.edu/bitstream/handle/.../fulltext.pdf.

Allen-Wardell, A.G., Bernhardt, P., Bitner, R., Burquez, A. and Buchmann, S. (1998). The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology* 12: 8-17.

Al-Wondawi, H. (1983). Chemical composition of seeds of two okra cultivars. *J. Agr. Food Chem.*, 31: 1355-1358.

Anonymous (1982). Guide to the Production of Okra. Extension Guide No 61, AERLS, *Ahmadu Bello University*, Zaria, 10pp.

Anonymous (2002). Annu. Rep., Horticulture Crop Statistics, *Karnataka, State at a Glance*, p.29.

API (2007). Crops, Browse and Pollinators: An Initial Stock taking. : Online at URL *:www.fao.org/docrep/010/a1504e/a1504e00.htm.*

Arita, L. H. and. Fujii, J. K. (1992). Quantity and seasonal variation of pollen types collected by honey bees at two localities on the island of Hawaii. *Proceedings of the Hawaiian Entomological Society* 31: 119-123.

Ariyo, O. J. (1993). Genetic diversity in West African Okra (*Abelmoschus caillei* (A. Chev.) Stevels) Multivariate analysis of morphological and agronomic characteristics. *Genet. Resour Crop Evol.* 40: 25-32.

Ashman, T.-L., Knight, T.M., Steets, J.A., Amarasekare, P., Burd, M. and Campbell, D.R (2004). Pollen limitation of plant reproduction: ecological and evolutionary causes and consequences. *Ecology,* 85, 2408–2421.

Azo'o Ela, M., Ali, M., Fohouo, F- N. T and Messi, J. (2012). The importance of a single floral visit of *Eucara macrognatha* and *Tetralonia fraterna* (Hymenoptera: Apidae) in the pollination and the yields of *Abelmoschus esculentus* in Maroua, Cameroon. *African Journal of Agricultural Research* Vol. 7(18), pp. 2853-2857, Available online at http://www.academicjournals.org/AJAR.

Azo'o, M. E., Fohouo, F-N. and Messi, J. (2011). Influence of the Foraging Activity of the Entomofauna on Okra (*Abelmoschus esculentus*) Seed Yield. *International Journal for Agriculture and Biology*. 13: 761-765. Online:www.fspublishers.org.

Banaszak, J., (1995). Changes in fauna of wild bees in Europe. Pedagogical University, *Bydgoszcz,* Poland.8: 2-7.

Batra, S.W.T. (1981). Biological control in agroecosystems. *Science* 215: 134-139.

Belize Ag Report (2010). Harvesting the Ag News from All of Belize. *BelizeAgReport.com*. Issue 6: pp8. Online at: www.belizeagreport.com/index.php?option=com_docman&task=doc_download&gid=7&Itemid=3.

Biesmeijer, J. C., Roberts, S.P.M., Reemer, M., Ohlemuller, R., Edwards, M. and Peeters, T. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science,* 313, 351–354.

Bish, I. S., Mahajan, R. K. and Rana, R. S. (1995). Genetic diversity in South Asian okra *(Abelmoschus esculentus)* germplasm collection. *Ann. Appl. Biol.* 126:539-550.

Brown, L., Rosner, B., Willett, W. W. and Sacks, F. M. (1999). Cholesterol-lowering effects of dietary fiber: a meta-analysis. *Am. J. Clin Nutr* 1999; 69:30–42.

Burd, M. (1994). Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *Bot. Rev.*, 60, 81–109.

Burkill, H. M. (1997). The useful plant of West Tropical Africa, 2nd Edition Vol. 4, families M-R, *Royal Botanic Gardens, Kew*. United Kingdom p. 969.

Campbell, D. R. and Dooley, J. L. (1992). The spatial scale of genetic differentiation in a hummingbird-pollinated plant: comparison with models of isolation by distance. *American Naturalist* 139: 735–748.

Candlish, J. K., Gourley, L. and Lee, H. P. (1987). Dietary fiber and starch contents of some Southeast Asian vegetables. *J. Agr. Food Chem.* 35:319-321.

Cane, J. H. (1998). The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conserv. Biol.,pp* 12 ,8.

Cane, J. H. (2001). Habitat fragmentation and native bees: a premature verdict. *Conservation Ecology* 5(1): 3 [online] URL: http://www.consecol.org/vol5/iss1/art3.

Cane, J. H. and Tepedino, V. J. (2001). Causes and extent of declines among native North American invertebrate pollinators: detection, evidence, and consequences. *Conservation Ecology* 5(1): 1. [online] URL: http://www.consecol.org/vol5/iss1/art1/(accessed on 17 November 2011).

Chauhan, D. V. S. (1972). Vegetable Production in India (3rd ed.). Ram Prasad and Sons, Agra. Pp15.

Collins, *A.* M. and Kubasek, K. J. (1982). Field test of honey bee (Hymenoptera, Apidae) colony defensive behavior. *Annals of the Entomological Society of America* 75: 385- 387.

Corbet, S.A., Fussell, M., Ake, R., Fraser, A., Gunson, C., Savage, A. and Smith, K. (1993).Temperature and the pollinating activity of social bees. *Ecol Entomol,* 18: 17-30.

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hamon, B. Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., and Van den Belt, M. (1997).The value of the world's ecosystem services and natural capital. *Nature* 387, 253 – 260.

Crawford, T. R. (1984). The estimation of neighbourhood parameters for plant populations. *Heredity* 52: 273–283.

Crane, E. (1991). *Apis* species of tropical Asia as pollinators and some rearing methods for them. *Acta Hortic.*, 288: 29–48.

Daily, G.C. (1997). Nature's Services: Societal Dependence on Natural Ecosystems. *Island Press, Washington, DC. pp*365-374.

De Marco, Jr. P. and Coelho, F.M. (2004). Services performed by the ecosystem: Forest remnants influence agricultural cultures, pollination and production. *Biodiversity and Conservation,* v.13, p. 1245-1255.

Desneux, N., Decourtye, A. and Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annu. Rev. Entomo*. 2007. 52:81-106. (Online) URL www.ento.annualreviews.org.

Diao, X. (2010) . Economic Importance of Agriculture for Sustainable Development and Poverty Reduction: Findings from a Case Study of Ghana. (online) URL: www.oecd.org/dataoecd/50/2/46341169.pdf *(accessed on 12th January, 2012).*

Dunn, R. R. (2005). Modern insect extinctions, the neglected majority. *Conserv. Biol*., 19, 1030–1036.

Düzyaman, E. (1997). Okra: Botany and Horticulture. *Hortic. Rev*. 21: 41- 72.

Ellstrand, N. C., Torres, A. M. and Levin, D. A. (1978). Density and the rate of apparent outcrossing in Helianthus annuus (Asteraceae). *Systematic Botany* 3: 403–407. Ellstrand NC, Devlin.

ESA (Ecological Society of America) (2008). Communicating Ecosystem Services Pollination Toolkit: Pollination Fact Sheet - Revealing Secrets About the Birds and the Bees. Updated June 20, 2008. [online] URL: www.esa.org/ecoservices (accessed *on 19th Nov.2011).*

Ezeakunne, C. O. (1984). Large scale fruit and vegetable production in Nigeria. Short Communication. Department of Agronomy, Ahmadu Bello University, Zaria, 8pp.

FAO (2011). Biodiversity:Pollinators. [online] URL: www.fao.org/biodiversity/components/pollinators/en *(accessed on* 17th Nov 2011).

FAOSTAT (2006), FAO database, Rome, Italy, *http://faostat.fao.org/*.

FAOSTAT (2008). Food and Agricultural Organization of the United Nations. On-line and Multilingual Database, http://faostat.fao.org/foastat/.

Farinde, A. J., Owolarafe, O. K. and Ogungbemi, O. I. (2007). "An overview of Production, Processing, Marketing and Utilisation of Okra in Egbedore Local Government Area of Osun State, Nigeria " Agricultural Engineering International : *the CIGRE journal manuscript* No. MES 07002. Vol.IX (online) URL:www.cigrjournal.org/index.php/Ejournal/article/view/959/1119 (accessed on13th January 2012).

Forest Services Division (FSD) (1996). *Annual Report*. Ministry of Lands and Forestry, Accra, Ghana, pp 67.

Free, J. B. (1976). Insect pollination of tropical crops. *Report of the Central Association of Beekeepers.*pp 12.

Free, J.B. (1993). Insect Pollination of Crops. *Academic Press*, London, UK.

George, R .A. T. (1985). Vegetable Seed Production. Longman, London and New York, pp23-30.

Gilbert, L. E. (1980). Food web organization and the conservation of neotropical diversity. *In: Conservation Biology*: An Evolutionary–ecological Perspective *(eds* SouléM.E. *&* Wilcox, B.A.*). Sinauer Associates, Sunderland, MA, pp.* 11–34.

Greenleaf, S. and Kremen, C. (2006). Wild bee species increase tomato production but respond differently to surrounding land use in Northern California. *Biol. Conserv*., 133, 81–87.

Griffin, C. A. M and Eckert, C. G. (2003). Experimental analysis of biparental inbreeding in a self fertilizing plant. *Evolution* 57: 1513–1519.

Grubben, G. J. H., Tindall, H. D and Williams, J. T. (1977). Tropical Vegetable and their Genetic Resources. International Board of Plant Genetics Resources. FAO, Rome. Pp: 18-20.

Grubben, G.H. (1997). Tropical Vegetables and Their Genetic Resources. Edited by Tindall and J.T. Williams, *FAO,* Rome, Italy, 137pp.

Gulsen, O., Karagul, S. and Abak, K. (2007). Diversity and relationships among Turkish germplasm by SRAP and Phenotypic marker polymorphism. *Biologia*, *Bratislava*, 62(1): 41-45.

Gustafson, C. D. and Bergh, B.O. (1966). History and Review of Studies on Cross-Pollination of Avocados. *California Avocado Society 1966 Yearbook* 50: 39-49. [online] URL: www.avocadosource.com/Find.asp?ID=GustafsonCD1966(accessed on 19th Nov. 2011).

Gyasi, E. A., Agyepong , G. T., Ardayfio-Schandorf , E., Enu-Kwesi, L., Nabila, J. S. and Owusu-Bennoah, E. (1995). Production pressure and environmental change in the forest-savanna zone of southern Ghana. *Global Environmental Change* 5 (4): 355–366.

Hall, J. B. (1987). Conservation of forest in Ghana. *Universitas* 8: 33–42.

Hamon, S. and Koechlin, J. (1991). The reproductive biology of Okra. Self-fertilization kinetics in the cultivated Okra (*Abelmoschus esculentus*), and consequences for breeding. *Euphytica*, 53:49-55.

Hamon, S. and Nairot, M. (1991). Some proposed procedures for obtaining a core collection using quantitative plant characterization. International Workshop on okra genetic resources held at NBPGR. *International Crop Network Series* No. 5: 89-94.

Hamon, S. and Charrier, A. (1997). Les gombos. In*: Charrier, A., Jacquot, M. ., Hamon,* S and Nicholas, D. (Editors). L'ame'lioration des plantes tropicales, *CIRAD/ORSTOM, Montpellier*, France. Pp. 313-333.

Hamon, S., Charrier, A., Koeklin, J. and Van Sloten, D. H. (1990). Potential contributions to okra breeding through the study of their genetic resources. *In: Report of an International workshop on okra genetic resources*. NBPGR. New Delhi, India. p133.

Hamon, S., Koechliu, J., Charrier, A. and van Sloten, D. H. (1991). Les apports potentiels a' l'amélioration ge'nénétique des gombos (*Abelmoschus* spp.) par l'étude de leurs ressources génétiques. FAO/IBPGR, *Pl. Genet. Resources Newsl.* Pp. 77-88.

Harder, L. D, and Barrett, S. C. H. (1995). Mating costs of large floral displays in hermaphrodite plants. *Nature* 373: 512–514.

Harder, L. D, and Barrett, S. C. H. (1996). Pollen dispersal and mating patterns in animal-pollinated plants. In: Lloyd DG, Barrett SCH. eds. Floral biology: studies on floral evolution in animal-pollinated plants. New York: *Chapman and Hall*, 140–190.

Hawthorne, W. D., and Abu- Juan, M. (1995). Forest protection in Ghana with particular reference to vegetation and plant species. *IUCN/ODA* , Ghana. Pp6.

Helmholtz Association of German Research Centres (2008). Economic Value Of Insect Pollination Worldwide Estimated At U.S. $217 Billion. *Science Daily*. Retrieved August 15, 2012, from http://www.sciencedaily.com /releases/2008/09/080915122725.htm.

Herrera, C.M. (2000). Flower-to-seedling consequences of different pollination regimes in an insect-pollinated shrub. *Ecology*, 81, 15–29.

Hussein, H. A.,Metwally, A. K., Farghaly, K. A. and Bahawirth, M. A. (2011). Effect of Irrigation Interval (Water Stress) on Vegetative Growth and Yield in Two Genotypes of Okra. *Australian Journal of Basic and Applied Sciences*, 5(12): 3024-3032.

Incalcaterra, G. and Curatolo, G. (1997). Biodiversità di una popolazione siciliana di melone d'inverno (Cucumis melo Var .Inodorus naud.). Atti del 3° Convegno Nazionale Biodiversità - Tecnologie - Qualità. *Reggio Calibria* - 16/17 Giugno.

Joshi, A. B. and Hardas, M. W. (1976). Okra Simmonds, N.W. Evolution of Crop Plants, London: Longman, pp 194-195.

Joshi, A. B., Gadwal, V. R. and Hardas, M. W. (1974). Okra. *Abelmoschus esculentus* (Malvaceae), In: Hutchinson , J . B. (ed.). Evolutionary Studies in World Crops. Diversity and change in the Indian subcontinent. Cambridge, 99-105.

Justo, V. P. (2011). Okra Integrated pest management, an ecological guide. National

Crop Protection Center. University of the Philippines Los Baños College, *Laguna, Philippines* 4031(online) URL: www.vegetableipmasia.org/docs/ecological guide./OKRA ECO GUIDE.pdf (accessed on 12th January, 2012).

Karron, J. D, Holmquist, K.G, Flanagan, R.J. and Mitchell, R. J. (2009). Pollinator visitation patterns strongly influence among-flower variation in selfing rate. *Annals of Botany* 103: 1379–1383.

Kasina, M. (2009). Pollination: Key to Food Security and Environmental Health. *The African Executive*. Online at URL: www.africanexecutive.com/modules/magazine/articles.php (accessed *on 17th Nov.2011).*

Kearns, C., Inouye, D. and Waser, N. (1998). Endangered mutualisms: the conservation of plant–pollinator interactions. *Annu. Rev. Ecol. Syst.*, 29, 83–112.

Kevan, P. G. (1975). Forest application of the insecticide Fenithrothion and its effect on wild bee pollinators (Hymenoptera: Apoidea) of lowbush blueberries (*Vaccinium* spp.) in southern New Brunswick, Canada. *Biological Conservation* 7: 301-309.

Kevan, P. G. (1991). Pollination: keystone process in sustainable global productivity. *Acta Hortic.* 288:103-110.

Kitroo, A. and Abrol D. P. (1996). Studies on abundance, diversity and importance of native pollinators for fruit production in litchi (Litchi chinensis sonn.). *Journal of Animal Morphology and Physiology* 43(2): 149-156. {a} 351/4 Channi Himmat Housing Colony, Jammu 180 011 J K, India.

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunnigham, S. A., Kremen C., and Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc.*, 274(2): 303–313.

Kochhar, S. L. (1986). Tropical Crops. A text book of Economic Botany. Macmillan Publishers Ltd. London and Basingstoke; Macmillan Indian Ltd. 467 pp. pp.263-264.

Kreuss, A. and Tscharntke, T. (2002). Grazing intensity and the diversity of grasshoppers, butterflies, and trap nesting bees and wasps. - *Conservation Biology* 16: 1570-1580.

Kudom, A. A. and Kwapong, P. K. (2010). Floral visitors of *Ananas comosus* in Ghana: A preliminary assessment. *Journal of pollination ecology*. pp 27-32.

Larsen, T.H., Williams N. and Kremen, C. (2005). Extinction order and altered community structure rapidly disrupt ecosystem functioning. *Ecol. Lett.* 8, 538–547.

Levin, D. A. (1988). The paternity pools of plants. *American Naturalist* 132: 309–317.

Levin, D.A. and Kerster, H. W. (1969). The dependence of bee-mediated pollen and gene dispersal upon plant density. *Evolution* 23:560-571.

Levin, D.A. and Kerster, H.W. (1968). Local gene dispersal in Phlox. *Evolution* 22: 130–139.

Losey, J. E. and Vaughan, M. (2006). The Economic Value of Ecological Services Provided Insects. *BioScience* 56 (4):311-323. 2006. doi: http://dx.doi.org/10.1641/0006-3568 (2006) 56 [311: TEVOES] 2.0.CO; 2(14th January, 2012).

Luig, J., Peterson, K. and Poltimäe, H. (2005). Human impacts on pollinators and pollination services. [online] URL: www.seit.ee/files/SEIT_DP1_03_11_2005.pdf (accessed on17th Nov.2011*)*.

Lundberg, J. and Moberg, F. (2003). Mobile link organisms and ecosystem functioning: implications for ecosystem resilience and management. *Ecosystems*, 6, 87–98.

MacGillvray, T. (1953). Vegetable Production. *Blakiston Coy, Inc*. New York., 66p

Mann, J. D. and E. G. Jaworski (1970). Comparison of stresses which may limit soybean yields. *Crop. Sci.* 10:620-624.

Manzoor-ul- Haq, Rafie-ul-Din M. and Ghaffar, A. (1978). Effect of insect pollination on fruit bearing in kinnow mandarin (*Citrus reticulata*) and physical and chemical properties of fruit. *J. Apic. Res.*, 17, 47-9.

Marsh, L. (1992). Emergence and seedling growth of okra genotypes at low tempetaures. *Hortscience* 27:1310-12.

Marshall, D.L. (1991). Nonrandom mating in wild radish: variation in pollen donor success and effects of multiple paternities among one- to six-donor pollinations. *Am. J. Bot*., 78, 1401–1418.

Martin, F. W. (1982). A Second Edible Okra Species and its Hybrids with Common Okra. *Ann. Bot.,* August 1982; 50: 277 - 283.

Martin, F. W. (1983). Natural outcrossing of okra in Puerto Rico. *J. Agric.* Univ. Puerto. 67:50-52.

Martin, F. W. and Roberts, R. (1990). Milling and uses of okra seed meal at the household level. *J. Agric.* Univ., 16:21– 27.

Martin, F.W. and Rhodes, A.M. (1983). Seed characteristics of okra and related *Abelmoschus* species qualities plantarum. *Pl. Foods Human Nutr.*, 33: 41-49.

Mbagwu, J.S.C. and Adesipe, F.A. (1987). Response of three okra (*Abelmoschus esculentus* L. Moench) cultivars to irrigation at specific growth stages. *Scien. Hort*., 31(1-2): 35-43.

McGregor, S. E. (1976). Insect pollination of cultivated crop plants. Agriculture Handbook No. 496, *Agricultural Research Service, USDA, Washington*, DC.

Mensah, A., Kudom, A. A. (2011). Foraging dynamics and pollination efficiency of *Apis mellifera* and *Xylocopa olivacea* on *Luffa aegyptiaca* mill (cucurbitaceae) in southern Ghana. *Journal of pollination ecology* pp 34-38.

Mesquida, J., Le Guen, J., Tasei, J. N., Carre, S., and Morin, G. (1990). Effect of pollination treatments on reproductive organ abortion rates, yield and crossing rates in 2 lines of spring faba bean (Vicia faba L var equina Steudel). *Apidologie*, 21: 511-525. Online at http://dx.doi.org/10.1051/apido:

Michener, C. D. (2000). The bees of the world. *Johns Hopkins University Press*, New York, New York.

Miliczky, E. R. and Osgood, E. A. (1979). The effects of spraying with sevin-4-oil on insect pollinators and pollination in a spruce-fir forest. *Life Sciences and Agriculture Experiment Station University of Maine at Orono Technical Bulletin*.90.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Well-being: Synthesis. *World Resources Institute, Washington, DC.*

Mills, L. (1988). Common tomato disorders under desert conditions. *University of Nevada. Cooperative Extension*. FS-88-60.

Mishra, R. C., Kumar, J. and Gupta, J.K. (1987). Effect of mode of pollination on fruit characteristics of okra. *Abelmoschus esculentus* (L.) Moench. *Proc. Indian. Nat. Sci. Acad. B* 53: 157-160.

Mitidieri, J. and Vencovsky, R. (1974). Rivista de Agriculture. Brazil. 49:3-6.

Muth, M.K. and Thurman, W.N. (1995). Why support the price of honey. *Choices*, 10, 19–23.

NARP (1993). National Agricultural Research Project, *Horticultural crops*. Vol. 3, July 1993. NARP, CSIR, Accra.

National Research Council (NRC) (2007). Status of pollinators in North America. Washington, DC: *National Academies Press.*

National Research Council of the National Academies (NRC) (2006). Status of Pollinators in North America. *National Academy Press, Washington, DC.*

Nieh, J. C. (1998). The role of scent beacon in the communication of food location by the stingless bee, Melipona panamica. *Behaviour Ecology Sociobiology* 43: 47-58.

Nieh, J. C., and Roubik, D. W. (1998). Potential mechanisms for the communication of height and distance by a stingless bee, Melipona panamica. *Behaviour Ecology Sociobiology* 43: 387-399.

Njoya, M. T., Wittmann, D. and Schindler, M. (2005). Effect of Bee Pollination on Seed Set and Nutrition on Okra (*Abelmoschus esculentus*) in Cameroon. The Global Food & Product Chain—Dynamics, Innovations, Conflicts, Strategies. *Deutscher Tropentag, Hohenheim*.pp11-13.

Nonnecke, I. L. (1989). Vegetable Production. *Van Nostrand Reinhold AVI Publishing*. Pp.608-609.

Norman, J. C. (1992). Tropical vegetable crops. Pg 97 – 103.

O'Toole, C. (1993). Diversity of native bees and agroecosystems, In: Hymenoptera and Biodiversity (eds LaSalle, J. and Gauld, I.), pp. 69-106. *Commonwealth Agricultural Bureau International*, London, UK.

Olasantan, F. O. (2003). Effects of season and cassava/okra intercropping systems on okra production in South-Western Nigeria. *Nigeria Journal of Horticultural Science*: 8, 88-94pp.

Oppong-Sekyere, D., Akromah, R., Nyamah, E.Y., Brenyah, E. and Yeboah, S. (2011) Characterization of okra (*Abelmoschus spp.* L.) germplasm based on morphological characters in Ghana. *Journal of Plant Breeding and Crop Science* Vol. 3(13), pp. 367-378. Available online http://www.academicjournals.org/jpbcs.

Otis, G. W. (1990). Diversity of Apis in Southeast Asia. In G. K. Vearesh, B. Malik, and H. Viraktanathan (Eds.), *Social insects and Environment* (pp. 725-726). Oxford: IBA.

Oyolu, C. (1977). Variability in photoperiodic response of okra (*Hibiscus esculentus* L.). *Acta Horticulture* 52: 207-15.

Partap, T. (2001). Mountain agriculture, marginal land and sustainable livelihoods: Challenges and opportunities. *International Symposium on Mountain Agriculture in HKH Region* (21-24 May 2001). ICIMOD, Kathmandu, Nepal.

Posey, A. F., Katayama, R. W. and Burleigh, J. G. (1986). The abundance and daily visitation patterns of bees (Hymenoptera: Apoidea) onoil seed sunflower, Helianthus annuus L., in Southeastern Arkansas. *J Kansas Entomol Soc* 59:494–499.

Potts, S. G., Vulliamy, B., Dafni, A., Ne'eman, G., O'Toole, C., Roberts, S. and Willmer, P.G. (2003). Response of plant-pollinator communities following fire: changes in diversity, abundance and reward structure. *Oikos* 101:103-112.

Price, P. (1975). Insect Ecology. *John Wiley and Sons*, New York. USA. 21-30.

Purewal, S. W. and Rhandawa, S. W. (1957). Studies in *Hibiscus esculentus* (lady's finger) 1. Chromosome and pollination studies. Indian. *J. Agri. Sci*., 17: 129-136.

Purseglove, J. W (1974). Tropical Crops: Dicotyledons. *Longman Group*, EUA, London, pp.17–30. 1993.

Pushpalatha, B.T. (2008). Effect Of Seed Priming On Storability And Field Performance In Okra (*Abelmoschus esculentus* (L.) Moench) Msc. Thesis ,University Of Agricultural Sciences, Dharwad. *Hortic*. 288:103–10.

Ramu, P. M. (1976). Breeding Investigation in Okra (*Abelmoshus esculentus* (L.) Moench) *Mysore J. Agr. Sci.* **10(1)**:146.

Rathod, P. D. and Singh, S. P., (1990). Studies on flowering and fruiting in okra (*Abelmoschus esculentus* (L.) Moench) cv. Pusa Savani as influenced by nitrogennutrition and plant density, Part I. *Advances in Horticulture and Forestry*, 1 : 215-221.

Richards, K.W. (1993) Non-Apis bees as crop pollinators. *Review Suisse Zoology* 100:807–822.

Ricketts, H. T. (2004). Tropical forest fragments enhance pollinator's activity in nearby coffee crops. *Conservation Biology*, v. 18, n. 5, p. 1262-71.

Riketts, H. T., Daily, G.C., Ehrlich. P. R. and Michener, C.D. (2004). Economic value of tropical forest to coffee production. *Proc. of National Academy of Sciences*, v. 101, n.34, p.12579-12582.

Robertson, A.W. (1992). The relationship between floral display size, pollen carryover and geitonogamy in Myosotis colensoi (Kirk) Macbride (Boraginaceae). *Biological Journal of the Linnean Society* 46: 333–349.

Robinson, W.E., and Morse, R.A. (1989). The value of honeybees as pollinators of US crops. *American Bee Journal* 129 (1): 477-487.

Roubik, D.W. (2002). The value of bees in coffee harvest. *Nature* 417: 708

Sawadogo, M., Zombre, G. and Balma, D. (2006). Behaviour of different ecotypes of okra (*Abelmoschus esculentus* L.) under water deficit during budding and flowering phases. *Biotechnol. Agron. Soc. Environ.* 10 (1), 43–54.

Schippers R.R. (2000). Africa Indigenous Vegetables an overview of the Cultivated Species. *Natl. Res. Inst.* Tech. Center Agric. Rural Cooperation, Chathan *UK.*, pp. 89-98.

Schneeman, B. O. (1998). Dietary fiber and gastrointestinal function. *Nutr Res* 1998; 18:625–32.

Seely, T. D. (1985). Labour Specialization by Workers. Honeybee Ecology. Prinecton: *New Jersy*. pp. 31-35.

Sefa-Dedeh , S. (2006). Ghana's fresh produce hits the markets with increased volume, diversified and premium quality products (online) URL: www.gepcghana.com/assets/file/Sefa_Dedeh_Article.pdf(accessed on 23rd January, 2012).

Seghatoleslami, M.J., Kafi, M., Majidi,I., Nour-Mohammadi, G. and Darvish, F. (2007). Effect of water stress at different growth stages on yield and water use efficiency of five genotypes of proso millet (Panicum miliaceum) in South Khorasan. *Science and Technology of Agriculture and Natural Resources.* 1: 215-226.

Sekercioglu, C. H. (2006). Increasing awareness of avian ecological function. *Trends in ecology and evolution* vol.21 no.8.

Sharma, B.R. and Arora, S.K. (1993), Improvement of okra. In: *Advances in Horticulture,*Vegetable Crops Part I (Ed.) Chadha, K.L. and Kalloo, G., *Malhotra Publishing House*, New Delhi, pp.243-364.

Shrestha, J. B. (2008). Honeybees: the pollinator sustaining crop diversity. Msc.Thesis. *The Journal of Agriculture and Environment* Vol:9 . Online at www.moac.gov.np/publications/journal/11jagadish_b.pdf,(accessed on 19th Nov.2011).

Siemonsma, J. S. (1991). *Abelmoschus*: A taxonomical and cytogenetical overview. Int. Crop Network Ser. 5. *Int. Board Plant Genet. Resources, Rome, Italy* (1991), 52-68.

Siemonsma, Y. (1982). La culture du gombo *(Abelnioschus* spp.) Itgume fruit tropical avec référence spéciale ;i la C6te d'Ivoire. Thesis, University of Wageningen, The Netherlands.

Singh, M. P. (1984). Studies on the activities of some insect pollinators on jujube (*Zizyphus mauritiana* Lamk.). *Entomong*. 9:177-180.

Sinnadurai, S. (1973). Vegetable Production in Ghana. *Acta Hort.* (ISHS) 33:25-28.

Snow, A. A, Spira, T. P., Simpson, R. and Klips, R. A. (1996). The ecology of geitonogamous pollination. In: Lloyd DG, Barrett SCH. eds. Floral biology: studies on floral evolution in animal-pollinated plants. New York: Chapman and Hall, 191–216.

Soderman, G. and Leinonen, R. (2003). Suomen mesipistiäiset ja niiden uhanalaisuus. *Tremex Press Oy, Helsinki*, 420 pp.

Sona Thampi, K. and Indira, V. (2000). Nutritive value and organoleptic evaluation of thamaravenda genotypes (*Abelmoschus caillei* L.). *J. Tropical Agric.*, 38: 38-40.

Statistical Analysis System (SAS) Institute Inc. (2011). SAS/OR 9.3 User's Guide: Mathematical Programming. Cary. NC: SAS Institute Inc.

Stanghellini, M. S., Ambrose, J. T. and Schultheis, J. R. (1997). The effects of honey bee and bumble bee pollination on fruit set and abortion of cucumber and watermelon. *American Bee Journal* 137: 386-391.

Stevels, J. M. C. (1988). Une nouvelle combinaison dans *Abelmoschus* Medik, un gombo d'Afrique de l'Ouest et Centrale. *Bull. Mus. Hist. Naturl,* Paris, 4Q série, 10, section B., Adansonia, NO2 137-144. *Les apports potentiels*, 67 : 50-52.

Sumner, D.A. and Boriss, H. (2006). Bee-economics and the leap in pollination fees. Giannini Found. *Agric. Econ*. Update, 9, 9–11.

Tammy, H. (2008). Honey bee: A history. Online at topics.blogs.nytimes.com/2008/04/11/honey-bees-a-history/

Tanda, A.S. (1984). Insect pollination in okra (*Abelmoschus esculentus*). Proc. III orient ent. *Symp. Kariavattom*, India. 25.

Tanda, A.S. (1985). Floral biology, pollen disposal and foraging behaviour of honeybees in okra (*Abelmoschus esculentus*). *J. Apic. Res*. 24: 225-227.

Thamburaj, S. (1972). Response of okra (*Abelmoschus esculentus* (L.) Moench) to thermo and photoperiods. *Madras Agric. Journal* 59(6): 339-46.

Thapa, R. B. (2006). Honeybees and other insect pollinators of cultivated plants: a review. J. *Inst. Agric. Anim*. Sci. 27:1-23.

Turner, B. L., Clark, W. C., Kates, R. W., Richards, J. F., Matthews, J. T. and Meyers, W. B. (1990). The earth as transformed by human action. *Cambridge University Press*, Cambridge. 163-78.

Turner, M. E, Stephens, J. C. and Anderson, W. W. (1982). Homozygosity and patch structure in plant populations as a result of nearest-neighbor pollination. *Proceedings of the National Academy of Sciences of the USA* 79: 203–207.

Underhill, R. (2009). The peace bee farmer. Available online at peacebeefarm.blogspot.com/.../create-pollinator-habitat.html (accessed on 22nd Nov. 2011).

UNEP (2010). Emerging Issues: Global Honey Bee Colony Disorder and Other Threats to Insect Pollinators. [online] URL: www.unep.org/.../Global_Bee_Colony_Disorder_and_Threats_insect.(accessed *on 17th Nov.2011).*

USDA (1980). Beekeeping in the United States: Agricultural Handbook Number 335. *Science and Education Administration*, Washington.

USDA, NRCS. (2009) United State Department of Agriculture, Natural Resources Conservation Services. Plant Enhancement Activity-PLT01-Establish pollinator habitat. [online] URL:www.or.nrcs.usda.gov/programs/csp/csp_data/.../PLT01_OR.pdf (accessed on 22nd Nov. 2011).

Vaissière, B. E. and Vinson, B. (1994). Pollen morphology and its effect on pollen collection by honey bees, *Apis mellifera* L. (Hymenoptera: Apidae), with special reference to upland cotton, *Gossypium hirsutum* L. (Malvaceae). *Grana*, 33: 128-138.

Vickery, M. L. and Vickery, B. N. (1979). Plant Products of Tropical Africa. *Macmillan Press Ltd*, London, 67p.

Walters, S.A. and Taylor, B.H. (2006). Effect of honey bee pollination on pumpkin fruit and seed yield. *Hortscience*, v.41, p.370-373.

Welby, E.M. and McGregor, B. (1997). Agricultural export transportation handbook. USDA Agricultural Handbook, United States Department of Agriculture (URL: http:/www.ams Usda.gov./tmd/export/index.htm. 10pp.

Westrich, P. (1989). Die Wildbienen Baden-Württembergs. Allgemeiner Teil: Lebensräume, Verhalten, Ökologie und Schutz. *Verlag Eugen Ulmer*, Stuttgart, Germany.

Wright, S. (1946). Isolation by distance under diverse systems of mating. *Genetics* 31: 39–59.

Wuver, A.M; and Attuquayefio, D. K. (2006). The Impact of Human Activities on Biodiversity Conservation in a Coastal Wetland in Ghana. *West Africa Journal of Applied Ecology* (WAJAE) –ISSN: 0855-4307 Volume 9 [online] URL: *www.ajol.info/index.php/wajae/article/viewFile/45690/29169.* (accessed on 19th 2011).

APPENDIXES

APPENDIX A. ANOVA TABLES OF MAJOR SEASON

Major season number of flowers per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	13.488889	6.744444	0.16	0.8550 NS
Error	87	3739.800000	42.986207		
Corrected Total	89	3753.288889			

NS-Not Significant at 5% (p=0.05)

Major season number of pods harvested per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	72.0222222	36.0111111	3.38	0.0384*
Error	87	925.7666667	10.6409962		
Corrected Total	89	997.7888889			

* Significant at 5% (p=0.05)

Major season number of flowers aborted per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	48.200000	24.100000	1.47	0.2347 NS
Error	87	1422.700000	16.352874		
Corrected Total	89	1470.900000			

NS-Not Significant at 5% (p=0.05)

Major season yield per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	0.17580027	0.08790013	26.65	<.0001 *
Error	87	0.28691333	0.00329785		
Corrected Total	89	0.46271360			

* Significant at 5% (p=0.05)

Major season number of seeds per pod

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	1742.60000	871.30000	7.75	0.0008 *
Error	87	9775.40000	112.36092		
Corrected Total	89	11518.00000			

* Significant at 5% (p=0.05)

APPENDIX B: ANOVA TABLES OF MINOR SEASON

Minor season number of flowers per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	15.622222	7.811111	0.23	0.7984 NS
Error	87	3010.166667	34.599617		
Corrected Total	89	3025.788889			

NS-Not Significant at 5% (p=0.05)

Minor season number of pods harvested per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	85.422222	42.711111	3.54	0.0334 *
Error	87	1051.033333	12.080843		
Corrected Total	89	1136.455556			

* Significant at 5% (p=0.05)

Minor season number of aborted flowers per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	29.622222	14.811111	1.18	0.3114 NS
Error	87	1089.666667	12.524904		
Corrected Total	89	1119.288889			

NS-Not Significant at 5% (p=0.05)

Minor season yield per plant

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	0.33003287	0.16501643	14.77	<.0001*
Error	87	0.97196953	0.01117206		
Corrected Total	89	1.30200240			

* Significant at 5% (p=0.05)

Minor season number of seed per pods

Source	Degree of freedom	Sum of squares	Mean square	F value	Pr >F
Module	2	1620.15556	810.07778	5.86	0.0041 *
Error	87	12017.00000	138.12644		
Corrected Total	89	13637.15556			

* Significant at 5% (p=0.05)